A harmonized computational structure for LCA, LCC and E/E

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- Computational structure of LCA
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  - price vector
  - value added
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- Harmonization and integration

LCA, LCC, LCSA and E/E (1)

- LCA
  - LCA typically does not address the economic or social aspects of a product, but the life cycle approach and methodologies described in this International Standard may be applied to these other aspects.
  - LCC
  - LCSA
  - E/E

LCA, LCC, LCSA and E/E (2)

- LCA
  - compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040)
  - $\mathbf{g} = \mathbf{B}\mathbf{A}^{-1}\mathbf{f}; \mathbf{h} = \mathbf{Q}\mathbf{g}$
  - R. Heijungs & S. Suh, The computational structure of life cycle assessment. Kluwer, 2002

LCA, LCC, LCSA and E/E (3)

- LCC
  - All costs associated with the life cycle of a product that are directly covered by 1 or more actors in that life cycle
  - $$LCC = \sum_{\text{life cycle phase } 1}^{\text{life cycle phase } n} \sum_{\text{process } 1}^{\text{process } i} \left(\mu_i \times \sum_{\text{cost el. } 1}^{\text{cost el. } p} \sum_{\text{flow } 1}^{\text{flow } q} amount_q \times costs_p \right)$$
  - D. Hunkeler, K. Lichtenvort & G. Rebitzer, Environmental life cycle costing. CRC Press, 2008

LCA, LCC, LCSA and E/E (4)

- Life cycle sustainability assessment
  - covering environmental, economic and social aspects
  - $LCSA = LCA + LCC + LCSA$
  - W. Klöpffer, Life cycle sustainability assessment of products. International Journal of Life Cycle Assessment 13:2 (2008), 89-94

LCA, LCC, LCSA and E/E (5)

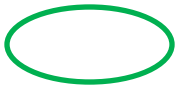
- Eco-efficiency
  - covering economic and environmental aspects
  - $$EE = \frac{cost}{environmental\ impact} = \frac{LCC}{LCA result}$$
  - G. Huppes & M. Ishikawa, Quantified eco-efficiency. Springer, 2007

LCA, LCC, LCSA and E/E (6)

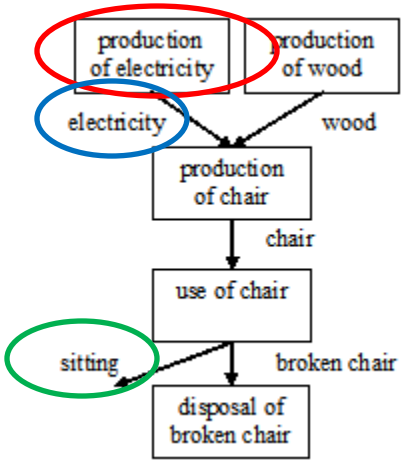
- Eco-efficiency
  - $$EE = \frac{LCC}{LCAresult}$$
  - Need to calculate
  - LCC (Hunkeler et al., 2007)
  - LCA result (Heijungs & Suh, 2002)

Computational structure of LCA (1)

- Simple example:
  - LCA of a chair
  - 1 yr of sitting



Computational structure of LCA (2)

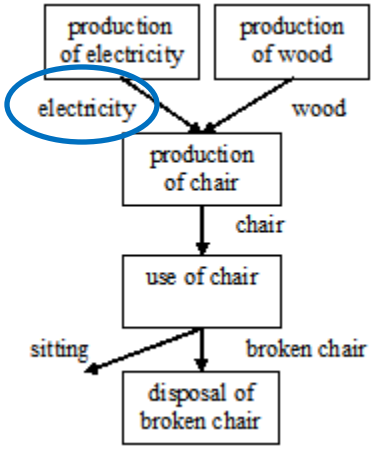


Process	Product	Physical amount
production of electricity	electricity	1 MJ
production of wood	wood	1 kg
production of chair	electricity	–2 MJ
idem	wood	–5 kg
idem	chair	1 piece
use of chair	chair	–5 pieces
idem	broken chair	5 pieces
idem	sitting	10 yr
disposal of broken chair	broken chair	–1 piece

$$\mathbf{A} = \begin{pmatrix} 1 & 0 & -2 & 0 & 0 \\ 0 & 1 & -5 & 0 & 0 \\ 0 & 0 & 1 & -5 & 0 \\ 0 & 0 & 0 & 5 & -1 \\ 0 & 0 & 0 & 10 & 0 \end{pmatrix} \quad \mathbf{f} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix} \quad \mathbf{s} = \mathbf{A}^{-1}\mathbf{f} = \begin{pmatrix} 1 \\ 2.5 \\ 0.5 \\ 0.1 \\ 0.5 \end{pmatrix}$$

Computational structure of LCC (2)

- Define a price vector (in €/kg, €/MJ, etc.)



$$\mathbf{p} = \begin{pmatrix} 5 \\ 1 \\ 25 \\ -2 \\ 0 \end{pmatrix}$$

Computational structure of LCC (3)

- Calculate monetary flows, per process, for 1 yr of sitting

$$\mathbf{A}_{\mathrm{m,scaled}} = \mathrm{diag}(\mathbf{p})\mathbf{A}\mathrm{diag}(\mathbf{s}) = \begin{pmatrix} 5 & 0 & -5 & 0 & 0 \\ 0 & 2.5 & -2.5 & 0 & 0 \\ 0 & 0 & 12.5 & -12.5 & 0 \\ 0 & 0 & 0 & -1 & 1 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

- Aggregate for each process, to obtain value added, per process, for 1 yr of sitting

$$\mathbf{v} = \left(\mathbf{1}\mathrm{diag}(\mathbf{p})\mathbf{A}\mathrm{diag}(\mathbf{s})\right)^{\mathbf{T}} = \begin{pmatrix} 5 \\ 2.5 \\ 5 \\ -13.5 \\ 1 \end{pmatrix}$$

Computational structure of LCC (4)

- LCC = minus value added for the use process

$l = -v_s = 13.5$

Computational structure of LCC (5)

- Some complications:
  - price inhomogeneity
  - cost of environmental services
  - non-stand-alone products
  - non-final-use products
  - multiple reference flows
  - discounting

Harmonized computational structure for LCA and LCC (1)

- LCA

$$\mathbf{g} = \mathbf{B}\mathbf{A}^{-1}\mathbf{f};\ \mathbf{h} = \mathbf{Q}\mathbf{g}$$

- LCC

$$l = \mathbf{1}diag\ \ \mathbf{p}\ \ \mathbf{A}^{-1}\mathbf{f}_{ref.pr.}$$

- E/E

$$EE = \frac{g_i}{l};\ EE = \frac{h_i}{l}$$

Harmonized computational structure for LCA and LCC (2)

- Features:
  - seen from LCA: only one extra data requirement: price vector **p**
  - seen from LCC: only one extra data requirement: intervention matrix **B**

Harmonized computational structure for LCA and LCC (3)

- Easy incorporation in matrix-based LCA software (like CMLCA)