Normalisation and weighting as applied in Environmental Footprint

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Joint Research Centre

European Commission

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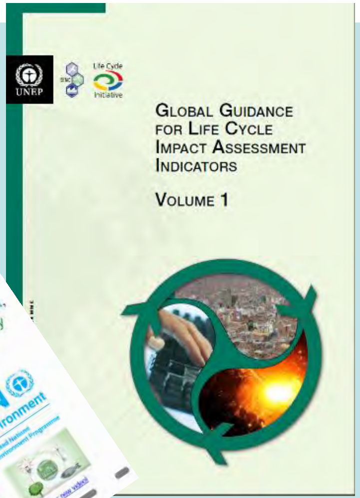
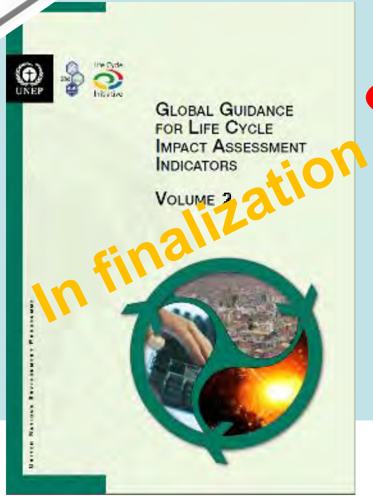
- Unep-Setac life cycle initiative: status quo on normalization and weighting discussion
- Normalisation in Environmental Footprint
- Weighting in Environmental Footprint
- Ongoing research and outlook

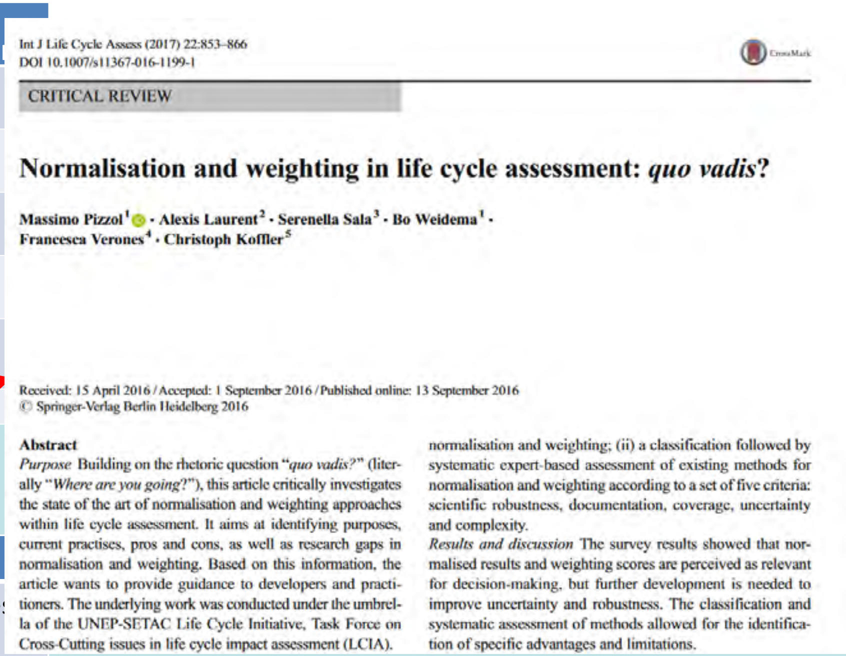
UNEP-SETAC Life Cycle Initiative - LCIA guidance





Frischknecht and Jolliet, 2016 & 2018

Topic	Task Force leaders	Pellston worksho
Greenhouse gas emissions and climate change impacts	Annie Levasseur, Francesco Cherubini	x
Particulate matter emissions and respiratory effects	Peter Fantke, Tom Mc Kone, Olivier Jolliet	x
Water use related impacts: water scarcity and human health effects	Anne-Marie Boulay, Stephan Pfister	x
Land use related impacts on biodiversity	Asumpció Anton, Ottar Michelsen	x
Overall framework and cross-cutting issues	Francesca Verones, Olivier Jolliet, Rolf Frischknecht	x
Footprint indicators	Brad Ridoutt	


Int J Life Cycle Assess (2017) 22:853–866
DOI 10.1007/s11367-016-1199-1

CRITICAL REVIEW

Normalisation and weighting in life cycle assessment: *quo vadis*?

Massimo Pizzol[1] · Alexis Laurent[2] · Serenella Sala[3] · Bo Weidema[1] · Francesca Verones[4] · Christoph Koffler[5]

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Abstract
Purpose Building on the rhetoric question "*quo vadis?*" (literally "*Where are you going?*"), this article critically investigates the state of the art of normalisation and weighting approaches within life cycle assessment. It aims at identifying purposes, current practises, pros and cons, as well as research gaps in normalisation and weighting. Based on this information, the article wants to provide guidance to developers and practitioners. The underlying work was conducted under the umbrella of the UNEP-SETAC Life Cycle Initiative, Task Force on Cross-Cutting issues in life cycle impact assessment (LCIA). normalisation and weighting; (ii) a classification followed by systematic expert-based assessment of existing methods for normalisation and weighting according to a set of five criteria: scientific robustness, documentation, coverage, uncertainty and complexity.
Results and discussion The survey results showed that normalised results and weighting scores are perceived as relevant for decision-making, but further development is needed to improve uncertainty and robustness. The classification and systematic assessment of methods allowed for the identification of specific advantages and limitations.

TF	Topic	Task Force leaders
1	Overall framework and cross-cutting issues	Alexis Laurent*, Francesca Verones, Olivier Jolliet, Rolf Frischknecht
2.1	Acidification & Eutrophication	Andrew Henderson
2.2	Ecotoxicity	Michael Hauschild
3	Human toxicity (including indoor)	Tom Mc Kone & Peter Fantke
4	Ecosystem services, soil quality	Tim Grant
5	Mineral primary resources	Markus Berger & Thomas Sonderegger
6	Water use ecosystem damage indicator	Anne-Marie Boulay & Stephan Pfister
7	Footprint indicators	Brad Ridoutt

Pizzol M, Laurent A, Sala S, Weidema B, Verones F, Koffler C (2017) **Normalisation and weighting in life cycle assessment: Quo Vadis?** International Journal of LCA, 22(6):853-866, doi: 10.1007/s11367-016-1199-1

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Main outcome of the UNEP SETAC life cycle initiative working group on normalization and weighting

Activities performed by the group

(i) an **online survey** to investigate the perception of the LCA community regarding the scientific quality and current practice concerning normalisation and weighting;

(ii) a **classification** followed by systematic **expert-based assessment** of existing methods for normalisation and weighting according to a set of five criteria: scientific robustness, documentation, coverage, uncertainty and complexity.

The recommendations from UNEP-SETAC should not be seen as recommendations to use any specific normalisation or weighting methods or as recommendations to use normalisation or weighting at all but as **recommendations for good practice for the practitioners when it has been decided to use normalisation or weighting**.

- **Normalisation**
  - Global normalisations considered the better reference to be pursued
- **Weighting**
  - Focus on robustness and transparency
  - Covering all impact categories
  - Prioritize development of approaches at the endpoint
  - Assessing uncertainties

Pizzol M, Laurent A, Sala S, Weidema B, Verones F, Koffler C (2017) **Normalisation and weighting in life cycle assessment: Quo Vadis?** International Journal of LCA, 22(6):853-866, doi: 10.1007/s11367-016-1199-1

Normalisation and weighting in Environmental Footprint (EF)

- Evolution of normalization and weighting during the Environmental Footprint development, including alignment with the evolution of LCIA recommendations
- Methods for calculating normalization and weighting factors
- Areas of current refinements / further development of the factors

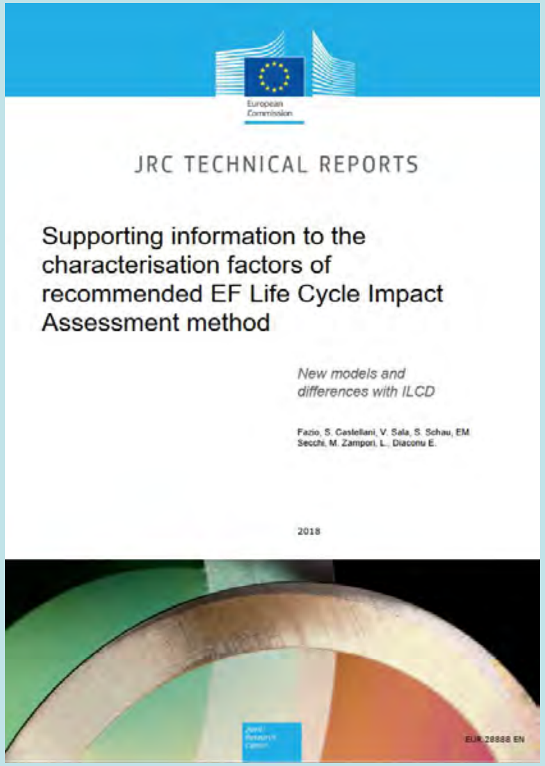
Normalisation

Internal				
External	Production-based		EU domestic	Statistics plus modelling
			Global normalization	Statistics plus modeling
	Consumption-based	Final consumption	Consumption Footprint top-down	Stats + I/O LCA
			Consumption Footprint bottom-up	Stats + Process-based LCA
		Household consumption	Consumer Footprint	Process-based LCA
			Household Footprint	I/O LCA
Absolute	Planetary boundaries			

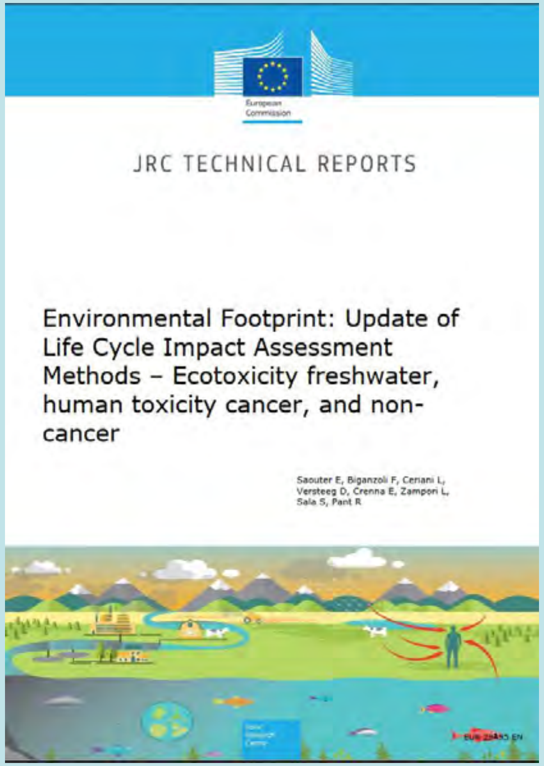
Normalisation and weighting in PEF – the LCIA recommendations evolution

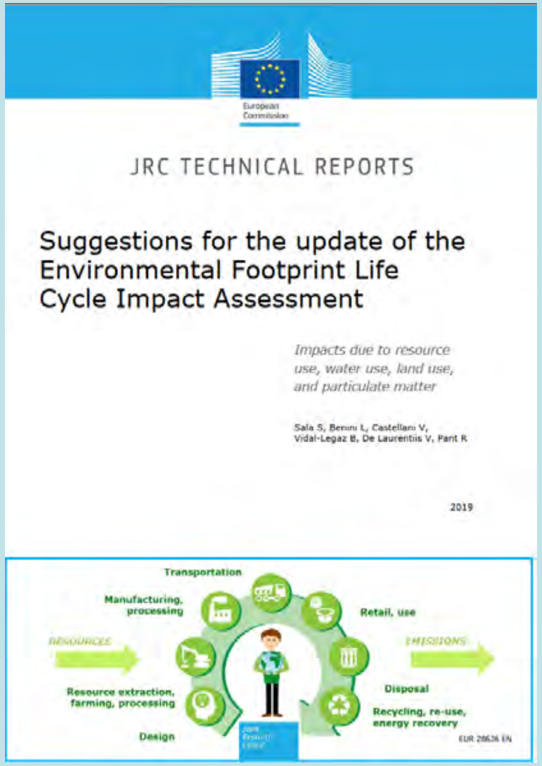
ILCD/EF at start

EF2.0



EF3.0





- EC-JRC (2011). **International Reference Life Cycle Data System (ILCD) Handbook - Recommendations based on existing environmental impact assessment models and factors for Life Cycle Assessment in a European context** .Ispra: European Commission - Joint Research Centre - Institute for Environment and Sustainability (IES).
- Saouter, E., Biganzoli, F., Ceriani, L., Versteeg, D., Crenna, E., Zampori, L., Sala, S, Pant, R. (2018). **Environmental Footprint: Update of Life Cycle Impact Assessment Methods – Ecotoxicity freshwater, human toxicity cancer, and non-cancer.** EUR 29495 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-98182-1
- Sala S, Benini L, Castellani V, Vidal Legaz B, De Laurentiis V, Pant R. (2019) **Suggestion for the update of the Environmental Footprint Life Cycle Impact Assessment. Impacts due to resource use, water use, land use and particulate matter.** EUR 28636 EN Luxembourg (Luxembourg): Publications Office of the European Union; ISBN 978-92-79-69336-6.

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Normalisation

EU references ILCD

EU 27 in 2010
Statistical sources plus modelling of emissions as reported in Sala et al. 2015

Global references ILCD and EF 3.0

World in 2010
Statistical sources plus modelling of emissions as reported in Crenna et al. 2019

- Crenna E, Secchi M, Benini L, Sala S (2019) **Global environmental impacts: data sources and methodological choices for calculating normalisation factors.** International Journal of LCA, p.1-27, https://doi.org/10.1007/s11367-018-1534-9
- Sala S., Benini L., Mancini L., Pant R. (2015) **Integrated assessment of environmental impact of Europe in 2010: data sources and extrapolation strategies for calculating normalisation factors.** International Journal of LCA, 20(11):1568-1585; DOI: 10.1007/s11367-015-0958-8

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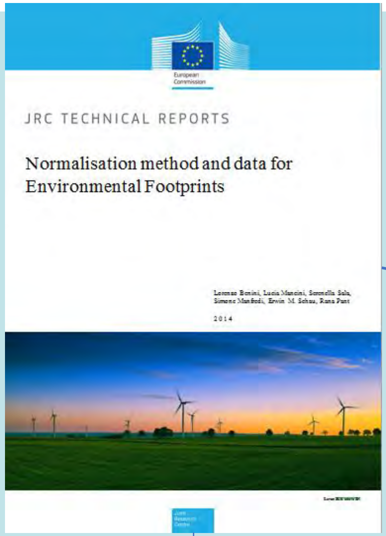
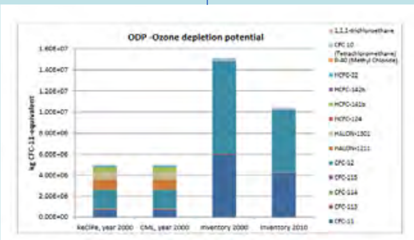
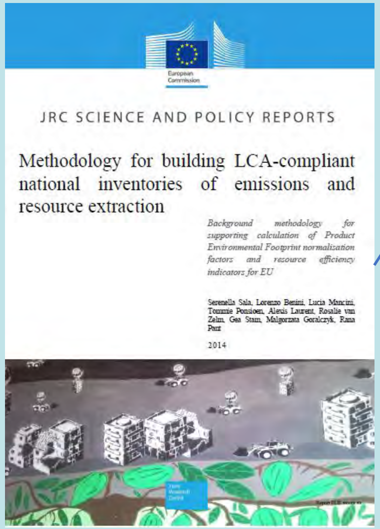
Normalisation references at EU scale

- **Building the EU domestic inventory**
  - **Domestic inventory: hierarchical approach** in selecting source of data + **extrapolation** and **data gap filling** procedures (**Sala et al., 2014 and Sala et al. 2015**)
  - Comparison with inventories of previous sets (e.g. Recipe/CML year 2000)
- **Quality assessment → completeness and robustness**







EU references ILCD

EU 27 in 2010
Statistical sources plus modelling of emissions as reported in Sala et al. 2015

- Sala S, Benini L, Mancini L, Ponsioen T, Laurent A, Van Zelm R, Stam G, Goralczyk M, Pant R. (2014) **Methodology for building LCA-compliant national inventories of emissions and resource extraction. Background methodology for supporting calculation of Product Environmental Footprint normalisation factors and resource efficiency indicators for EU.** EUR 26871. Luxembourg (Luxembourg): Publications Office of the European Union
- Benini L., Mancini L., Sala S., Manfredi S., Schau E. M., Pant R. (2014) **Normalisation method and data for Environmental Footprints.** European Commission, Joint Research Center, Institute for Environment and Sustainability, Publications Office of the European Union, Luxemburg, ISBN: 978-92-79-40847-2
- Sala S., Benini L., Mancini L., Pant R. (2015) **Integrated assessment of environmental impact of Europe in 2010: data sources and extrapolation strategies for calculating normalisation factors.** International Journal of LCA, 20(11):1568-1585; DOI: 10.1007/s11367-015-0958-8

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Approaches in developing the EU domestic inventory

Approach	Description
1. Officially reported data	Datasets reported by EU and **international bodies** which are based on **agreed models/methods/standards**, with **documented metadata** and periodical **quality checks** on completeness and robustness. (e.g. Eurostat, FAO, OECD, BGS)
2. Activity-based estimations	Based on the following equation: **Activity x Emission factor** Activity data are taken from reported data; emission factors are based on scientific literature, Life Cycle Inventories (LCIs), grey literature (e.g. sectorial reports).
3. Statistically significant proxies	**Proxies such as time and similar flows** are identified and correlations are tested.
***4. Ad-hoc* assumptions**	**Assumptions** based on expected cause-effect relationships among variables models, **not statistically significant**. Very often used for **filling-in punctual data gaps** (e.g. figure available for 2009 not for 2010 and no evident underlying trend).

Robustness

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Contribution by elementary flow

- Few elementary flows dominate the normalization (e.g. NOx)
- The relative relevance of substances may significantly change when changing LCIA method

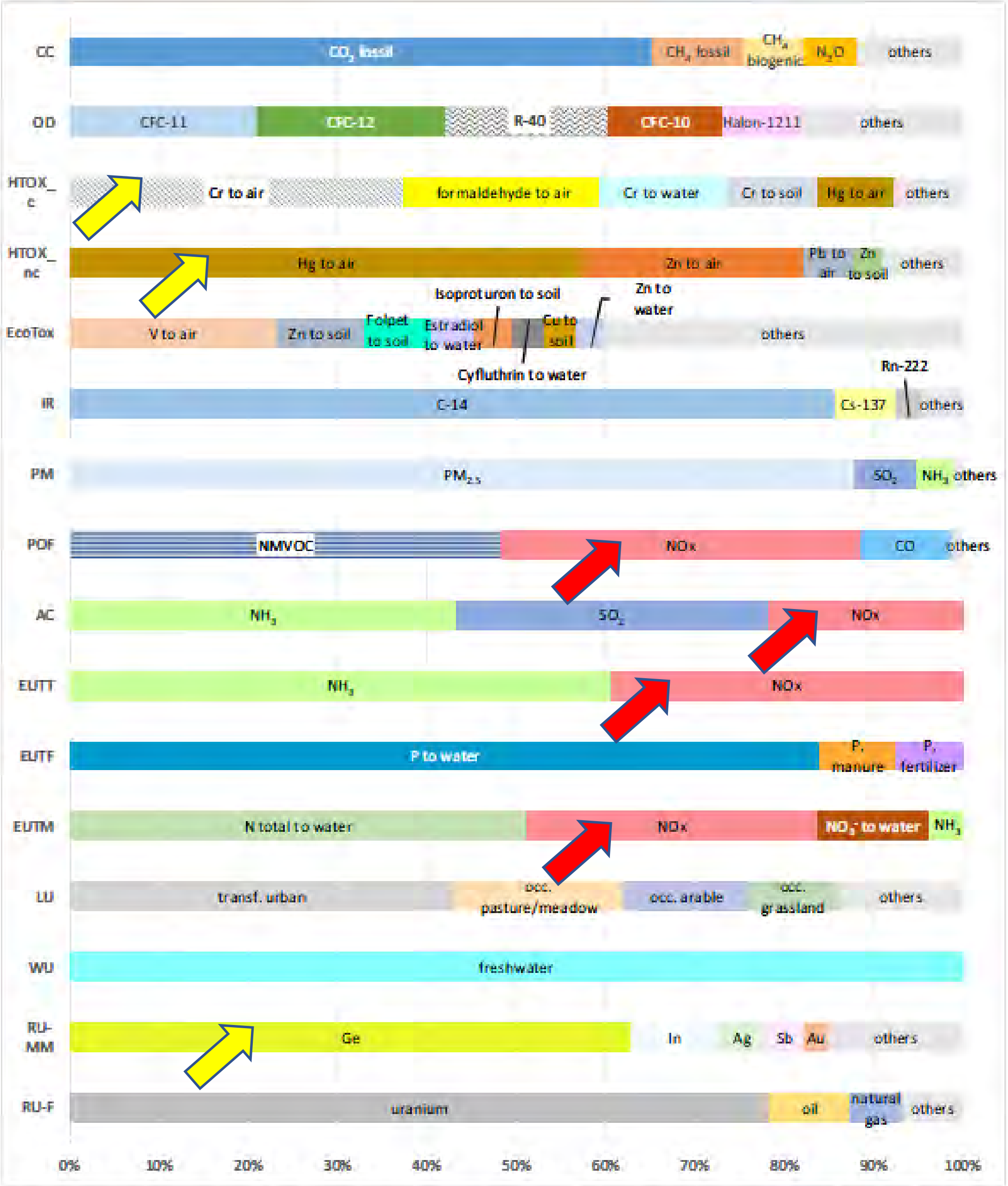
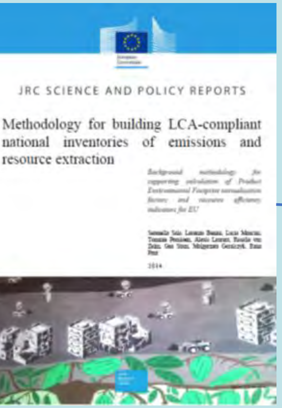


Fig. 1 Overview of the main contributing substances, in terms of percentage of the overall impact of different impact categories, characterized with ILCD CFs, for climate change (CC); ozone depletion (OD); human toxicity-cancer effects (HTOX_c) and non-cancer effects (HTOX_nc); ecotoxicity (EcoTOX); ionizing radiation (IR); particulate matter (PM); photochemical ozone formation (POF); acidification (AC); eutrophication terrestrial (EUTT), freshwater (EUTF) and marine (EUTM); resource use both minerals and metals (RU-MM) and fossils (RU-F)

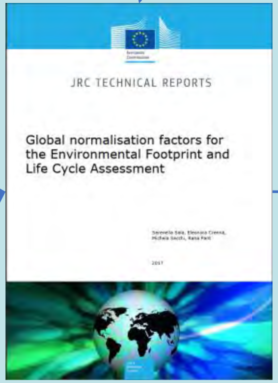
Normalisation references at global scale

-Officially reported data at global scale
- Literature at global scale

Global references ILCD and EF 3.0



Modelling principles for some impact categories

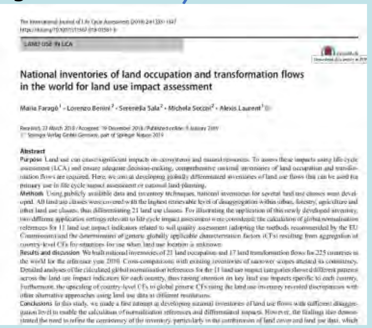


As basis for extrapolation

Cucurachi et al. 2019

Leclerc et al. 2019

Farago' et al. 2019



World in 2010
Statistical sources plus modelling of emissions as reported in Crenna et al. 2019

Sensitivity analysis of different sources

- Crenna E, Secchi M, Benini L, Sala S (2019) **Global environmental impacts: data sources and methodological choices for calculating normalisation factors.** International Journal of LCA, p.1-27
- Cucurachi S., Sala S., Laurent A., Hejiungs R., (2014) **Building and characterizing regional and global emission inventories of toxic pollutants.** Environmental Science and Technology 48 (10):5674–5682
- Leclerc A., Sala S., Secchi M., Laurent A. (2019) **Building national emission inventories of toxic pollutants in Europe**. Environment International, 130, 104785
- Faragò M; Benini L; Sala S; Secchi M; Laurent A. (2019) **National inventories of land occupation and transformation flows in the world for land use impact assessment.** International Journal of LCA, 24 (8):1333-1347
- Sala S, Benini L, Mancini L, Ponsioen T, Laurent A, Van Zelm R, Stam G, Goralczyk M, Pant R. (2014) **Methodology for building LCA-compliant national inventories of emissions and resource extraction. Background methodology for supporting calculation of Product Environmental Footprint normalisation factors and resource efficiency indicators for EU.** EUR 26871Publications Office of the European Union

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Key issues

- Availability of data:
  - Hierarchical approach to data sources selection
  - Modelling approaches
  - Extrapolation strategies
  - Data gap filling procedures
- Approach to characterization:
  - Regionalisation/ use of default factors (Benini et al. 2016)
  - Marginal/average characterization factors (Boulay et al. 2019)
- Consistency inventory normalisation and inventory in LCA dataset

The International Journal of Life Cycle Assessment
https://doi.org/10.1007/s11367-019-01604-y

POLICIES AND SUPPORT IN RELATION TO LCA

Check for updates

Global environmental impacts: data sources and methodological choices for calculating normalization factors for LCA

Eleonora Crenna[1] · Michela Secchi[1] · Lorenzo Benini[1,2] · Serenella Sala[1]

Received: 2 February 2018 / Accepted: 5 September 2018

Abstract
Purpose Characterizing environmental impacts at the global scale is crucial to define references against which compare the environmental profile of products and systems. Within this study, global emissions and resource uses have been collected and characterized for the following impact categories: climate change, ozone depletion, human toxicity (cancer and non-cancer), ecotoxicity, particulate matter, ionizing radiation, photochemical ozone formation, acidification, eutrophication (terrestrial, marine, and freshwater), land use, water use, and resource use. The results can be used as normalization factors (NFs) in the context of the life cycle assessment (LCA).
Material and methods The global NFs are built on an extensive collection of data on emissions and resources extracted at a global scale in 2010, gathering different sources and comparing them. A hierarchical approach was applied to the selection of data sources. Extrapolations, mainly temporal data-gap filling, were applied for complementing the inventories for missing data. In order to calculate NFs, the inventory was characterized by using the International Reference Life Cycle Data System (ILCD) midpoint indicators and the EU Environmental Footprint (EF) set, which includes recently released models.

- Benini L., Sala S (2016) **Integrated assessment of environmental impact of Europe in 2010: uncertainty and sensitivity of the normalisation factors to methodological assumptions.** International Journal of LCA, 21(2):224-236, doi: 10.1007/s11367-015-1013-5
- Boulay AM, Benini L., Sala S. (2019) **Non-marginal impact assessment in life cycle assessment and application to the AWARE water scarcity method**. International Journal of LCA https://doi.org/10.1007/s11367-019-01680-0

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Normalisation with ILCD and EF3.0 in Crenna et al. 2019

Several issues affect the final figures!!

ILCD 2011					EF 3.0				Inventory assessment, applicable to both ILCD and EF 3.0	
Impact category	Unit	ILCD global NFs	Alternative results adopting different sources/assumptions	Robustness of ILCD impact assessment[3]	Impact category	Unit per year (2010)	Global NFs for EF 3.0	Robustness of EF 3.0 impact assessment[4]	Inventory coverage completeness[1]	Inventory robustness[2]
Climate change	kg CO_2 eq	4.95E+13	2.37E+13	I	Climate change	kg CO_2 eq	5.55E+13	I	II	I
Ozone depletion	kg CFC-11 eq	3.34E+08	3.39E+08	I	Ozone depletion	kg CFC-11 eq	3.33E+08	I	III	II
Human toxicity, cancer	CTUh	3.37E+05	9.16E+04 (avg. based)[5] 2.66E+05 (Hg based) 4.06E+04 (GDP based) 7.12E+04 (CO_2 based) 1.80E+05 (HMs adjusted)	II/III	Human toxicity,	CTUh	1.28E+05	II	III	III
Human toxicity, non-cancer	CTUh	5.91E+06	1.13E+06 (avg. based) 3.27E+06 (Hg based) 5.01E+05 (GDP based) 8.77E+05 (CO_2 based) 3.37E+06 (HMs adjusted)	II/III	Human toxicity, non-cancer	CTUh	1.59E+06	II	III	III
Ecotoxicity freshwater	CTUe	5.78E+13	2.75E+13 (avg. based) 8.15E+13 (Hg based) 1.21E+13 (GDP based) 2.12E+13 (CO_2 based) 8.15E+13 (HMs adjusted)	II/III	Ecotoxicity freshwater	CTUe	2.94E+14	II	III	III
Particulate matter	kg $PM_{2.5}$ eq (urban/non--urban CFs)	9.27E+10	4.61E+10	I	Particulate matter	Disease incidences (emission height-specific CFs, and urban/non--urban)	4.11E+06	I	I/II	I/II
	kg $PM_{2.5}$ eq (average CFs)	5.37E+10				Disease incidences ... CFs)	1.24E+07			
Ionizing radiation	kBq U-235 eq	9.54E+				...5 eq	9.54E+11	II	II	III
Photochemical ozone formation	kg NMVOC eq	2.80E+				...C eq	2.80E+11	II	III	I/II
Acidification	mol H^+ eq	3.83E+					3.83E+11	II	II	I/II
	mol N eq	1.22E+					1.22E+12	II	II	I/II

Extrapolation strategies

Model selection and assumptions on compartments

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ILCD 2011					EF 3.0				Inventory assessment, applicable to both ILCD and EF 3.0	
Impact category	Unit	ILCD global NFs	Alternative results adopting different sources/assumptions	Robustness of ILCD impact assessment[3]	Impact category	Unit per year (2010)	Global NFs for EF 3.0	Robustness of EF 3.0 impact assessment[4]	Inventory coverage completeness[1]	Inventory robustness[2]
Eutrophication, terrestrial			8.68E+11		Eutrophication, terrestrial					
Eutrophication, freshwater	kg P eq	1.11E+10	n.a.	II	Eutrophication, freshwater	kg P e				
Eutrophication, marine	kg N eq	1.35E+11	n.a.	II	Eutrophication, marine	kg N (				
Land use	kg C deficit	8.83E+14	n.a.	III	Land use	Pt (country-specific CFs)	5.65E+15	III	II	II
						Pt (global default CFs)	7.19E+15			
Water depletion	m^3 water eq (country--specific CFs)	7.67E+13	4.81E+13	III	Water use	m^3 water eq of deprived water (country-specific CFs, marginal approach)	7.91E+13	III	I	II
	m^3 water eq (global default CFs)	7.10E+11	5.01E+11			m^3 water eq of deprived water (global default CFs, marginal approach)	7.89E+13			
Resource depletion	kg Sb eq					MJ	4.48E+14	III	I	II
						kg Sb eq	4.39E+08	III		

Regionalised or global default CFs

Marginal or not marginal approach to characterisation

[1] It represents the completeness of the dataset used for building the final inventory and is estimated as the ratio between the retrieved inventory data over the available flows in ILCD for the specific impact category

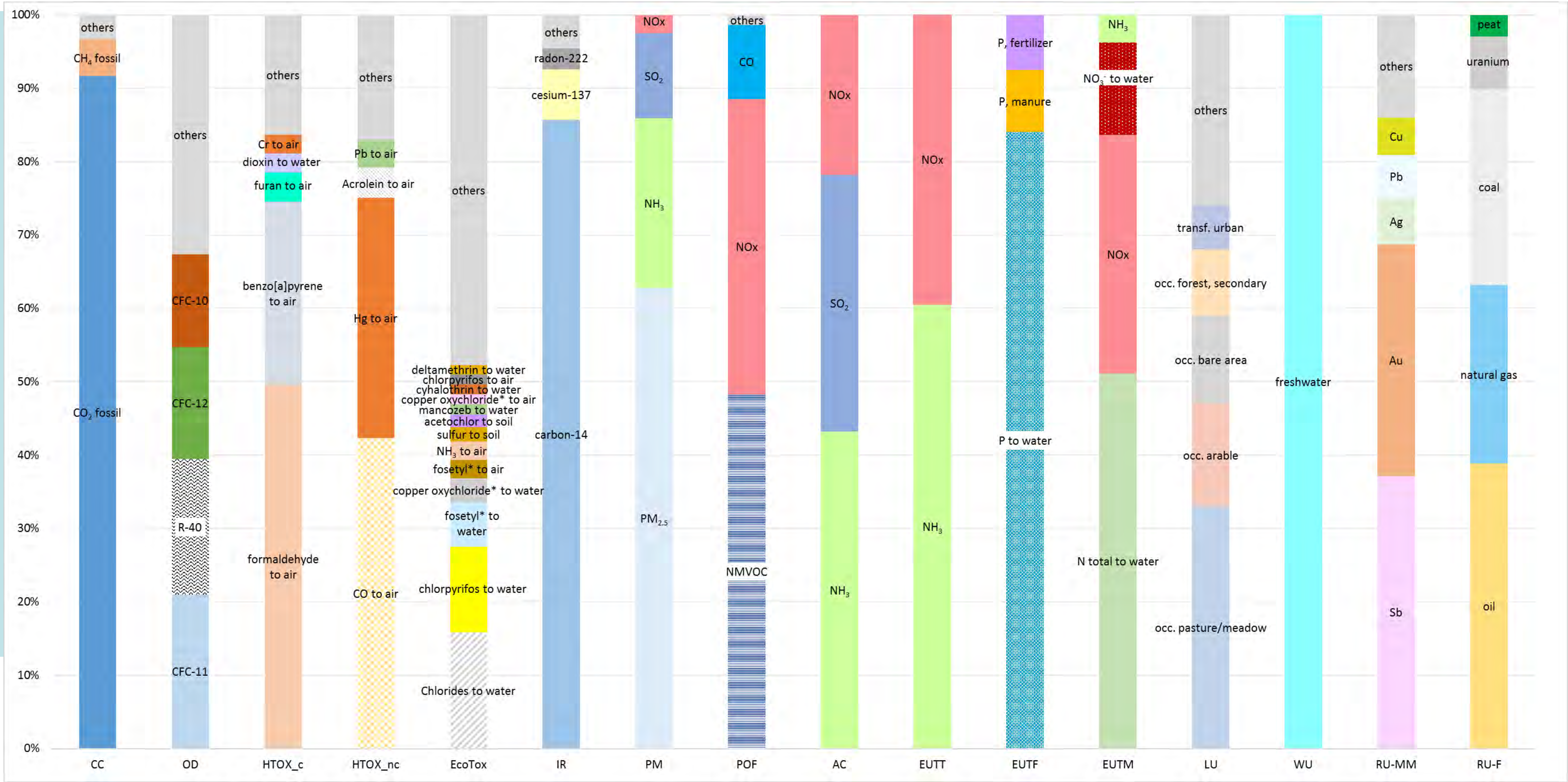
[2] It is based on data quality, entailing the combination of different sources, and the adoption of extrapolation strategies

[3] This corresponds to the classification of recommended models in ILCD (EC-JRC 2011)

[4] This corresponds to the classification of suggested models in the EF 3.0 (Zampori & Pant, 2019a,b; Fazio et al., 2018b)

[5] Toxicity-related impact categories extrapolation strategies: Avg. based, the geometric mean of available extrapolations (namely GDP, HM, and CO_2); GDP based, extrapolation based on GDP per country; CO_2 based, extrapolation based on CO_2 emission per country; HMs adjusted, HMs emission from manure corrected as for Leclerc and Laurent (2017)

Contribution by flow- global



EU vs global references

Table 4 Overview of the relative environmental impacts of the European system compared to the world and expressed as a percentage. The share is reported, for each impact category according to the calculations from (i) this study; (ii) the NFs calculated in the Prosuite Project, Laurent et al. (2013); and (iii) the NFs of Sleeswijk et al. (2008)

		EU/global NFs ratio (%)		
ILCD impact category	Unit according to ILCD*	As in this study (ILCD v.1.010)[a]	As in PROSUITE (Laurent et al. 2013)[b]	As in Sleeswijk et al. (2008)[c]
Climate change	kg CO_2 eq	9	8	12
Ozone depletion	kg CFC-11 eq	3	4	3
Human toxicity, cancer	CTUh	6	5	10
Human toxicity, non-cancer	CTUh	5	4	10
Particulate matter	kg $PM_{2.5}$ eq	2[d]	10	8
Ionizing radiations	kBq U-235 eq	61[e]	6	36
Photochemical ozone formation	kg NMVOC eq	6	4	8
Acidification	mol H^+ eq	6	7	8
Eutrophication, terrestrial	mol N eq	7	11	n.a.
Eutrophication, freshwater	kg P eq	7	17	9
Eutrophication, marine	kg N eq	6	13	10
Land use	kg C deficit	4	2	6
Ecotoxicity freshwater	CTUe	8	21[f]	20
Water depletion (water use in EF)	m^3 water eq	< 1	20	n.a.
Resource depletion (resource use in EF)	kg Sb eq	1	2	n.a.

- Issues in EU normalization are associated with specific features of EU current production and consumption system, e.g.:
  - Relevance of production of energy from nuclear compared to ROW
  - Limited resource extraction in EU

- Crenna E, Secchi M, Benini L, Sala S (2019) **Global environmental impacts: data sources and methodological choices for calculating normalisation factors.** International Journal of LCA, p.1-27

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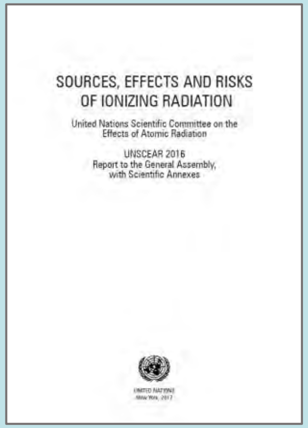
Example of consistency issue– Ionizing Radiation (IR)

Current references



UNSCEAR Report (2017a,b)


The International Journal of Life Cycle Assessment

POLICIES AND SUPPORT IN RELATION TO LCA

Global environmental impacts: data sources and methodological choices for calculating normalization factors for LCA

Eleonora Crenna[1] · Michela Secchi[1] · Lorenzo Benini[1,2] · Serenella Sala[1]

Received: 2 February 2018 / Accepted: 5 September 2018

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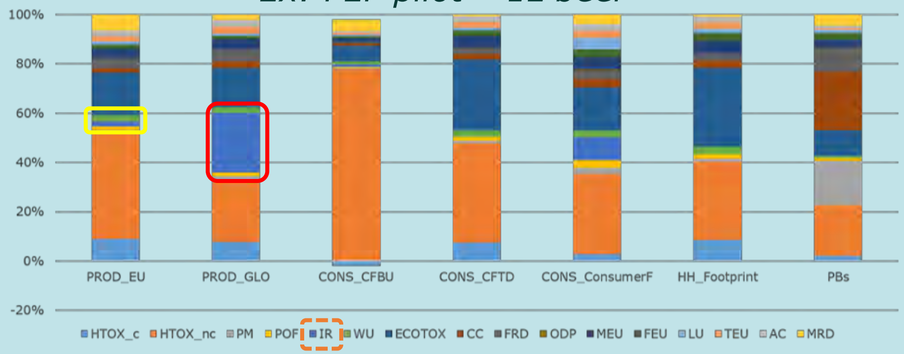
Crenna et al. (2019)

Includes nuclear spent-fuel reprocessing.

The Issue

Ex: PEF pilot – 1L beer



- **At global level** – Normalized IR emissions exhibit an highest than expected relevance among all other impact categories.
- **At EU level** – Effect is mitigated because of the several nuclear sites present in Europe.

Consumption based approach could help with this kind of issue

Ongoing Analysis

1. **Ecoinvent 3.5 overview**
   Analysis of foreground/background most relevant processes for IR emissions from electricity production (Nuclear BWR/PWR, Coal, Oil, Gas, Geothermal);
2. **Global emissions from electricity production**
   Analysis global IR emissions from electricity production (Nuclear BWR/PWR/Other, Coal, Oil, Gas);
3. **Global emissions from extraction**
   Analysis global IR emissions from mining and extraction of raw materials (Uranium, Coal, Oil, Natural gas).

Updated/Suggested Normalization Factor for IR at global scale

- UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) (2017b) **UNSCEAR 2016 Report on the General Assembly, Annex A: sources, effects and risks of ionizing radiation.** 118p. New York.
- UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) (2017a) **UNSCEAR 2016 Report on the General Assembly, Annex B: sources, effects and risks of ionizing radiation.** 108p. New York.
- Crenna, E., Secchi, M., Benini, L., & Sala, S. (2019) **Global environmental impacts: data sources and methodological choices for calculating normalization factors for LCA.** The International Journal of Life Cycle Assessment, 1-27.

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Normalisation

Internal				
External	Production-based		EU domestic	Statistics plus modelling
			Global normalization	Statistics plus modeling
	Consumption-based	Final consumption	Consumption Footprint top-down	Stats + I/O LCA
			Consumption Footprint bottom-up	Stats + Process-based LCA
		Household consumption	Consumer Footprint	Process-based LCA
			Household Footprint	I/O LCA
Absolute	Planetary boundaries			

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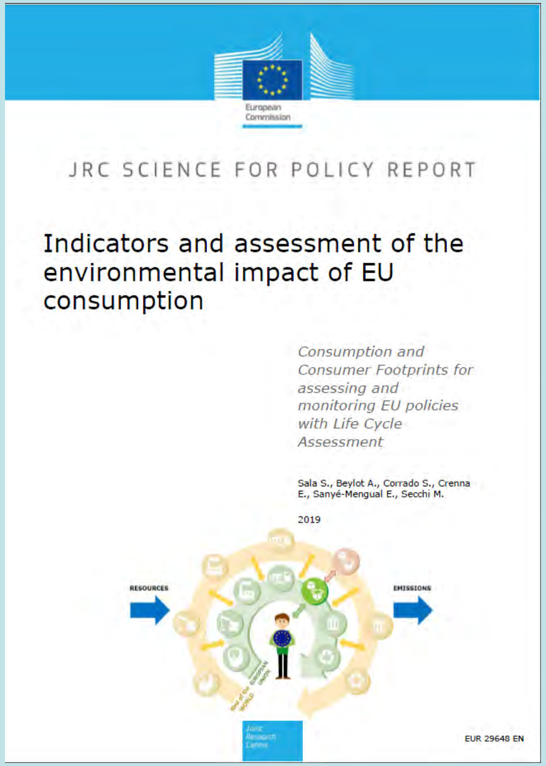
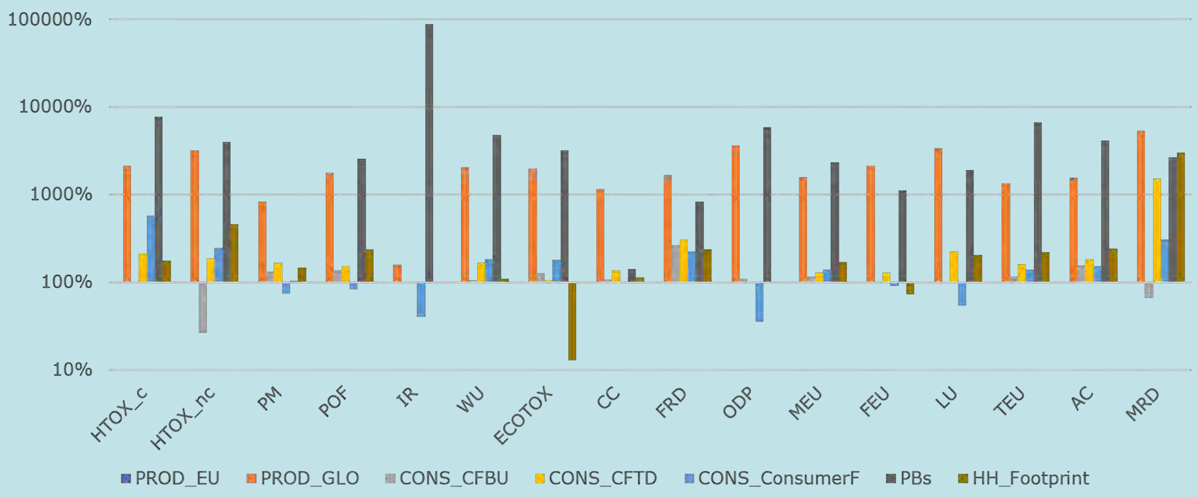
Consumption-based normalisation

- Consumption-based normalization may help overcome some known issues in normalization:
  - e.g. the mismatch of flows from process-based inventories and the environmental profile of products (as in the example on ionizing)

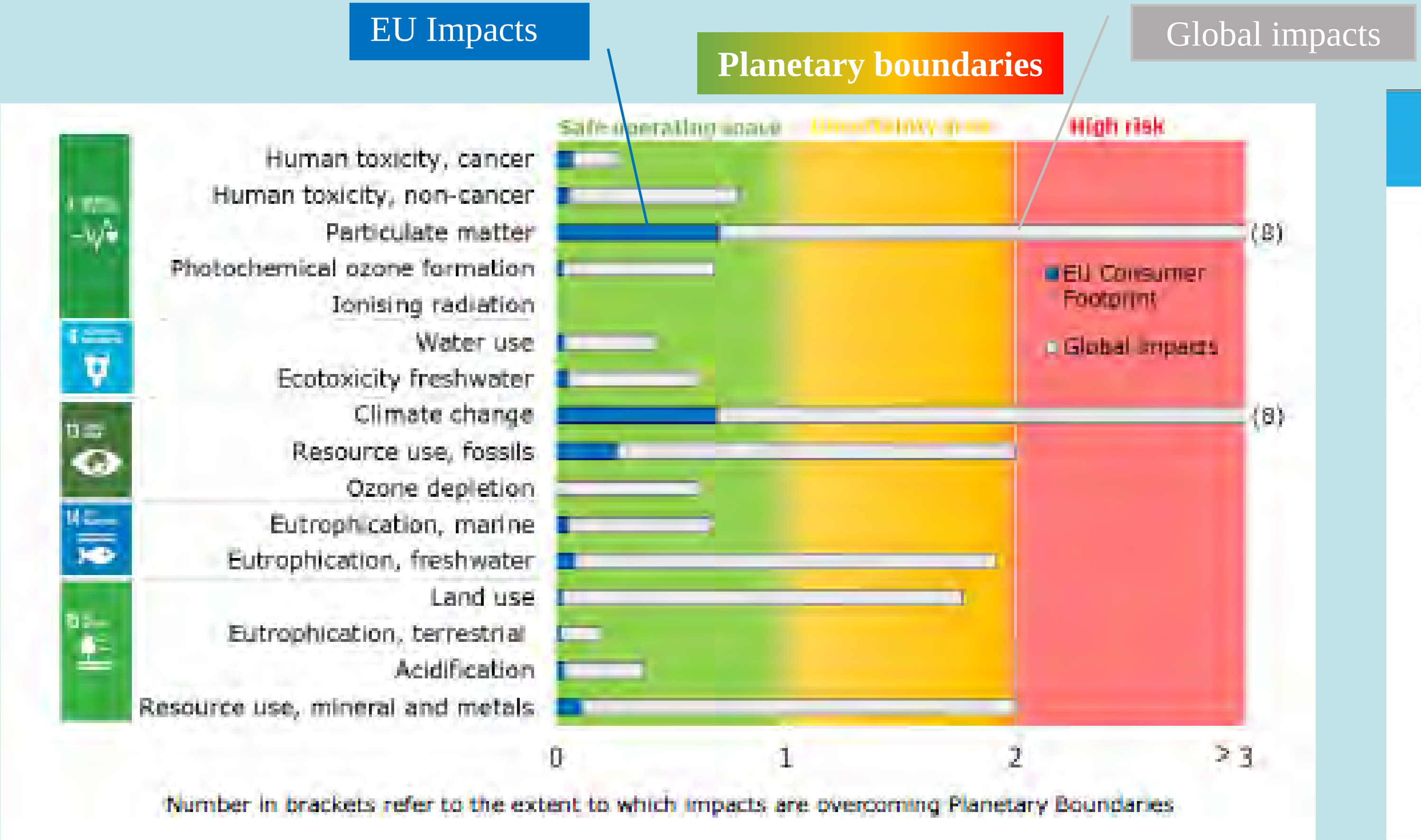


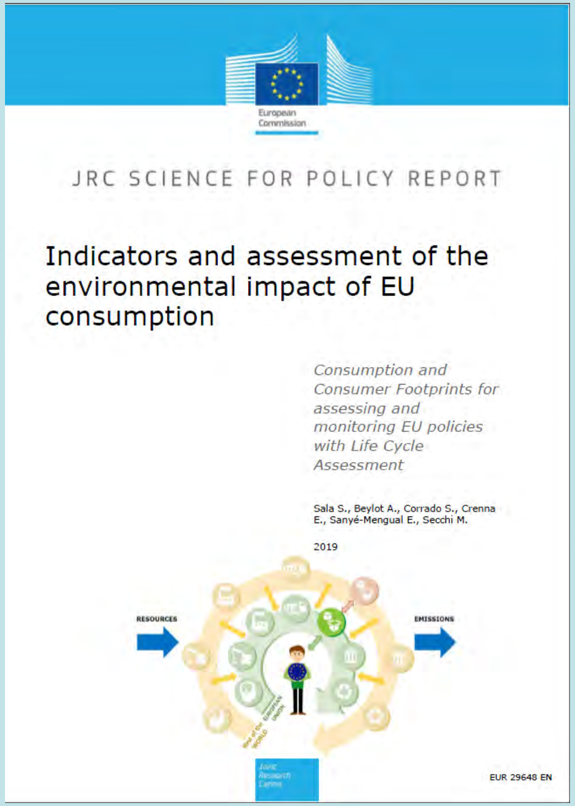


Sala S., Beylot A., Corrado S., Crenna E., Sanyé-Mengual E, Secchi M. (2019a) **Indicators and Assessment of the environmental impact of EU consumption. Consumption and Consumer Footprint for assessing and monitoring EU policies with Life Cycle Assessment**. Science for policy report. Publications Office of the European Union.

Planetary boundaries

Development of a set of planetary boundaries - based references to be applied to EF LCIA impact categories (Sala et al. 2019a,b)




JRC SCIENCE FOR POLICY REPORT

Indicators and assessment of the environmental impact of EU consumption

Consumption and Consumer Footprints for assessing and monitoring EU policies with Life Cycle Assessment

Sala S., Beylot A., Corrado S., Crenna E., Sanyé-Mengual E., Secchi M.

2019

RESOURCES

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EUR 29648 EN

Sala S., Beylot A., Corrado S., Crenna E., Sanyé-Mengual E, Secchi M. (2019a) **Indicators and Assessment of the environmental impact of EU consumption. Consumption and Consumer Footprint for assessing and monitoring EU policies with Life Cycle Assessment**. Science for policy report. Publications Office of the European Union.

Sala S., Crenna E., Secchi M., Sanye- Menigual E. (2019b) **Environmental sustainability of European production and consumption assessed against planetary boundaries.** Submitted to Journal of Environmental Management

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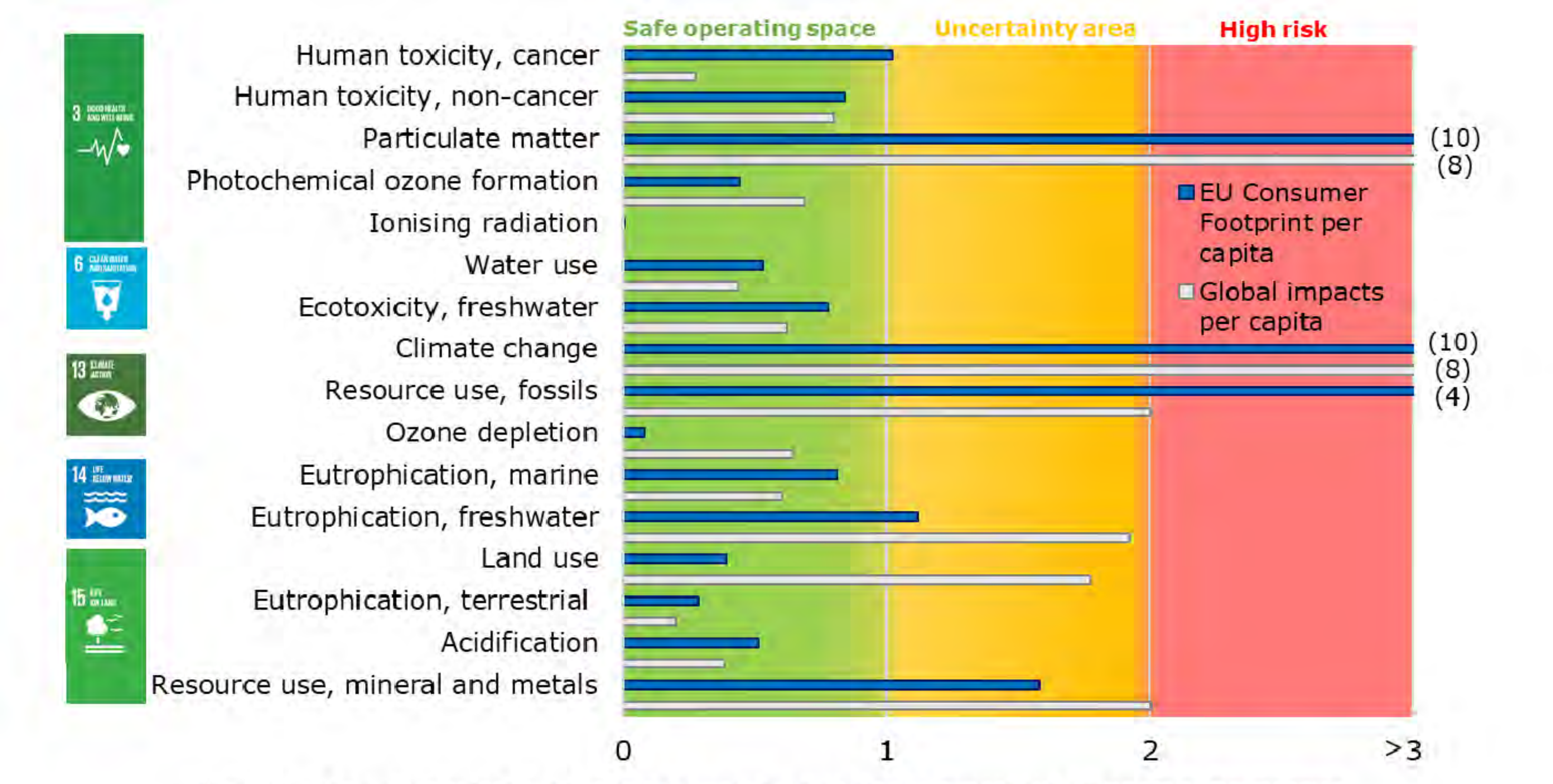
Per capita assessment



According to an equal allocation of the boundaries per person, the average impact of an European citizen is compared to an average global citizen

Sala S., Beylot A., Corrado S., Crenna E., Sanyé-Mengual E, Secchi M. (2019a) **Indicators and Assessment of the environmental impact of EU consumption. Consumption and Consumer Footprint for assessing and monitoring EU policies with Life Cycle Assessment**. Science for policy report. Publications Office of the European Union.
Sala S., Crenna E., Secchi M., Sanye- Menigual E. (2019b) **Environmental sustainability of European production and consumption assessed against planetary boundaries.** Submitted to Journal of Environmental Management

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Weighting in Environmental Footprint

- Current EF recommendations for weighting are the result of a process of:
  - Review and assessment of weighting schemes available until 2018 in synergy with the UNEP-SETAC life cycle initiative working group (Pizzol et al. 2017)
  - Workshop with EF pilots to assess main issues and needs associated with weighting
  - Ad-hoc development of a weighting set

Sala, S., Cerutti, A. and Pant, R., (2018) **Development of a weighting approach for the Environmental Footprint.** EUR 28562 EN, Publications Office of the European Union, Luxembourg, doi: 10.2760/446145
Pizzol M, Laurent A, Sala S, Weidema B, Verones F, Koffler C (2017) **Normalisation and weighting in life cycle assessment: Quo Vadis?** International Journal of LCA, 22(6):853-866, doi: 10.1007/s11367-016-1199-1

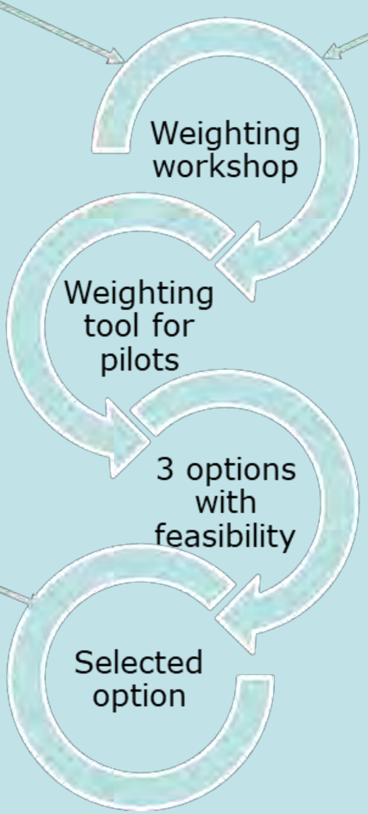
Steps of the development of the EF weighting set

Initial set for EF

Impact categories	Weighting factors 1-1-1
Climate change	7.14
Ozone depletion	7.14
Human toxicity, cancer effects	7.14
Human toxicity, non-cancer effects	7.14
Particulate matter	7.14
Ionizing radiation, human health	7.14
Photochemical ozone formation, HH	7.14
Acidification	7.14
Eutrophication	7.14
Land use	7.14
Ecotoxicity freshwater	7.14
Resource use, water	7.14
Resource use, mineral and metals	7.14
Resource use, fossils	7.14

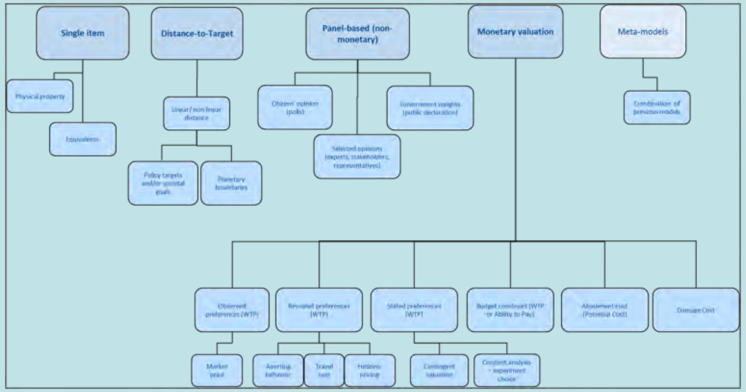
Distance to target weighting set for EU 2020

Castellani et al.2016



Horizon scanning: literature review of papers, reports, proposals from PEF pilots, UNEP-SETAC process

Pizzol et al., 2017



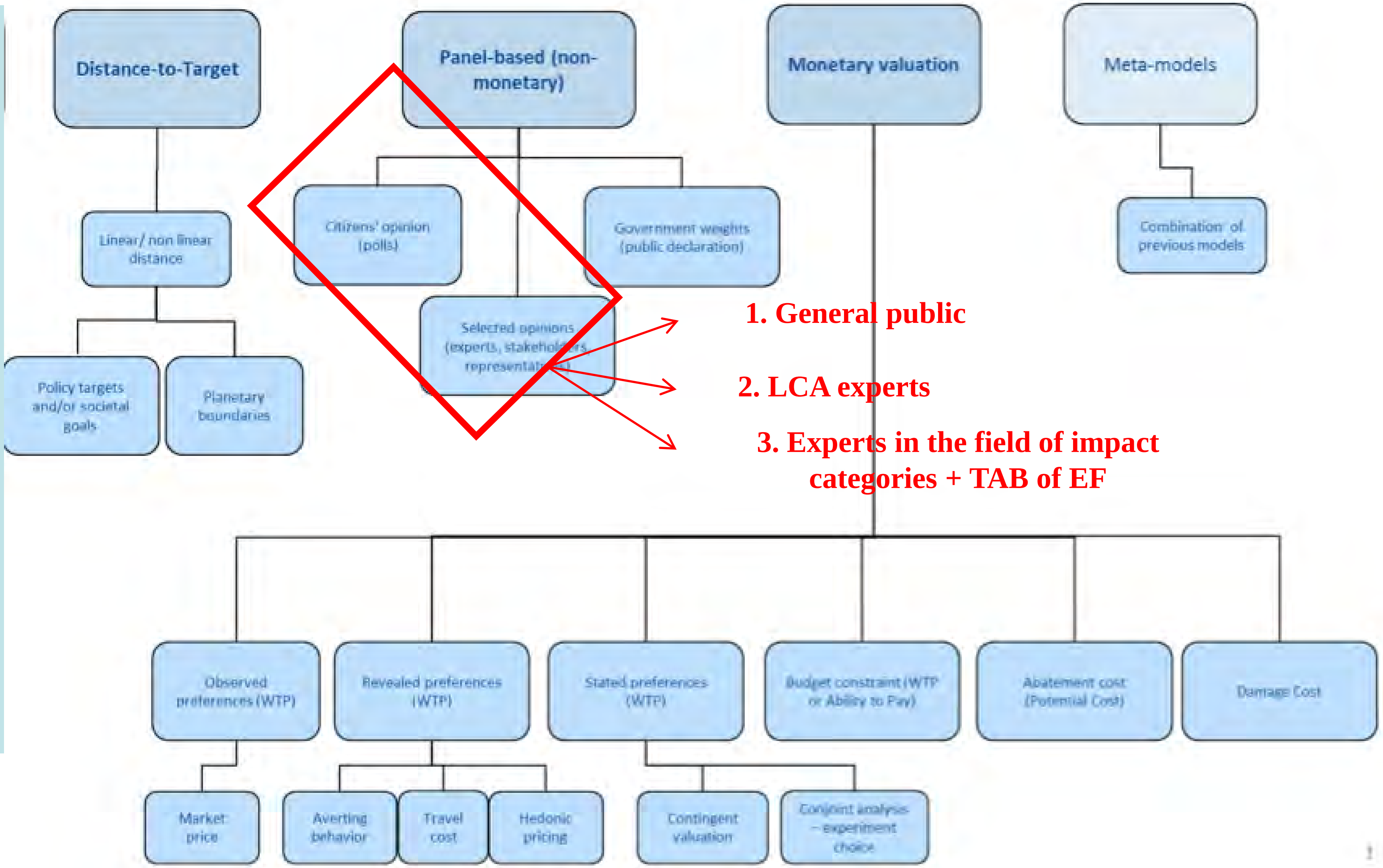
Assessing pro’s and con’s of the options and proposing a strategy for aggregation of results

Development of the EF weighting set according to the preferred option:
a hybrid evidence- and judgement-based weighting set

- Panel-based for public and experts
- Evidence- based webinar for experts

- Pizzol M, Laurent A, Sala S, Weidema B, Verones F, Koffler C (2017) **Normalisation and weighting in life cycle assessment: Quo Vadis?** International Journal of LCA, 22(6):853-866, doi: 10.1007/s11367-016-1199-1
- Castellani V, Benini L, Sala S, Pant R (2016) **A distance-to-target weighting method for Europe 2020** International Journal of LCA, 21(8):1159-1169 doi: 10.1007/s11367-016-1079-8

Use of multiple stakeholders' preferences



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Criteria for evaluating the relevance of the impacts

The weighting set built by experts accounts for aspects related to:

- **environmental relevance**
- **socio-political relevance**;
- **scientific robustness**

- Criteria adapted from Soares et al. 2006 have been selected to be used to assess the relevance of the different impact categories.

- Criteria aim at reflecting aspects of the impacts which are inherentely related to the nature of the impact and the way it is exerted, namely related to questions such as:
- Where? ***Spread of impact***
- For how long? ***Time span of generated impact***
- *Is it reversible?* ***Reversibility***
- *Is the actual level close to Earth carrying capacity?* ***Planetary boundary***
- *How severe are the impacts on ecosystem health, human health, or natural resource availbility?* ***Severity***

Soares, S. R., L. Toffoletto, and L. Deschênes. 2006. **Development of weighting factors in the context of LCIA**. Journal of Cleaner Production 14:649-660.

Table for experts inspired by Soares approach

Used in webinar with impact assessment experts

Impact category	Scale of impacts	Spread of pressure	Duration of impact	Reversibility	Planetary boundary	Effect on human health	Effect on ecosystem quality	Effect on resources availability
Climate change	Global	Globally present	Very long term	Natural (partial)	Greater	High	Low	Medium
Ozone depletion	Global	Highly diffused	Medium term	Natural (complete)	Far smaller	Very high	High	Not-existing
Human toxicity, cancer effects	Global	Widespread	Very long term	Irreversible	Greater	Very high	Not-existing	Not-existing
Human toxicity, non-cancer effects	Global	Widespread	Long term	Solely artificial (partial)	Of the same order	Very high	Not-existing	Not-existing
Particulate matter/Respiratory inorganics	Local	Widespread	Long term	Solely artificial (partial)	Greater	High	Not-existing	Not-existing
Ionizing radiation, human health	Global	Little diffused	Very long term	Irreversible	Of the same order	Very high	Low	Not-existing
Photochemical ozone formation, human health	Local	Medium diffused	Long term	Solely artificial (partial)	Of the same order	High	Low	Not-existing
Acidification	Regional	Highly diffused	Medium term	Natural (partial)	Far smaller	Not-existing	High	Medium
Eutrophication terrestrial	Regional	Highly diffused	Medium term	Natural (partial)	Far greater	Not-existing	High	Medium
Eutrophication freshwater	Regional	Highly diffused	Medium term	Natural (partial)	Far greater	Not-existing	High	Medium
Eutrophication marine	Regional	Medium diffused	Medium term	Natural (partial)	Far greater	Not-existing	High	Medium
Land use	Local	Little diffused	Long term	Natural (partial)	Of the same order	Not-existing	Very high	High
Ecotoxicity freshwater	Global	Little diffused	Long term	Solely artificial (partial)	Far greater	Not-existing	Very high	High
Resource depletion water	National	Little diffused	Medium term	Solely artificial (partial)	Far smaller	Very high	Very high	Very High
Resource depletion, mineral	Global	Little diffused	Very long term	Irreversible	n.a.	Low	High	Very High
Resource depletion, fossils	Global	Little diffused	Very long term	Solely artificial (partial)	n.a.	Low	High	Very High

Results for weighting from questionnaires and webinar

- Summary of the three weighting sets (survey to public, to expert and webinar) at the midpoint level, including toxicity related impact categories.

	Public	Experts	Webinar
Climate change	16.25	17.72	9.12
Ozone depletion	4.57	3.92	6.38
Human toxicity, cancer effects	6.26	5.66	6.99
Human toxicity, non-cancer effects	4.96	4.82	6.36
Particulate matter/Respiratory inorganics	4.48	5.52	5.45
Ionizing radiation, human health	4.43	3.90	6.65
Photochemical ozone formation, human health	3.84	4.31	4.86
Acidification	4.09	3.71	5.93
Eutrophication terrestrial	4.04	3.38	2.14
Eutrophication freshwater	4.25	4.03	2.14
Eutrophication marine	3.84	3.50	2.14
Ecotoxicity freshwater	4.18	4.24	8.13
Land use	10.60	10.93	7.97
Resource depletion: water	10.26	12.45	8.65
Resource depletion: mineral and metals	6.30	5.94	8.15
Resource depletion: fossil fuels	7.64	5.97	8.94

Robustness factors

Building on a table assessing the uncertainties of LCIA/normalisation/ inventory

Int J Life Cycle Assess (2015) 20:1568–1585 1575

Table 3 Normalisation factor for EU 27 in 2010 for domestic emission and resource extraction, the scoring is given from I—highest to III—lowest

Impact category	Unit	NFs for EU 27	NFs per person	Coverage completeness[a]	Robustness inventory[b]	Robustness impact assessment[c]	Overall robustness
Climate change	kg CO_2 eq	4.60E+12	9.22E+03	I/II	I	I	High
Ozone depletion	kg CFC-11 eq	1.08E+07	2.16E−02	II	III	I	Medium
Particulate matter	kg $PM_{2.5}$ eq	1.90E+09	3.80E+00	I	I/II	I	High
Photochemical ozone formation	kg NMVOC eq	1.58E+10	3.17E+01	I	II	II	Medium
Acidification	mol H^+ eq	2.36E+10	4.3E+01	I	II	II	Medium
Terrestrial eutrophication	mol N eq	8.76E+10	1.76E+02	I/II	I	II	Medium
Freshwater eutrophication	kg P eq	7.41E+08	1.48E+00	I/II	II/III	II	Medium to low
Marine eutrophication	kg N eq	8.44E+09	1.69E+01	II	II	II	Medium to low
Land use	kg C deficit	3.78E+13	7.58E+04	II/III	II	III	Low
Resource depletion water	m^3 water eq	4.06E+10	8.14E+01	III	II	III	Low
Mineral, fossil and renewable resource depletion	kg Sb eq	5.03E+07	1.01E−01	II	II	II	Medium
Human toxicity cancer	CTUh	1.88E+04	3.77E−05	III	III	II/III	Low
Human toxicity non-cancer	CTUh	2.69E+05	5.39E−04	II	III	II/III	Low
Freshwater ecotoxicity	CTUe	4.46E+12	8.94E+03	III	III	II/III	Low
Ionising radiations	kBq U_{235} eq	5.64E+11	1.13E+03	I	II	II	Medium

[a] Completeness of the dataset used for the inventory. Coverage estimate based on the extent to which the inventory data are available compared to available flows in ILCD for the specific impact category. A detailed table is reported in SI. Double values reflect the fact that the coverage is depending on completeness for different compartments

Normalisation

Global

Weighting

Public and expert elicitation

Robustness factors (interpret.)

LCIA models and normalisation robustness

Level of robustness	Associated score in scale 1-0.5	Associated score in scale 1-0.1
I	1	1
I/II	0.9	0.8
II	0.8	0.6
II/III	0.7	0.4
III	0.6	0.2
III/interim*	0.5	0.1

Final EF recommendations weighting set

The recommended weighting set for EF includes:

- weighing factors from all the three options (**a**-survey to public, **b**-survey to LCA experts, **c**-webinar with impact assessment experts)
- those are weighted as two different models, therefore calculating a 50:50 [(a+b):(c)] contribution, and
- including the robustness factors considering the scale from 1 to 0.1.

	Aggregated weighting set	Robustness factors	Intermediate Coefficients	Final weighting factors (incl. robustness)
	(A)	(B)	C=A*B	C scaled to 100
Climate change	12.90	0.87	11.18	**21.06**
Ozone depletion	5.58	0.60	3.35	**6.31**
Human toxicity, cancer effects	6.80	0.17	1.13	**2.13**
Human toxicity, non-cancer effects	5.88	0.17	0.98	**1.84**
Particulate matter	5.49	0.87	4.76	**8.96**
Ionizing radiation, HH	5.70	0.47	2.66	**5.01**
Photochemical ozone formation, HH	4.76	0.53	2.54	**4.78**
Acidification	4.94	0.67	3.29	**6.20**
Eutrophication, terrestrial	2.95	0.67	1.97	**3.71**
Eutrophication, freshwater	3.19	0.47	1.49	**2.80**
Eutrophication, marine	2.94	0.53	1.57	**2.96**
Ecotoxicity freshwater	6.12	0.17	1.02	**1.92**
Land use	9.04	0.47	4.22	**7.94**
Water use	9.69	0.47	4.52	**8.51**
Resource use, mineral and metals	6.68	0.60	4.01	**7.55**
Resource use, fossils	7.37	0.60	4.42	**8.32**

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Comparison with other sets

EF Impact Category	Unit	Global NFs recommended	Aggregated weighting set (50:50 approach) (%)	Final weighting factors (including robustness (%)	*Distance to policy target EU2020 (Castellani et al. 2016)* (%)	Planetary boundaries resulting from the webinar (%)	Planetary boundaries (Bjørn & Hauschild 2015) (%)
Climate change	kg CO_2 eq.	5.35E+13	12.90	**21.06**	6.72	9.65	25
Ozone depletion	kg CFC-11 eq.	1.61E+08	5.58	**6.31**	6.03	3.16	1
Human toxicity, cancer effects	CTUh	2.66E+05	6.80	**2.13**	6.46	8.02	na
Human toxicity, non-cancer effects	CTUh	3.27E+06	5.88	**1.84**	5.85	6.35	na
Particulate matter	disease incidences	4.28E+06	5.49	**8.96**	6.99	8.33	na
Ionizing radiation, human health	kBq U^{235} eq.	2.04E+12	5.70	**5.01**	5.77	6.02	na
Photochemical ozone formation, human health	kg NMVOC eq.	2.80E+11	4.76	**4.78**	7.37	6.69	34[5]
Acidification	mol H^+ eq.	3.83E+11	4.94	**6.20**	6.80	3.51	1
Eutrophication, terrestrial	mol N eq.	1.22E+12	2.95	**3.71**	6.57	3.45	1
Eutrophication, freshwater	kg P eq.	5.06E+09	3.19	**2.80**	5.82	3.45	9
Eutrophication, marine	kg N eq.	1.95E+11	2.94	**2.96**	6.53	3.45	1
Land use	pt	1.98E+16	9.04	**7.94**	5.77	9.43	25
Ecotoxicity freshwater	CTUe	8.15E+13	6.12	**1.92**	6.06	9.6	2
Water use	m^3 water eq.	7.91E+13	9.69	**8.51**	5.77	5.65	1
Resource use, fossils	MJ	4.50E+14	7.37	**7.55**	5.77	7.81	na
Resource use, minerals and metals	kg Sb eq.	3.99E+08	6.68	**8.32**	5.77	5.43	na

Conclusion and way forward

- So far normalization is driving the relevance of impact categories more than weighting, in performed tests.
- Need of improving and refining global references are focusing on extending sensitivity to modelling choices
- Consistency between inventories used for normalisation and characterisation
- Science based weighting: e.g. on reversibility
- Endpoint methods: improving robustness still an open issue
- Monetization
- Absolute sustainability assessment (e.g. against planetary boundaries) is a pivotal area of future development