An Integrated Framework for Life Cycle Engineering

Michael Z. Hauschild, Christoph Herrmann, Sami Kara
1) Motivation

2) Life Cycle Engineering Framework

3) Combining top-down and bottom-up

4) Outlook
1. Motivation

2. Life Cycle Engineering Framework

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4. Outlook
Sustainability?

Brundtland Commission:
A sustainable development “…meets the needs of the present without compromising the ability of future generations to meet their own needs”

Three dimensions interact in the creation of sustainable solutions
• Environment
• Society
• Economy

![Diagram showing the intersection of Environment, Economy, and Society in Sustainability]
Weak and strong sustainability

Triple bottom line:

• Three dimensions or pillars of sustainability
• Optimization of Financial capital, Social capital and Natural capital
• Trade-offs between the dimensions?
• Can the three dimensions be traded off freely?

Based on Rockström, 2015
United Nation’s Sustainable Development goals

17 goals to ‘end poverty, protect the planet, and ensure prosperity for all as part of a new sustainable development agenda’
Circular economy

- eco-design
- increased **efficiency of manufacturing**
- reduced use of chemicals (accumulate through loops)
- **product-service systems, sharing economy**
- use of **recycled materials and resources**
- industrial symbiosis

Products must be planned and engineered in a life cycle perspective
Life Cycle Engineering (LCE)

Life cycle engineering (LCE) has a central role to play, but what is it?

- a systematic “cradle to grave” approach that “provides the most complete environmental profile of goods and services”\(^1\)
- Focus on **design** and **manufacture** of **products**, optimizing the product life cycle and **minimizing pollution and waste**\(^2\) while at the same time **encouraging economic progress**
- **LCE** tools are **life cycle-oriented**:
  - Analysis tools like LCA and LCC
  - Synthesis tools under the heading of Life cycle design
- ... or life cycle **stage-oriented**:
  - Green Material Selection, Design for Disassembly (DfD), Design for Recycling (DfR), energy efficient manufacturing, ...

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1 Keoleian and Menerey, 1993; Alting and Jørgensen, 1993
2 Jeswiet, 2003, Hauschild et al., 2005
Life Cycle Engineering (LCE) framework – why and how?

Why?
• Position engineering activities relative to other efforts to achieve a sustainable development
• Guide LCE practitioners towards creating engineering solutions that are sustainable in absolute terms

How?
• Organize engineering activities throughout the life cycle of a product or a technology
• Position them according to their leverage in terms of promoting sustainable production systems and a sustainable society
• ... considering the dimensions of scale and time
• ... introducing absolute boundaries for sustainability
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Life Cycle Engineering Framework

Scope of Temporal Concern

Scope of Environmental Concern
Life Cycle Engineering Framework

Scope of Temporal Concern

Scope of Environmental Concern

Generations

Sustainable Development

Societies
Life Cycle Engineering Framework

- Societies
- Economies
- Sustainable Development
- Industrial Ecology

Scope of Temporal Concern

Scope of Environmental Concern
Life Cycle Engineering Framework

Scope of Environmental Concern

- Societies
- Economies
- X Companies
- One Company

Scope of Temporal Concern

- Sustainable Development
- Industrial Ecology
- Life Cycle Management
Life Cycle Engineering Framework

Scope of Temporal Concern

Scope of Environmental Concern

Generations

Societies
Economies
X Companies
One Company
X Products

Sustainable Development
Industrial Ecology
Life Cycle Management
Life Cycle Engineering
Life Cycle Engineering Framework

- Societies
- Economies
- X Companies
- One Company
- X Products
- One Product
- Multi Product Life Cycle
- Single Product Life Cycle
- Raw Materials Extraction
- Manufacturing
- Product Development
- After Sales-/Service Engineering
- Reuse, Remanufacturing, Recycling, Disposal
- Sustainable Development
- Industrial Ecology
- Life Cycle Management
- Life Cycle Engineering
- Scope of Temporal Concern
- Scope of Environmental Concern
Keeping the planet in the Holocene

International Geosphere Biosphere Programme (2015)
Planetary boundaries

Steffen et al. (2015)
Life Cycle Engineering Framework
Life Cycle Engineering Framework
The sustainability challenge

\[ I = P \cdot A \cdot T = Pop \cdot \frac{GDP}{\text{person}} \cdot \frac{I}{GDP} \]

- \( I \) is the environmental impact
- \( Pop \) is the global population
- \( GDP \) is the **Affluence**, the material standard of living per person
- \( \frac{I}{GDP} \) is the **Technology factor** – environmental impact per created value

*Ehrlich and Holdren (1971)*
*Commoner (1972)*
*Graedel and Allenby (1995)*
Life Cycle Engineering Framework

IMPACT
POPULATION
AFFLUENCE
TECHNOLOGY

Raw Materials Extraction
Product Development
Reuse, Remanufacturing, Recycling, Disposal
After Sales-/Service Engineering
Manufacturing

Earth's Life Support System
Societies
Economies
Companies
Products

Sustainable Development
Industrial Ecology
Life Cycle Management
Life Cycle Engineering

Scope of Temporal Concern
Scope of Environmental Concern

Civilization Span
Life Cycle Engineering Framework

- IMPACT
- POPULATION
- AFFLUENCE
- TECHNOLOGY

- Earth's Life Support System
- Societies
- Economies
- X Companies
- One Company
- X Products
- One Product

- Raw Materials Extraction
- Manufacturing
- Product Development
- Methods and Tools to support Life Cycle Engineering
- Reuse, Remanufacturing, Recycling, Disposal
- After Sales/Service Engineering

- Top-Down
- Bottom-Up

- Scope of Environmental Concern
- Scope of Temporal Concern

- Sustainability
- Sustainable Development
- Industrial Ecology
- Life Cycle Management
- Life Cycle Engineering

- Civilization Span

- Scope of Environmental Concern:
  - IMPACT
  - POPULATION
  - AFFLUENCE
  - TECHNOLOGY

- Scope of Temporal Concern:
  - Single Product Life Cycle
  - Multi Product Life Cycle
Combining top-down and bottom-up

<table>
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<tr>
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<th>Impact</th>
<th>Pollutants</th>
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<td></td>
<td>$\text{impact} = \text{population} \times \text{affluence} \times \text{technology}$</td>
<td>$\text{pollutants} = \frac{\text{population} \times \text{product output}}{\text{population}} \times \frac{\text{pollutants}}{\text{product output}}$</td>
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- **Top-down**: 
  - Population growth
  - Consumer behaviour, life style
  - Energy-/resource efficiency

- **Bottom-up**: 
  - Innovations based on eco-effectiveness and sufficiency
  - Function innovation, system innovation
  - Incremental improvement; redesign

Planetary boundaries

Impact = population \times affluence \times technology

Pollutants = \frac{population \times product output}{population} \times \frac{pollutants}{product output}
The sustainability challenge

\[ \text{impact} = \text{population} \cdot \frac{\text{products}}{\text{person}} \cdot \frac{\text{impact}}{\text{products}} \]

• The global population may level off around 10 billion
• Material standard of living will grow strongly in newly industrialised countries (Asia, South America)
• The environmental impact already exceeds sustainable levels in many areas
• So what is the challenge?
Factor 4, 10 or 20

The technology factor $\frac{\text{impact}}{\text{products}}$ must decrease 4-20 times in order to

• counterbalance the expected growth in population and material consumption

• achieve the needed reduction in the environmental impact

...i.e. to be environmentally sustainable
Combining top-down and bottom-up

**Impact** = population \times affluence \times technology  \quad (1)

**Pollutants** = \frac{population \times product output}{population} \times \frac{pollutants}{product output}  \quad (2)

*Path towards sustainability*

- **Top-down**
  - **Planetary boundaries**
  - Population growth
  - Consumer behaviour, life style
  - Energy/resource efficiency

- **Bottom-up**
  - Innovations based on eco-effectiveness and sufficiency
  - Function innovation, system innovation
  - Incremental improvement; redesign

**Life Cycle Impact Assessment**
- Global Warming, POCP, Acidification, ...

**Life Cycle Inventory**
- Σ CO₂, Σ VOC, Σ CH₄, ...

**Product Life Cycle**
- Raw Material Production
- Manufacturing
- Use/Service
- Recycling, Disposal
Combining top-down and bottom-up innovations based on eco-effectiveness and sufficiency.

**Impact**

\[ \text{impact} = \text{population} \times \text{affluence} \times \text{technology} \quad (1) \]

**Pollutants**

\[ \text{pollutants} = \frac{\text{population} \times \text{product output}}{\text{population}} \times \frac{\text{pollutants}}{\text{product output}} \quad (2) \]

**Path towards sustainability**

- **Planetary boundaries**
  - **Population growth**
  - **Absolute innovations based on eco-effectiveness and sufficiency**
  - **Relative innovations**
  - **Function innovation, system innovation**
  - **Incremental improvement; redesign**

**Methods and Tools to support Life Cycle Engineering**

**Life Cycle Impact Assessment**
- Global Warming, POCP, Acidification, ...

**Life Cycle Inventory**
- \( \Sigma \text{CO}_2 \Sigma \text{VOC} \Sigma \text{CH}_4 \) ...

**Product Life Cycle**
- **Raw Material Production**
- **Manufacturing**
- **Use/Service**
- **Recycling, Disposal**
Combining top-down and bottom-up innovations based on eco-effectiveness and sufficiency.

**Top-down**

\[
\text{impact} = \text{population} \times \text{affluence} \times \text{technology} \tag{1}
\]

\[
\text{pollutants} = \frac{\text{population} \times \text{product output}}{\text{population}} \times \frac{\text{pollutants}}{\text{product output}} \tag{2}
\]

**Path towards sustainability**

- Population growth
- Consumer behaviour, life style
- Energy-/resource efficiency
- Innovations based on eco-effectiveness and sufficiency
- Absolute
- Relative
- Function innovation, system innovation
- Incremental improvement; redesign

**Methods and Tools to support Life Cycle Engineering**

**Life Cycle Impact Assessment**
- Global Warming, POCP, Acidification, ...

**Life Cycle Inventory**
- \( \Sigma \text{CO}_2, \Sigma \text{VOC}, \Sigma \text{CH}_4, ... \)

**Product Life Cycle**
- Raw Material Production
- Manufacturing
- Use/Service
- Recycling, Disposal

**Life Cycle Engineering**
LCE in absolute terms

LCE is thus redefined as

• sustainability-oriented product development activities within the scope of one to several product life cycles

• aiming to achieve sustainable manufacturing that allows fulfilling needs of both present and future generations without exceeding the boundaries of Earth’s life support systems
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Outlook

Sustainability pushed into national and corporate agendas by UN’s World goals for 2030 and quest for circular economy

Emphasis on importance of life cycle engineering

Focus of LCE must shift from triple-bottom line thinking towards
• environmental sustainability dimension (Earth’s life support function)
• absolute sustainability targets rather than relative improvements
• developing tools that target eco-effectiveness rather than eco-efficiency improvements
• operationalizing large scale sustainability targets at the level of companies

The presented LCE framework aims to support this development
References


