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Comparison of Life Cycle Measures of Sustainability

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» Introduction

- Many methods available to perform LCAs
- Simple and complex indicator schemes
- Different methods may provide different results
- Which method should we use?
- Focus on single score methods

» Aim of the study

- Comparison of seven single-score methods by statistical analysis of the predicted impact scores for more than 1000 product systems
- Detection of patterns in the rating of products between the seven single-score methods

- → Reveal **options to simplify LCA for practitioners**

» Method overview

- Seven LCIA-methods with fundamentally different backgrounds
- Life cycle impact assessment by means of

- Energy:
  - Cumulative Energy Demand (non-renewable) → CED
  - Cumulative Exergy Demand (non-renewable) → CExD

- Material:
  - Material Intensity → MIT

- Land:
  - Ecological Footprint → EF

- Impact on human health and/or environment
  - EcoScarcity → ES
  - Environmental Priority Strategy → EPS
  - EcoIndicator 99 → EI

Shortcut methods

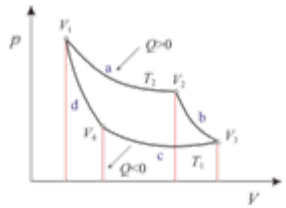
•assessing demand/use
•only resources

Aggregating methods

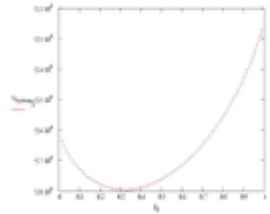
•assessing damage
•resources and emissions

» Method: Cumulative Exergy Demand

- Exergy is the max. work obtainable from energy or matter in a reference environment
- Energy carriers: exergy-to-energy ratio
  - e.g. temperature (carnot efficiency): $\eta=1-T_c/T_h$
  - high ΔT -> high exergy-to-energy ratio (e.g. nuclear reaction)
  - low ΔT -> low exergy-to-energy ratio (e.g. heat extraction from ground, water, air)



- Materials: chemical formation reaction
  - $ex°_{ch} = \Delta_f G° + \Sigma n_{el} ex°_{ch,el}$



Boesch ME, Hellweg S, Huijbregts MAJ, Frischknecht R: Applying Cumulative Exergy Demand (CExD) indicators to the ecoinvent database; submitted to International Journal of LCA

» Data selection

- Ecoinvent v1.2 database
  - Energy production (n=263)
  - Material production (n=750)
    - Building materials (n=96)
    - Coatings (n=17)
  - Transport (n=40)
  - Waste treatment (n=215)
    - Incineration (n=73)
    - Recycling (n=28)

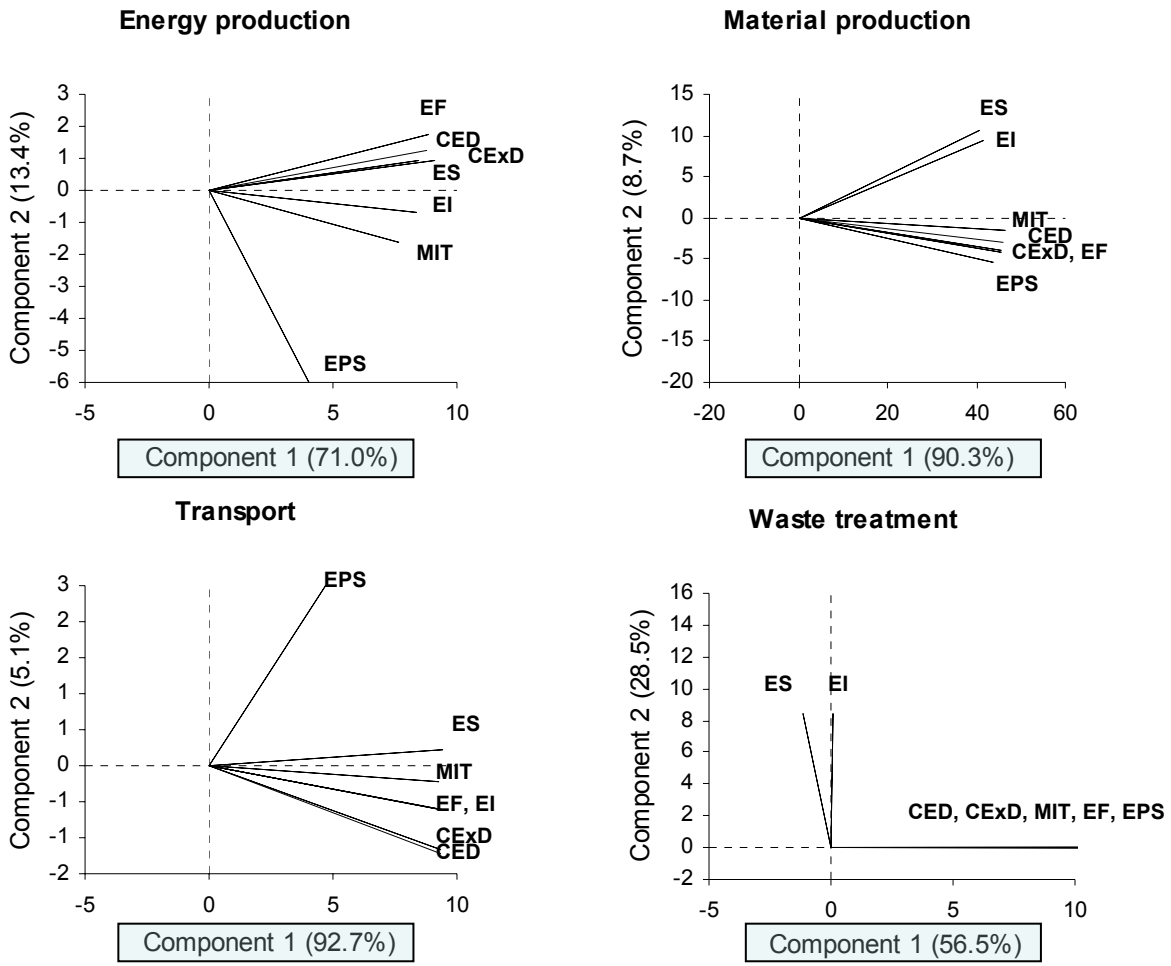
» Statistical analysis

- Principal Component Analysis
  - Detect a simpler structure for a set of variables (LCIA-method scores)
  - Extraction of uncorrelated ‘Principal Components’ that explain the variance of the dataset
- Univariate log-linear regression analysis with shortcut methods as explaining variable
  - $\log(IS) = a \cdot \log(SC) + b$

IS = Impact score of all methods

SC = Impact score of shortcut methods (CED, CExD, MIT, EF)

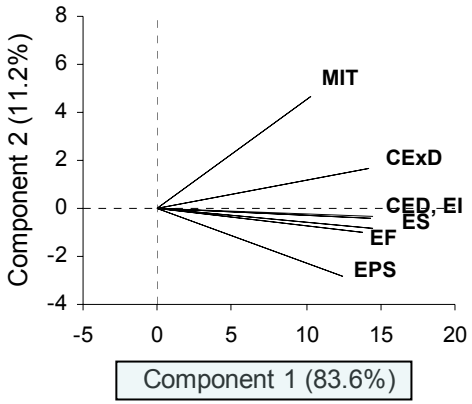
» Principal Component Analysis (I)



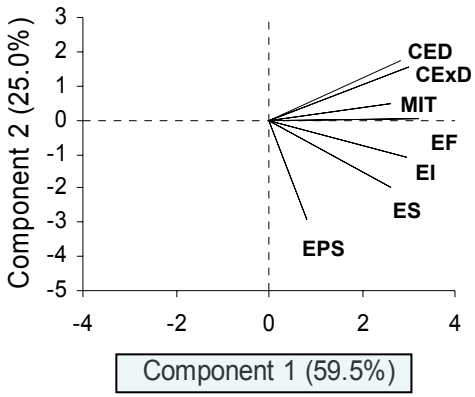
» Principal Component Analysis (II)

Material production

Building materials

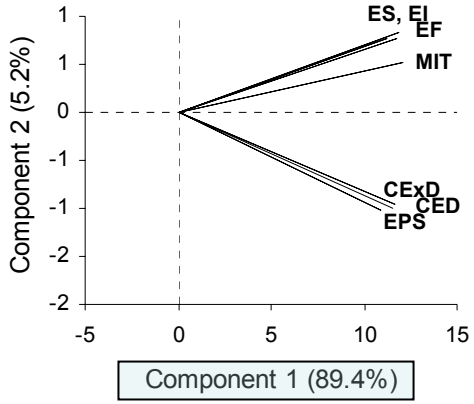


Coatings

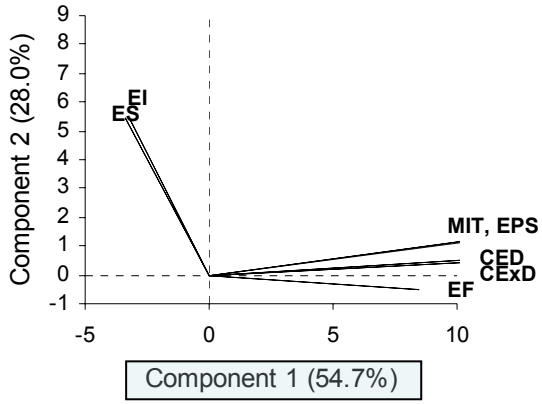


Waste treatment

Recycling



Incineration



» Principal Component Analysis (III)

- The first principal component has a high explained variance (≥56%) for the categories energy production, material production, transport, and waste treatment
- The first two principal components explain >85% of the variance in the four categories
- Differences between product groups in the four categories

→ There is an underlying driving force common to all methods

» Regression Analysis (I)

- r^2 of log(*IS*) = a · log(*CExD*) + b

IS = Impact Score

CExD = Cumulative Exergy Demand

IS / Categories	Energy (n=263)	Materials (n=750)	Transport (n=40)	Waste (n=215)
CED	0.73	0.93	0.99	0.99
MIT	0.64	0.89	0.90	0.68
EF	0.87	0.84	0.99	0.53
ES	0.73	0.79	0.96	0.24
EPS	0.51	0.75	0.92	0.54
EI	0.75	0.77	0.96	0.20

r^2 <0.70

r^2 ≥0.70

» Regression Analysis (II)

- r^2 of log(*IS*) = a · log(*CExD*) + b

	Material production		Waste treatment	
IS / Product groups	Building m. (n=96)	Coatings (n=17)	Recycling (n=28)	Incineration (n=73)
CED	0.89	0.97	0.99	0.99
MIT	0.80	0.21	0.96	0.42
EF	0.86	0.33	0.90	0.20
ES	0.73	0.27	0.77	0.05
EPS	0.73	0.07	0.86	0.33
EI	0.69	0.30	0.70	0.17

r^2 <0.70

r^2 ≥0.70

» Discussion

- High explained variances:
  - Clusters of similar processes in ecoinvent database
  - Connection of different LCIA-methods to the use of non-renewable energy

    Multiple cause-effect-chains:

    Shortcut Methods:
    - CExD: most energy carriers have high exergy contents
    - MIT: water (for cooling), combustion air
    - EF: area for sequestration of CO_2

    Aggregating Methods (ES, EPS, EI):
    - Greenhouse gas emissions
    - Priority air pollutant emissions (CO, NO_x, SO_2)
    - Radiative Emissions

» Discussion

- Low explained variances for some product groups
  - Due to non-energy related (toxic) emissions and resources

- Several impacts missing in current state-of-the-art damage assessment methods: water use, salination, indoor exposure, social aspects etc.

  → may be relevant; unlikely that they are related to non-renewable resource use

» Conclusion & Outlook

- High correlation between results of analysed methods

→ Shortcut indicators such as CED, CExD, MIT and EF are performing rather well as screening indicators for the majority of products

- Caution is advised when using shortcut methods: Not all environmentally relevant aspects are covered

» Thank you for your attention!

Further information:

- Huijbregts MAJ, Rombouts LJA, Hellweg S, Frischknecht R, Dik van de Meent JH, Ragas AMJ, Reijnders L, Struijs J: Is Cumulative Fossil Energy Demand a Useful Indicator for the Environmental Performance of Products?, Environmental Science and Technology 40 (3), 2006, 641-648
- Boesch ME, Hellweg S, Huijbregts MAJ, Frischknecht R: Applying Cumulative Exergy Demand (CExD) to the ecoinvent database, submitted to International Journal of LCA