EXTERNAL NORMALIZATION OF LC(S)A RESULTS FOR OUTRANKING METHODS IN MCDA

Discussion Forum on LCA 72 — Normalization and weighting. The forgotten theme in LCA.

9TH SEPTEMBER 2019 I CHRISTINA WULF, PETRA ZAPP, ANDREA SCHREIBER, WILHELM KUCKSHINRICHS

INSTITUTE FOR ENERGY AND CLIMATE RESEARCH – SYSTEMS ANALYSIS AND TECHNOLOGY EVALUATION (IEK-STE)

MOTIVATION

- External normalization is an established way in LCA to compare different impact categories
- Multi-Criteria Decision-Analysis can help as a structured guidance of the decision-making process
- Outranking methods prevent compensation of indicators → Consideration of order relations
- Example: Option A 3x best results; Option B 2x best results → Option A better than B
- PROMETHEE is the chosen method, which uses a pairwise comparison of different options
- Outranking methods do not involve normalization

→ External normalization can be basis for generation of weihgting factors

LCSA INDICATORS

- Indicator selection based on Sustainable Development Goals and Indicators
- LCA
  - Recommendations ILCD + guidance UNEP/SETAC [1,2]
  - Midpoint level
  - Implemented in GaBi 7
- S-LCA
  - Based on UNEP/SETAC guidelines [3]
  - Implemented in PSILCA database 2.0 [4]
  - PSILCA provides hotspot risk assessment
- LCC
  - Guidance European Investment Bank [5]

→ No double or triple counting

EXTERNAL NORMALIZATION

- ILCD: Normalization against environmental impacts at the global scale [6]
- PSILCA: Normalization against the social impact at the US sector for 1 US$
- Economy: No external normalization available
- Conversion of external normalization into weighting factors

EXTERNAL NORMALIZATION TO WEIGTHING FACTORS

1. Calculating absolute values

2. Normalizing absolute values

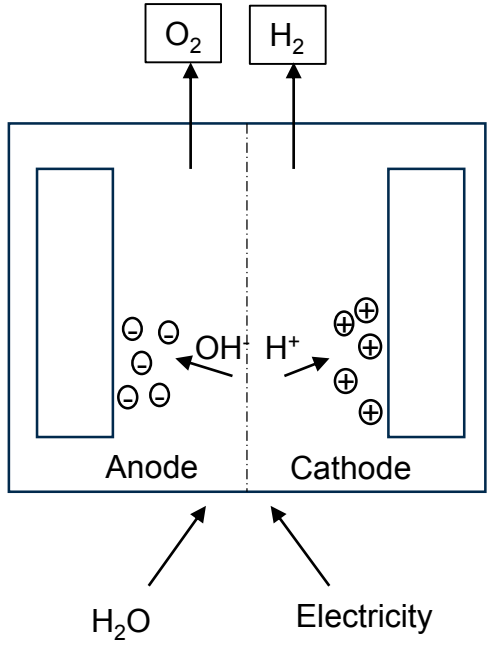
3. Calculating indicator shares on the total impact for each option

4. Building the average of the indicator shares across all options for each indicator

CASE STUDY

Comparison of hydrogen production with an alkaline water electrolyzer in three different countries

- Industrial hydrogen production by alkaline water electrolysis
- Comparison of Germany, Spain and Austria as production sites → different structures of electricity generation
- Same electrolyzer for all sites
- 1 kg hydrogen as functional unit
- Main inputs electricity and water

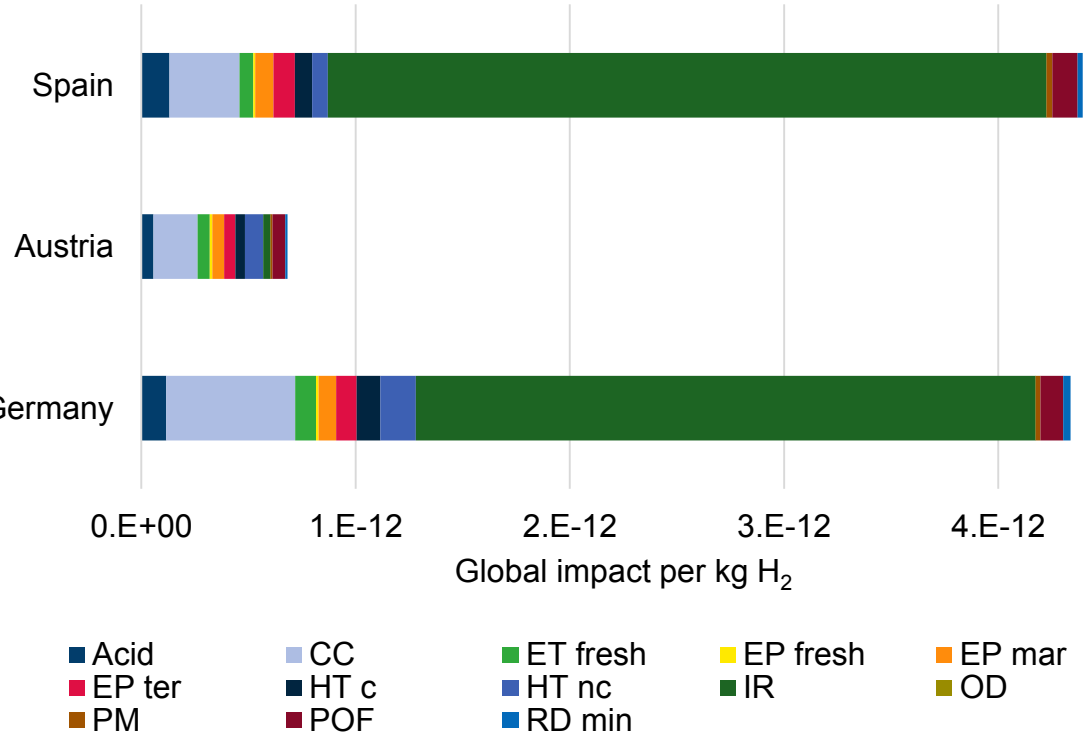


ECOLOGICAL RESULTS

Absolute Values

	Germany	Austria	Spain	WF Ecology
A Mole H+ eq.	0.045	0.022	0.050	0.046
CC kg CO2-eq	30	10	16	0.172
ET f CTUe	5.6	3.3	3.7	0.040
EP f kg P eq	1.3E-04	1.3E-04	9.3E-05	0.007
EP m kg N-eq	1.1E-02	7.3E-03	1.2E-02	0.039
EP t Mole N eq.	1.2E-01	6.5E-02	1.2E-01	0.041
HT c CTUh	3.8E-08	1.5E-08	2.7E-08	0.036
HT nc CTUh	9.8E-07	5.1E-07	4.3E-07	0.060
IR Bq U235 eq	2.760	0.033	3.200	0.494
OD kg CFC-11 eq	6.3E-08	4.4E-08	5.0E-08	0.000
PM kg PM2.5 eq	2.0E-03	8.7E-04	2.5E-03	0.008
POF kg NMVOC	3.0E-02	1.6E-02	3.3E-02	0.046
RD kg Sb-eq	1.3E-04	3.9E-05	9.4E-05	0.010

Normalized Values



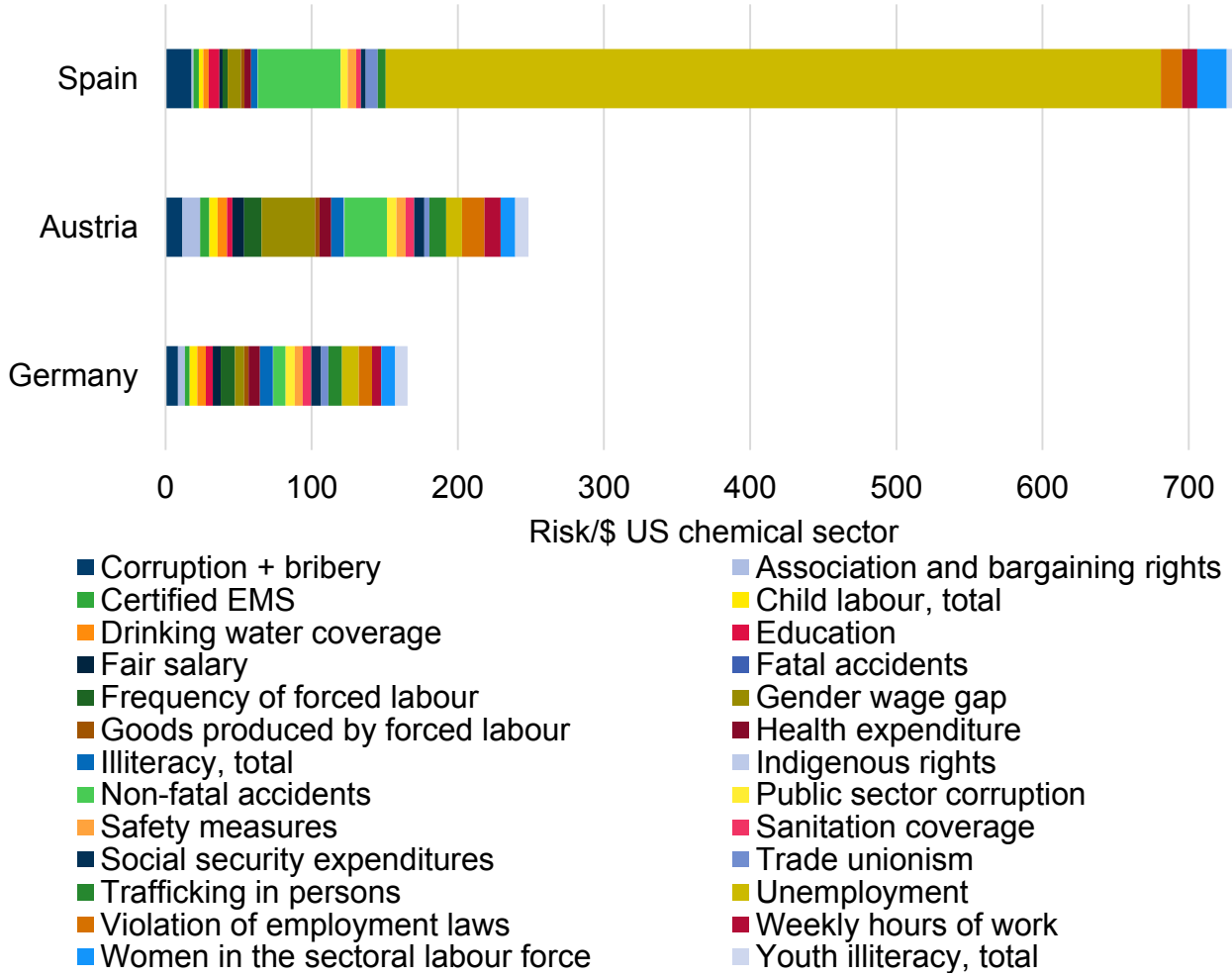
Absolute values from [7]

SOCIAL RESULTS

Absolute Values

	Germany	Austria	Spain	WF Social
Corruption + bribery	2.1	2.9	4.6	0.013
Association and bargaining rights	6.5	16.5	1.8	0.009
Certified EMS	19.4	37.2	20.5	0.005
Child labour, total	1.0	1.1	0.6	0.006
Drinking water coverage	2.6	2.9	1.7	0.007
Education	3.0	2.3	4.6	0.006
Fair salary	5.5	7.7	2.3	0.007
Fatal accidents	0.4	0.5	0.3	0.010
Frequency of forced labour	0.5	0.6	0.2	0.012
Gender wage gap	5.5	31.9	8.0	0.021
Goods produced by forced labour	0.3	0.3	0.2	0.004
Health expenditure	6.1	6.2	3.6	0.009
Illiteracy, total	4.5	4.4	2.2	0.010
Indigenous rights	1.4	1.8	0.8	0.000
Non-fatal accidents	4.0	13.8	27.1	0.026
Public sector corruption	16.0	16.9	12.7	0.008
Safety measures	4.9	5.7	5.1	0.007
Sanitation coverage	13.9	14.2	8.2	0.007
Social security expenditures	5.8	5.7	2.6	0.008
Trade unionism	25.7	18.5	43.9	0.006
Trafficking in persons	2.3	2.8	1.3	0.012
Unemployment	0.8	0.8	37.4	0.092
Violation of Employment laws	1.9	3.2	3.0	0.015
Weekly hours of work	0.3	0.5	0.4	0.010
Women in the sectoral labour force	1.9	1.9	3.9	0.013
Youth illiteracy, total	0.7	0.8	0.4	0.010

Normalized Values



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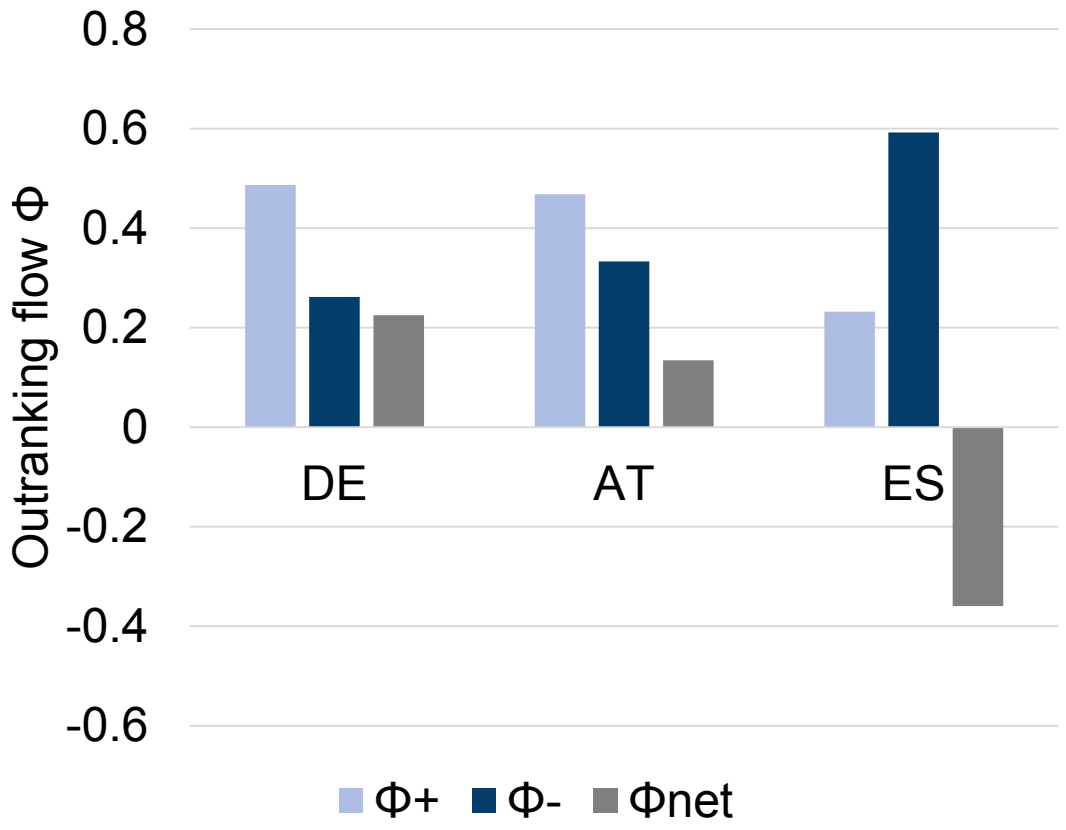
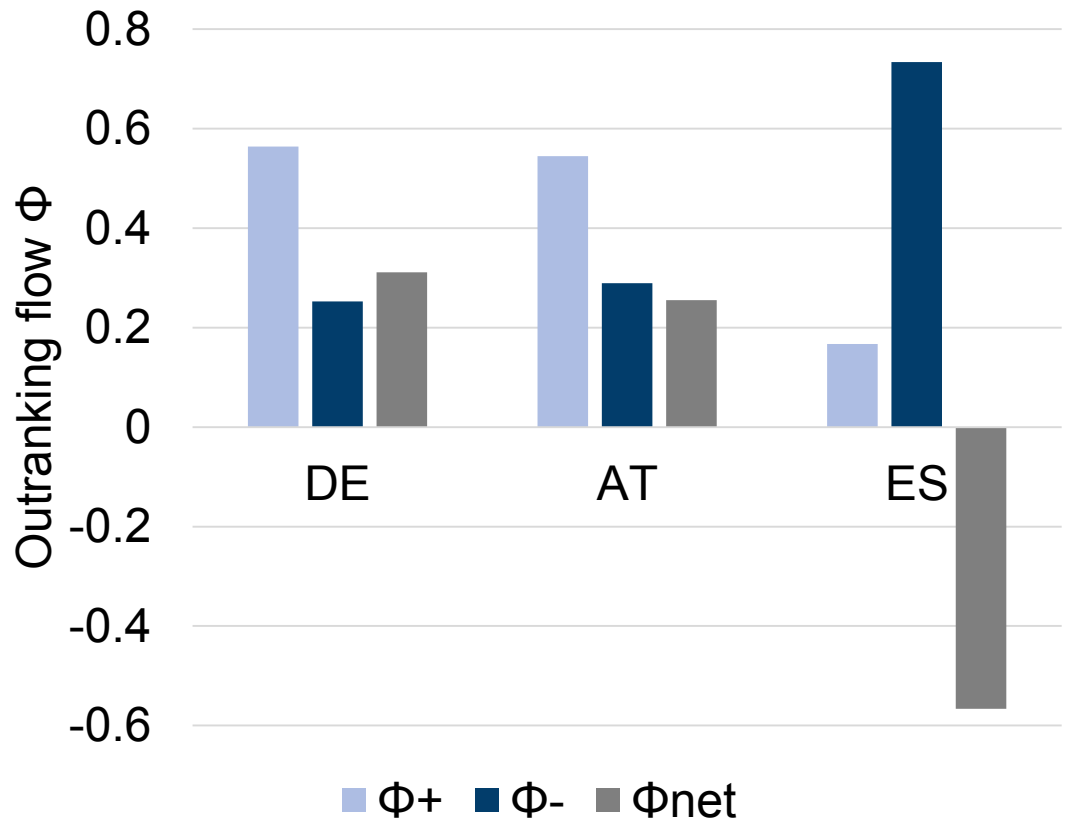
COMPARISON PROMETHEE RESULTS

Equally weighted results



Weighted results based on normalization



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DISCUSSION AND CONCLUSIONS

- Ionizing radiation impact category with the biggest weight (16.5 % of the overall result)
- Impact category climate change most sensitive to change overall ranking – with higher weighting factor (now 5.7 %, change at 8.3 %) Austria is more favorable for hydrogen production than Germany
- Limitations
  - Case study specific weighting factors
  - Severe impacts are overemphasized
  - Results are a snapshot: Spanish unemployment rate is decreasing since 2016 (reference year), Germany to phase out nuclear energy by 2022

→ As always in LCA, analysis of different scenarios and sensitivity analysis

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[1] UNEP SETAC, Global Guidance for Life Cycle Impact Assessment Indicators: Volume 1, United Nations Environment Programme, Sustainable Lifestyles, Cities and Industry Branch, Paris, 2017.

[2] EU-JRC, Recommendations for Life Cycle Impact Assessment in the European context - based on existing environmental impact assessment models and factors, International Reference Life Cycle Data System (ILCD) handbook, European Commission-Joint Research Centre - Institute for Environment and Sustainability, Luxembourg, 2011.

[3] E.S. Andrews, L.-P. Barthel, T. Beck, C. Benoît Norris, A. Ciroth, et al., Guidelines for Social Life Cycle Assessment of Products: Social and socio-economic LCA guidelines complementing environmental LCA and Life Cycle Costing, contributing to the full assessment of goods and services within the context of sustainable development, United Nations Environment Programme, Paris, 2009.

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[5] European Investment Bank, The Economic Appraisal of Investment Projects at the EIB, European Investment Bank, Luxembourg, 2013.

[6] Crenna, E., M. Secchi, L. Benini, and S. Sala. 2019. Global environmental impacts: data sources and methodological choices for calculating normalization factors for LCA. The International Journal of Life Cycle Assessment. DOI 10.1007/s11367-019-01604-y

[7] C. Wulf, J. Werker, P. Zapp, A. Schreiber, H. Schlör, W. Kuckshinrichs, Sustainable Development Goals as a Guideline for Indicator Selection in Life Cycle Sustainability Assessment, Procedia CIRP 69(-) (2018) 59-65.

BACKUP

EXTERNAL NORMALIZATION TO WEIGTHING FACTORS

1. Calculating absolute values

$$x_{ij}$$

2. Normalizing absolute values

$$x_{ij}/n_i = y_{ij} \ , \sum_i^n y_i = Y_j$$

3. Calculating indicator shares on the total impact for each option

$$y_{ij}/Y_j = a_{ij}$$

4. Building the average of the indicator shares across all options for each indicator

$$\frac{\sum_j^m a_{ij}}{j} = w_i$$

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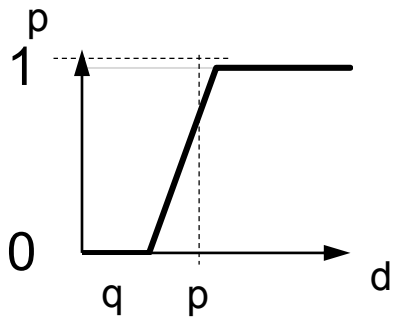
PROMETHEE

Preference Ranking Organisation Method for Enrichment Evaluation

- Outranking Methode
- Definition von Präferenzfunktionen, z. B. lineare Präferenz mit Indifferenzzone
- Standard: q: 5 % vom Minimalwert, p: 10 % vom Minimalwert



	DE	AT	ES
Versauerung mol H^+ eq	0.0445	0.0216	0.0503
Klimaänderung, kg CO_2-eq	29.8	10.2	16.2
Wasser, AWARE m^3 world-eq	22.0	22.3	43.1

Versauerung

	DE	AT	ES
DE	0	0	1
AT	1	0	1
ES	0	0	0

Klimaänderung

	DE	AT	ES
DE	0	0	0
AT	1	0	1
ES	1	0	0

Waser

	DE	AT	ES
DE	0	0	1
AT	0	0	1
ES	0	0	0

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PROMETHEE II

- Aufsummieren aller Einzelvergleiche

$$\pi(A_i, A_j) = \sum_{k=1}^{K} w_k * p_k(A_i, A_j)$$

- Gewichtung kann hinzugefügt werden

	DE	AT	ES
DE	0	0	0,66
AT	0,66	0	1
ES	0,33	0	0

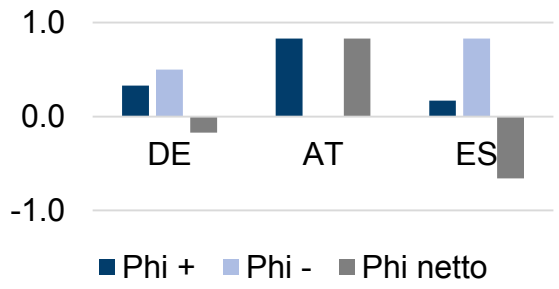
PROMETHEE II

- Aufsummieren aller Einzelvergleiche

$$\pi(A_i, A_j) = \sum_{k=1}^{K} w_k * p_k\,(A_i, A_j)$$

- Gewichtung kann hinzugefügt werden
- Berechnung der Aus- und Eingangsflüsse Φ^+ und Φ^-

$$\Phi_i^+ = \frac{1}{n-1}\sum_{j=1}^{n} \pi\,(A_i, A_j) \qquad \Phi_i^- = \frac{1}{n-1}\sum_{j=1}^{n} \pi\,(A_j, A_i)$$



	DE	AT	ES	Φ+
DE	0	0	0,66	0,33
AT	0,66	0	1	0,83
ES	0,33	0	0	0,17
Φ-	0,50	0	0,83	