European Commission

JRC TECHNICAL REPORTS

Global normalisation factors for the Environmental Footprint and Life Cycle Assessment

Serenella Sala, Eleonora Crenna,
Michela Secchi, Rana Pant

2017

EUR 28984 EN

Contact information
Name: Serenella Sala
Address: Via E. Fermi, 2749, Ispra (VA), Italy
Email: serenella.sala@ec.europa.eu

JRC Science Hub
https://ec.europa.eu/jrc

JRC109878

EUR 28984 EN

PDF	ISBN 978-92-79-77213-9	ISSN 1831-9424	doi:10.2760/88930
Print	ISBN 978-92-79-77214-6	ISSN 1018-5593	doi:10.2760/775013

Luxembourg: Publications Office of the European Union, 2017

How to cite this report: Sala S., Crenna E., Secchi M., Pant, R., *Global normalisation factors for the Environmental Footprint and Life Cycle Assessment*, EUR (28984), Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-77213-9, doi:10.2760/88930, JRC109878

Acknowledgment

A part of the data gathering work to develop global normalisation factors has been funded by the European Commission, DG Environment, in the context of the Administrative Arrangement "Technical support for Environmental Footprinting, Material Efficiency and the European Platform on LCA" (2013-11 07.0307/ENV/2013/SI2.668694/A1).

Contents

Abstract

This report quantitatively characterizes environmental impacts at global scale in relation to the 16 impact categories of the Environmental Footprint (EF) and Life Cycle Assessment (LCA), namely: climate change; ozone depletion; human toxicity, cancer; human toxicity, non-cancer; freshwater ecotoxicity; particulate matter; ionising radiation; photochemical ozone formation; acidification; eutrophication, terrestrial; eutrophication, marine; eutrophication, freshwater; land use; water use; resource use, fossils and resource use, minerals and metals.

The results are recommended to be used as normalisation factors (NFs) in the context of the Environmental Footprint (EF) for assessing the relevance of the impacts associated to a product or system.

In LCA, according to ISO 14044 (ISO 2006), normalisation (similar to weighting) is an optional steps of Life Cycle Impact Assessment (LCIA).

The normalisation factors represent the total impact of a reference region for a certain impact category (e.g. climate change, eutrophication, etc.) in a reference year. For the EF, due to the international nature of supply chains, the use of global normalisation factors is recommended.

Normalisation has a relevant role to play in the Environmental Footprint to support the identification of the most relevant impact categories, life cycle stages, process and resource consumptions or emissions to ensure that the focus is put on those aspects that matter the most and for communication purposes.

The global normalisation factors reported here are built on a vast collection of data on emissions and resources extracted at global scale in 2010. Key choices were made for compiling the inventories, which were then characterised by using the EF midpoint LCIA method. The results are reported for each impact category. Coverage, completeness and robustness of the underpinning inventories are discussed.

With this, the report supports the generation of life cycle based indicators for monitoring the environmental dimension of the sustainability of supply chains, including contributions to global environmental impacts in relation to planetary boundaries. This in turn enables a life cycle based assessment of the sustainability of the intensification of primary production for a greening EU economy.

Executive summary

Companies that want to highlight the environmental performance of their organisation or their products face currently numerous obstacles. They have to choose between several assessment methods promoted by public and private initiatives, they are often forced to pay multiple costs for generating environmental information, and they have to deal with the potential mistrust of consumers who are confused by the proliferation of too many communication tools with different information that makes products difficult to compare.

The Communication on '*Building the Single Market for Green Products*' (COM (2013) 196 final) and the related Recommendation 2013/179/EU on use of common methods to measure and communicate the environmental life-cycle performance of products and organisations, aim to ensure that environmental information in the EU market is comparable and reliable, and can be used confidently by consumers, business partners, investors, other company stakeholders, and policy makers.

In this context, the step of prioritising and aggregating the results for the 16 environmental impact categories evaluated in the life cycle based Environmental Footprint (EF) - covering e.g. climate change, acid rain, human and eco-toxicity, particulate matter but also impacts due to the use of water, land and resources – has a high relevance.

In Life Cycle Assessment (LCA), according to ISO 14044 (ISO 2006), normalisation (similar to weighting) is an optional step of Life Cycle Impact Assessment (LCIA). Those steps allow aggregating LCA results, giving different weight to the different environmental impacts.

Normalisation has a relevant role to play in the Environmental Footprint to support the identification of the most relevant impact categories, life cycle stages, process and resource consumptions or emissions to ensure that the focus is put on those aspects that matter the most and for communication purposes.

This report quantitatively characterizes environmental impacts at global scale in relation to the impact categories of the Environmental Footprint. The normalisation references express the total impact of a reference region for a certain impact category (e.g. climate change, eutrophication, etc.) in a reference year. For the EF, due to the international nature of supply chains, the use of global normalisation factors is recommended.

The global normalisation factors (NFs) reported here are built on a vast collection of data on emissions and resources extracted at global scale in 2010. Key choices were made for compiling the inventories, which were then characterised by using the EF midpoint method. The results are reported for each impact category. Coverage completeness and robustness of the underpinning inventories, as well as impact assessment methods are discussed.

On the inventory side, it was observed a general scarce availability of information on environmental emissions and resource extraction, which led to the adoption of extrapolation strategies for better complementing the inventories. On the impact assessment side, in the majority of the impact categories, only few elementary flows make up a significant share of the overall impact, contributing for example 40% (e.g. CFC-11 for ozone depletion) up to about 70% (e.g. $PM_{2.5}$ for particulate matter), likely due to the structure of the underpinning inventories.

This report provides an up to date picture of global normalisation figures and represents an improvement over existing studies in this area. However, we also can indicate areas for further improvement aiming at overcoming the uncertainties identified both at the inventory (e.g. difficulty in retrieving recent data) and characterization levels (e.g. consistency between inventory and impact assessment regarding the regionalisation of impacts). Any assessment based on the use of NFs should be discussed and interpreted taking into account also the limitations discussed in this report.

Table 1. Global normalisation factors for emissions and resource extraction in 2010, based on EF 2017 method (Sala et al 2017). The attributed score is from I-highest to III-lowest

Impact category	Model	Unit	global NF for EF	global NF for EF per person *	Inventory coverage completeness	Inventory robustness	Recommendation level of EF impact assessment
Climate change	IPCC (2013)	kg CO_2 eq	5.79E+13	8.40E+03	II	I	I
Ozone depletion	WMO (1999)	kg CFC-11 eq	1.61E+08	2.34E-02	III	II	I
Human toxicity, cancer	USEtox (Rosenbaum et al., 2008)	CTU_h	2.66E+05	3.85E-05	III	III	II/III
Human toxicity, non-cancer	USEtox (Rosenbaum et al., 2008)	CTU_h	3.27E+06	4.75E-04	III	III	II/III
Particulate matter	Fantke et al., 2016	disease incidences	4.95E+06 [(a)]	7.18E-04	I/II	I/II	I
Ionising radiation	Frischknecht et al., 2000	kBq U-235 eq.	2.91E+13	4.22E+03	II	III	II
Photochemical ozone formation	Van Zelm et al., 2008 as applied in ReCiPe (2008)	kg NMVOC eq.	2.80E+11	4.06E+01	III	I/II	II
Acidification	Posch et al., 2008	mol H^+ eq	3.83E+11	5.55E+01	II	I/II	II
Eutrophication, terrestrial	Posch et al., 2008	mol N eq	1.22E+12	1.77E+02	II	I/II	II
Eutrophication, freshwater	Struijs et al., 2009	kg P eq	5.06E+09	7.34E-01	II	III	II
Eutrophication, marine	Struijs et al., 2009	kg N eq	1.95E+11	2.83E+01	II	II/III	II
Land use	Bos et al., 2016 (based on)	pt	9.64E+15 [(b)]	1.40E+06	II	II	III
Ecotoxicity freshwater	USEtox (Rosenbaum et al., 2008)	CTUe	8.15E+13	1.18E+04	III	III	II/III
Water use	AWARE 100 (based on; UNEP, 2016)	m^3 water eq of deprived water	7.91E+13 [(b)]	1.15E+04	I	II	III
Resource use, fossils	ADP fossils (van Oers et al., 2002)	MJ	4.50E+14	6.53E+04	I	II	III
Resource use, minerals and metals	ADP ultimate reserve (van Oers et al., 2002)	kg Sb eq	4.39E+08	6.36E-02	I	II	III

* World population used to calculate the NF per person: 6895889018 people. Source: UNDESA (2011)
(a) NF calculation takes into account the emission height, in both the inventory and the impact assessment
(b) The NF is built by means of regionalised CFs

1 Introduction

The assessment of the environmental performance of supply chains is needed to improve sustainability of products and companies. In the context of the interpretation of the life cycle impact assessment (LCIA) results, normalisation represents a powerful tool for better understanding the relative environmental significance of impacts across categories.

According to ISO 14044 (ISO, 2006), normalization is an optional step of life cycle assessment (LCA) studies, in which impacts of a specific supply chain are compared with reference scores –the so-called "normalisation factors" (NFs)– describing the impacts associated with a reference product or a given system, e.g. a region, a country or the entire globe.

Nowadays, normalisation is widely practiced in LCA-based decision support and policy analysis. In 2016, the UNEP/SETAC Life Cycle Initiative has been discussing the role of normalisation (Pizzol et al. 2016), recommending the use of global normalisation factors since perceived as more relevant for decision-making by helping better understand the meaning of LCIA results. In fact, normalisation can play an important role in providing information on the magnitude of impacts, by comparing them with a reference state, thus facilitating the communication to stakeholders as well as supporting decision making.

Over time, several normalisation factors have been proposed at different level, e.g. Sleeswijk et al. (2008) for Europe and globally, Laurent et al. (2013) for the global scale, Sala et al. (2015) for Europe, specifically EU27. Important key limitations have been identified in the previous studies, especially related to high uncertainty due to data gaps and the use of different possible sources or methodological approaches (as extensively highlighted in Benini and Sala, 2016).

The present study aims at developing a set of normalisation factors, applicable to the LCA context, as a reference situation of the impacts at the global scale for the year 2010, to be applied with the Environmental Footprint (EF) 2017 LCIA method (Sala et al., 2017). They are the result of an effort in building a normalisation inventory of emissions and resource use, describing also strengths, limitations and possible uncertainties associated with the final factors.

2 Source and modelling approach for calculating global normalisation factors

Global normalisation factors are built on inventories covering both emissions into the environmental compartments (i.e. air, water and soil), and resources extracted on global scale in 2010. Different options exist as data source for the reference year 2010. Therefore, a hierarchical procedure, as proposed by Sala et al. (2015) complementing the criteria of Sleeswijk et al. (2008), was used to guide the data selection. Some key choices, such as those related to data-gap filling strategies, were applied for populating the inventories when data were missing for the reference year or the spatial scale needed. For example, in the case of temporal data gaps, we prioritized sources, choosing data as follows: a) data related to years which are different from the reference, preferably between 2008 and 2011, coming from the primary source; b) data for 2010 from an alternative source; c) if no one of the previous alternatives was possible, we selected data for a year that is different from the reference one, coming from an alternative source.

In a few cases, e.g. toxicity-related categories, freshwater and marine eutrophication, land use and resource use, it was not possible to strictly follow the procedure as above, thus we had to operate case-specific data-gap filling procedures. In fact, the global NF for the toxicity-related impact categories were calculated by upscaling the European NF from Sala et al. (2015), based on the ratio of European/global NF from Cucurachi et al. (2014). To estimate the global NF for freshwater and marine eutrophication, the total emissions of phosphorus (P) and nitrogen (N) to soil and water were estimated from the publication of Bouwman et al. (2013). According to the linear growth of global P and N amount underlined by the study, supported by FAOSTAT (2016) data on the 12-year (i.e. 2002-2014) linear trend of production and consumption of both fertilizers and manure, a linear extrapolation strategy was applied for calculating the annual increase of phosphorus at global level between the years 2000 and 2050. The figures related to 2010 were then punctually estimated. Concerning land use impact category, the inventory was developed by Farago et al. (2018), based on their own criteria and extrapolation strategies. Finally, a specific extrapolation procedure was adopted for arsenic, chromium, phosphorus, potassium and rare earths in order to build the inventory for the resource use related global NF. The retrieved data were representative for the oxide compound of the element (e.g. arsenic trioxide, chromite, potash) which is effectively mined, and not on the metal content itself as generally provided by mine production data. Therefore, the amount of these elements themselves was extrapolated by using the molecular weight of the oxide compound and the atomic weight of the element.

After their classification into the ILCD compliant elementary flows, the final inventories were characterized by using the characterization factors (CFs) from the EF 2017 midpoint method (Sala et al 2017). Regarding the specificity of the emission compartment, "unspecified" CFs were generally used (e.g. "emission into water, unspecified" instead of "emission to freshwater"). For a few impact categories, it was possible to use country-specific CFs (i.e. for land use and water use), or CFs detailed by the height of the emission source (i.e. for particulate matter). This was possible benefitting from the high detail of the underpinning inventory for these categories.

Table 2 reports the data sources, by impact category, used for compiling the global inventories of the year 2010.

Table 2. List of available data covering the elementary flows and sources by impact category included in the global inventory for the calculation of the global normalisation factors.

Impact category	Substance groups	Data sources
Climate change	Carbon dioxide, methane, nitrous oxide both from direct emissions and those associated to LULUCF (land use, land-use change and forestry); PCFs; HFCs; sulphur hexafluoride	EDGAR v. 4.2 (EC-JRC & PBL, 2013)
	HCFC-22; CFC-11; Halon-1211	Fraser et al. (2014)
	HCFC-141b;HCFC-142b; Halon-1001	Fraser et al. (2011)
Ozone depletion	HCFC-140	Fraser et al. (2015)
	CFC-11	Fraser et al. (2014)
	HCFC-22;Halon-1211, Halon totals	Fraser et al. (2013)
	Halon-1001;HCFC-141b;HCFC-142b	Fraser et al. (2011)
Human toxicity (cancer and non-cancer), Ecotoxicity freshwater	Air emissions: Heavy metals Organics non-NMVOC, dioxins, PAH, HCB, etc. Releases in water: Industrial releases of HMs + organics Urban wastewater treatment plants (heavy metals + organics) Releases in soil: Industrial releases (heavy metals, POPs) Sewage sludge (containing organics and metals) Manure Pesticides: Active ingredients breakdown (i.e. disaggregated into EU countries and major types of crops) combined with dosage statistics.	Cucurachi et al. (2014)
Particulate matter	Nitrogen oxides; ammonia; sulfur dioxide; carbon monoxide; PM_{10}, $PM_{2.5}$	EDGAR v. 4.3.1. (EC-JRC & PBL, 2016)
Ionising radiation	Emissions of radionuclides to air and water from nuclear sources for electricity generation, i.e. uranium mining and milling, nuclear power plants, coal, natural gas and oil combustion, geothermal energy extraction	UNSCEAR (2017)
	Emissions of radionuclides to air and water from nuclear spent-fuel reprocessing	RADD (2016); UNSCEAR (2016); WNA (2016a)

Impact category	Substance groups	Data sources
Photochemical ozone formation	NMVOC; nitrogen oxides; methane; carbon monoxide	EDGAR v. 4.3.1 (EC-JRC & PBL, 2016)
Acidification	Nitrogen oxides; sulphur dioxide; ammonia	EDGAR v. 4.3.1 (EC-JRC & PBL, 2016
Eutrophication, terrestrial	Nitrogen oxides; ammonia	EDGAR v. 4.3.1 (EC-JRC & PBL, 2016)
Eutrophication, freshwater	Phosphorous to soil and water, from agriculture	Bouwman et al. (2013)
Eutrophication, marine	Nitrogen oxides; ammonia Nitrogen to water, from agriculture	EDGAR v. 4.3.1 (EC-JRC & PBL, 2016) Bouwman et al. (2013)
Land use	"Land occupation" and "land transformation": forest, cropland, grassland, settlements, unspecified	Farago et al. (2018) based on data from FAO (2010; 2014), FAOSTAT (2016) and NASA (2016)
Water use	Gross water consumption	WaterGAP (Müller Schmied et al. 2014; Flörke et al., 2013; Aus der Beek et al., 2010)
Resource use	Fossils	WNA (2016b); IEA (2014)
	Metals and minerals	USGS (2011 a, b)

A qualitative assessment of the completeness and robustness of datasets used for building the inventories as well as the robustness of the impact assessment models underpinning the characterization of global impacts was performed for each impact category, according to the specific criteria showed in Table 3. The information behind this evaluation aims at drawing attention to the potential sources of uncertainty underlying the calculation of the normalisation factors. Therefore, the robustness of the NFs is summarized by an overall score covering the inventory coverage completeness, the inventory robustness (based on data quality, entailing the combination of different sources and the adoption of extrapolation strategies) and the robustness of the impact assessment method (according to the recommendation from the ILCD (EC-JRC, 2011) and according to Sala et al. (2017).

Table 3. Criteria for evaluating the robustness of the global normalisation factors.

Analysed features: definition	**Score[a] and description**	
Inventory coverage completeness, i.e. the extent to which the inventory data cover the list of flows available in ILCD, for each impact category	I	high (60% to 100%)
	II	medium (30% to 59%)
	III	low (0 to 29%)
Inventory robustness, i.e. the quality of data, assessed by considering both the combination of different sources and the adoption of extrapolation strategies	I	high (data from published datasets from official data sources, subjected to a quality assurance procedure and limited use of extrapolation methods, i.e. <20 % of the impact derived from extrapolation)
	II	medium (non-publicly available or peer reviewed datasets and/or use of extrapolation methods for more than 20% but less than 80% of the impact)
	II	low (use of extrapolation methods for more than 80% of the impact)
Level of recommendation of the impact assessment method, according to the classification of the ILCD recommended characterization models (EC-JRC, 2011; Sala et al., 2017) based on model quality	I	the model is recommended and satisfactory
	II	the model is recommended, but in need of some improvements
	III	the model is recommended, but to be applied with caution

[a] adapted from Sala et al. (2015)

3 Global normalisation factors

The global normalization factors, by impact category, are summarized in Table 4. The coverage completeness and robustness of the underpinning inventory as well as the reference to the impact assessment model used and its robustness are reported.

Combining reported data from different data sources, as for the final inventories of several categories (e.g. climate change, ionizing radiation, land use, etc.), may lead to uncertainties, such as over- or under-estimation of the final factor. Furthermore, in certain cases, as for climate change, ozone depletion and ionizing radiation, the NFs are likely to be underestimated due to missing data for some important substances, like HFCs, HCFCs and emissions from non-nuclear activities (e.g. phosphate and ceramics industry) respectively. In fact, limited data on such substances are available in the scientific literature, although their recognized environmental relevance. For instance, HCFCs from developing countries in 2008 accounted for 74% and 73% of total ODP-weighted HCFC consumption and production, respectively (UNEP, 2010).

Uncertainties in the calculation of the global NFs may derive also from the classification of elementary flows, as well as the selection of characterization factors, namely we generally used unspecified CFs due to lack of detailed information at the inventory level.

According to the contribution analysis we performed, namely the analysis of the extent to which the inventoried substances contribute, as a percentage, to the global normalisation factor for each selected category, in the majority of the impact categories only few elementary flows make up a significant share of the overall impact. Additionally, for the majority of the impact categories a single flow drives the impact, by contributing for example 40% (e.g. CFC-11 for ozone depletion) up to about 70% (e.g. $PM_{2.5}$ for particulate matter) to the overall impact. The reasons underpinning this aspect are extensively discussed in Sala et al. (2015) and are reasonable also for the global normalisation factors. In particular, for climate change, ionizing radiation and toxicity-related impacts, the rationale for building the inventories are generally based on the same set of rules and the CFs adopted in the characterization step come from the same models. For the other categories, the results of the contribution analysis at EU27 and global level are generally similar, with high share of impacts deriving from the combustion of fossil fuels (e.g. carbon dioxide, nitrogen oxides, $PM_{2.5}$) just to name an example.

Table 4. Global normalisation factors for emissions and resource extraction in 2010, based on EF 2017 method (Sala et al 2017). The attributed score is from I-highest to III-lowest

Impact category	Model	Unit	global NF for EF	global NF for EF per person *	Inventory coverage completeness	Inventory robustness	Recommendation level of EF impact assessment
Climate change	IPCC (2013)	kg CO_2 eq	5.79E+13	8.40E+03	II	I	I
Ozone depletion	WMO (1999)	kg CFC-11 eq	1.61E+08	2.34E-02	III	II	I
Human toxicity, cancer	USEtox (Rosenbaum et al., 2008)	CTUh	2.66E+05	3.85E-05	III	III	II/III
Human toxicity, non-cancer	USEtox (Rosenbaum et al., 2008)	CTUh	3.27E+06	4.75E-04	III	III	II/III
Particulate matter	Fantke et al., 2016	disease incidences	4.95E+06 [(a)]	7.18E-04	I/II	I/II	I
Ionising radiation	Frischknecht et al., 2000	kBq U-235 eq.	2.91E+13	4.22E+03	II	III	II
Photochemical ozone formation	Van Zelm et al., 2008 as applied in ReCiPe (2008)	kg NMVOC eq.	2.80E+11	4.06E+01	III	I/II	II
Acidification	Posch et al., 2008	mol H^+ eq	3.83E+11	5.55E+01	II	I/II	II
Eutrophication, terrestrial	Posch et al., 2008	mol N eq	1.22E+12	1.77E+02	II	I/II	II
Eutrophication, freshwater	Struijs et al., 2009	kg P eq	5.06E+09	7.34E-01	II	III	II
Eutrophication, marine	Struijs et al., 2009	kg N eq	1.95E+11	2.83E+01	II	II/III	II
Land use	Bos et al., 2016 (based on)	pt	9.64E+15 [(b)]	1.40E+06	II	II	III
Ecotoxicity freshwater	USEtox (Rosenbaum et al., 2008)	CTUe	8.15E+13	1.18E+04	III	III	II/III
Water use	AWARE 100 (based on; UNEP, 2016)	m^3 water eq of deprived water	7.91E+13 [(b)]	1.15E+04	I	II	III
Resource use, fossils	ADP fossils (van Oers et al., 2002)	MJ	4.50E+14	6.53E+04	I	II	III
Resource use, minerals and metals	ADP ultimate reserve (van Oers et al., 2002)	kg Sb eq	4.39E+08	6.36E-02	I	II	III

* World population used to calculate the NFs per person: 6895889018 people. Source: UNDESA (2011)
(a) NF calculation takes into account the emission height, in both the inventory and the impact assessment
(b) The NF is built by means of regionalised CFs

4 Outlook

In this study, a set of normalisation factors for the year 2010 has been estimated with the aim of describing and quantitatively assessing the level of pressure to the environment at the global scale. Global normalisation factors can be used in the decision-making context for improving the interpretation of LCIA results, thus enhancing the achievement of sustainability goals in the supply chain management. In fact, normalisation factors help interpret the scores of each impact category, converting them in fraction of impact of a reference situation's system (e.g. the global system as presented in this study).

Calculations herein presented are based on inventory data of emissions and resource use at global scale, mainly retrieved from official statistics. This report provides an up to date picture of global normalisation figures and represents an improvement over existing work in this area. However, we also can indicate areas for further improvement aiming at overcoming the uncertainties identified both at the inventory (e.g. difficulty in retrieving recent data) and characterization levels (e.g. consistency between inventory and impact assessment regarding the regionalisation of impacts). Any assessment based on the use of NFs should be discussed and interpreted taking into account also the limitations discussed in this report. As previously indicated by Sala et al. (2015) and Benini and Sala (2016) for the EU27 normalisation factors, areas for further improvement include: (i) completeness of the inventory; (ii) methodological choices, and (iii) completeness and robustness of the impact assessment.

Completeness of the inventories. More robust inventories for several impact categories should be set, focusing on their coverage completeness in terms of elementary flows available for each impact category. Generally, global inventories are affected by limited availability of recent data on emissions and resource use from the original sources. An option of overcoming this issue has been evaluated by building inventories based on data proceeding from different reliable data sources. In fact, having a complete normalisation inventory is fundamental in order to avoid over- or under-estimations of the overall environmental impacts as well as generating misleading interpretation of the characterised LCIA results. Currently, the level of harmonization among the underpinning approaches used for obtaining data can still be improved. Therefore, a systematic collection of more detailed and precise data associated to the global emission profile and resource use is always needed, thus ensuring consistency of assumptions and extrapolations.

Methodological choices. As reported in Benini and Sala (2016), the classification of elementary flows represents one of the most significant sources of uncertainty issues due to several aspects. For instance, the use of different names in the sources for identifying the same substance may generate inconsistencies in the final flow mapping and in the identification of the corresponding CFs. Besides, the lack of CFs in the applied LCIA methods for several substances which are instead available in the statistics prevents a more comprehensive assessment of the impacts.

Impact assessment. Global normalisation factors have been calculated by using the EF 2017 method (Sala et al., 2017). For several impact categories, e.g. water use and land use, regionalized characterization models for impact assessment have been adopted, which are crucial for supply chain assessment where environmental pressures have site-specific characteristics (e.g. climate, soil type, water availability). Regionalisation in impact assessment is a relatively young area, which is under constant development and more consistency between characterisation and normalisation should be ensured over time.

References

Aus der Beek, T., Flörke, M., Lapola, D.M., Schaldach, R., 'Modelling historical and current irrigation water demand on the continental scale: Europe', *Advances in Geosciences,* Vol. 27, 2010, pp. 79-85

Benini, L., Sala, S., 'Integrated assessment of environmental impact of Europe in 2010: uncertainty and sensitivity of the normalisation factors to methodological assumptions'. International Journal of Life Cycle Assessment, Vol. 21, No 2, 2016, pp. 224-236

Bos, U., Horn, R., Beck, T., Lindner, J.P., Fischer, M., *LANCA® - Characterisation Factors for Life Cycle Impact Assessment, Version 2.0*, Fraunhofer Verlag, Stuttgart, 2016, ISBN: 978-3-8396-0953-8.

Bouwman, L., Goldewijk, K.K., Van Der Hoek, K.W., Beusen, A.H., Van Vuuren, D.P., Willems, J., Rufino, M., Stehfest, E., 'Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period', *Proceedings of the National Academy of Science*, Vol. 110, No 52, 2'13, pp. 20882-20887.

Cucurachi S., Sala S., Laurent A., Heijungs R., 'Building and characterizing regional and global emission inventories of toxic pollutants', *Environmental Science and Technologies*, Vol. 48, No 10, 2016, pp. 5674-5682.

European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL). 'Emission Database for Global Atmospheric Research (EDGAR), released version 4.2 FT2010'. 2013. http://edgar.jrc.ec.europa.eu/overview.php?v=42FT2010. Accessed October 2016.

European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL). 'Emission Database for Global Atmospheric Research (EDGAR), released version 4.3.1'. 2016. http://edgar.jrc.ec.europa.eu/overview.php?v=431. Accessed October 2016.

Fantke, P., Evans, J., Hodas, N., Apte, J., Jantunen, M., Jolliet, O., McKone, T.E., 'Health impacts of fine particulate matter'. In: Frischknecht, R., Jolliet, O. (Eds.), *Global Guidance for Life Cycle Impact Assessment Indicators: Volume 1. UNEP/SETAC Life Cycle Initiative*, Paris, 2016, pp. 76-99.

FAO, Food and Agriculture Organization of United Nations. *Global forest resources assessment 2010 - Main report*. Rome, 2010.

FAO, Food and Agriculture Organization of United Nations. Global Land Cover SHARE - Share of year 2014 (GLC-SHARE). Beta released version 1.0. 2014. http://www.glcn.org/databases/lc_glcshare_downloads_en.jsp. Accessed August 2016.

FAOSTAT, Statistical databases of the Food and Agricultural Organization of United Nations, 2016. http://faostat3.fao.org/download/R/RL/E. Accessed September 2017.

Farago, M., Benini, L., Sala, S., Secchi, M., Laurent, A., 'National inventories of land occupation and transformation flows in the world for land use impact assessment'. 2018, *in preparation.*

Flörke, M., Kynast, E., Bärlund, I., Eisner, S., Wimmer, F., Alcamo, J., 'Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study', *Global Environmental Change*, Vol. 23, 2016, pp. 144-156.

Fraser, P., Krummel, P., Dunse, B., Steele, P., Derek, N., Allison, C., *DSEWPaC research projects 2010–11*. Centre for Australian Weather and Climate Research, Aspendale, 2011, 34 pp.

Fraser, P., Dunse, B., Krummel, P., Steele, L., Derek, N., *Australian Atmospheric Measurements & Emissions Estimates of Ozone Depleting Substances and synthetic Greenhouse Gases*. Centre for Australian Weather and Climate Research, Aspendale, 2013, 42 pp.

Fraser, P., Dunse, B., Krummel, P., Steele, L., Derek, N., *Australian & Global Emissions of Ozone Depleting Substances*. Centre for Australian Weather and Climate Research, Aspendale, 2014, 29 pp.

Fraser, P., Dunse, B., Krummel, P., Steele, L., Derek, N., *Australian & Global Emissions of Ozone Depleting Substances*. Collaboration for Australian Weather and Climate Research, Aspendale, 2015, 29 pp.

Frischknecht, R., Braunschweig, A., Hofstetter, P., Suter, P., 'Modelling human health effects of radioactive releases in Life Cycle Impact Assessment', *Environmental Impact Assessment Review*, Vol. 20, No 2, 2000, pp. 159-189

IEA*,* International Energy Agency, *Key world energy statistics*, Paris, 2014, 80 pp.

IPCC, Intergovernmental Panel on Climate Change, *Climate Change Fifth Assessment Report: Climate Change 2013.* http://www.ipcc.ch/ipccreports/assessments-reports.htm.

ISO, International Organization for Standardization, *Environmental management— life cycle assessment. Requirements and guidelines.* ISO 14044, Geneva, Switzerland, 2006.

Laurent, A., Hauschild, M.Z., Golsteijn, L., Simas, M., Fontes, J., Wood, R., *Normalisation factors for environmental, economic and socio-economic indicators*. Deliverable 5.2 of PROSUITE (FP7 project), 2013

Müller Schmied, H., Eisner, S., Franz, D., Wattenbach, M., Portmann, F.T., Flörke, M., Döll, P., Sensitivity of simulated global-scale freshwater fluxes and storages to input data, hydrological model structure, human water use and calibration. *Hydrology and Earth System Sciences*, Vol. 18, No 9, 2014, pp. 3511-3538.

NASA, National Aeronautics and Space Administration. UN-Adjusted Population Density, version 4: Gridded Population of the World (GPW), v4 | SEDAC. 2016. http://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-adjusted-to-2015-unwpp-country-totals/data-download. Accessed August 2016.

Pizzol, M., Laurent, A., Sala, S., Weidema, B., Verones, F., Koffler, C., 'Normalisation and weighting in life cycle assessment: Quo Vadis?', The International Journal of Life Cycle Assessment, Vol. 22, No 6, 2016, pp. 853-866

Posch, M., Seppälä, J., Hettelingh, J.P., Johansson, M., Margni M., Jolliet, O., The role of atmospheric dispersion models and ecosystem sensitivity in the determination of characterisation factors for acidifying and eutrophying emissions in LCIA. *International Journal of Life Cycle Assessment*, Vol. 13, 2008, pp.477–486.

RADD, Radioactive Discharges Database of the European Commission, 2016. http://europa.eu/radd/. Accessed April 2016.

Rosenbaum, R.K., Bachmann, T.M., Gold, L.S., Huijbregts, M.A.J., Jolliet, O., Juraske, R., Köhler, A., Larsen, H.F., MacLeod, M., Margni, M., McKone, T.E., Payet, J., Schuhmacher, M., van de Meent, D., Hauschild, M.Z., USEtox - The UNEPSETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in Life Cycle Impact Assessment. *International Journal of Life Cycle Assessment*, Vol. 13, No 7, 2008, pp. 532-546

Sala, S., Benini, L., Mancini, L., Pant, R. 'Integrated assessment of environmental impact of Europe in 2010: data sources and extrapolation strategies for calculating normalisation factors'*. International Journal of Life Cycle Assessment*, Vol. 20, No 11, 2015, pp. 1568-1585.

Sala, S., Benini, L., Castellani, V., Vidal Legaz, B., Pant, R. *Environmental Footprint - Update of Life Cycle Impact Assessment methods for resources, water, land and particulate matter.* 2017 (in print)

Sleeswijk, A.W., van Oers, L.F., Guinée, J.B., Struijs, J., Huijbregts, M.A., 'Normalisation in product life cycle assessment: An LCA of the global and European economic systems in the year 2000'. *Science of the Total Environment*, Vol. 390, No 1, 2008, pp. 227-240

Struijs, J., Beusen, A., van Jaarsveld, H., Huijbregts, M.A.J., 'Aquatic Eutrophication. Chapter 6'. In: Goedkoop, M., Heijungs, R., Huijbregts, M.A.J., De Schryver, A., Struijs, J., Van Zelm, R., *ReCiPe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. Report I: Characterisation factors*, 1st edition, 2009.

UNDESA, United Nations, Department of Economic and Social Affairs, Population Division. *World Population Prospects: The 2010 Revision*. Extended Dataset. 2011. United Nations publication, Sales No. E.11.XIII.7)

UNEP, United Nations Environment Program, *Environmental Effects of Ozone Depletion and Its Interactions with Climate Change: 2010 Assessment*. ISBN 92-807-2312-X. 330 pp. Nairobi, Kenya, 2010.

UNEP, United Nations Environment Program, *Global guidance for life cycle impact assessment indicators*, Vol. 1, 2016, ISBN: 978-92-807-3630-4.

UNSCEAR, United Nations Scientific Committee on the Effects of Atomic Radiation. *Collection of national and regional data on ionising radiation. Releases from nuclear fuel cycle reprocessing plants in airborne and liquid effluents*, 2016, http://www.survey.unscear.org/doku.php. Accessed April 2016.

UNSCEAR, United Nations Scientific Committee on the Effects of Atomic Radiation, *UNSCEAR 2016 Report to the General Assembly, Annex B: sources, effects and risks of ionizing radiation*. 108 pp. New York, 2017.

USGS, United States Geological Survey. *Mineral commodity summaries 2011: U.S. Geological Survey*, 2011a, 198 pp. http://minerals.usgs.gov/minerals/pubs/mcs/2011/mcs2011.pdf. Accessed November 2016.

USGS, United States Geological Survey, *Mineral Yearbook 2011 - Metals & Minerals*, Vol. 1., 2011b http://minerals.usgs.gov/minerals/pubs/commodity/myb/. Accessed November 2016.

van Oers, L., de Koning, A., Guinee, J.B., Huppes, G., 'Abiotic Resource Depletion in LCA'. Road and Hydraulic Engineering Institute, Ministry of Transport and Water, Amsterdam, 2002.

Van Zelm, R., Huijbregts, M.A.J., Den Hollander, H.A., Van Jaarsveld, H.A., Sauter, F.J., Struijs, J., Van Wijnen, H.J., Van de Meent, D., 'European characterization factors for human health damage of PM10 and ozone in life cycle impact assessment'. *Atmospheric Environment*, Vol. 42, 2008, pp. 441-453.

WMO, World Meteorological Organisation, *Scientific Assessment of Ozone Depletion: 1998. Global Ozone Research and Monitoring Project - Report* No. 44, ISBN 92-807-1722-7, Geneva, 1999.

WNA, World Nuclear Association. *World commercial reprocessing capacity, from "Processing of Used Nuclear Fuel"*, 2016a. http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/processing-of-used-nuclear-fuel.aspx. Accessed November 2016.

WNA, World Nuclear Association. *World uranium mining production*, 2016b. http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Mining-of-Uranium/World-Uranium-Mining-Production/. Accessed March 2016.

List of abbreviations and definitions

CFs	Characterization factors
CTUh	Comparative toxic unit, human health
CTUe	Comparative toxic unit, ecosystem
EF	Environmental Footprint
EU27	European Union-27 (countries)
HCB	Hexachlorobenzene
ILCD	International Reference Life Cycle Data System
ISO	International Organization for Standardisation
LCA	Life cycle assessment
LCIA	Life cycle impact assessment
LULUCF	Land use, land-use change and forestry
NFs	Normalisation factor
NMVOC	Non-methane volatile organic compounds
PAH	Polycyclic aromatic hydrocarbon
POPs	Persistent organic pollutants
Pt	points (related to the scores of the soil quality index)

List of tables

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: http://europea.eu/contact

On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

- by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

- at the following standard number: +32 22999696, or

- by electronic mail via: http://europa.eu/contact

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: http://europa.eu

EU publications

You can download or order free and priced EU publications from EU Bookshop at: http://bookshop.europa.eu. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see http://europa.eu/contact).

KJ-NA-28984-EN-N

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

Joint Research Centre

EU Science Hub

Publications Office

doi:10.2760/88930

ISBN 978-92-79-77213-9