LCIA framework and cross-cutting issues guidance within the UNEP-SETAC Life Cycle Initiative

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1. General case study description

The application of the topical indicators recommended in the UNEP-SETAC global guidance report (particulate matter formation, global warming, water consumption and land stress) was demonstrated with a common case study for rice production and preparation with three different scenarios (production in rural China, consumption in urban China; production and consumption in rural India; production in the US, consumption in Switzerland). More details about the case study and data used can be found in Frischknecht et al. (2016).

2. Empirical results relevant for cross-cutting issues

Here we present results of the case study (Frischknecht et al. 2016), which are relevant for the cross-cutting issues. The aim is to highlight the compliance and relevance for the recommendations made for cross-cutting issues. For further details and interpretation of the results, see Frischknecht et al. (2016).

2.1. Update to the LCIA framework

The topical indicators covered in the recommendation currently cover different parts of the LCIA framework (Figure S1). One indicator (water stress) is a proxy-midpoint, meaning that it is not situated on the direct impact pathway to any of the existing Areas of Protection. Climate change and particulate matter formation have recommended models and characterization factors (CFs) for midpoint indicators that are on the cause-effect pathways to damage level. Further, indicators and models are recommended at damage level for particulate matter formation, water use impacts on human health and land stress impacts on biodiversity. Thus, the recommended framework does cover all options of the topical indicators recommended.

No recommended topical indicators exist yet for natural resources (outside the scope of the flagship's activities of this phase), as well as the Areas of Protection which are not yet operationalized.

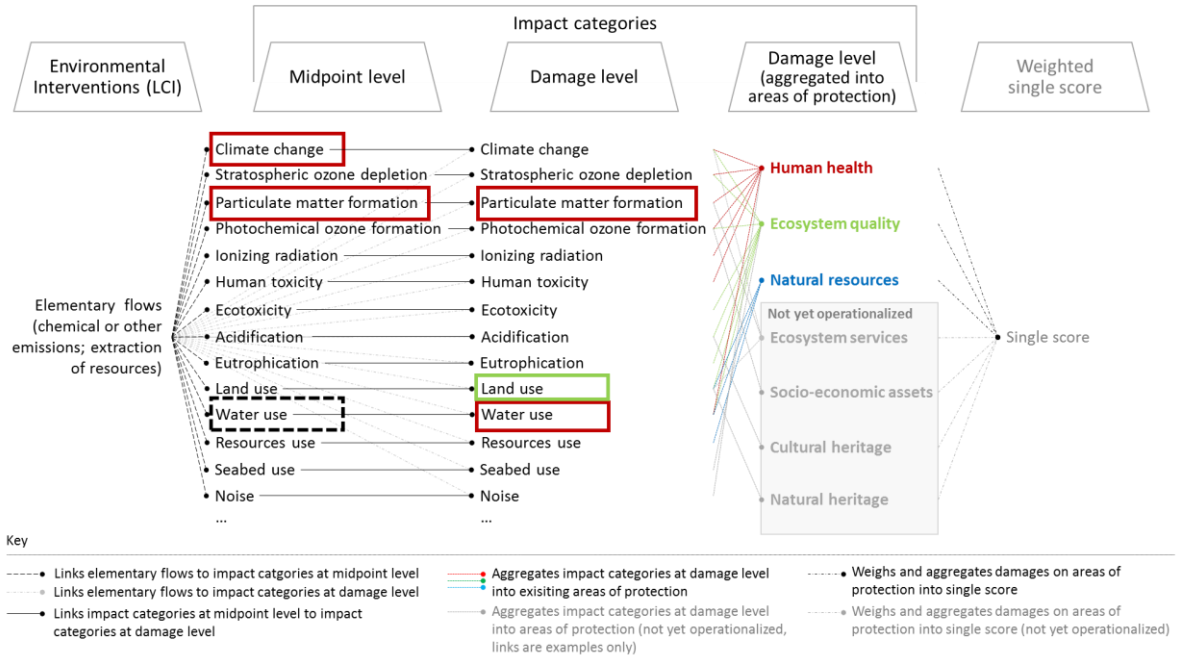

Figure S1: Updated LCIA framework with indication of coverage of the topical indicators. Boxes with solid lines indicate that this indicator is situated on the impact pathway for human health or ecosystem quality. The box with dashed lines indicates

a proxy-midpoint. Green shows the relation of the indicator to the Area of Protection ecosystem quality, red an affiliation to human health.

2.2. Results related to recommendations for individual Areas of Protection

These recommendations are targeted towards the compatible implementation of units and metrics in impact categories that reach the same Area of Protection. For the topical indicators recommended and used in the case study, this is especially relevant for particulate matter formation and water use impacts on a damage level, since for ecosystem quality only one indicator is recommended at damage level.

2.2.1. Human health

The recommended metric is for human health impacts on damage level is DALY (disability adjusted life years). Both recommended, topical indicators that are related to human health impacts on a damage level (particulate matter formation and water use) provide their characterization factors and results in DALYs (Table 2, main manuscript). Aggregation to total human health impacts is thus possible, if desired (but not necessary, as stressed in the main text).

For this case study, since the case study aims at offering cooked rice, it is also interesting to compare the malnutrition impacts of water consumption with the potential reduction in malnutrition impacts associated with the produced per kg rice. Using the same health effect factor of 4.55×10^{-8} [DALY/kcal] as that used to determine the impacts of water use and an energy content of the rice of 3700 kcal/kg (raw), this potential reduction amounts to 1.7×10^{-4} [DALY/kg_{rice}], and is substantially higher than the impacts of water consumption on human health.

2.2.2. Ecosystem quality

For ecosystem quality on a damage level one topical indicator (land use) is recommended. As is usually the case in current LCIA models dealing with ecosystem quality, this indicator is based on impacts related to species richness and is given in PDF (potentially damaged fraction) (Table S1). Land use impacts affect different types of land use, but are only targeting terrestrial species. Thus no disaggregated reporting between terrestrial, aquatic and marine species is required here.

However, it is important to distinguish between regional and global impacts and report these transparently. In Table S1 it is clearly indicated that impacts reported here are PDF_{global}, i.e. these impacts cover irreversible extinction. The clear indication of the scale prevents mixing of scales (regional and global) and is thus an important part of the recommended, transparent reporting.

Taxonomic groups included are birds, mammals, reptiles, amphibians and vascular plants. They are reported here as an aggregated indicator, following the recommendations made in Verones et al. (2015). This information is crucial for transparent reporting, as it is not visible in Table S1.

Ideally, the cross-cutting issues recommendations stress that taxa-specific results should be reported. This is not the case here, as tables reporting results for five taxa and six land use classes become confusing and reduces the ease of application. Characterization factors are however available for the individual taxa (Frischknecht and Jolliet 2016).

Table S1 determines the results of the case study considering that that the rice (arable foreground) is grown within the identified ecoregion (regions IM0120, IM0118 and NA0409 in India, China and US respectively), while for all other land use, including forestry for firewood, national averages are used. For the USA-Switzerland case, rice production (arable foreground) is located to USA and its consumption in Switzerland.

Table S1: Results of the topical indicator «land use» for ecosystem quality at a damage level, showing an occupation impact. The functional unit (FU) is 1 kg of white, cooked rice (cooked at home in rural India, urban China, or Switzerland). The columns show the different land use types involved in the calculation of the land use impacts. Further detail of the case study can be found in Frischknecht et al. (2016).

	Arable (foreground)	**Arable (background)**	**Permanent crops**	**Forest intensive**	**Forest extensive**	**Urban**
Inventory flow	[m^2-year/FU]	[m^2-year/FU]	[m^2-year/FU]	[m^2-year/FU]	[m^2-year/FU]	[m^2-year/FU]
Rural India	2.69E+00	3.02E-03	7.02E-05	5.58E-01	2.87E-05	1.05E-02
Urban China	1.46E+00	2.85E-03	7.14E-05	1.09E-01	3.62E-05	1.04E-02
US/Switzerland	1.40E+00	3.09E-03	7.54E-05	7.64E-02	3.34E-05	9.69E-02
CFs	[PDF_{global}/m^2]	[PDF_{global}/m^2]	[PDF_{global}/m^2]	[PDF_{global}/m^2]	[PDF_{global}/m^2]	[PDF_{global}/m^2]
Rural India	2.10E-15	3.21E-15	2.33E-15	1.77E-15	6.25E-16	3.54E-15
Urban China	1.72E-15	1.22E-15	8.49E-16	5.53E-16	1.42E-16	1.37E-15
US/Switzerland	8.71E-16	1.78E-15	1.22E-15	4.98E-16	3.45E-16	1.95E-15
[PDF_{global}-year/FU]	[PDF_{global}-year/FU]	[PDF_{global}-year/FU]	[PDF_{global}-year/FU]	[PDF_{global}-year/FU]	[PDF_{global}-year/FU]	[PDF_{global}-year/FU]
Rural India	5.6E-15	9.7E-18	1.6E-19	9.9E-16	1.8E-20	3.7E-17
Urban China	2.5E-15	3.5E-18	6.1E-20	6.0E-17	5.1E-21	1.4E-17
US/Switzerland	1.2E-15	5.5E-18	9.2E-20	3.8E-17	1.2E-20	1.9E-16

2.3. Results related to recommendations for midpoint and proxy-midpoint indicators

Global warming recommendations for topical indicators are on a midpoint level and distinguish between long- and short-term impacts for different greenhouse gases (Table S2). The recommended method for water stress is a midpoint indicator too (Table S3). However, as mentioned under the framework section and shown in Figure S1, this indicator does not lead further to human health or ecosystem quality impacts and has therefore to be considered as a proxy midpoint indicator.

Since every midpoint indicator features its own metric, there is no cross-comparison possible and desired. No recommendations were made for the metrics used at midpoint level.

Table S2: Impacts for global warming at a midpoint level for global warming potential (GWP) and the global temperature potential (GTP). For details about the indicators, see Frischknecht and Jolliet (2016). The functional unit (FU) is 1 kg of white, cooked rice (cooked at home in rural India, urban China, or Switzerland). Further detail of the case study can be found in Frischknecht et al. (2016).

	Indicator	**CO_2**	**CH_4**	**N_2O**	**Others**
Rural India	GWP100 [$kgCO_2eq$-short/FU]	1.29E+00	1.14E+00	2.72E-01	1.03E-03
	GTP100 [$kgCO_2eq$-long/FU]	1.29E+00	3.76E-01	2.71E-01	1.34E-03
Urban China	GWP100 [$kgCO_2eq$-short/FU]	1.13E+00	1.04E+00	2.59E-01	6.32E-03
	GTP100 [$kgCO_2eq$-long/FU]	1.13E+00	3.42E-01	2.58E-01	8.15E-03
US/Switzerland	GWP100 [$kgCO_2eq$-short/FU]	1.03E+00	1.41E+00	2.02E-01	2.93E-03
	GTP100 [$kgCO_2eq$-long/FU]	1.03E+00	4.60E-01	2.01E-01	3.79E-03

Table S3: Results for water stress impacts at a /proxy-)midpoint level, including spatial detail. The functional unit (FU) is 1 kg of white, cooked rice (cooked at home in rural India, urban China, or Switzerland). Further detail of the case study can be found in Frischknecht et al. (2016).

	Spatial region	Water consumed [m^3/FU]	Characterization factor [m^3-eq/ m^3]	AWARE score [m^3-eq/FU]
Rural India	Average India	0.78	30	23
	Ganges		13.8	10.74
	Godavari		2.22	1.72
Urban China	Average China	0.46	45	21
	Yellow River		90.6	41.5
	Pearl River		0.49	0.22
US/Switzerland	Average US	0.08	36	2.9
	Red River		0.15	0.01
	Arkansas River		2.66	0.21

2.4. Spatial aspects

Spatial aspects become increasingly important, as mentioned in the main text. The case study results of the topical indicators (Table S1 to Table S3 and Table 2 in the main manuscript) all include spatial aspects to some degree, with the exception of global warming. Particulate matter impacts (Table 2) use spatial archetypes, methods related to water use (**Error! Reference source not found.** 2 and Table S3) are based on watershed level and land use impacts distinguish different land use types and different ecoregions (Table S1). Including these aspects is important, as highlighted in the main text. Differences regarding water stress can easily surpass a factor of 200 between different watersheds. For land use, impacts of the same land use category, but in different world regions may differ several orders of magnitude, but also impacts within one region differs for different land use types, depending on the species community living there and whether regional or global losses are considered.

As recommended in the main text, topical indicators should use an appropriate "native scale". The spatial detail at this original level therefore differs between the categories (watersheds for water use, ecoregions for land stress, population density archetypes for particulate matter formation).

2.5. Reference states

Reference states of the different topical indicators are not easily visible from case study results. Here it is of utmost importance to adhere to the recommendations related to transparent reporting. Each model needs to specify which reference state was chosen for providing the characterization factors. The reference states for all topical indicators are given in Table 2.2 in the global guidance report (Frischknecht and Jolliet 2016) and shortly summarized in Table S4. With the exception of land use, all indicators use the "current situation" as baseline, i.e. they do not look at historic conditions. Also, all except for land use have fixed reference states, i.e. they are for example set to a specific year (e.g. year 2015 for global warming). Normativity addresses the rationale for the choice of reference states and in almost all cases this is a pragmatic reason, such as data availability. Only for land use it is normative, i.e. reflecting a desired state regarding the number of species in a natural state, as compared to the current situation.

Reporting these reference states transparently is important, as different reference states (e.g. whether it is based on a historic background or current situation) can considerably influence the results.

Topical indicators recommended do follow the recommendation for transparent reporting and, as shown in Table S4 all except land use are compatible. This is especially relevant for particulate matter formation and water use impacts on a damage level, since these are directly comparable in the Area of Protection Human Health.

Table S4: Summary of reference states of the topical indicators used in the case study, based on table 2.2 in Frischknecht and Jolliet (2016). For details, see Frischknecht and Jolliet (2016)

Topical indicator	Type	Flexibility	Normativity
Global warming	Current situation	Fixed	Pragmatic
Water use, human health	Current situation	Fixed	Pragmatic
Water use, water stress	Current situation	Fixed	Pragmatic
Land use	Natural situation	Individual	Normative
Particulate matter formation	Current situation	Fixed	Pragmatic

In addition, characterization factors may be modelled following marginal or average approaches. We recommend the reporting of both marginal and average values, if possible and to transparently report the choice of approach. As shown in Table 2, this recommendation is fulfilled by the particulate matter formation category.

3. References

Frischknecht, R. and O. Jolliet. 2016. *Global Guidance for Life Cycle Impact Assessment Indicators, Volume 1*. Paris, France: United Nations Environment Programme.

Frischknecht, R., P. Fantke, L. Tschümperlin, et al. 2016. Global guidance on environmental life cycle impact assessment indicators: progress and case study. *The International Journal of Life Cycle Assessment*: 1-14.

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