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Normalization and weighting of sustainability indicators: current status and main challenges

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Introduction

"There is a tendency to avoid discussions on weighting methods"

(Ahlroth et al. 2011)

Source: LCA discussion forum

Introduction

Can we properly weigh and add up such diverse impacts as for instance summer smog, extinct species and the ozone hole? No, of course we can't. But we must in order to provide a complete picture. If we don't, some people will cherry-pick the effects and results that suit them.

The broad use of weighting methods illustrates that it is perceived as useful by practitioners.

Weighting sets that are well known and often used may facilitate the communication and the acceptability and legitimacy.

We all use weighting implicitly if not explicitly.

Source: LCA discussion forum

Aggregation of environmental indicators

Constructing one single composite indicator for **ecological sustainability** requires

- Life cycle inventory (LCI) — >1000 elementary flows
- Classification/Characterization — 10-15 impact indicators
- Normalization — normalized impact indices
- Grouping Weighting — single score indicator or multiple scores

Conflict between degree of detail and adaption to target audience

Normalization of environmental impacts

- ISO 14044 (2006): Normalization is the calculation of the magnitude of the category indicator results relative to some reference information.

  Normalization transforms an indicator *S* result by dividing it by a selected reference value *R*: *N=S/R*

  Examples for a reference system:

  - geographical area over a reference year (e.g. the impact of the European Union for 2010);
  - geographical area over a reference year on a *per capita* basis (e.g. the impact of a European citizen in 2010).

- Normalization is an optional step in LCIA
- Can be performed at mid- and endpoint level
- Gives information on relative significance
- Does *NOT* give the relevance to other impact indicators
- Easier to understand for non-LCA experts (-> 'per yr and pers.')

Normalization: Methods

- Internal normalization (impacts normalized with alternatives to the study -> needs more than one alternative)

  no ISO standard!

  ✓ Division by baseline

  ✓ Division by maximum

  ✓ Division by sum

- External normalization (reference is external and thus independent of the object of the LCA)

  ✓ Global normalization

  ✓ Production based, territorial system (activities in a region)

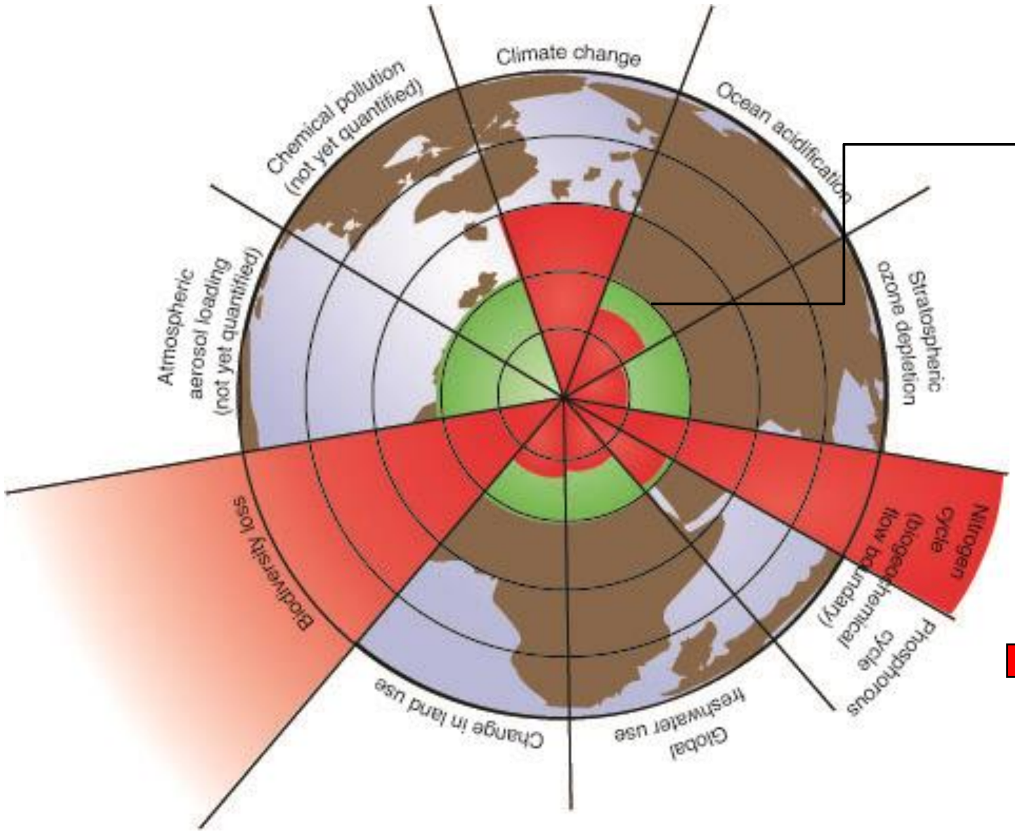
  ✓ Consumption based, territorial system

  ✓ Carrying capacity based (-> planetary boundaries)

(main) Source: Pizzol et al., 2017, J LCA

Planetary Boundaries

Nine Earth system processes of crucial importance to prevent unacceptable environmental change on a global scale



"safe operating space"

SOS: concept of **S**afe **O**perating **S**pace

Three of these boundaries have already been **passed**

Source: Johan Rockström et al. (2009); http://www.stockholmresilience.org/

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Normalization: Current status

Increasing interest in detailed information on normalization, e.g.

- ✓ Number of papers has significantly increased
- ✓ Different comparisons of normalization factors have been performed
- ✓ ILCD handbook / EF2.0/ EF3.0 reports propose methods to perform LCIA normalization
- ✓ A huge range of databases (and other sources such as reports) are used for building (domestic) inventories (EDGAR database, EMEP/CEIP database, …)

- ✓ Benini et al., 2014: Recommended normalization factors for the EU-27
- ✓ Castellani et al., 2016: Normalization factors for 2010 and 2020
- ✓ Sala et al., 2018: Recommended normalization factors at midpoint level
- ✓ Fazio et al., 2018/ Sala et al., 2019: reference package EF 3.0

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Normalization sets

ILCD Impact Category	Unit	EC-JRC EU27 (2010), per person[a]	EC-JRC Global (2010 or 2013), per person[b]	PROSUITE Global (2010 or 2000), per person[c]
Climate change	kg CO_2 eq.	9.22E+03	7.07E+03	8.10E+03
Ozone depletion	kg CFC-11 eq.	2.16E-02	1.22E-02	4.14E-02
Human toxicity, cancer effects	CTUh	3.69E-05	1.24E-05	5.42E-05
Human toxicity, non-cancer effects	CTUh	5.33E-04	1.55E-04	1.10E-03
Particulate matter/Respiratory inorganics	kg PM2.5 eq.	3.80E+00	5.07E+00	2.76E+00
Ionizing radiation, human health	kBq U^{235} eq. (to air)	1.13E+03	2.41E+02	1.33E+03
Photochemical ozone formation, human health	kg NMVOC eq.	3.17E+01	4.53E+01	5.67E+01
Acidification	mol H+ eq.	4.73E+01	5.61E+01	4.96E+01
Eutrophication terrestrial	mol N eq.	1.76E+02	1.64E+02	1.15E+02
Eutrophication freshwater	kg P eq.	1.48E+00	6.54E+00	6.20E-01
Eutrophication marine	kg N eq.	1.69E+01	3.04E+01	9.38E+00
Land use	kg C deficit	7.48E+04	5.20E+06	2.36E+05
Ecotoxicity freshwater	CTUe	8.74E+03	3.74E+03	6.65E+02
Resource depletion water	m^3 water eq.	8.14E+01	6.89E+01	2.97E+01
Resource depletion, mineral, fossils and renewables	kg Sb eq.	1.01E-01	1.93E-01	3.13E-01

Source: Zamori et al., 2016. JRC technical report

Normalization: Challenges

- Consistence of reference system (global, national, catchment,…) with studied system
- Consistence of reference year and year of the study
- Different methods for the studied system and the reference system (e.g. different number of greenhouse gases included)
- Generation of complete inventories of resource consumptions and emissions (at different regional levels)
- Missing/incomplete impact categories (world data on land use and water depletion)
- Missing/incomplete interventions: normalization factors for depletion of fossil fuel and other elements
- Toxic emission inventories for the world are incomplete (missing data are extrapolated)

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Weighting of environmental impacts

- ISO 14044 (2006): Weighting is based on **value choices** (e.g. monetary choices, distance to target). Different individuals, organizations and societies may have different preferences.
- Weighting is an **optional step** in LCIA
- Generally only **normalized** data can be weighted (if units differ, no normalization is needed when monetization is applied at endpoint level)

- Weighting may be performed at **midpoint** & **endpoint** level
- Weighting enables the ranking of alternatives
- **All** weighting methods have theoretical and technical **pros** and **cons**

Weighting: Methods

- Distance to target (distance from a desired state based on regulations -> socio-political agreeement)
  - Method: Normative targets
- Panel weighting (opinion of a group of people: stakeholders, experts, citizens)
  - Methods: stakeholder/expert panel, multi-attribute decision method
- Monetary weighting (weighting according to economic value -> different types of economic values, e.g. damage costs avoided (e.g. based on willingness-to-pay) or costs for providing substitute)
  - Methods: Observed/revealed/stated preferences
- Binary weighting (no weight or equal importance)
  - Methods: Equal weighting (most common); footprinting (certain impacts are ignored)

(main) Source: Pizzol et al., 2017, J LCA

Weighting: Methods (cont.)

Many statistical methods support the weighting process, e.g.

Reduction of dimensionality

- ✓ Principal Component Analysis (PCA)
- ✓ Regression analysis
- ✓ Cluster analysis

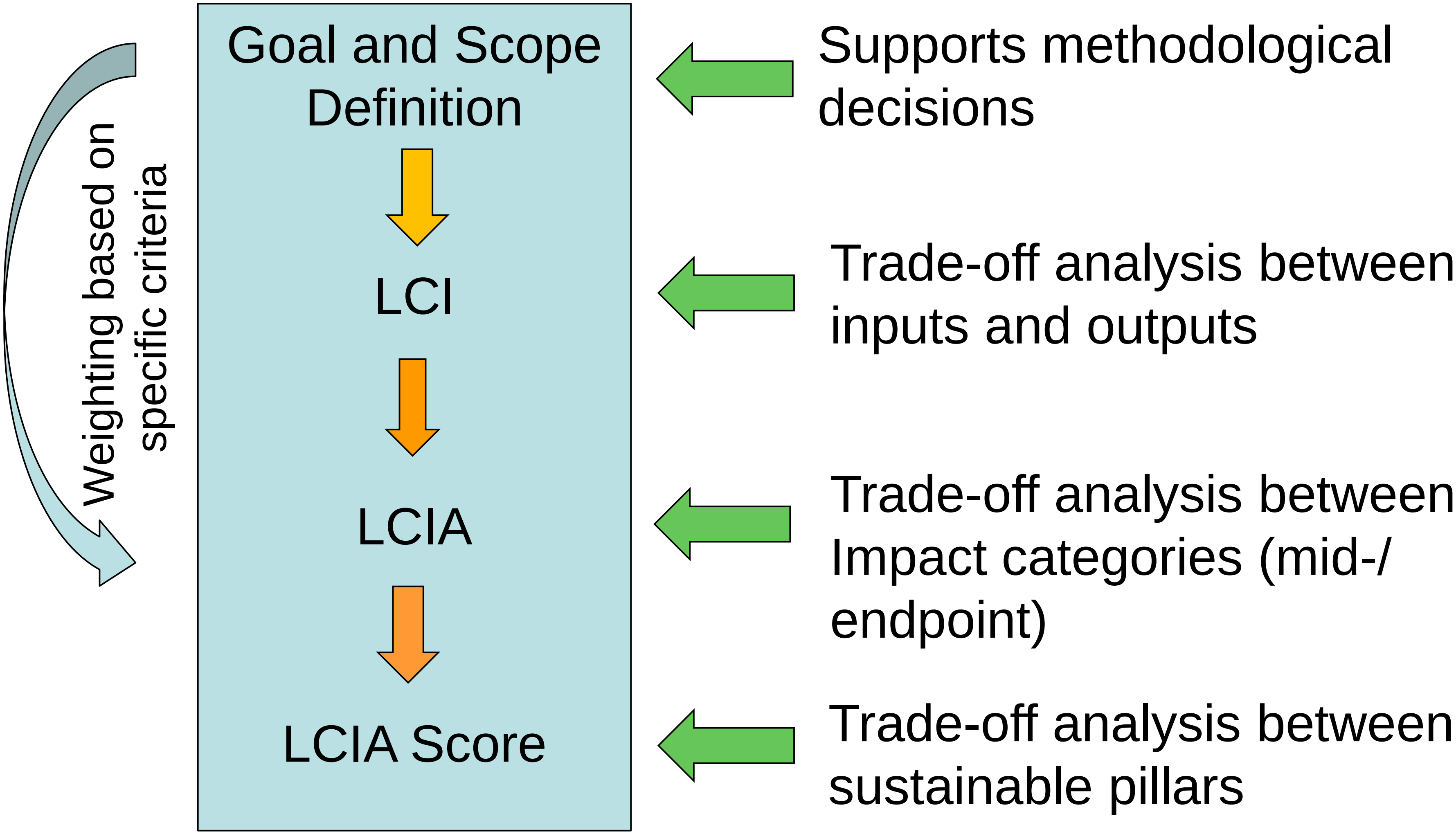
Multi criteria decision analysis (MCDA), e.g.

Analytical hierarchy process (AHP)
Budget Allocation Process (BAP)
Decision Expert decision model DEXi

(Mainly for) productivity data

- ✓ Data Envelopment Analysis (DEA)

Multi Criteria Decision Analysis MCDA



Source: Zanghelini et al. (2018)

Weighting: Current status

- Castellani et al., 2016: (Policy based) target references for EU-27 (2020)
- Pizzol et al. (2017): Survey on level of use and confidence in weighting methods
- Sala et al. (2018): Recommended weighting factors at midpoint level (including robustness factors)

- Different methods are available (see presentation of Serenella Sala). Each has pros and cons. There is no "best" method.
- "Consensus" in the scientific community that different methods should be used for different purposes/applications

- Level of endpoint: equal weighting is often suggested (e.g. IMPACT World+, ReCiPe)

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Weighting: Challenges

- Composition of the panel may influence the weighting factors
- Design of the questionnaire impacts on the result
- Monetary methods may be critical due to ethical reasons (value of health and life)
- Policy documents do not cover all non-binding targets for all impact categories used in LCIA (and do not always give quantitative information)
- Different weighting sets lead to significant differences in the final conclusions

How to tackle the challenges?

- ✓ Use different weighting factors and weighting methods
- ✓ Conduct systematic sensitivity analyses to assess the consequence on the LCIA results (uncertainties and robustness)
- ✓ Assessment of robustness of composite indicators (e.g. effect of different normalization rules)
- ✓ The recommendation not to use weighting in comparative LCA studies disclosed to the public should be reconsidered

Recommendations

Normalization

- ✓ Use regionalized normalization factors (if useful)
- ✓ Use complete normalization inventory (emitted and extracted substances)
- ✓ Fill gaps with sound estimation techniques or reliable sources (official reports and peer-reviewed papers)
- ✓ Make sure that the normalization factors fit to your calculated impact categories (method *and* time)

Weighting

- ✓ Use generally accepted weighting factors
- ✓ Prefer weighting methods that include all impacts
- ✓ Do not adapt your decision on the weighting sets (made in scope & goal def.) later in your study
- ✓ If LCIA method provides both midpoint and endpoint indicators (e.g. ReCiPe or IMPACT World+) => use results at both levels
- ✓ If necessary: Apply different weighting methods (sens. analysis)

Outlook

- ✓ Studies/papers on the effect on different normalization and weighting schemes should be specially promoted.
- ✓ Consensus method(s) should be further refined.
- ✓ Normalization and weighting factors should be regularly updated and completed (consider new findings / include more precise data)

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Thank you very much for your attention

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Table 1 The symmetric questionnaire structure

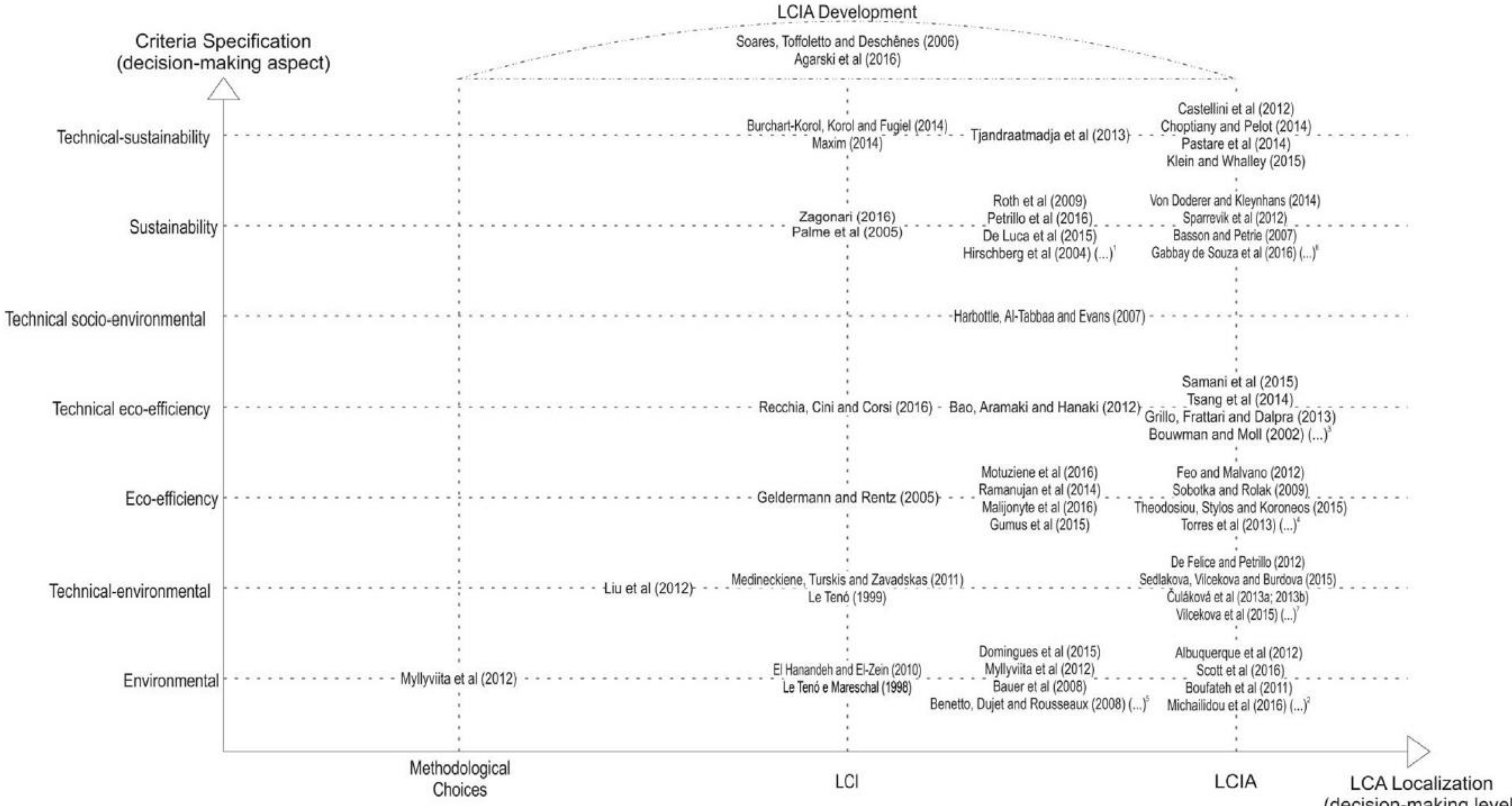
Subject	Area of investigation	Variable	Question
Normalisation	Scientific quality "*In your opinion…*" (1 = not at all; 9 = extremely)	Robustness	*How robust are normalisation factors?*
		Transparency	*How transparent are normalisation factors?*
		Uncertainty	*How uncertain are normalisation factors?*
		Relevance	*How relevant are normalised impact results in a decision making context?*
		Validity	*How well does normalisation meet its purpose?*
	Current practice "*How often are these situations occurring in your practice with normalisation?*" (1 = never; 9 = always)	Calculation	*When performing a LCA study, I calculate normalised impact results*
		Communication	*When presenting LCA results, I use normalised impact results*
		Selection	*I use normalisation to determine the most relevant impact categories for an LCA*
		Choice	*I experience difficulties in selecting which set of normalisation factors to use*
		Coverage	*I apply more than one normalisation method*
Weighting	Scientific quality "*In your opinion…*" (1 = not at all; 9 = extremely)	Robustness	*How robust are weighting factors?*
		Transparency	*How transparent are weighting factors?*
		Uncertainty	*How uncertain are weighting factors?*
		Relevance	*How relevant are weighted impact scores in a decision making context?*
		Validity	*How well does weighting capture the values of the group involved?*
	Current practice "*How often are these situations occurring in your practice with weighting?*" (1 = never; 9 = always)	Calculation	*When performing a LCA study, I calculate weighted impact scores.*
		Communication	*When presenting LCA results, I use weighted impact scores.*
		Selection	*I use weighting to determine the most relevant impact categories for an LCA.*
		Choice	*I experience difficulties in selecting which set of weighting factors to use.*
		Coverage	*I apply more than one weighting method.*

Source: Pizzol et al., 2017, J LCA

Table 20 Summary of weighting sets used in the sensitivity analysis by Castellani et al. (2016)

	Distance to target						Damage oriented	Panel-based
	Policy targets				Planetary boundaries		Mid-to-endpoint	
	Castellani et al. 2016 WFsA	Castellani et al. 2016 WFsB	EDIP 2003 (Stranddorf et al., 2005)	Tuomisto et al. 2012	Bjørn & Hauschild - European 2015	Bjørn & Hauschild – Global 2015	Ponsioen & Goedkoop 2016	Huppes et al. 2012
ILCD Impact Category	**dimensionless (%)**							
Climate change	7.1%	5.4%	2%	10%	25%	26%	44%	23.2%
Ozone depletion	6.4%	4.9%	87%	8%	1%	2%	0%	3.6%
Human toxicity, cancer effects	6.9%	5.2%	2%	n.a	n.a	n.a	1%	6.5%
Human toxicity, non-cancer effects	6.2%	4.7%	2%	n.a	n.a	n.a	4%	4.1%
Particulate matter/Respiratory inorganics	7.4%	5.6%	n.a	n.a	n.a	n.a	8%	6.6%
Ionizing radiation, human health	6.1%	4.6%	n.a	n.a	n.a	n.a	0%	6.5%
Photochemical ozone formation, human health	7.8%	5.9%	2%	n.a	34%	48%	0%	5.4%
Acidification	7.2%	5.5%	2%	8%	1%	1%	0%	4.2%
Eutrophication terrestrial	7.0%	5.3%	2%	28%	1%	0%	0%	2.3%
Eutrophication freshwater	6.2%	4.7%	1%	7%	9%	2%	0%	2.3%
Eutrophication marine	6.9%	5.2%	2%	28%	1%	1%	0%	2.3%
Land use	6.4%	5.3%	n.a	6%	25%	16%	19%	10.2%
Ecotoxicity freshwater	6.1%	5.1%	0%	n.a	2%	0%	0%	10.9%
Resource depletion water	6.1%	29.6%	n.a	5%	1%	4%	3%	5.1%
Resource depletion, mineral, fossils and renewables	6.1%	3.0%	0%	n.a	n.a	n.a	19%	6.9%

Fig. 4. Levels where MCDA may be integrated to aid interpretation on LCA approach.



(...)[1] Elghali et al (2006), Weiss et al (2012), Basson and Petrie (2007), Bogacka (2015), Lolli et al (2016), De Felice, Campagiorni and Petrillo (2013), Hirschberg, Danes and Gantner (2000)
(...)[2] Hermann, Kroeze and Jawjit (2007), Bloemhof-Ruwaard, Koudijs and Vis (1995), Kumar et al (2016)
(...)[3] Allacker and De Troyer (2012), Ahmed et al (2012)
(...)[4] Allacker et al (2008), Neto et al (1998), Lee et al (2014), Kucukvar, Egilmez and Tatari (2016)
(...)[5] Moretti, Di Mascio and D'Andrea (2013), Azapagic et al (2013), Myllyviita, Leskinen and Seppala (2014)
(...)[6] Santoyo-Castelazo and Azapagic (2014), Atilgan and Azapagic (2016), Al-Nassar et al (2016), De Luca et al (2015), Loh, Dawood and Dean (2009), Pettit et al (2011), Sardinha et al (2010), Linkov et al (2006), Linkov and Seager (2011)
(...)[7] Sedlakova et al (2014)