European Commission

JRC TECHNICAL REPORTS

Normalisation method and data for Environmental Footprints

Lorenzo Benini, Lucia Mancini, Serenella Sala,
Simone Manfredi, Erwin M. Schau, Rana Pant

2014

Report EUR 26842 EN

Joint
Research
Centre

European Commission
Joint Research Centre
Institute for Environment and Sustainability

Contact information
Serenella Sala
Address: Joint Research Centre, Via Enrico Fermi 2749, TP 290, 21027 Ispra (VA), Italy
E-mail: serenella.sala@jrc.ec.europa.eu
Tel.: +39 0332 786417
Fax: +39 0332 786 645
JRC Science Hub
https://ec.europa.eu/jrc

JRC91531

EUR 26842 EN

ISBN 978-92-79-40847-2

ISSN 1831-9424

doi: 10.2788/16415

Luxembourg: Publications Office of the European Union, 2014

Abstract

According to ISO 14044 (ISO 2006), normalisation, in the context of Life Cycle Assessment (LCA), is an optional step of Life Cycle Impact Assessment (LCIA) which allows the practitioner to express results after the characterisation step using a common reference impact. This supports the comparison between alternatives using reference numerical scores. The normalisation factors express the total impact occurring in a reference region for a certain impact category (e.g. climate change, eutrophication, etc.) within a reference year. This document provides normalisation factors (NFs) for the implementation of the EU Environmental Footprint methodology (EC - European Commission, 2013).
The calculation of NFs is based on a 'EU-27 domestic inventory' i.e. an extensive collection of emissions into air, water and soil as well as resources extracted in EU-27 with reference to 2010 (Sala et al., 2014). The International Reference Life Cycle Data System (ILCD) impact assessment methods and related characterisation factors (EC-JRC, 2011) were applied to the domestic inventory so to calculate the normalisation factors. In this report, the main methodological steps used to calculate the normalisation factors are described and discussed, and an overview is given of the improvements of current figures compared to similar studies (CML, 2013; Wegener Sleeswijk, et al., 2008; Wegener Sleeswijk and Huijbregts, 2010). Although the consideration of international trade in normalisation factors would allow for a more comprehensive picture of the actual environmental impacts due to EU production and consumption processes, this study shows, through a comparative assessment, that the present level of methodological development and data availability in modelling trade are not sufficiently mature. The main reasons are: i) significant variability in the results obtained using different methods for selecting and up-scaling products; ii) the ratio of imports to domestic products appears to be underestimated. The recommendation for normalisation factors in the Environmental Footprint context is therefore to rely on domestic figures for 2010.

Normalisation method and data for Environmental Footprints

Suggested citation

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

Disclaimer

The dataset underpinning the normalisation factors is in its first release version. Identified limitations to the robustness of the figures are highlighted in the text. Although due care has been taken in compiling the data, additional limitations and errors cannot be excluded. The European Commission accepts no responsibility or liability whatsoever with regard to the information in this report. Any use of the report and the data contained therein is entirely the responsibility of the user.

Acknowledgment

The project to develop normalization factors was funded by the European Commission, DG Environment in the context of the Administrative Arrangement '*Environmental Footprint and Material Efficiency Support for Product Policy*' (No. 70307/2012/ENV.C.1/635340). This document represents Deliverable 2 of the above mentioned Administrative Arrangement.

Contents

List of tables

List of figures

Executive Summary

According to ISO 14044 (ISO 2006), normalisation, in the context of Life Cycle Assessment (LCA), is an optional step of Life Cycle Impact Assessment (LCIA) which allows the practitioner to express results after the characterisation step using a common reference impact. This supports the comparison between alternatives using reference numerical scores. The normalisation factors express the total impact occurring in a reference region for a certain impact category (e.g. climate change, eutrophication, etc.) within a reference year.

This document provides normalisation factors (NFs) for the implementation of the EU Environmental Footprint methodology (EC - European Commission, 2013). The calculation of NFs is based on a refinement and update of the 'Life Cycle Indicators for Resources' dataset (EC - JRC, 2012b), which is used as the inventory for the study. These indicators were developed within the Life Cycle Indicators framework (EC - JRC, 2012a) in the context of the Roadmap to a resource-efficient Europe (within the Europe 2020 Strategy's flagship initiative for a resource-efficient Europe). The aim of the Life Cycle Indicators is to monitor the environmental impacts associated with European production, consumption and waste management within the EU, including the impacts of international trade (imports and exports).

The Life Cycle Indicators for Resources are based on the collection of data related to domestic emissions and resource extraction (domestic inventories) complemented with process-based LCA for representative traded goods. They are designed to provide information on the environmental impacts linked to European consumption and production by adopting an 'apparent consumption' approach i.e. by adding the environmental impacts associated to imported goods to those originating from activities taking place in a given territory (the domestic inventory) and by subtracting those associated to exported goods. Although the 'apparent consumption' approach was adopted in the initial formulation of the Life Cycle Indicators, the current version of the normalisation factors is calculated on the basis of domestic inventories only.

The domestic inventory underlying the normalisation factors is based on an extensive collection of emissions into air, water and soil as well as resources extracted in EU. The data were derived from an update of the Life Cycle Indicators for Resources (EC - JRC, 2012b) updated for 2010 at EU-27and country levels (Sala et al., 2014) The data gaps related to missing flows of emissions and resource extraction in the domestic inventory have been overcome by adopting a series of estimation strategies (details on estimation strategies are reported in Sala et al., 2014).

The International Reference Life Cycle Data System (ILCD) impact assessment methods and related characterisation factors (EC-JRC, 2011) were applied to calculate the normalisation factors as in done in Benini et al. (2014) for EU-27 and member countries.

In this report, the main methodological steps used to calculate the normalisation factors are described and discussed, and an overview is given of the improvements of current figures compared to similar studies (CML, 2013; Wegener Sleeswijk, et al., 2008; Wegener Sleeswijk and Huijbregts, 2010) and the limitations due to data gaps and extrapolations.

The consideration of international trade in normalisation factors would allow for a more comprehensive picture of the actual environmental impacts due to EU production and consumption processes. The original goal of the study was to develop normalisation factors that are based on an apparent consumption approach, as developed for the Life Cycle Indicators for Resources prototype. To calculate the impacts of consumption only, the impacts attributed to imported goods should be added to, and the impacts attributed to exported goods should be deducted from, the domestic figures for the EU-27.

However, the study shows that the present level of methodological development and data availability are not sufficiently mature for the results of impacts associated with trade to be recommended for use as normalisation values in the context of Environmental Footprint calculations or Life Cycle Assessments. The main reasons are: i) significant variability in the results obtained using different methods for selecting and up-scaling products; ii) the ratio of imports to domestic products appears to be underestimated.

The recommendation for normalisation factors in the Environmental Footprint context is therefore to rely on domestic figures for 2010, as these have been identified as being the most robust for this kind of application.

Table 1 provides the recommended normalisation factors for the EU-27 related to the domestic inventory in 2010. Per person normalisation factors have been calculated using Eurostat data on the EU-27 population in 2010; 499 million inhabitants (Eurostat, 2013b).

Table 1 Recommended Normalisation Factors (NFs) for EU-27 (2010) based on the domestic inventory

Impact category	Unit	Domestic	Normalisation Factor per Person (domestic)	Overall Robustness
Climate change	kg CO_2 eq.	4.60E+12	9.22E+03	Very High
Ozone depletion	kg CFC-11 eq.	1.08E+07	2.16E-02	Medium
Human toxicity - cancer effect	CTUh	1.84E+04	3.69E-05	Low
Human toxicity - non-cancer effect	CTUh	2.66E+05	5.33E-04	Low
Acidification	mol H^+ eq.	2.36E+10	4.73E+01	High
Particulate matter/Respiratory Inorganics	kg $PM_{2.5}$ eq.	1.90E+09	3.80E+00	Very High
Ecotoxicity for aquatic fresh water	CTUe	4.36E+12	8.74E+03	Low
Ionising radiations – human health effects	kBq U^{235} eq. (to air)	5.64E+11	1.13E+03	Medium
Photochemical ozone formation	kg NMVOC eq.	1.58E+10	3.17E+01	Medium
Eutrophication - terrestrial	mol N eq.	8.76E+10	1.76E+02	Medium
Eutrophication - freshwater	kg P eq.	7.41E+08	1.48E+00	Medium to Low
Eutrophication - marine	kg N eq.	8.44E+09	1.69E+01	Medium to Low
Land use	kg C deficit	3.74E+13	7.48E+04	Medium
Resource depletion - water	m^3 water eq.	4.06E+10	8.14E+01	Medium to Low
Resource depletion - mineral, fossil & renewable	kg Sb eq.	5.03E+07	1.01E-01	Medium

1 Introduction

According to ISO 14044 (ISO 2006), normalisation, in the context of Life Cycle Assessment (LCA), is an optional step of Life Cycle Impact Assessment (LCIA) which allows the practitioner to express results after the characterisation step using a common reference impact. This supports the comparison between alternatives using reference numerical scores. The normalisation factors express the total impact occurring in a reference region for a certain impact category (e.g. climate change, eutrophication, etc.) within a reference year.

This document provides normalisation factors (NFs) for the implementation of the EU Product Environmental Footprint methodology (EC - European Commission, 2013). The elementary flows adopted for the calculation of the NFs are derived from the Life Cycle Indicators framework (EC - JRC, 2012a), in particular from the Life Cycle Indicators for Resources (EC - JRC, 2012b). Updated data for 2010 at EU-27 and country levels have been used.

The Life Cycle Indicators for Resources are based on the collection of data related to territorial emissions (from domestic inventories) complemented with process-based LCA for representative traded goods. In fact, the Life Cycle Indicators have been designed to provide information on the environmental impacts linked to European consumption and production. The Life Cycle Indicators for Resources adopt the 'apparent consumption' approach by accounting for both the domestic extractions of resources and emissions in the EU-27 as well as the impacts due to international trade (imports and exports).

The Life Cycle Indicators for Resources are based on the collection of data related to domestic emissions and resource extraction (domestic inventories) complemented with process-based LCA for representative traded goods. They are designed to provide information on the environmental impacts linked to European consumption and production by adopting an 'apparent consumption' approach i.e. by adding the environmental impacts associated to imported goods to those originating from activities taking place in a given territory (the domestic inventory) and by subtracting those associated to exported goods. The normalisation factors are calculated by applying the International Reference Life Cycle Data System (ILCD) set of impact assessment methods and related characterisation factors (EC-JRC, 2011) to both trade and domestic inventories.

Although the 'apparent consumption' approach was adopted in the initial formulation of the Life Cycle Indicators, the current version of the normalisation factors is calculated on the basis of domestic inventories only.

In the following sections, the main methodological steps in the calculation of the normalisation factors are described and discussed, providing an overview of the improvements of current figures compared to others datasets available in literature as well as limitations due to data gaps and extrapolations. Chapter 2 explains the calculation methodology – including the framework of the Life Cycle Indicators that underpins the assessment – and its main assumptions. Details on estimation strategies adopted to overcome the data gaps in emissions and resource extraction are reported in Sala et al. (2014).

Chapter 3 presents the updated figures for the normalisation of the EU-27 data based on domestic inventories for each impact category, discussing the robustness of the assessment, comparing the results with existing normalisation values and reporting on the main limitations and sources of uncertainty. The results for the normalisation factors including international trade (imports and exports) are presented in Chapter 4. Chapter 5.1 provides an overview of the results, while Chapter 6 presents the main conclusions of the study.

2 Methodology

The calculation of normalisation factors for the Product Environmental Footprint (PEF) is based on a refinement and update of the 'Life Cycle indicators for Resources' dataset (EC - JRC, 2012b), used as inventory. These indicators were developed within the Life Cycle Indicators framework (EC - JRC, 2012a) in the context of the Roadmap to a resource efficient Europe, within the Flagship initiative - A resource-efficient Europe of the Europe 2020 Strategy. Their aim is to monitor the environmental impacts associated with European production and consumption, as well as waste management within the EU, by including also impacts from trade (imports and exports). In this chapter the architecture of the indicators is briefly described. The following chapters describe the general assumptions and limitations in the assessment of the territorial impacts, as well as in the consideration of the international trade.

The 'Life Cycle Indicators for Resources' dataset (LC Indicators) and the consequent set of NFs adopt an 'apparent consumption' approach to the assessment of the environmental burden associated to the EU economy. His means that the impacts associated with the imported products are summed to the impacts related to the activities taking place in the EU-27 territory (domestic), minus the impacts associated to the exported products. This concept is depicted in Figure 1.

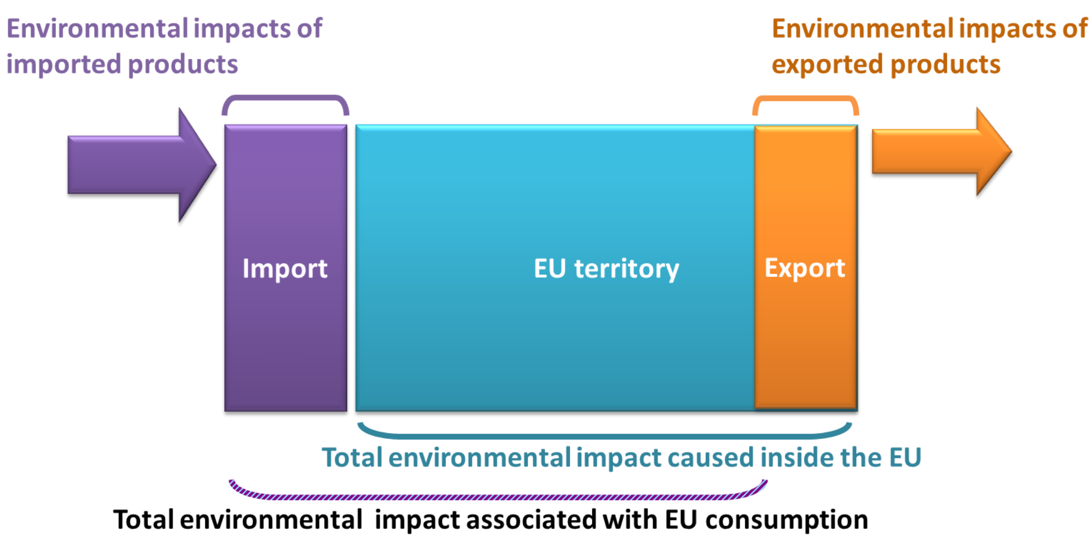


Figure 1 Total environmental impact associated with EU-27 apparent consumption (EC - JRC, 2012a)

The total environmental impact, according to LCA methodologies, is calculated in two steps. Firstly, the life cycle inventory should be built and secondly, the inventory should be characterised for a number of impact categories (14 in ILCD) in the impact assessment step.

At the inventory level, two datasets have been developed and are presented in Chapters 3 and 4, respectively:

- **EU domestic,** is based on extensive data collection on emission in air, water and soil as well as resource extraction in the EU territory in 2010.

- **EU trade**, entailing import and export, is based on bottom-up LCA of a selected number of representative products. The LCIs of those products, with proper up-scaling coefficients, represent the trade inventory.

Regarding the **life cycle impact assessment**, the ILCD recommended impact assessment methods (EC - JRC, 2011) and the related characterization factors (CF) (Sala et al. 2012) have been used for calculating NFs. Even if data in the territorial inventory are reported by country, default (non-country specific) CFs has been used. Additionally, notwithstanding the elementary flows descriptions identify specific emissions' details (e.g. emission into air- high stack), the default CFs for emission to air "unspecified" was chosen. This was mainly due to the fact that statistical data are too aggregated for allowing higher level of distinction in the emission. Characterization factors used for the assessment are not country-specific, but refer to the whole EU 27.

3 Environmental impacts from EU-27 domestic

In chapter 3.1 the data sources used for creating bthe domestic inventory are described.

From chapter 3.2 onwards, the NFs 2010 calculated for each impact category are presented and compared to other NFs (CML, 2013; Wegener Sleeswijk, et al., 2008; Wegener Sleeswijk and Huijbregts, 2010), as explained in chapter 3.1.1. The comparison is performed taking into account the elementary flows contributing to at least 80% of the total impact and using the ILCD CFs in all the methods. A comparison is performed also in terms of completeness of the datasets used for the calculation of the NFs.

The 2010 normalisation factors (NFs 2010) are expressed as total impact of the EU-27. Normalisation factors are also reported as per person equivalent, dividing the overall figure by the EU-27 population in 2010; 499 million inhabitants (Eurostat 2013b).

For each impact category the quality of the ILCD impact assessment methods is reported following the ILCD classification: level I correspond to a "recommended and satisfactory" method, level II is "recommended but in need of some improvement", level III "recommended but to be applied with caution"; the "interim" classification indicates that a method was considered the best among the analysed methods for the impact category, but still immature to be recommended (EC - JRC, 2011).

3.1 Domestic inventory and data sources

The domestic inventory has been compiled using the available statistics on emissions- into air, water and soil- and resources extracted in EU-27 territory. If compared with previous NFs dataset, the current dataset is much more complete in terms of substance covered. In fact, over the years, significant efforts have been made by national and international agency to collect better data.

Nonetheless, several assumptions were needed in order to estimate missing values and to map territorial statistics to the elementary flows in the ILCD format. The methodologies adopted to estimate missing values and data gaps, are described in Sala et al. (2014), along with the relative limitations.

The dataset which has been used for calculating NFs covers, in its current form, the whole EU-27 for the year 2010, by including the inventory of emissions and resource flows associated to representative imported and exported goods along with the inventory of the emissions and the resource extracted occurring within the EU-27 boundaries (domestic inventory).

The so-called 'domestic inventory' of emissions and resources extraction is mostly composed of datasets provided by international and European statistical agencies (Table 2), whereas, the inventories associated with the imported and exported products is based on life cycle inventories of representative products of import and export up-scaled to the total imports and exports per product category, as documented in (EC - JRC, 2012b). The statistical datasets have then been mapped into ILCD-consistent elementary flows so to allow for their compatibility with an ILCD compliant LCA calculation. When relevant data were partially covered or completely missing in statistical datasets, several estimations based on proxies have been developed to fill such gaps, as reported in Sala et al. 2014.

Table 2 Data sources used to compile the domestic inventory, by impact category (extended version in Annex 1).

Impact category	Substance groups	Data sources	Estimation technique (as in Sala et al. 2014)
Climate change	CO_2, CH_4, N_2O both from direct emissions and LULUCF	- UNFCCC (2013)	- Method S1
	HFCs, PFCs and SF_6	- UNFCCC (2013)	- Method S2
	Other substances (incl. 1,1,2-trichloro-1,2,2-trifluoroethane, methylenchloride, chloroform, tetrachloromethane, chlorodifluoromethane, dichlorofluoromethane, CFCs, Dichloromethane)	- Total NMVOC per sector from: - CORINAIR/EEA (2007; 2009) - EMEP/CEIP (2013a) for sector activity modelling - Literature sources (speciation per sectors)	- Method A
	HCFC-141b, HCFC-142b	- EDGARv4.2 (EC-JRC&PBL, 2011)	- Method B
	1,1,1-trichloroethane	- E-PRTR database (EEA, 2012a)	- Method C
Ozone Depleting Potential	CFCs, HCFCs, etc.	- Total NMVOC per sector from: - CORINAIR/EEA (2007; 2009) - EMEP/CEIP (2013a) 'EMEP_reported' for sector activity modelling Literature sources (speciation per sectors)	- Method A
	HCFC-141b, HCFC-142b	- EDGARv4.2 (EC-JRC&PBL, 2011)	- Method B
	1,1,1-trichloroethane	- E-PRTR database (EEA, 2013a)	- Method C
Human toxicity	*Air emissions*		
	Heavy metals (HM)	- EMEP/CEIP (2013a) 'EMEP_reported'	- Method C

Impact category	Substance groups	Data sources	Estimation technique (as in Sala et al. 2014)
(cancer, non-cancer) and ecotoxicity	Organics (non-NMVOC): e.g. dioxins, PAH, HCB, etc.	- EMEP/CEIP (2013a) 'EMEP_reported' - E-PRTR (EEA 2013a)	- Method C
	NMVOC	- Total NMVOC per sector from: - CORINAIR/EEA (2007; 2009) - EMEP/CEIP (2013a) for sector activity modelling - Literature sources (speciation per sectors)	- Method A
	Water emissions		
	Industrial releases of HM + organics	- E-PRTR (EEA, 2013a) - Waterbase (EEA, 2013b) - Eurostat (2013a)	- Method D
	Urban WWTP (HM + organics)	- Waterbase (EEA, 2013b), - OECD (2013a), - Eurostat (2013b)	- Method D
	Soil emission:		
	Industrial releases (HM, POPs)	- E-PRTR (EEA 2013a)	- Method E
	Sewage sludge (containing organics and metals)	- EEA (2012) + Eurostat (2013c) for usage - EC (2010) for HM composition - EC-JRC (2001) for dioxins	- Method E
	Manure	- FAOstat(2013a), Amlinger et al. (2004), Chambers et al. (2001)	- Method E
	Pesticides		
	Active ingredients (AI) breakdown	- Pesticide usage data: FAOstat (2013d; 2013e) (F, H, I, O + chemical classes) + Eurostat (2013f) for second check - Use of extrapolations for AI differentiations - Eurostat (2013d) for crop harvested areas; FAOstat (2013b) - FAOstat (2013c) for organic areas	- Method F
Particulate matter/respiratory inorganics	CO, NO2	- UNFCCC (2013)	- Method T1 and T2
	SO2, NH3	- EMEP/CEIP (2013b) – 'EMEP_modeled' dataset	- Method T1
	PM10, PM2.5	- EEA (2013c)	- Methods T1 and T3
	PM0.1	- EDGARv4.2 (EC-JRC&PBL, 2011)	- Method T4
Ionizing Radiations	emissions of radionuclides to air and water from energy production (nuclear and coal)	- UNSCEAR data on emissions factors (2008) for 14C, 3H, 131I; - nuclear energy production (Eurostat, 2013l; 2013m; 2013r) - Ecoinvent 3.01 (Weidema et al., 2013)	- Method M1
	emissions of radionuclides to air and water from nuclear spent-fuel reprocessing	- emission factors from UNSCEAR data (2008) on emissions of 3H, 14C, 60Co, 90Sr, 99Tc, 129I, 106Ru, 137Cs and 241Pu - spent fuel reprocessing statistics are from the International Panel on Fissile Materials (IPFM) (2008a, 2008b). -	- Method M2
	discharge of radionuclides from non-nuclear	- OSPAR Commission database (OSPAR, 2013b;	- Method N

Impact category	Substance groups	Data sources	Estimation technique (as in Sala et al. 2014)
	activities (radio-chemicals production and research facilities)	2013c) covering the following activities: radio-chemicals production and research facilities	
	discharge of radionuclides from oil&gas industry	- OSPAR Commission database (OSPAR, 2013) - overall oil production figures (Eurostat, 2013r)	- Method N
	emissions to air and water from the end-of-life scenario of gypsum boards	- Ecoinvent (v 3.01) unit processes; - PRODCOM data (PRODCOM/Eurostat 2013).	- Method O
Acidification	NO2	- UNFCCC (2013)	- Method T1 and T2
	SO2, NH3	- EMEP/CEIP (2013b) – EMEP_modeled dataset	- Method T1
Photochemical ozone formation	NMVOC	- Total NMVOC per sector from: - CORINAIR/EEA (2007; 2009) - EMEP/CEIP (2013a) 'EMEP_reported' - Literature sources (speciation per sectors)	- Method A
	NO2	- UNFCCC (2013)	- Method T1 and T2
	SO2	- EMEP/CEIP (2013b) – 'EMEP_modeled' dataset	- Method T1
Terrestrial eutrophication	NO2	- UNFCCC (2013)	- Method T1 and T2
	NH3	- EMEP/CEIP (2013b) – 'EMEP_modeled' dataset	- Method T1
Freshwater eutrophication	Phosphorous (total) to soil and water, from agriculture	- Eurostat (2013g) for phosphorous Input and Output data - UNFCCC (2013) for nitrogen input - FAOstat (2013b) for cultivated cereal surfaces - Bouwman et al. (2009) 10% loss of P to water as global average	- Methods I
	Phosphorous (total) to soil and water, from sewages	- removal efficiency of Phosphorous Van Drecht et al (2009) - Use of laundry detergents Risk and Policy Analysts (RPA) 2006 - Use of dishwasher detergents Risk and Policy Analysts (RPA) 2006 - Fraction of P-free laundry detergent Risk and Policy Analysts (RPA) 2006 - Percentage of people connected to wastewater treatment (no treatment/primary/secondary/tertiary) OECD (2013a) / Eurostat (2013h)	- Methods I
Marine Eutrophication	NOx	- UNFCCC (2013)	- Method T1 and T2
	NH3	- EMEP/CEIP (2013b) – 'EMEP_modeled' dataset	- Method T1
	Nitrogen (total) to water, from agriculture	- national inventories delivered to UNFCCC (2013) for: Ntot input data, losses to water, synthetic fertilizers, manure, losses to air. - N output is calculated by using the ratios (by country, by year) between Input and Output provided by Eurostat (2013g), then multiplied to Inputs from UNFCCC	- Methods I
	Nitrogen (total) to soil and water, from sewages	- protein intake FAOstat (2013f) - removal efficiency of Nitrogen Van Drecht et al (2009)	- Methods I

Impact category	Substance groups	Data sources	Estimation technique (as in Sala et al. 2014)
		- Percentage of people connected to wastewater treatment (no treatment/primary/secondary/tertiary)OECD (2013a) / Eurostat (2013h)	
Resource depletion, water	Gross freshwater abstraction (freshwater + groundwater)	- Eurostat (2013i) - OECD (2013b) - FAO-Aquastat (2013)	- Methods J
Land use	"land occupation" and "land transformation" flows: forest, cropland, grassland, settlements, unspecified	- UNFCCC (2013) national inventories - Corine Land Cover (EEA, 2012b) for CY and MT	- Method R
Resource depletion, minerals and fossils	metals	- BGS (1995, 2000, 2002, 2012) - RMG (2013) - WMD (2014)	- Method K3
	minerals	- PRODCOM (PRODCOM/Eurostat, 2013)	- Method K3
	energy carriers	- Eurostat (2013l; 2013m; 2013n; 2013o; 2013p; 2013q)	- Method K2
Domestic biomass production	crop residues, wood and fish, For fodder crops and grazed biomass	- Eurostat (2013d; 2013k)	- Method K1
	crop production	- FAOstat (2013b)	- Method Q

3.1.1 Comparison to previous normalisation datasets

In order to check for consistency as well as to assess whether improvements in the data compared to previous versions have been made, normalisation factors from the following datasets have been compared for each impact category:

- **Inventory 2010:** results of the present study, using as inventory the datasets of the 'Life Cycle Indicators for Resource' for the year 2010, for the EU-27 territory (Sala et al. 2014).
- **Inventory 2000:** using datasets of the 'Life Cycle Indicators for Resource' for the year 2000, for the EU-27 territory (Sala et al. 2014).
- **Prototype 2006**: normalisation factors resulting from a prototype version of 'Life Cycle Indicators for Resource' for the year 2006 and the EU-27 territory (EC - JRC, 2012b);
- **CML 2000**: inventory and NFs factors provided by CML (2013) and based on CML impact assessment method (Guinée, 2002), referring to the year 2000[1] and for the territorial unit EU25+3 (i.e. referring to the 25 countries of the European Union in 2006, supplemented with Iceland, Norway and Switzerland);
- **ReCiPe 2000**: inventory and NFs provided by the ReCiPe impact assessment method referring to the year 2000 and the territorial unit EU25+3 (Wegener Sleeswijk, et al., 2008) and latest release (Wegener Sleeswijk and Huijbregts, 2010)

[1] http://cml.leiden.edu/software/data-cmlia.html

As the normalisation data for 2010 cannot be directly compared to the others because of different impact assessment methods and time representativeness, the comparison was done by assessing the most contributing flows (accounting for more than 80%) per impact category and by taking, when possible, the same year of reference in order to avoid inconsistencies due to the selection of the time frame. Moreover, the elementary flows reported within each of the datasets have been mapped to ILCD elementary flows and these values have been multiplied by the respective characterization factors of the recommended LCIA method of the ILCD Handbook (EC-JRC, 2011) so to compare the overall impact estimated by each dataset[2]. For some flows reported in ReCiPe or CML there are no equivalent ILCD flows and/or CFs. In some cases, estimations of CFs for missing flows/CFs were made (e.g. for manure and fertilizers) in order to capture important components and to be able to conduct a more meaningful comparison.

The comparability of the overall normalisation figures by impact category to the other normalisation datasets is also limited due to the fact that the "Inventory 2010" is based on apparent consumption. The comparison is therefore performed considering results from domestic inventories only.

The main features of the different normalisation factors calculations taken into account for the comparison are reported in Table 3.

Table 3 main features of the comparison of normalisation datasets in this study

	Reference year	Geographical boundaries	Activity boundaries	Reference
Inventory 2010	2010	EU-27	Domestic inventory	Sala et al. (2014)
Inventory 2000	2000	EU-27	Domestic inventory	Sala et al. (2014)
Prototype 2006	2006	EU-27	Domestic inventory	(EC - JRC, 2012b)
CML 2000	2000	EU-25+3 (Iceland, Norway and Switzerland)	Domestic inventory	CML (2013)
ReCiPe 2000	2000	EU-25+3 (Iceland, Norway and Switzerland)	Domestic inventory	Wegener Sleeswijk and Huijbregts, (2010)

3.1.2 Uncertainty sources and limitations of present Normalisation Factors

Main sources of limitations and uncertainties affecting the NFs are due to methodological choices - both related to the data sources and to the estimation techniques adopted for the estimation and difficulties in properly mapping statistics into elementary flows consistent to the ILCD format. This is mainly due to the different structure of the statistics datasets usually available from international and national bodies and the nomenclature used in the LCA methodology as well as the different level of data aggregation. Where possible, limitations have been clearly identified and quantitatively assessed. Conversely, in

[2] This means that for some flows reported in ReCiPe or CML there are no equivalent ILCD flows and/or CFs. However, some strategies were adopted to estimating CFs for missing flows/CFs within the ILCD (e.g. manure and fertilizers) in order to capture these important components and having a more meaningful comparison.

some cases, a detail reporting of limitation was not possible because of the missing references to which compare the results.

3.2 Climate change

Impact category	Unit	DOMESTIC	NF per person	ILCD recommendation level for characterisation method
Climate change	kg CO_2 eq.	4.60E+12	9.22E+03	I

The main data source for gas emissions contributing to climate change is the UNFCCC (United Nations Framework Convention on Climate Change) (UNFCCC, 2013). Data on non-methane volatile organic compounds (NMVOC) contributing to climate change (i.e. CFCs and HCFCs) have been estimated through a reproducible methodology from data reported at sector level from the European Monitoring and Evaluation Programme (EMEP/CEIP, 2013a) (see Sala et al., 2014). Additional data on hydrofluorocarbons (HCFC-141b and HCFC142b) have been extrapolated from data of the EDGAR database (EC – JRC & PBL, 2011).

3.2.1 Completeness of the dataset

In the inventory 2010, the coverage of flows with respect to the ones reported in the ILCD is 24% (Table 4). Data on hydrofluorocarbons (HCFCs) and perfluorocarbons (PFCs) are not available for the single substance but are aggregated as a group and reported by UNFCCC (2013) as CO_2eq. The same holds for SF_6.

Table 4 Number and share of flows (related to ILCD flows) in different normalisation datasets for climate change

	CML/ReCiPe	Inventory 2000	Prototype 2006	Inventory 2010
Number of flows	20	24	10	24
Share of ILCD flows covered	20%	24%	10%	24%

3.2.2 Comparison to other normalisation datasets

CML and ReCiPe report the same normalisation results for climate change in EU 25+3, year 2000 (5.21E+12 kg CO_2 eq). The order of magnitude is consistent with the 2010 normalisation data calculated here and the difference between the two results reflects the combined effect of the economic crises that led to a reduction of EU industrial production, to the ongoing trend of production displacement in countries other than the EU, and to the efforts put in place to reach Kyoto targets as well as to the effect of mitigation measures, as acknowledged, in, e.g., EEA (2009). The coverage of flows in this assessment with respect to the flows mapped in the ILCD has slightly enlarged with respect to the CML/ReCiPe assessment (23% vs. 20%).

Figure 2 compares the results of inventory of CML/ReCiPe 2000 and 2010 with CML (2000), showing a decrease in the amount of greenhouse gases. This difference between CML and the inventory 2000 is partially due to the lack of data for some chlorofluorocarbons (CFCs) in the inventory; together these flows contribute for 3% of the impact in CML results.

Therefore, the NFs for climate change are likely to be slightly underestimated due to the missing data for some CFCs.

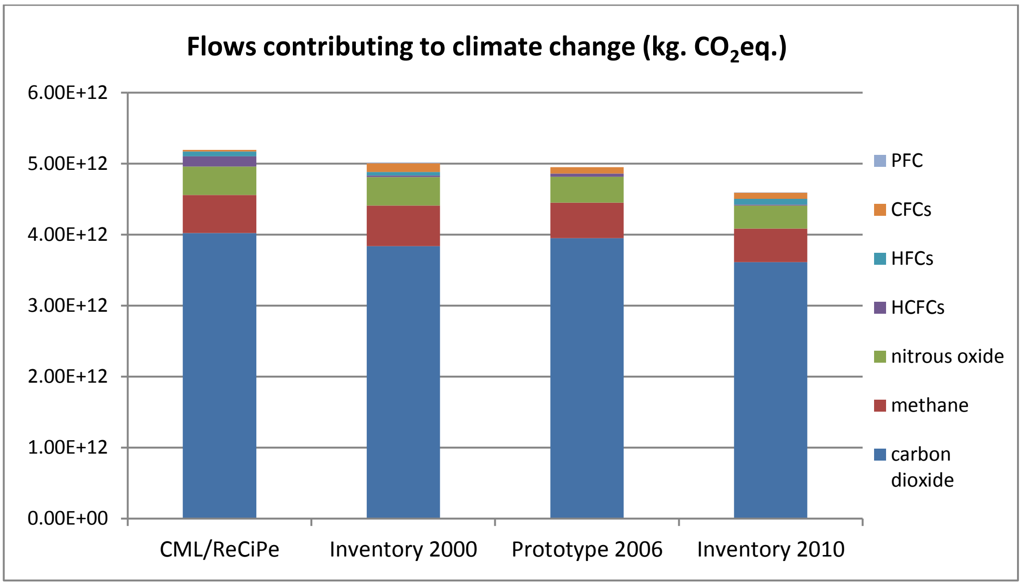


Figure 2 Comparison between normalisation factors for climate change calculated with ILCD CFs

3.2.3 Contribution to the impact

Consistently with other methods, three substances – carbon dioxide, methane and dinitrogen oxide – dominate the overall impact, contributing to 98% of the total (Figure 3 and Figure 4**Error! Reference source not found.**).

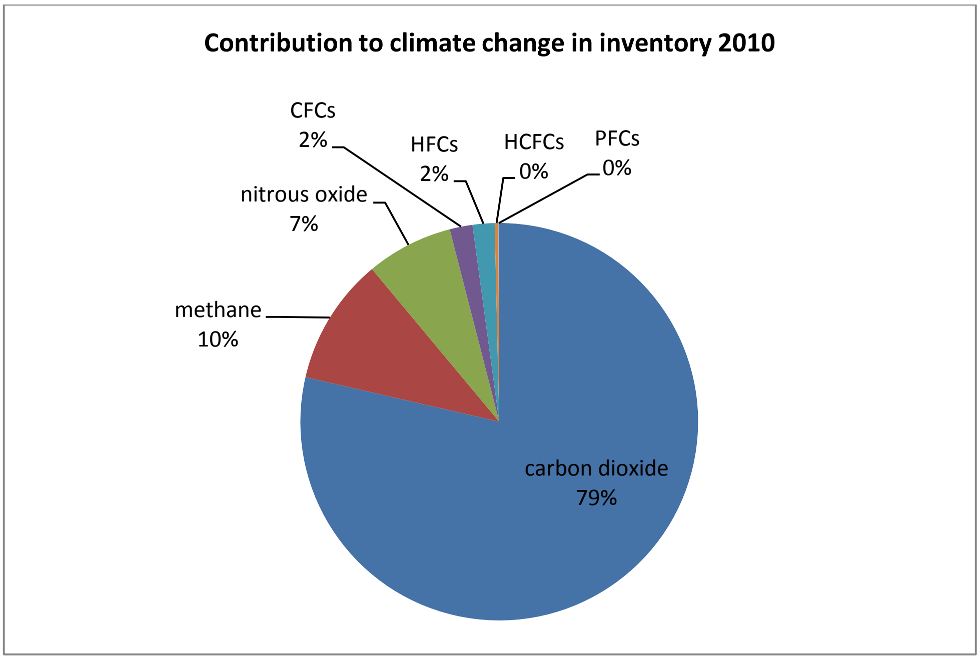


Figure 3 Contribution to climate change impact in Inventory 2010

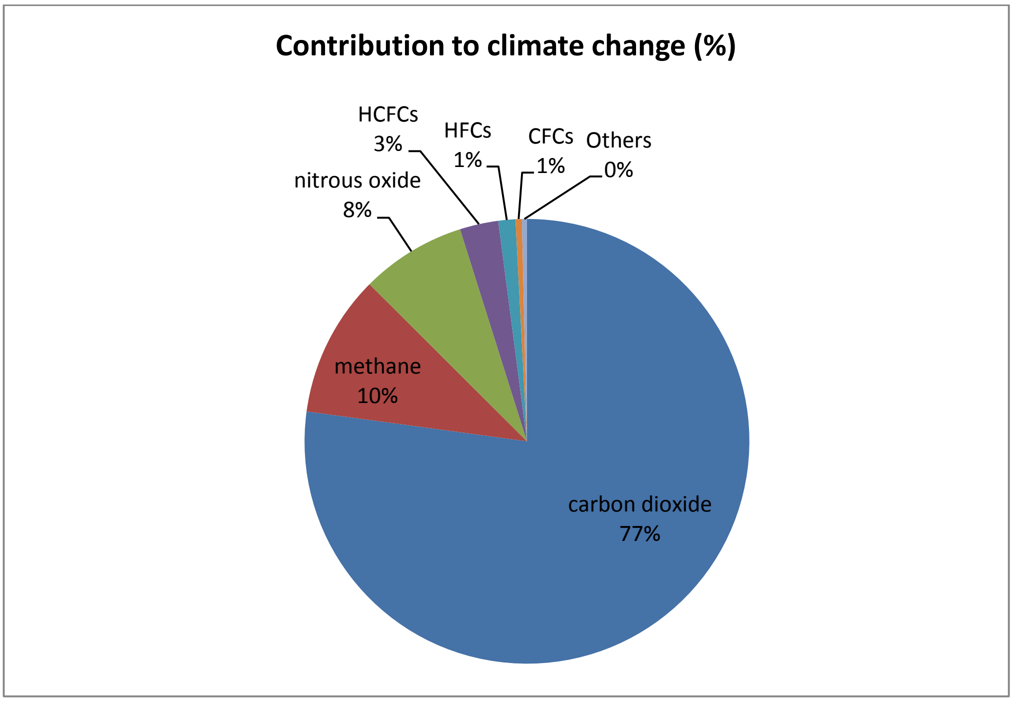


Figure 4 Contribution to climate change impact in CML/ReCiPe

3.2.4 Uncertainty sources and limitations

The main source of uncertainty affecting the result is the lack of disaggregated data for some substances (CFCs and HCFCs). The data used for the three main flows contributing to climate change are taken from UNFCCC (CO_2, CH_4, N_2O, PFCs, HFCs and SF_6), EMEP/CEIP (2013a) (CFCs) and EDGAR databases (HCFCs) (Table 2). An additional source of uncertainty lies in the application of an average CF to the group of HCFCs and PFCs.

3.3 Ozone depletion

Impact category	Unit	DOMESTIC	NF per person	ILCD recommendation level for characterisation method
Ozone depletion	kg CFC-11 eq	1.08E+07	2.16E-02	I

The elementary flows for 12 ODS contributing to ozone depletion have been estimated on the basis of NMVOC emission data retrieved from the European Monitoring and Evaluation Programme (EMEP), as reported by the Centre on Emission Inventories and Projections (CEIP) (EMEP/CEIP, 2013a) using "Officially reported emission data", and by combining speciation profiles (i.e. breakdown of NMVOC single substances) to each sectors (Laurent and Hauschild, 2014). Speciation profiles were retrieved from different literature sources as well as from CORINAIR emission inventory reports (2007, 2009). In addition, emissions of 1,1,1-trichloroethane were separately retrieved from the E-PRTR database (EEA, 2013a) and emissions of HCFC-141b and HCFC-142b, were retrieved from the EDGAR v4.2 database (EC – JRC & PBL, 2011).

3.3.1 Completeness of the dataset

Within the ReCiPe and CML normalisation datasets, 13 flows of emissions to air contributing to ozone depletion are reported for the year 2000. For this impact category, ReCiPe and CML build on the same data sources (Wegener Sleeswijk et al., 2008; on the basis of AFEAS, 2006; EnvCanada, 2006; NITE, 2006; UNEP, 2002; US-EPA, 2006) Within the domestic inventory (Sala et al., 2014), only 7 flows were estimated to contribute to ozone depletion, both for the years 2000 and 2010, In the Prototype 2006 (EC-JRC, 2012b) this impact category was disregarded because of the lack of data. 23 substances (as *Emissions to air, unspecified*) have a CF in the ILCD flows having a characterization factors for this emission category are 23 (limiting the list to *Emissions to air, unspecified*) (Table 5).

Table 5 Number and share of flows (related to ILCD flows) in different normalisation datasets for ozone depletion

	ReCiPe - year 2000, EU25+3	CML - year 2000, EU25+3	Inventory 2000	Prototype 2006	Inventory 2010
Number of flows reported within the normalisation dataset:					
- air	13	13	7	NA	7
Share of ILCD flows covered [(a)]:					
- air	56%	56%	30%	NA	30%

(a) Only the ILCD flows contributing to the ozone depletion impact category were considered, for a total of 23 flows. *Emissions to air, unspecified (long-term)*, *Emissions to lower stratosphere and upper troposphere*, *Emissions to non-urban air or from high stacks* and *Emissions to urban air close to ground* are not considered here as the inventory has been mapped only to *Emissions to air, unspecified* flows.

3.3.2 Comparison to other normalisation datasets

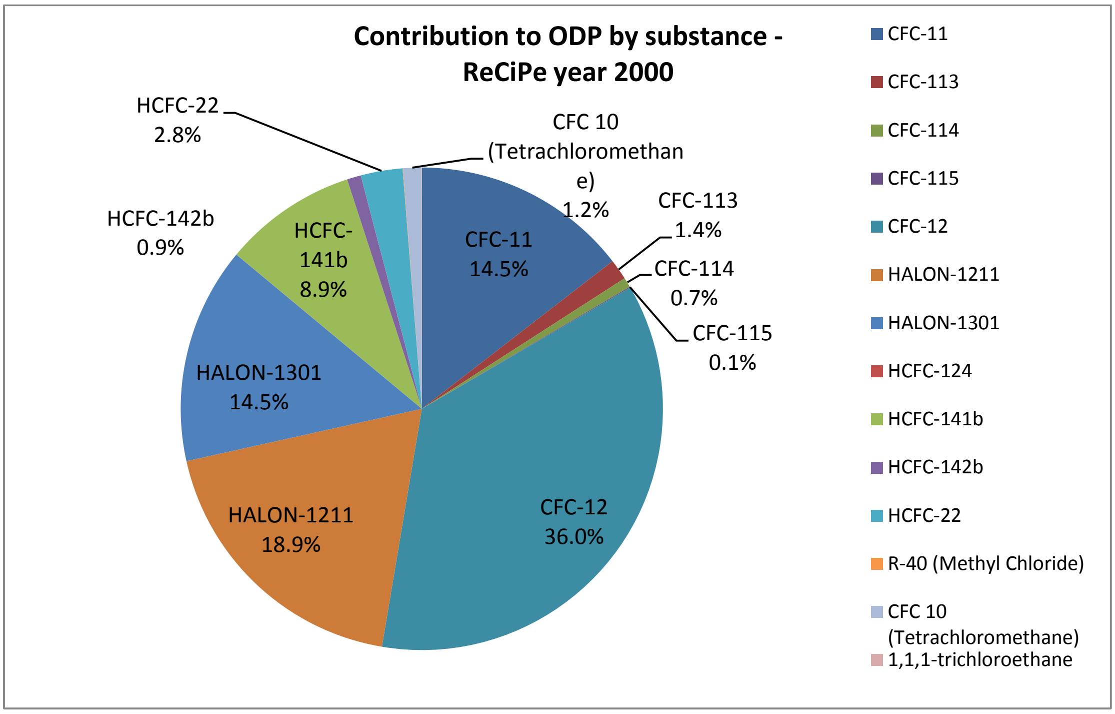


Figure 5 Contribution to the ozone depletion potential in ReCiPe and CML normalisation datasets

As it is possible to observe in Figure 6, the magnitude of the ozone depletion potential (ODP) is consistent among the two estimations (CML/ReCiPe and the Inventory, year 2000), even if a factor 2 between the Inventory 2000 and ReCiPe is found. There is a strong discrepancy among the datasets (CML/ReCiPe and the domestic inventories) at the level of the single substances emitted. The substances such as CFC-11 and CFC-12 are reported to be much lower by CML/ReCiPe than the Inventory 2000. Oppositely, according to CML/ReCiPe the Halons (e.g. Halon-1211, Halon-1301) contribute largely to ODP (Figure 5), whereas in our inventory such substances are not reported at all. Although it might be possible that in 2010 levels of HCFCs and Halons are significantly lower than those registered in the year 2000, it is hard to justify their complete absence in the domestic inventory relative to the year 2000. Such difference is very probably due to the different the datasets underpinning the estimations as well as to the estimations techniques adopted.

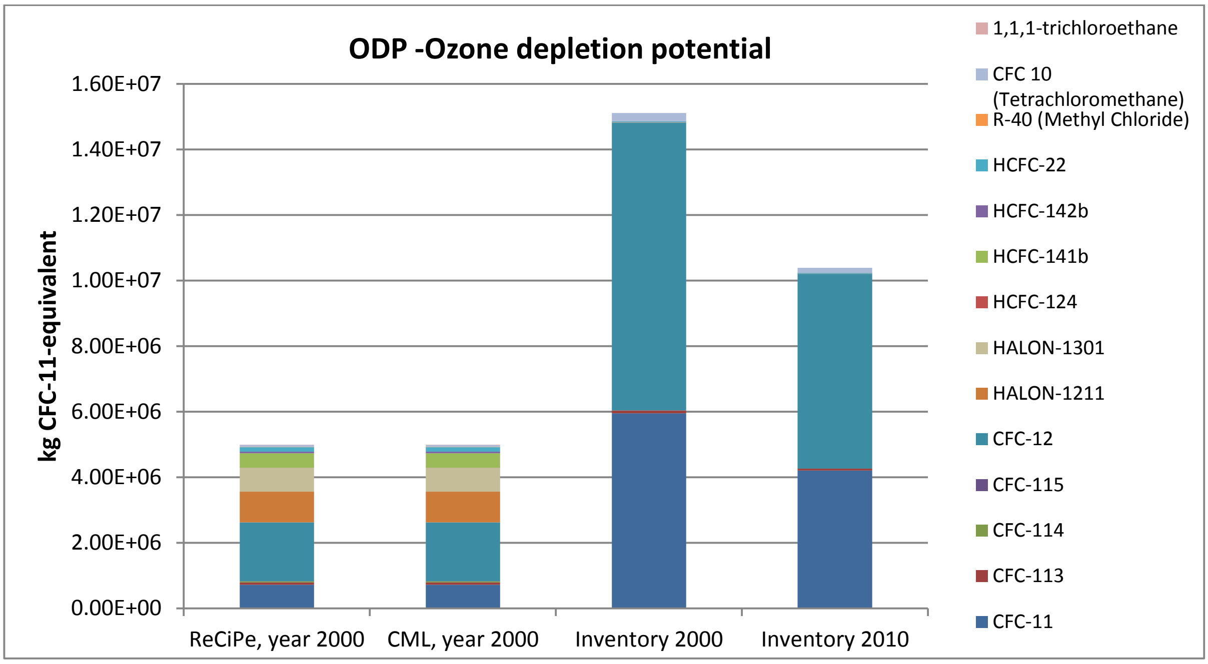


Figure 6 Comparison between normalisation factors for ozone depletion calculated with ILCD CFs

3.3.3 Contribution to the impact

As it can be observed in the following Figure 7, the highest contributor to the ozone depletion is the CFC-12, covering more than 57% of the overall impact. CFC-11 is the second highest, accounting for 40.5% of the ODP, while the other substances are marginal contributors.

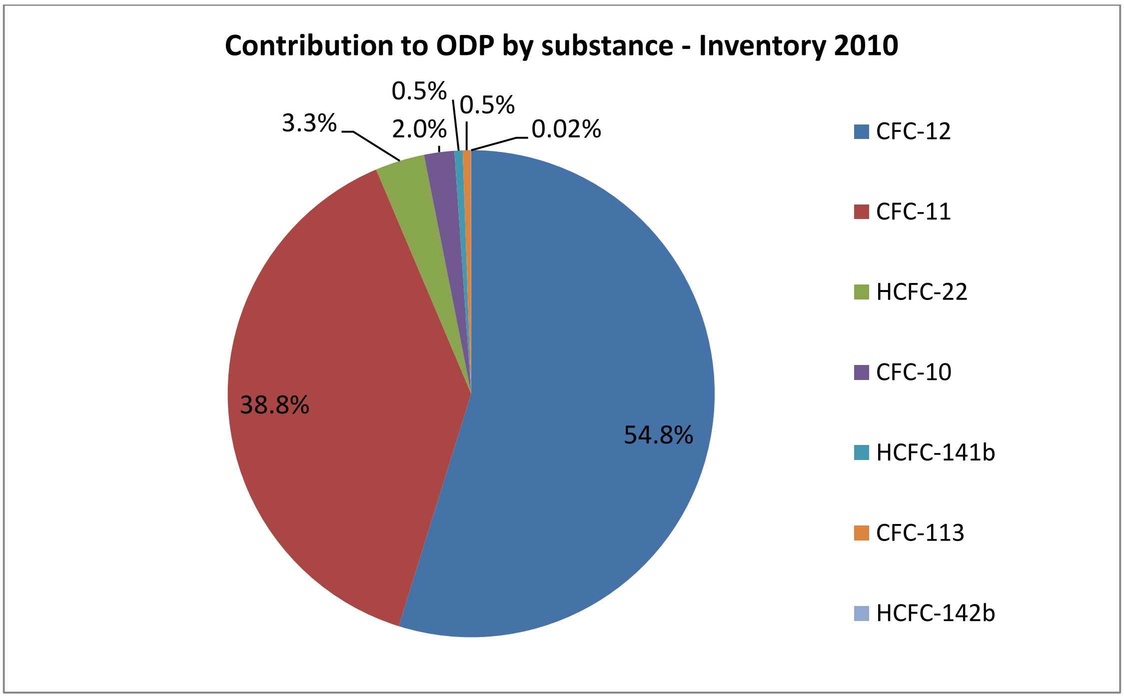


Figure 7 Contribution to the total ODP impact in inventory 2010 dataset

3.3.4 Uncertainty sources and limitations

According to the estimation done by Laurent and Hauschild (2014) and used within the inventory, at the level of the single flows contributing to ozone depletion, emissions of CFC-11 and CFC-12 are responsible, together, for more than 90% of the overall emissions of ozone depletion substances taking place EU-27 in the year 2010.

In order to evaluate the robustness of such estimate, a comparison between the total emissions of CFCs, Halons and HCFCs estimated in the inventory (i.e. CFC-11, CFC-12 and CFC-113) and the emissions reported under the E-PRTR (EEA, 2013a), has been performed (Table 6). From the results it is possible to derive that there is a substantial heterogeneity among the considered datasets, as the inventory and CML/ReCiPe show values for CFCs much higher than those reported in the E-PRTR (e.g. CFCs), whereas for HCFCs the different datasets are, overall, comparable. Halons reported in E-PRTR are much lower than those estimated in CML/ReCiPe; in the inventory 2000 and 2010 these values are not reported (also Figure 7).

According to E-PRTR (EEA, 2013a) in 2010 the facilities located in EU-27 have emitted overall 7.63 E+04 kg of chlorofluorocarbons (CFCs), whereas, according to the inventory 2010 the amount of CFCs released to air is equal to 1.04E+07 kg. Moreover, according to CML/ReCiPe, such value was 2.64E+06 in 2000. For what concerns CFCs, the values estimated in ReCiPe and in the Inventory are comparable, whereas the data retrieved from E-PRTR are much lower. As reported by the EEA (2013a), E-PRTR offers only a partial coverage of emissions, as only facilities above fixed thresholds are obliged to report such emission data. In addition to that, as reported in the E-PRTR website, the query that relates to CFC is affected by confidentiality issues which may affect the results as well. In spite of that, the values reported for the HCFCs in E-PRTR are slightly higher than those estimated in the inventory 2010 (Table 6).

Table 6 Main contributors to ozone depletion according to different normalisation datasets

Method	**Dataset**	**CML/ReCiPe, year 2000, EU25+3 (CH, NO, TR)**	**Inventory 2000, EU-27 (Sala et al., 2014)**	**Inventory 2010, EU-27 (Sala et al., 2014)**	**E-PRTR, year 2010, EU-27 (EEA, 2013a)**
	Estimation/ Reporting	Estimations based on consumption data and proxies for production	Estimations based on EMEP and sectors' breakdown (for CFCs) (Laurent and Hauschild, 2013) + EDGAR v4.2 (for HCFCs) (EC-JRC&PBL, 2011) + E-PRTR (for trichloroethene)	extrapolations based on EMEP and sectors' breakdown (for CFCs) (Laurent and Hauschild, 2013) + EDGAR v4.2 (for HCFCs) (EC-JRC&PBL, 2011) + E-PRTR (for trichloroethene)	Reporting by facilities above thresholds
Substance	CFCs (kg)	2.64E+06	1.52E+07	1.04E+07	7.60E+04
	HCFCs (kg)	7.20E+06	7.11E+05	4.17E+05	5.38E+05
	Halons (kg)	2.17E+05	NA	NA	1.24E+04

It is hard to say which of two methods (CML/ReCiPe and Inventory 2010) is the most accurate in general. The approach used in CML/ReCiPe is partially based on consumption statistics which are then up-scaled at some levels of production. As the European Union is the most important importer and exporter of chemicals in the world, it might be that the use of consumption statistics could have distorted the overall picture, leading to a substantial underestimation of the emissions taking place within the EU boundaries. Moreover, it is relevant to note that the estimations of CFCs reported in the inventory are done on the basis of a breakdown of the total NMVOCs emissions reported in EMEP by the member states and, hence, this methodology is consistent with the total emissions of NMVOCs. In addition to that, it is noteworthy that CML/ReCiPe has a different geographic scope than the inventory.

Overall, in Sala et al. (2014) is estimated that the current inventory covers more than 90% of the chlorine source emissions , whereas an additional gap lies with the unreported emissions of bromine source gases (e.g. halon-1211, halon-1301, methyl bromide). Even though, in the report is stated that based on expert's knowledge, about 70% of the ozone depletion potential is expected to be covered by the currently-defined emission inventory.

3.4 Ecotoxicity and Human toxicity

Impact category	Unit	DOMESTIC	NF per person	ILCD recommendation level for characterisation method
Human toxicity- cancer effect	CTUh	1.84E+04	3.69E-05	II/III
Human toxicity- non cancer effect	CTUh	2.66E+05	5.33E-04	II/III
Freshwater Ecotoxicity	CTUe	4.36E+12	8.74E+03	II/III

The impact categories related to toxicity both eco- and human are treated together as the qualitative and quantitative assessment for the inventory is based on the same input data, and for the impact assessment is based on the same model (USEtox).

Data for domestic emissions are taken from a variety of sources, both as direct raw data from source e.g. from EMEP/CEIP (2013a) and E-PRTR (EEA, 2013a) and extrapolated through other background data (in case of: emission to soil from sludge and manure; emission of pesticides in air, soil and water; emission of pharmaceuticals to water).

3.4.1 Completeness of the dataset (ecotoxicity)

The Table 7 below reports the numbers of flows reported in the different inventories.

Table 7 Number of flows taken into account in different normalisation datasets for ecotoxicity

	Total flows	To air	To soil	To water
CML	190	55	82	53
ReCiPe	665	197	294	174
Inventory 2010	1139	428	327	384

3.4.2 Comparison to other normalisation datasets

The comparison of the Domestic (EU-27 or for ReCiPe and CML EU 25+3) normalisation results, considering their respective impact assessment methods, present discrepancies in the share of contribution to the total impact, as follows:

- **Zinc** to soil contributes 42% in Inventory 2010, 2% in ReCiPe and 1% CML. Inventoried quantities are doubled in Inventory 2010 (as emission to soil due to sludge and manure were added using an extrapolation as explained in EC-JRC2013)
- **Zinc** to freshwater contributes 1% in Inventory 2010, 1% in ReCiPe (not in CML). Emitted quantities are 25% less in LC –indicator 2013
- **Copper** to soil contributed 22% in Inventory 2010, 4% in CML and 3% in ReCiPe. Also in this case, our quantities in 2010 inventory 2010 are doubled.
- **Copper** to air contributes 2% in Inventory 2010, and 1% in ReCiPe. It is missing in CML
- **Copper** to freshwater contributes 1% in Inventory 2010, as in ReCiPe (not present in CML)
- **17β-estradiol (E2)** to water contributes 4%, missing in the other inventory lists as specific extrapolation has been introduced for pharmaceuticals in inventory 2010
- **Folpet** to soil contributes 4% in Inventory 2010 and is missing in the other inventory lists.

- **Chlorpyrifos** to water contributes 1% in Inventory 2010, 1% also in ReCiPe and CML but as emitted to soil.
- **Nickel** to soil contributed 1% in Inventory 2010, 2% in ReCiPe and 3% in CML. Data in the inventory are of the same order of magnitude.

Overall, previous normalisations - as those done by CML and Recipe- lead to a different contribution of substances. For CML (Figure 8), aldicarb contributes for 57% of the impact, followed by cypermethrin and atrazine. For Recipe (Figure 9), atrazine contributes 46%, followed by cypermethrin 8% and N,N-dimethyldodecylamine N-oxide 4%. It has to be noted that the differences are mainly stemming from differences in the impact assessment method adopted rather than in the inventoried quantities.

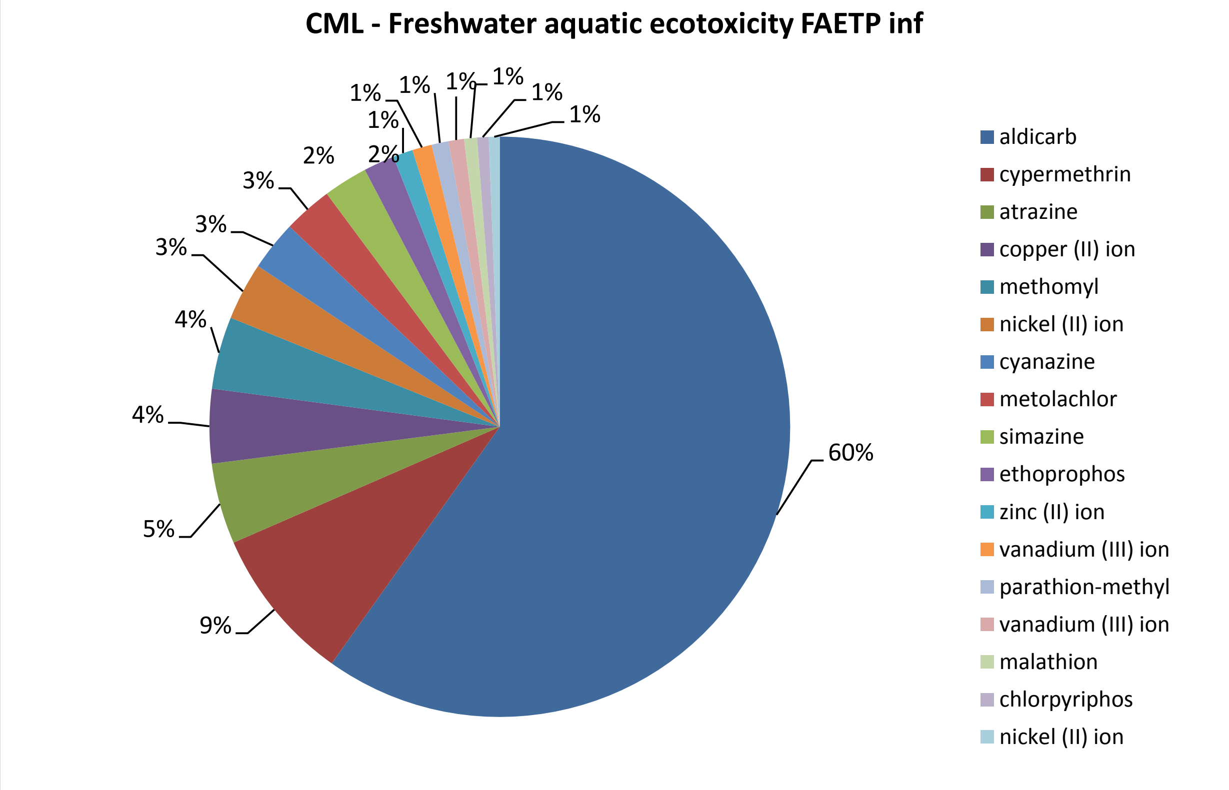


Figure 8 Contribution analysis of CML normalisation data for 2000 for ecotoxicity

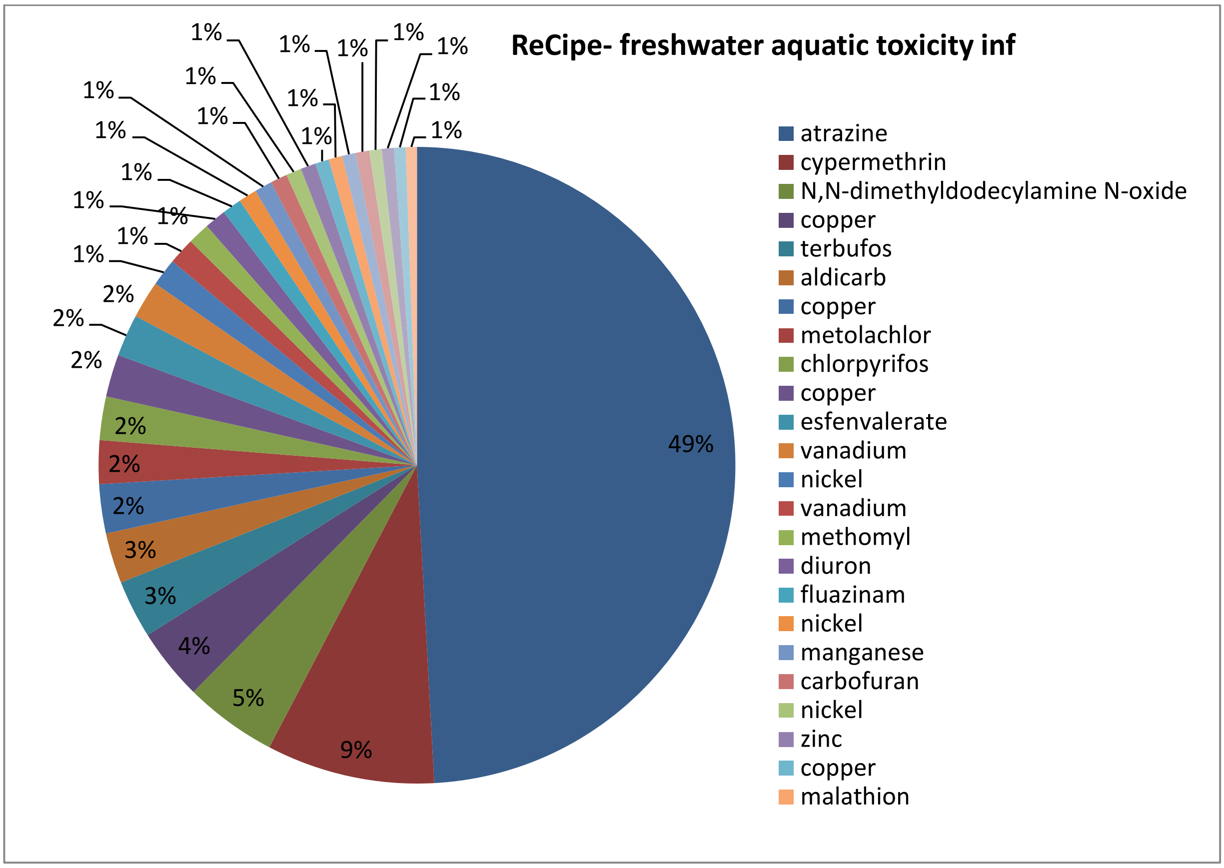


Figure 9 Contribution analysis of ReCiPe normalisation data for 2000 for ecotoxicity

3.4.3 Contribution to the impact (ecotoxicity)

For ecotoxicity, in the inventory 2010 (Figure 10), the impact is dominated by zinc emitted to soil (40%) followed by copper emitted to soil (20%), 17β-estradiol emitted to water (4.5%), folpet emitted to soil (4%), zinc emitted to air (2.5%). The relative contribution of the overall figures for ecotoxicity is as follows:

- 3.17 E+12 due to metals
- 9.34 E+11 due to pesticides
- 2.58 E+11 due to other organics (including pharmaceuticals) and non-metals

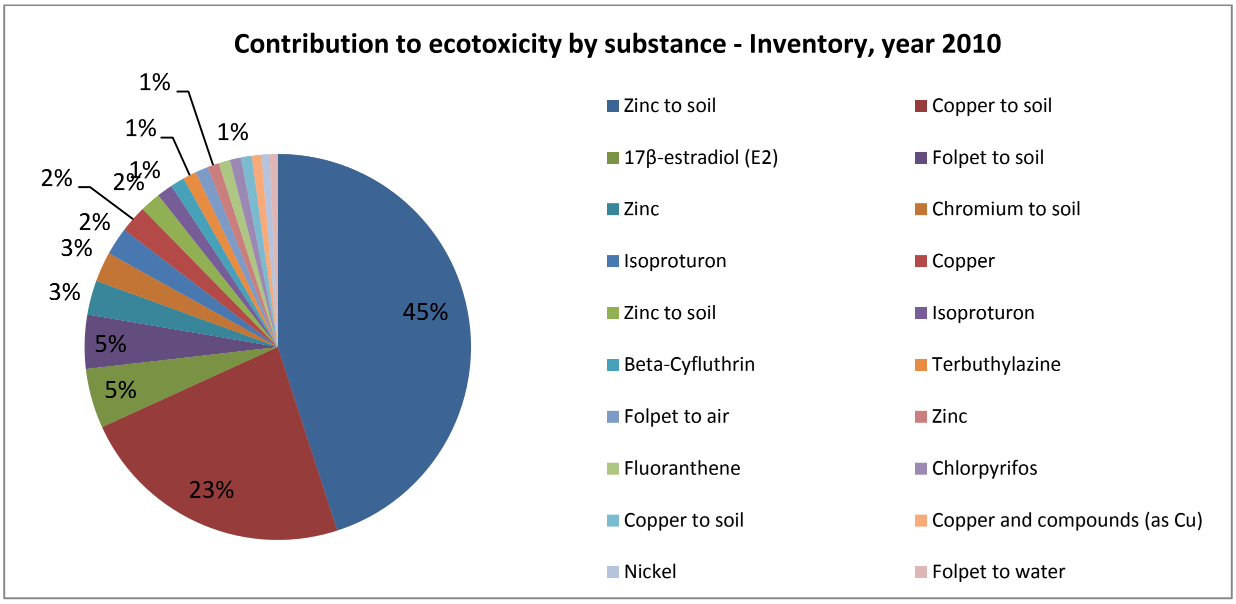


Figure 10 Contribution to the total Ecotoxicity impact in inventory 2010 dataset

Comparing the inventory data related to previous normalisation projects and applying the CFs of USEtox, there remains around a factor of 2 between the NFs calculated based on the CML inventory and on the Inventory 2010 for the year 2000 (2.41E+12 vs. 4.03E+12). In both cases, the relative share of contribution is strongly affected by metals (especially zinc and copper, Figure 11).

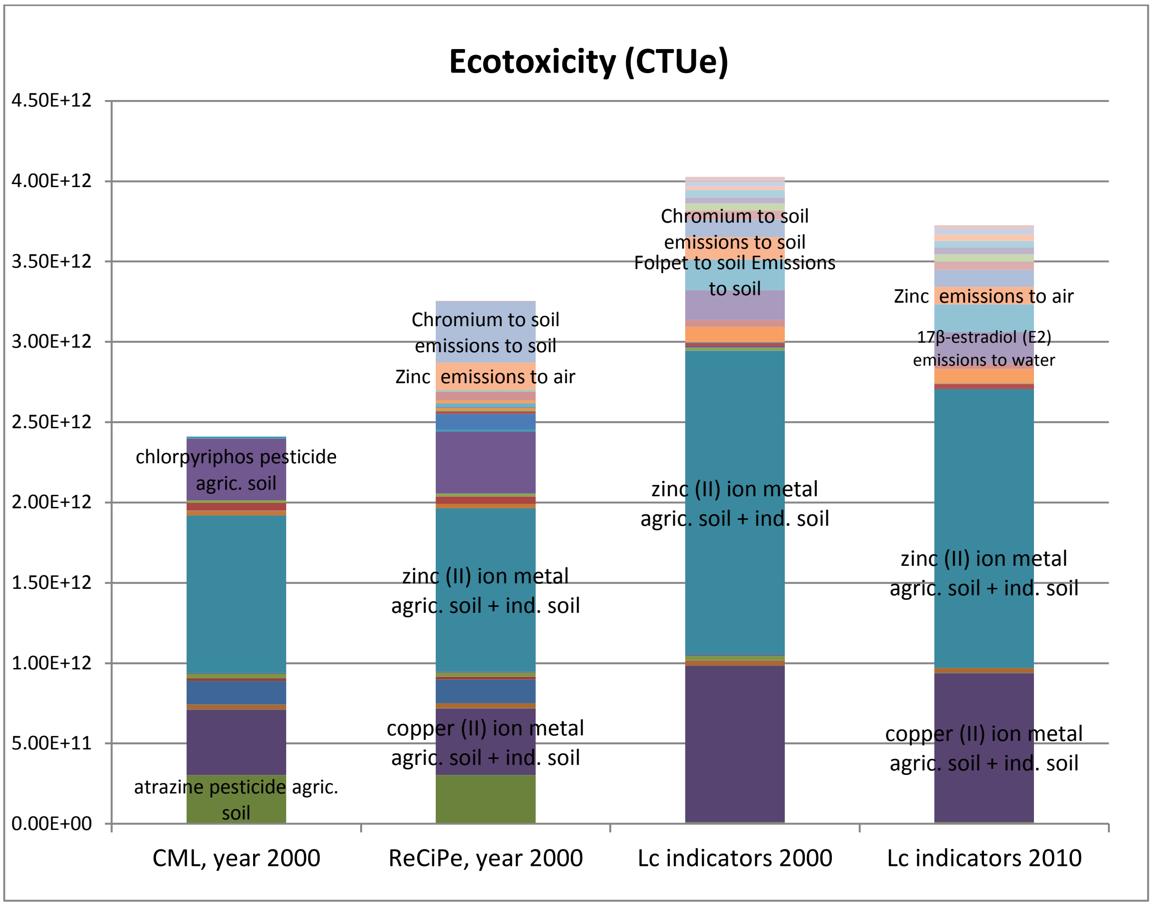


Figure 11 Comparison between normalisation factors for Ecotoxicity calculated with ILCD CFs

3.4.4 Completeness of the dataset (human toxicity)

Table 8 below reports the coverage of flows with the respect to the ones reported in the ILCD and with CF.

Table 8 Number of flows taken into account in different normalisation datasets for human toxicity

	Total flows	To air	To soil	To water
CML	184	52	83	49
ReCiPe	524	174	215	135
Inventory 2010 cancer	170	62	36	72
Inventory 2010 non-cancer	680	237	199	244

In Inventory 2010, human toxicity is dominated by metals.

3.4.5 Comparison to other normalisation datasets (human toxicity)

The comparison of the domestic (EU-27 or for ReCiPe and CML EU 25+3) normalisation results, considering their respective impact assessment methods, presents discrepancies in the share of contribution to the total impact, as follows:

- **Zinc to air** contributes 38.7% of Htox non-cancer for Inventory 2010, whereas 2% of overall human tox for ReCiPe and does not appear in CML
- **Zinc to soil** contributes 22.5% of Htox non-cancer for Inventory 2010, whereas 4% of overall human tox for ReCiPe and 1% CML
- **Mercury to air** contributes 23.5% of Htox non-cancer and 3% of Htox cancer for Inventory 2010 whereas 6% of overall human tox for ReCiPe and does not appear in CML
- **Lead to air** contributes 7.8% of Htox non-cancer for Inventory 2010, whereas 17% of overall human tox for ReCiPe and does not appear in CML, where only emission to soil is present and contributes 4%
- **Cadmium to air** contributes 1.7% of Htox non-cancer for Inventory 2010, whereas 2% of overall human tox for ReCiPe and 7% in CML
- **Arsenic to air** contributes 1.7% of Htox non-cancer for Inventory 2010, whereas 1 % of overall human tox for ReCiPe and 26% in CML
- **Arsenic to soil** contributes 0.9% of Htox non-cancer for Inventory 2010, whereas 1% of overall human tox for ReCiPe and does not in CML
- **Chromium to soil** contributes 57% of Htox -cancer for Inventory 2010, whereas does not appear in ReCiPe , and contributes 15% in CML
- **Formaldeyde to air** contributes 29% of Htox-cancer for Inventory 2010, whereas does not appear neither in ReCiPe nor in CML
- **Selenium to air** as top contributor in ReCiPe (does not appear neither in Inventory 2010 nor in CML as relevant contributor).

3.4.6 Contribution to the impact (human toxicity)

Within the inventory 2010, for human toxicity cancer effect (Figure 12), the impact is dominated by chromium emitted to soil (more than 56% due to sludge and manure) followed by formaldehyde (28%) and chromium emitted to air (4.5%).

For human toxicity non-cancer effect (Figure 13), the impact is dominated by metals, with zinc emitted in air contributing for 38%, zinc emitted in soil for 21% and mercury emitted in air for 23%.

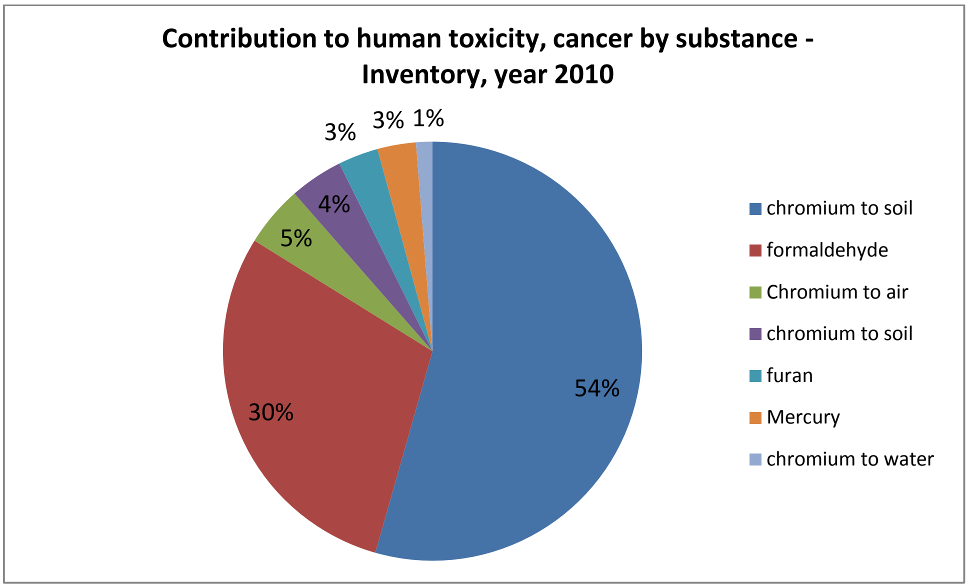


Figure 12 Contribution to the total human toxicity, cancer impact in inventory 2010 dataset

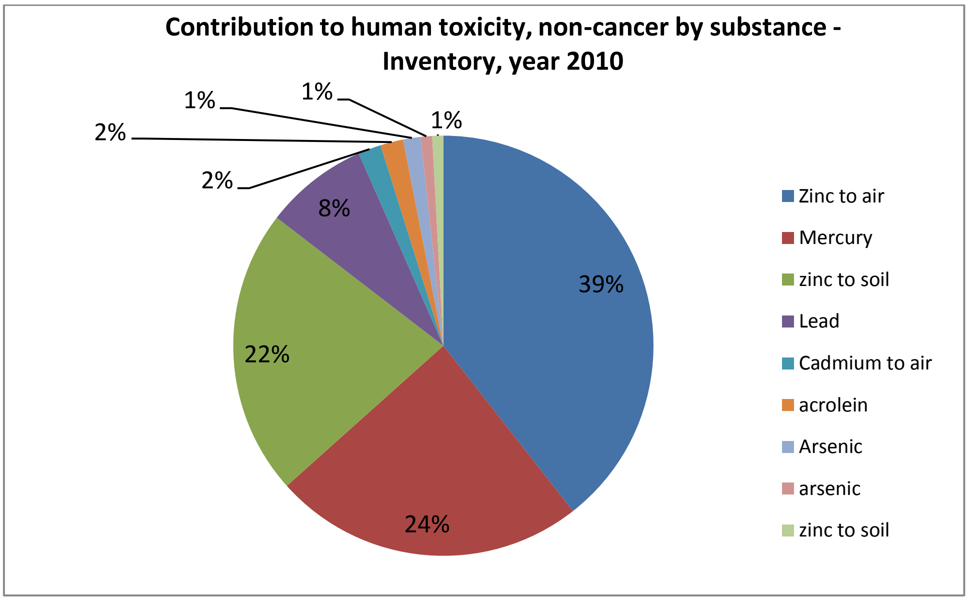


Figure 13 Contribution to the total human toxicity, non-cancer impact in inventory 2010 dataset

A comparison as for ecotoxicity (Figure 11) is not possible for human toxicity. This is due to the fact that in some impact assessment methods cancer and non- cancer effects are coupled and in other not.

3.4.7 Uncertainty sources and limitations

In case of human toxicity- both cancer and non-cancer- the classification of the characterization factor is II/III depending on the single flow/substance. Similarly for ecotoxicity, the classification is II/III. It has to be mentioned that terrestrial and marine ecotoxicity are not taken into account and this may lead to relatively high underestimation of the overall ecotoxicity potential. It has to be mentioned that characterization factors for metals are still considered not robust and research activities are ongoing in the scientific community to overcome limitation of existing approaches.

Hence, main uncertainties may be summarized as follows:

- Few flows are covered if compared to the overall number of flows of chemical substances for which a characterization factor exists[3] (100 out of 3000).
- Main contributors are metals, for which characterization factors are considered less robust (Rosenbaum et al., 2008). Indeed, in the impact assessment models (USEtox) these factors are marked as “interim” For a number of substances, possible outliers should be double checked.
- Additionally, in case of ecotoxicity, data on 17β-estradiol are based on sales volume assuming 100% of the quantity released in water, as for other pharmaceutical in the inventory.
- As reported in Sala et al. (2014) to fill in data gaps on airborne emissions of organic substances from industrial sources from E-PRTR, a relationship between process outputs and their emissions should have been investigated. However, such correlation would be time-dependent because of continuous incentives from air pollution abatement policies (e.g. EEA, 2012a). Therefore, in the absence of further information, it was deemed more appropriate to only integrate the emission data reported, and only concentrate the extrapolations on filling in gaps for unreported years. Such choice leads to underestimation of the inventory associated with airborne emissions of organics pollutants.

[3] Moreover, the substances for which a CF exists, are only 3000 out of over 100000 chemical substances currently used in EU

3.5 Acidification

Impact category	Unit	DOMESTIC	NF per person	ILCD recommendation level for characterisation method
Acidification	mol H+ eq	2.36E+10	4.73E+01	II

The current inventory 2010 is based on UNFCCC and EMEP/CEIP data. Other models and datasets such as EEA 'EEA_consolidated' (2013c), EDGAR v4.2 (EC-JRC& PBL, 2011) and GAINS (IIASA, 2013) report data for NOx, SOx and NH_3. The choice of the dataset has been done on the basis of the following elements: coverage of the EU-27 member states, coverage of sectors responsible for the emissions, existence of a (international) review and quality assessment process, timing of the updates. The UNFCCC is a trusted source of data reported by countries and reviewed by an international scientific panel. EMEP provides two types of datasets: National Inventories and Data used in EMEP models. The latter dataset is an aggregated and data-gap filled version of the former; this version has been used when available, on the basis of a systematic quality and review process. EDGAR v4.2 is a bottom-up modelling exercise based on activity data and emission factors. It covers up to 2008 (as a result of the fast-track expansion of EDGAR v4.1) and it has the advantage of being coherent among the different member states. However, there is no periodical review and update process. Hence, coherently to what decided by a team of experts from EC-JRC, PBL, UNFCCC, EMEP as reported in EC-JRC (2012c) on the basis of ECE (2010) the priority in selecting the data sources for the flows mentioned above was: UNFCCC > EMEP_modeled = EEA_consolidated > EMEP_reported > EDGARv4.2.

The flows that contribute to acidification within the domestic Inventory, 2010, are: ammonia, nitrogen dioxide and sulphur dioxide emitted to air. The order of magnitude of the emission is consistent with the prototype developed for the year 2006 by the EC - JRC (2012a) and the overall indicator was resulted in moles H+. Within the inventory 2010, only three flows contribute to acidification: ammonia, sulphur dioxide and nitrogen dioxide, covering, respectively 46%, 25% and 29% of the impact category in that category in 2010. The original data sources are UNFCCC for NOx (reported as NO_2), the EMEP/CEIP database for SO_x (reported as SO_2) and NH_3 (EMEP/CEIP, 2013b).The flows of NO_x and SO_x retrieved from the statistics have been mapped into the respective ILCD flows: nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) and the respective ILCD characterization factors have been used for calculating the midpoint impact category indicator.

3.5.1 Completeness of the dataset

In Table 9, the overall coverage of ILCD flows for each of the inventory dataset used for comparison is reported. The inventory for the year 2010 covers only 50% of the flows covered by the ILCD. In particular, the missing flows are: nitrogen monoxide, sulphur trioxide and sulphur oxides. This is due to the fact that no statistics on sulphur trioxide were available and to the fact that NO_x and SO_x were mapped as NO_2 and SO_2, as the actual ratio NO/NO_2 is very specific of the combustion process that generates the emission and such value is usually not reported in national inventories. It is relevant to note that the ILCD does not contain characterization factors for those acidifying substances which are emitted to soil, such as manure and fertilizers, which, on the contrary, are well covered in ReCiPe.

3.5.2 Comparison to other normalisation datasets

The coverage of each flow on the overall impact estimated in each of the normalisation dataset is shown in the following pie-charts. The charts report the relative contribution of the single flow over the totals, as estimated by the different datasets. Such contribution CML 2000 and ReCiPe 2000 are calculated with the method AP100 (Huijbregts, 1999; average Europe total, A&B), whereas the Inventory 2000 and 2010 are calculated through the ILCD characterization factors.

Table 9 Number and share of flows (related to ILCD flows) in different normalisation datasets for acidification

	ReCiPe - year 2000, EU25+3 AP100 kg SO2-eq	**CML - year 2000, EU25+3** AP baseline (CML, 1999)	**ReCiPe - year 2000, EU25+3** moles H+	**CML - year 2000, EU25+3** moles H+	**Inventory 2000** moles H+	**Prototype 2006** moles H+	**Inventory 2010** moles H+
Number of flows included in the normalisation dataset:							
- air	3	3	3	3	3	3	3
-soil	26	0	0	0	0	0	0
Share of ILCD flows covered [(a)]:							
- air	50%	50%	50%	50%	50%	50%	50%
-soil	NA	NA	NA	NA	NA	NA	NA

a) Only the ILCD flows contributing to the acidification impact category were considered, for a total of 6 flows. *Emissions to air, unspecified (long-term)*, *Emissions to lower stratosphere and upper troposphere*, *Emissions to non-urban air or from high stacks* and *Emissions to urban air close to ground* are not considered here as the inventory has been mapped only to "*Emissions to air, unspecified* " flows.

As it is possible to see from the pie charts below, the emission of sulphur dioxide is the major contributor to the acidification for CML (Figure 15) and ReCiPe in 2000 (Figure 14). In 2010, according to the JRC Inventory, the most contributing flow results to be ammonia, covering the 46% of the overall impact. Such difference is mainly due to the different methodology used within ReCiPe, as emissions to soil from manure and fertilizers are accounted separately. In total the emissions to soil within ReCiPe account for 36% of the impact. This is not the case for what concerns CML, where the flows of NH_3 into soil are not accounted for.

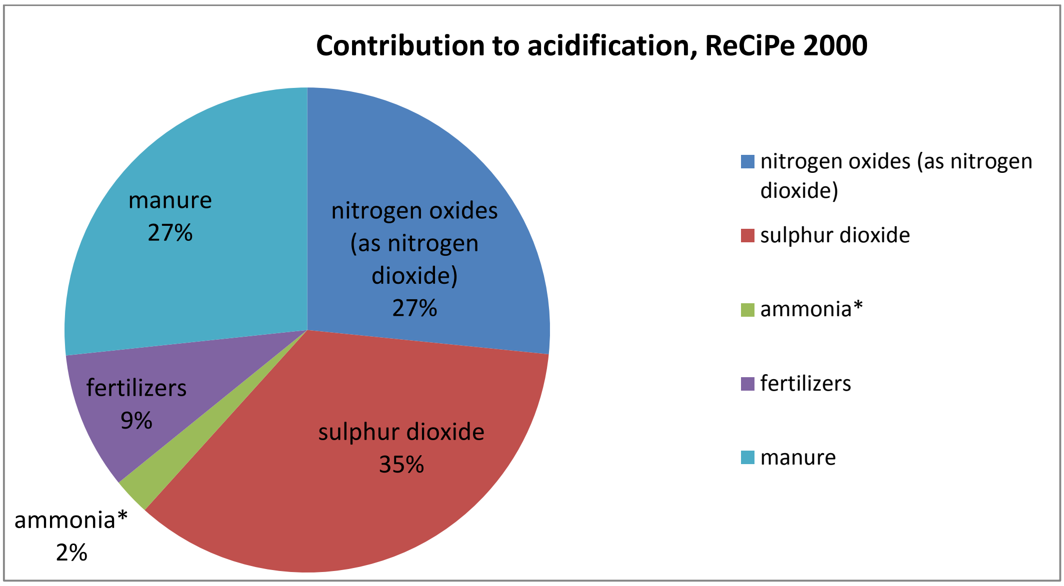


Figure 14 Contribution to the total acidification impact in ReCiPe normalisation dataset (year 2000)

(*) as reported in ReCiPe (Wegener Sleeswijk et al., 2010): "...the values for ammonia emissions to air exclude emissions from manure and fertilizer to air. These emissions are here considered as emissions of nitrogen compounds to soil, with subsequent volatilisation in the field situation. The reason for this choice is that the ReCiPe characterisation factors for N-emissions to soil account for this volatilisation. According to our own calculations, manure and fertiliser are responsible for an additional (secondary) ammonia emissions of 3.45E+09 kg ammonia and thus to a dominating effect of animal manure and fertiliser on total (direct and indirect) ammonia emissions to air."

Although the ILCD does not provide CFs for pesticides and fertilizers contributing to acidification, in order to provide a more complete picture and to make comparable the figures provided by ReCiPe and those estimated in the Inventory 2000 and 2010 the equivalent impact from manure and fertilizers is converted to ILCD units by converting their value expressed in SO_2 equivalent (AP100 method, Huijbregts, 1999) into moles of H+ equivalent by applying the ILCD CF for SO_2. From the results, is possible to see that there is overall consistency in the order of magnitude among the normalisation datasets. In particular, sulphur dioxide and nitrogen dioxide figures are comparable over the period observed. However, for the year 2000 the figures vary sensibly for SO_2 between the Inventory 2000 and CML/ReCiPe (Figure 16). Although the data sources are the same in both datasets (EMEP/CEIP), the difference might be explained by the fact that EMEP/CEIP is periodically updated and reviewed, as well as data gap filled. NH_3 emissions coming from volatilization of manure and fertilizers are included in NH3 totals, leading to 27% of the overall impact for CML.

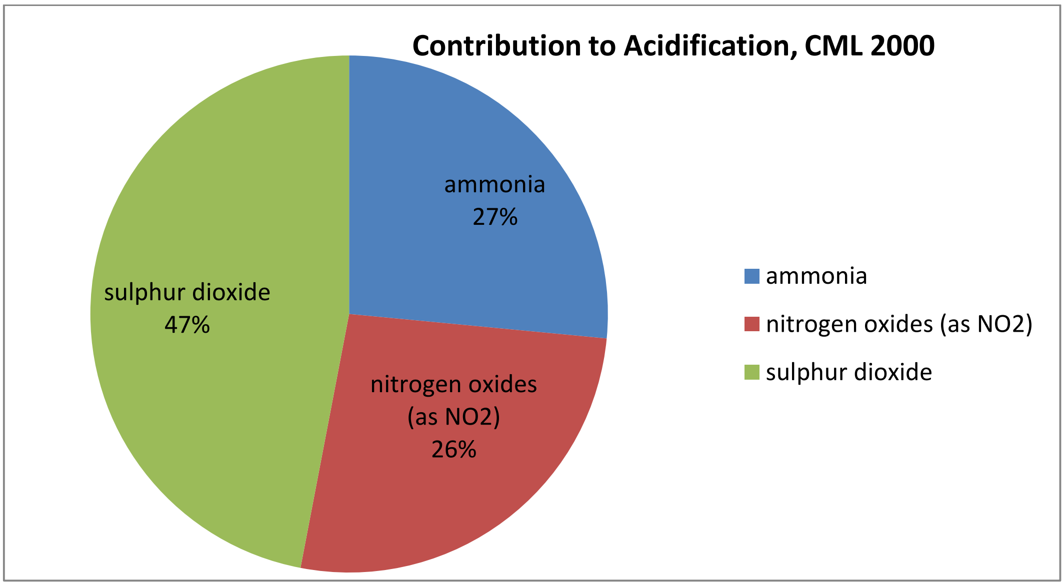


Figure 15 Contribution to the total acidification impact in CML normalisation dataset (year 2000)

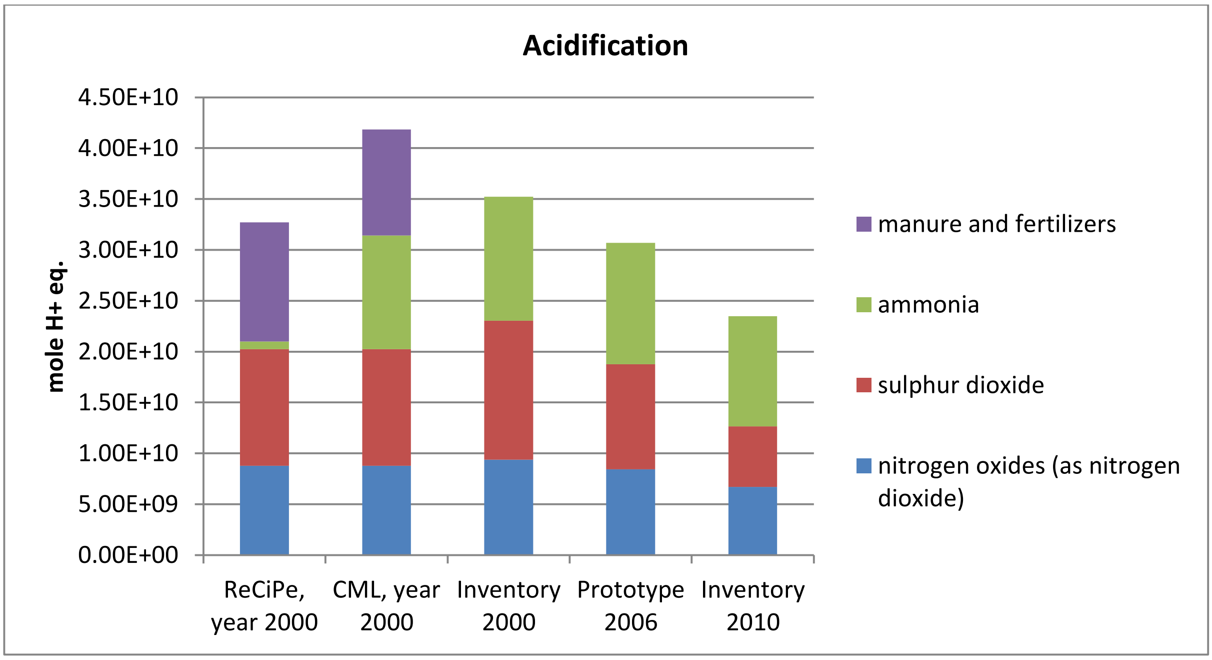


Figure 16 Comparison between normalisation factors for acidification calculated with ILCD CFs

3.5.3 Contribution to the impact

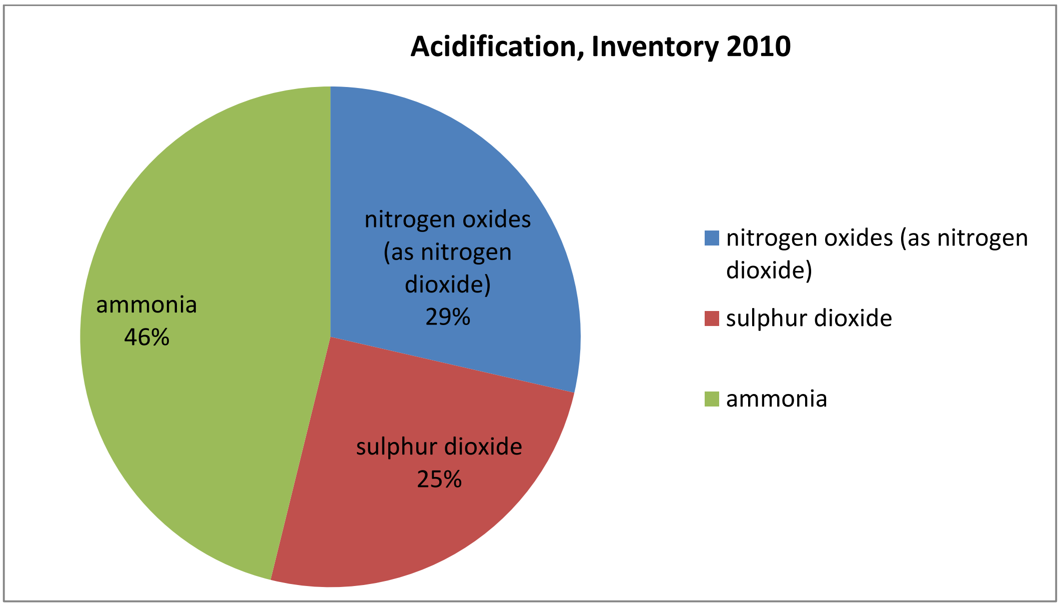


Figure 17 Contribution to the total acidification impact in Inventory 2010 normalisation dataset

As it is possible to see from the results (Figure 17), ammonia has the highest share in acidification potential for the EU-27, in 2010. SO_2 and NO_2 are of extreme relevance as well, covering, respectively, 25% and 29% of the total impact.

3.5.4 Uncertainty sources and limitations

Uncertainties affecting this normalization factor are found both at the level of the inventory data and the characterization factors.

Inventory

As mentioned above, the data sources for the acidification were different. In Table 10 below, the difference observed between the EMEP_modeled and the EDGARv4.2 data (with extrapolation to 2010) is shown. The impact calculated with the Inventory 2010 is 32% higher than the same impact calculated on the basis of EMEP/CEIP statistics. By single substance flow, it is possible to note that the SO_2 and the NO_2 emissions are the ones significantly inconsistent among the two datasets. It is relevant to note that also a comparison with the GAINS model (IIASA, 2013) performed by EMEP/CEIP (2009) has shown that the EMEP/CEIP figures are, in general, lower than those estimated by GAINS. Although it is hard to quantify the uncertainty associated to these figures, it is arguable that there is a consistent mismatch between bottom-up modelling exercises and officially reported data. Whether this is due to systematic errors in modelling or not it is hard to say. However, because of the review process and of the level of update of UNFCCC and EMEP/CEIP, these sources have to be considered as the most reliable for building normalization factors upon.

Another key assumption which could lead to a slight underestimation of the normalisation factors is related to the mapping of NOx into NO_2. The CF for NO is twice as the one for NO_2, however, the available statistics only provide data expressed in NO_2 equivalents.

Table 10 Results comparison between Inventory 2010 and EMEP 2010

Flow	**EDGAR v4.2 and extrapolations to 2010** moles H+	**EMEP/CEIP 'modeled' 2010 (2013b)** moles H+	**Relative difference**
nitrogen dioxide	7.34E+09	6.72E+09	9.1%
sulphur dioxide	8.76E+09	5.95E+09	47.2%
ammonia	1.51E+10	1.09E+10	38.4%
Total	3.12E+10	2.36E+10	32.3%

Characterisation factors

For the same flow emitted to air e.g. for NOx, there are different CFs that could be applied to this inventory, as CFs vary according to the height of the stacks, the time perspective (long-term) and also to the geographic location. As introduced at the beginning of this document the CFs used for calculating the normalization factors reflects the most generic choice possible ("unspecified" height of the stack and unknown geographic location). This is because of the fact that the resolution of the underlying inventory, being built on aggregated national reporting, does not contain information on the modality of the emissions. Hence, it is not possible to differentiating among the CFs. The location-specific CFs are not used in here in order to avoid distortions in the results, hence allowing for comparability with other methods that do not have country-specific CFs.

3.6 Particulate Matter/Respiratory inorganics

Impact category	Unit	DOMESTIC	NF per person	ILCD recommendation level for characterisation method
Particulate matter	kg PM2.5 eq	1.90E+09	3.80E+00	I

The elementary flows contributing to Particulate Matters / Respiratory inorganics impact category within the domestic inventory 2010, are: PM_{10}, $PM_{2.5}$, NH_3, NO_2, CO and SO_2. The relative shares are reported in figures 18, 19, 20. The original data sources are UNFCCC for NOx (reported as NO_2) and CO; EMEP/CEIP database 'modeled' (2013b) for SO_x (reported as SO_2) and NH_3; EEA (2013c) for $PM_{2.5}$ and PM_{10}.The flows of NO_x and SO_x reported in the original statistics as NO_2 and SO_2,have been mapped into the following ILCD flows: nitrogen dioxide (NO_2) and sulphur dioxide (SO_2). The respective ILCD characterization factors have been used for calculating the midpoint impact category indicator although the underlying data refer to a combination of nitrogen (or sulphur) monoxide and nitrogen (or sulphur) dioxide, in a proportion which is not possible to determine. Although data on both PM_{10} and $PM_{2.5}$ were retrieved from EEA, as the latter is a fraction of the former, only one of the two flows had to be included in the impact assessment phase, so to avoid double-counting[4]. $PM_{2.5}$ was chosen as the underlying impact assessment method (Humbert, 2009) assumes $PM_{2.5}$ to be the only responsible for the health impacts due to PM_{10} exposure.

3.6.1 Completeness of the dataset

The coverage of flows for each of the normalisation datasets is provided in Table 11 along with a comparison with the ILCD elementary flows coverage. The Inventory 2000 and 2010 cover the 67% of the ILCD elementary flows for respiratory inorganics. The ILCD flows contributing to this impact category are 9 in total: particles - PM_{10}, particles - $PM_{2.5}$, carbon monoxide, nitrogen dioxide, nitrogen monoxide, ammonia, sulphur trioxide, sulphur oxides, sulphur dioxide. No elementary flow and characterization factor is available in the ILCD for emissions to soil for this impact category, only ReCiPe accounts for these flows. The flows which are not missing within the Inventory 2010 are: nitrogen monoxide, sulphur trioxide and sulphur oxides. The CML normalisation dataset does not include respiratory inorganics as impact category; however the flows contributing to this impact category are reported within the dataset.

Table 11 Number and share of flows (related to ILCD flows) in different normalisation datasets for PM

	ReCiPe - year 2000, EU25+3 PMFP - $kgPM_{10}/m^3.yr$	**CML - year 2000, EU25+3** PMFP - $kgPM_{10}/m^3.yr$	**ReCiPe - year 2000, EU25+3 (ILCD factors)** kg $PM_{2.5}$ eq	**CML - year 2000, EU25+3 (ILCD factors)** kg $PM_{2.5}$ eq	**Inventory 2000** kg $PM_{2.5}$ eq	**Prototype 2006** kg $PM_{2.5}$ eq	**Inventory 2010** kg $PM_{2.5}$ eq
Number of flows reported within the normalisation dataset:							
- air	5	5	6	6	6	6	6

4 personal communication by Sebastien Humbert, September 2014

- soil	26	0	0	0	0	0	0
Share of ILCD flows covered [(a)]:							
- air	56%	56%	67%	67%	67%	67%	67%
- soil	NA	NA	NA	NA	NA	NA	NA

(a) Only the ILCD flows contributing to the particulate matter/respiratory inorganics impact category were considered, for a total of 9 flows.

3.6.2 Comparison to other normalisation datasets

The pie chart in Figure 18 reports the results for the ReCiPe normalisation dataset. The underlying methodology is built on a different method than one recommended within the ILCD and used for the Inventory 2000, 2010 and for the Prototype 2006. CO and $PM_{2.5}$ have no CFs in the ReCiPe methodology.

The impact associated with the Inventory normalisation datasets, both for the years 2000 and 2010, is higher than what estimated in CML and ReCiPe (Figure 19). This is substantially due to the contribution of $PM_{2.5}$. In ReCiPe and CML the flow $PM_{2.5}$ does not have a characterization factor; only PM_{10} has. In this assessment only the share of $PM_{2.5}$ figures were taken into account because of the reasons explained above. In the impact assessment method recommended by the ILCD the flow related to $PM_{2.5}$ has a characterization factor much higher than the one of PM_{10} and this might be one of the reasons of such large difference observed. Another relevant source of difference is related to the emission of ammonia. In ReCiPe the values for ammonia emissions to air do not include direct emissions originating from manure and fertiliser. In order to allow for comparability, the emissions of NH_3 originating by volatilisation from manure and fertilizers in the field are added to ReCiPe, similarly to what was done for acidification impacts. The estimations done in the domestic inventory are substantially in line with what reported in the prototype, year 2006.

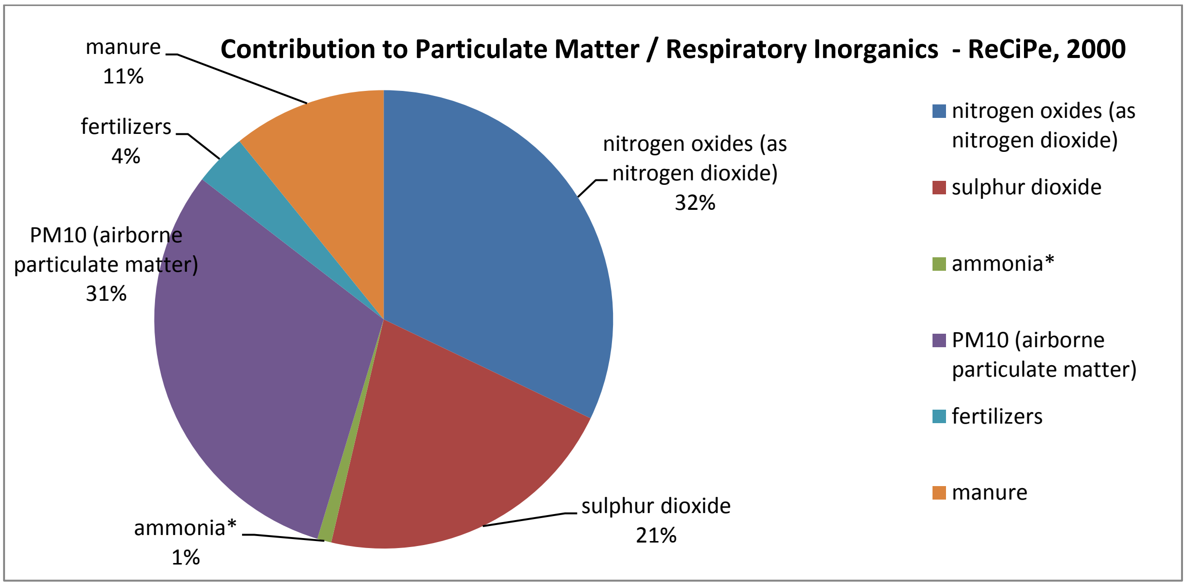


Figure 18 Contribution to the total PM/Respiratory Inorganics impact in ReCiPe normalisation dataset (year 2000)

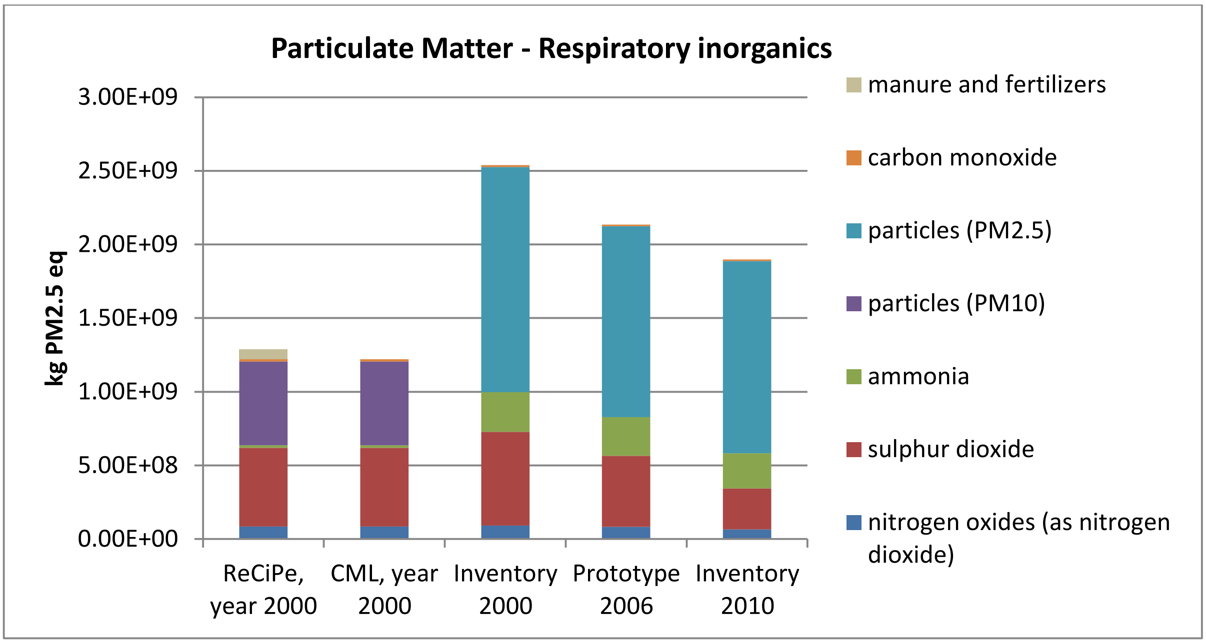


Figure 19 Comparison between normalisation factors for Particulate Matter/Respiratory Inorganics calculated with ILCD CFs

3.6.3 Contribution to the impact

As it can be observed in Figure 20, the highest contributor to the particulate matter impact category is the $PM_{2.5}$, covering 69% of the overall impact. SO_2, NH_3 and NO_2 summed together cover the remaining 30.5% of the impact and minor role is exerted by carbon monoxide. Manure and fertilizers are not accounted within the Inventory 2010.

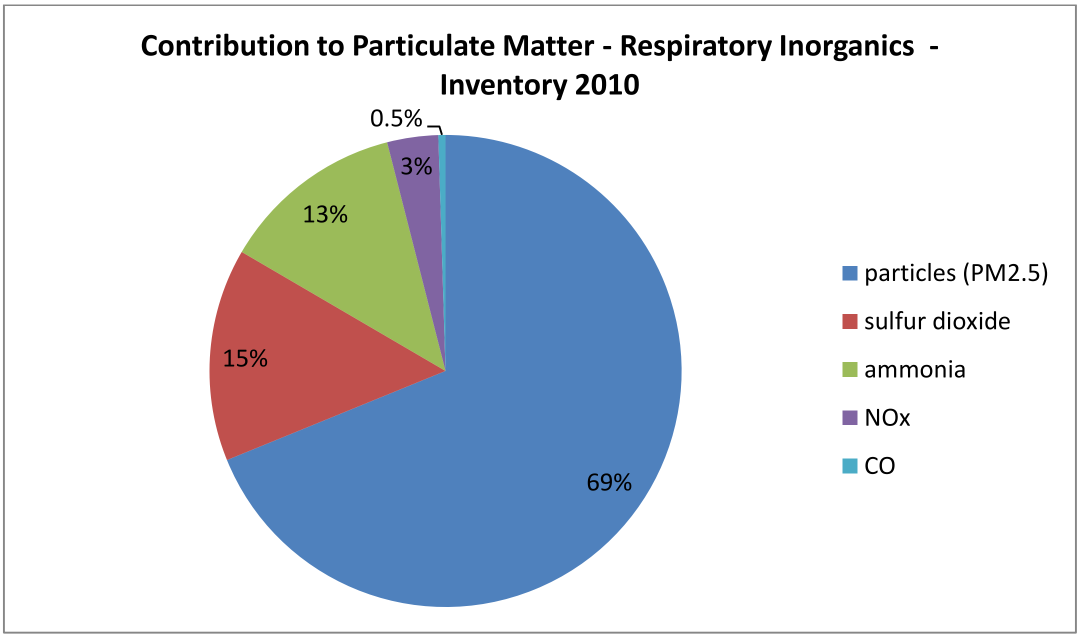


Figure 20 Contribution to the total PM/Respiratory Inorganics impact in Inventory 2010 as share of the overall figure expressed as kg $PM_{2.5eq}$

3.6.4 Uncertainty sources and limitations

As already discussed for acidification, the data sources used in this calculation show differences with other international emission inventories (e.g. EDGARv4.2). On top of the discrepancies discussed for SO_2, NH_3 and NO_2 for what concerns acidification, the values reported by EEA (2013c) for PM10 and PM2.5 emissions is respectively 27% and 25% lower than the figures reported in the EDGARv4.2 database. However, because of the review and quality assessment process which the UNFCCC, EMEP and EEA datasets are subject of, these sources of information are considered to be reliable enough for being used as basis for the normalization factors.

3.7 Ionizing radiation

Impact category	Unit	DOMESTIC	NF per person	ILCD recommendation level for characterisation method
Ionizing radiations	kBq U^{235} eq	5.64E+11	1.13E+03	II

The impacts associated with 'ionizing radiation – human health' have been estimated for the Inventory 2010 on the basis of the following emission sources: 1. emissions of radionuclides to air and water from energy production (nuclear and coal); 2. emissions of radionuclides to air and water from nuclear spent-fuel reprocessing; 3. discharge of radionuclides from non-nuclear activities (radio-chemicals production and research facilities) 4. discharge of radionuclides from offshore oil&gas industry and 5. emissions to air and water from the end-of-life scenario of gypsum boards.
The emissions associated to energy production have been estimated on the basis of radionuclides airborne and waterborne emissions per GWh of electricity generated from nuclear power plants, by combining UNSCEAR data on emissions factors (2008) for ^{14}C, ^{3}H, ^{131}I, and nuclear energy production (Eurostat, 2013r). Additional emissions of radionuclides coming from nuclear and hard-coal production have been estimated using unit processes from Ecoinvent 3.01 (Weidema et al., 2013) for nuclear and hard coal and energy statistics (Eurostat, 2013l; 2013m). The amount of radionuclides emitted from fuel reprocessing is estimated on UNSCEAR data (2008) on emissions of ^{3}H, ^{14}C, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{129}I, ^{106}Ru, ^{137}Cs and ^{241}Pu and combined with spent fuel processing statistics from the International Panel on Fissile Materials (IPFM) (Forwood, 2008; Schneider and Marignac, 2008). The data on radionuclides discharge from non-nuclear activities (including offshore oil&gas activity) has been taken from the OSPAR Commission[5] database (OSPAR, 2013), for those countries belonging to the OSPAR convention. No estimations for non-OSPAR countries were performed with exception of offshore oil and gas activity. The latter have been estimated for the EU-27 countries on the basis of average discharges per MJ (lower heating value) of oil produced and combining the result with overall oil production figures (Eurostat, 2013b). Emissions associated with end-of-life scenario of gypsum boards have been estimated by combining Ecoinvent (v 3.01) unit processes and PRODCOM data (PRODCOM/Eurostat, 2013).

3.7.1 Completeness of the dataset

Table 12 Number and share of flows (related to ILCD flows) in different normalisation datasets for ionizing radiation

	ReCiPe - year 2000, EU25+3 kg U235 eq	**CML - year 2000, EU25+3** kg U235 eq	**ReCiPe - year 2000, EU25+3** kg U235 eq	**CML - year 2000, EU25+3** kg U235 eq	**Inventory 2000** kg U235 eq	**Prototype 2006** kg U235 eq	**Inventory 2010** kg U235 eq
Number of flows reported within the normalisation dataset:							
- air	22	11	11	11	47	14	47
- water	24	7	13	7	49	0	49

[5] OSPAR Commission - OSPAR is the mechanism by which fifteen Governments of the western coasts and catchments of Europe, together with the European Union, cooperate to protect the marine environment of the North-East Atlantic. http://www.ospar.org/

Share of ILCD flows covered [(a)]:							
- air	22/21	11/21	11/21	11/21	21/21	14/21	47/21
- water	24/21	7/21	13/21	7/21	13/21	0/21	49/21

(a) The ILCD elementary flows that have been included are those which are associated to a characterization factor belonging to the categories: 'emissions to air, unspecified' and 'emissions to water, unspecified'. Few exceptions are represented by americium-241, antimony-125, carbon-14, curium, plutonium, strontium-90 for which the 'emissions to sea water' have been used instead, as the generic characterization factor 'emissions to water, unspecified' was not available for those substances.

The number of elementary flows covered by the inventory developed by ReCiPe is 46 and is sensibly higher than those included in both CML and the Prototype 2006. The inventory for the year 2010 covers an even larger number of elementary flows, 96 in total (Table 12). The elementary flows that have a characterization factors available within the impact assessment method used in ReCiPe and suggested within the ILCD for mid-point impact assessment (Frischknecht et al., 2000), are much less than the elementary flows listed within ReCiPe and the Inventory 2000 and 2010. The impact assessment method provides characterization factors for 14 pollutants emitted to sea water, 14 emitted to freshwater and 21 emitted to air. Hence, many of the flows which are quantified through the inventory are not actually captured within the impact assessment phase.

3.7.2 Comparison to other normalisation datasets

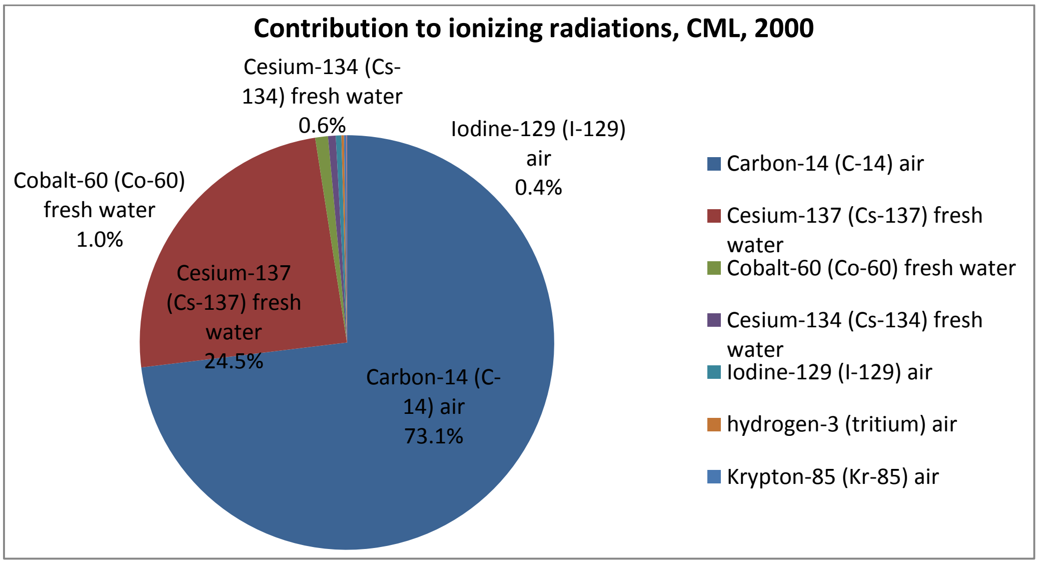


Figure 21 Contribution to the total Ionizing radiations impact in CML normalisation dataset (year 2000)

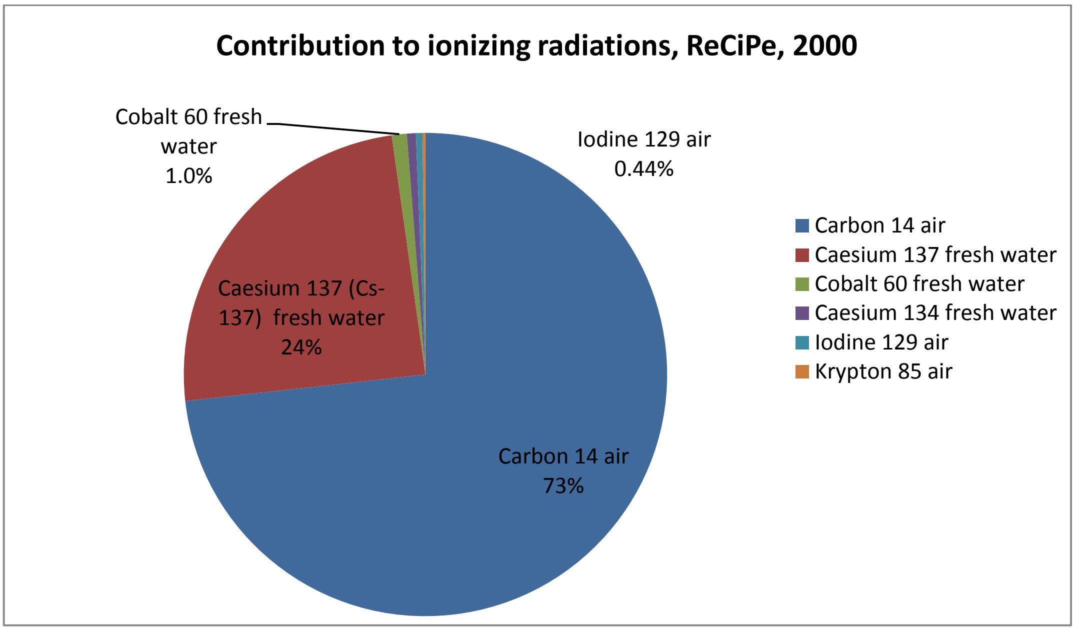


Figure 22 Contribution to the total Ionizing radiations impact in ReCiPe normalisation dataset (year 2000)

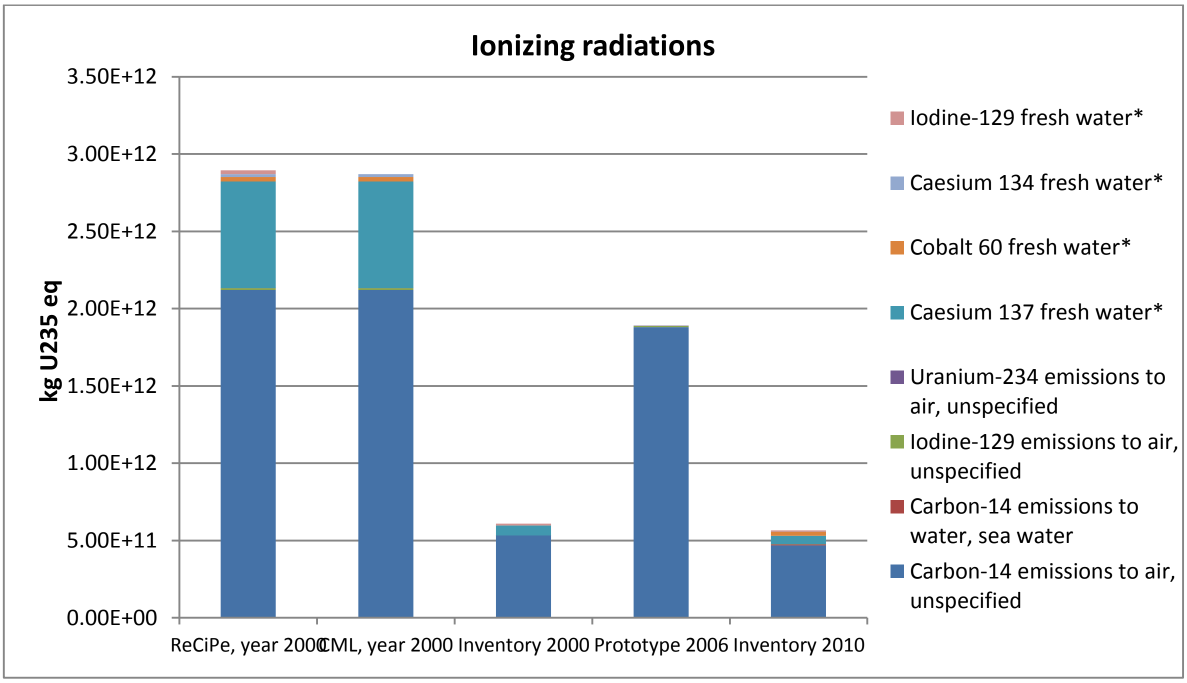
Both ReCiPe and CML present the same key contributors to the impact category (Figure 21 and Figure 22) as the overall impact is dominated by the same key substances i.e. ^{14}C to air (73%) and ^{137}Cs to water (24%).

As it is possible to see in Figure 23, the estimated impact in the Inventory 2000 and 2010 is sensibly lower than ReCiPe 2000 and the Prototype 2006. Overall, the Inventory 2000 accounts for 20% of ReCiPe 2000 and 30% of the Prototype 2006. The Prototype 2006 only accounts for emissions to air, neglecting all the emissions to water; the main contributor is ^{14}C, covering more. The differences observed among the datasets are mainly arising from the data sources and the extrapolation methods that have been used to build the datasets. The different territorial coverage among the datasets (i.e. EU25+3 vs. EU-27) cannot explain itself the incongruence among the results observed for ReCiPe/CML and Inventory 2000 and 2010. This is because that the difference among the two groups of countries in terms of nuclear installed capacity is negligible in comparison to the EU-27 totals, as it concerns only Switzerland (not included in the EU-27 Inventory 2000, 2010 totals and Prototype 2006), Bulgaria and Romania (not included in ReCiPe and CML EU25+3). According to the International Atomic Energy Agency (IAEA) (2013) Switzerland had an installed capacity of 3'278 MW(e)[6] in 2012, Bulgaria had 1'906 MW(e) and Romania 1'300 MW(e) and they account for, respectively, less than 3%, 2% and 1.6% of the total EU-27 installed capacity.

On the contrary, the data sources which have been used for estimating normalization factors are substantially different. Both ReCiPe and CML inventories are based on Wegener Sleeswijk et al. (2008) figures and subsequent updates (Wegener Sleeswijk et al. 2010 for ReCiPe and CML 2013). As reported in that paper, the data on emissions of radioactive substances have been taken from the UK Environment Agency pollution inventory (EA, 2006) and extrapolated to EU25+3 through the use of data on nuclear power capacity, retrieved by the authors from the Australian National University

[6] MW(e) = electric MW

(ANU, 2006). The estimation of the data for the Prototype 2006 is based on UK EA data and installed nuclear power capacity data (Eurostat, 2013b). Such estimation does not take into account several elements that have been considered in the Inventory 2000 and 2010, such as the distinction between typologies of nuclear reactors, the difference between emissions associated to energy production and to fuel reprocessing, and, more importantly the consequent country-specificity. Such distinction can be extremely relevant, as, for instance, in the period 1998-2002 the average emission of ^{14}C to air from UK reactors was 127 MBq/GWh, whereas in France and Germany was 25 MBq/GWh and 32 MBq/GWh, respectively (JRC elaborations based on UNSCEAR data, 2008), because of the different typology of reactors among the countries. In the same period, the nuclear energy produced in the UK contributed to 7% of the totals in the EU-27, whereas France and Germany contributed respectively to 44% and 19% (JRC elaborations based on UNSCEAR data, 2008). This means that the UK average emissions factors used within CML, ReCiPe and the Prototype 2006 were not representative of the average emission of ^{14}C per GWh at the EU25+3 scale and leaded to a large overestimation of radioactive emissions. Similarly, another source of overestimation is represented by the emissions of ^{137}Cs to water arising from spent-fuel reprocessing. This is because such emissions are very high in comparison to those emitted from electricity production and take place only where the specialized plants for spent fuel reprocessing are located and not all the countries that produce nuclear energy have such facilities. As reported by the World Nuclear Association (WNA) (2013) commercial facilities which have been active within the EU-27 territory are currently located in the United Kingdom, France (and Germany, dismissed), whereas the rest of the EU-27 countries do not have such plants. Hence, using the UK EA pollution inventory (EA, 2006) and extrapolating that value through installed power capacity as done by Wegener Sleeswijk et al. (2008) had leaded to an overestimation of ^{137}Cs emissions.



* water unspecified Inventory 2000, 2010

Figure 23 Comparison between normalisation factors for ionizing radiation calculated with ILCD CFs

3.7.3 Contribution to the impact

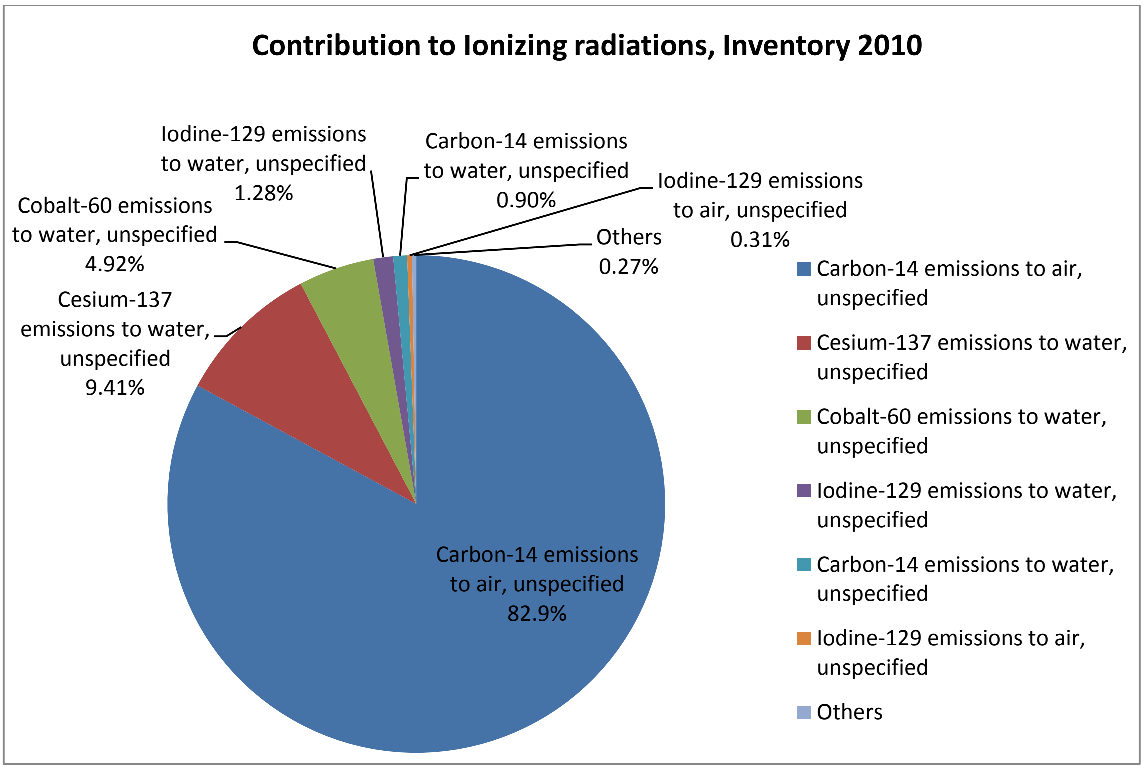


Figure 24 Contribution to the total ionizing radiation impact in Inventory 2010

The emissions of ^{14}C to air cover the highest share of impact for the Inventory 2010 (83%, Figure 24), mainly coming from electricity production and fuel reprocessing, whereas and the second contributor is ^{137}Cs to water (9%) coming from nuclear fuel reprocessing as well as ^{60}Co to water (5%).

3.7.4 Uncertainty sources and limitations

The main limitations on completeness and robustness of the Inventory 2010 are discussed below. Overall, because of the multiplicity of sources of emissions considered, the detail of the original statistics used for making estimates (emissions reported at power plant) and the sound extrapolation techniques, this impact category is assumed to cover the vast majority of ionizing radiations emitted into the environment.

Uncertainties associated to energy production and fuel reprocessing

Figures on net-electricity production statistics have been used instead of data on gross-electricity production figures for extrapolating emissions from nuclear power plants; hence the results for EU-27 are likely to be underestimated by 5-6%, as this is the difference between gross and net energy production (EC-JRC estimations on the basis of Eurostat data 2013r). The data on spent-fuel processing are lacking for the years 2008 to 2010. Prospective estimates have been used instead (Schneider and Marignac, 2008) for the plants located in the UK. For what concerns the facility located in France, the last reported data on spent-fuel processed was taken as representative for 2008, 2009 and 2010. It is likely that the figures on reprocessing spent fuel for 2007 are representative for the following years as between 2007 and 2010 the production of nuclear energy in EU-27 has not changed much between, oscillating between +0.2% and -4% (EC-JRC elaborations on Eurostat data 2013r). Additional data on liquid discharges from nuclear installations had been made recently available by the OSPAR Commission (2013a) however it is yet included in the current inventory.

Uncertainties associated to non-energy production related activities

The inventory does not include the emissions associated to particle-born radioactive substances, nor to the emissions of noble gases (mainly Radon and Xenon), which account roughly 1% of the total radionuclide emissions in the EU-27 for the year 2000, in terms of Bq. The emissions of ^{137}Cs to air are not quantified in the inventory. The characterization factor for this radionuclide ranks 8^{th} among the emissions to air in terms of impacts, as reported by Frischknecht et al. (2000). ReCiPe accounts ^{137}Cs in 2000 to be contributing only to less than 0.01% of the totals, resulting negligible. However, an updated quantification would be needed in order to assess whether this radionuclide is contributing to a higher extent to this impact category.

For non-OSPAR countries the inventory is less complete as there are less data available. The emissions of radioactive substances arising from non-nuclear activities (research, healthcare) are not properly accounted for. Discharges from oil&gas production have been estimated also for non-OSPAR countries on the basis of oil primary production, however no distinction between offshore and onshore emissions was possible.

The inventory lacks emissions of radionuclides from uranium mining; although the overall value in EU-27 should not be high, it can be very relevant for Czech Republic and Romania where the mining activities are located.

The emission of radionuclides from gypsum boards used in construction is partially accounted for within the inventory, covering only the end-of-life stage. The use phase is not assessed but it could be relevant to assess emissions of radon isotopes. Emissions associated to tiles should be assessed as well.

3.8 Photochemical ozone formation

Impact category	Unit	DOMESTIC	NF per person	ILCD recommendation level for characterisation method
Photochemical ozone formation	kg NMVOC eq	1.58E+10	3.17E+01	II

3.8.1 Completeness of the dataset

The flows that contribute to photochemical ozone formation in the Inventory 2010 are derived with the same rationale in selecting sources as for acidification (see chapter 0, explaining the rationale for choosing the data sources as UNFCCC > EMEP_modeled > EMEP_reported > EDGARv4.2), as well as from the application of a method for NMVOC breakdown, according to economic sectors (Laurent and Hauschild, 2013). It combines available speciation profiles, i.e. distributions of substances emitted per type of sources, and sectorial NMVOC information to reach country-specific, substance-specific emission profiles.

3.8.2 Comparison to other normalisation datasets

CML and ReCiPe reported similar figures for the emissions of CO, SO_2 CH_4, NOx and toluene but the characterisation methods are different and, hence, the contribution to the impact. In CML (Figure 25), the impact are expressed as kg of ethylene$_{eq}$ (kg C_2H_4-eq.) and the major contributor are non-methane volatile organic compounds (NMVOC) (38%) followed by NO_2 (24%), CO (22%), SO_2 (9%) and methane (3%) toluene (2%). Conversely, in ReCipe (Figure 26), the impact are expressed in terms of kg of NMVOC$_{eq}$ and the major contributors are NO_2 (44.8%) and NMVOC (44.2%), followed by CO (6.5%), SO_2 (2.7%) and CH_4 (0.8%).

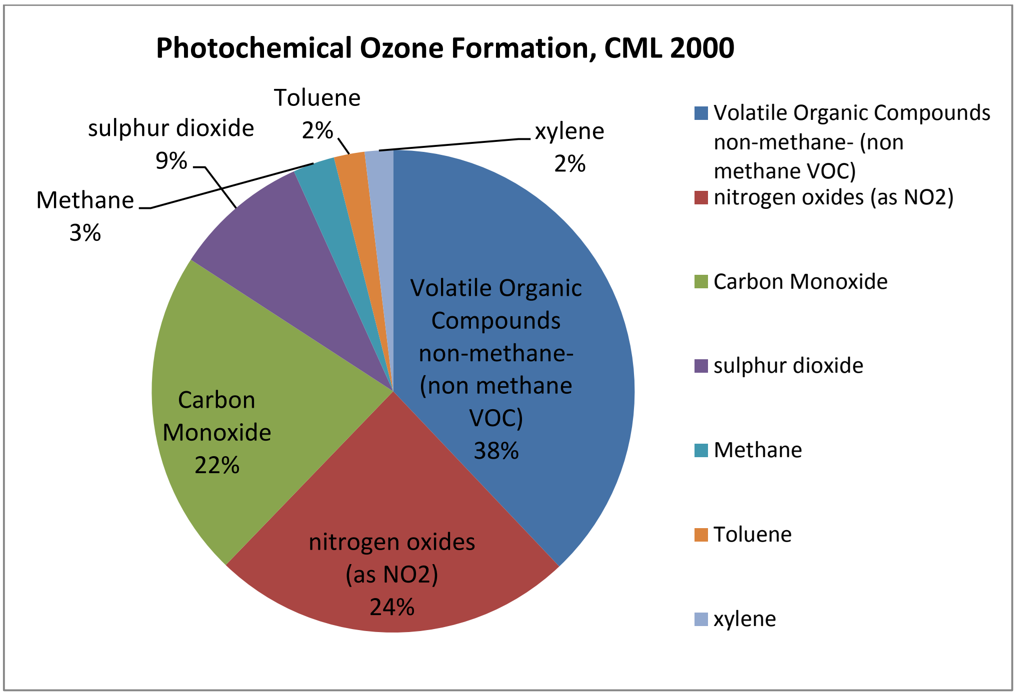


Figure 25 Contribution to the total photochemical ozone formation CML

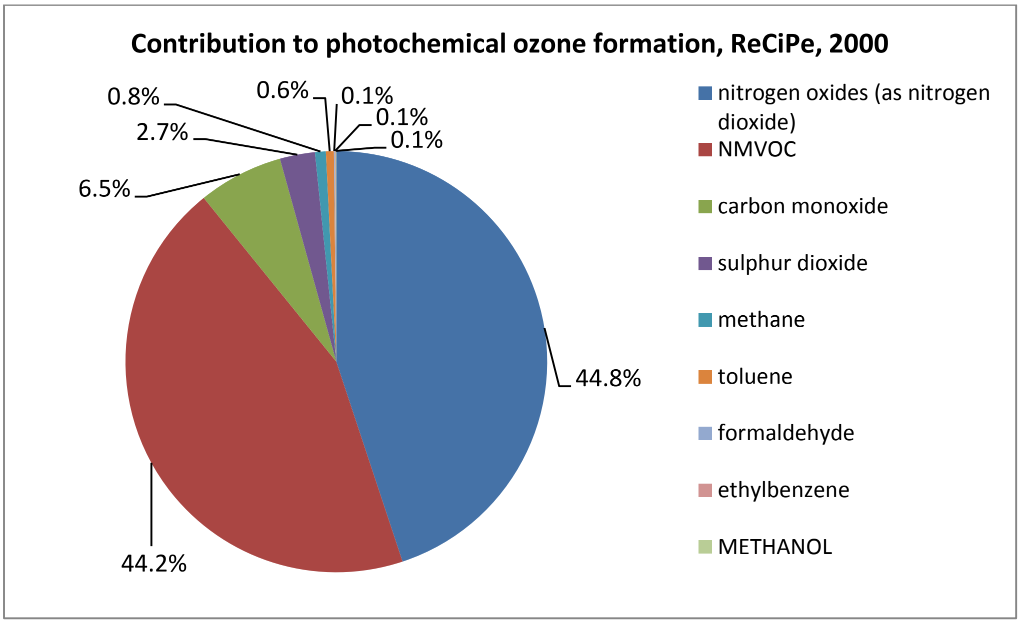


Figure 26 Contribution to the total photochemical ozone formation ReCiPe

Regarding the results of the current inventory the order of magnitude of emissions is consistent with previous emission inventories in CML and ReCiPe (Figure 27) as well as with the prototype developed by EC – JRC (2012b), in which the contribution of the domestic was equal to 1.58E+10 kg of $NMVOC_{eq}$ in 2006. Within the prototype referring to 2006, four flows contribute the most to the overall results: nitrogen dioxide, NMVOC, sulphur dioxide and carbon monoxide (Figure 27). The main difference observed between the domestic inventory 2000 and 2010 and the other datasets is the absence of the NMVOC category. As explained above, in the domestic inventory (2000 and 2010) the NMVOC class has been disaggregated into specific flows of chemicals and, the consequent calculation of the impacts is based on the chemical-specific characterization factors. As it is possible to observe from the figure below, the impact calculated by disaggregating NMVOC into specific flows is lower than the one estimated by using an average characterization factor for the NMVOC class.

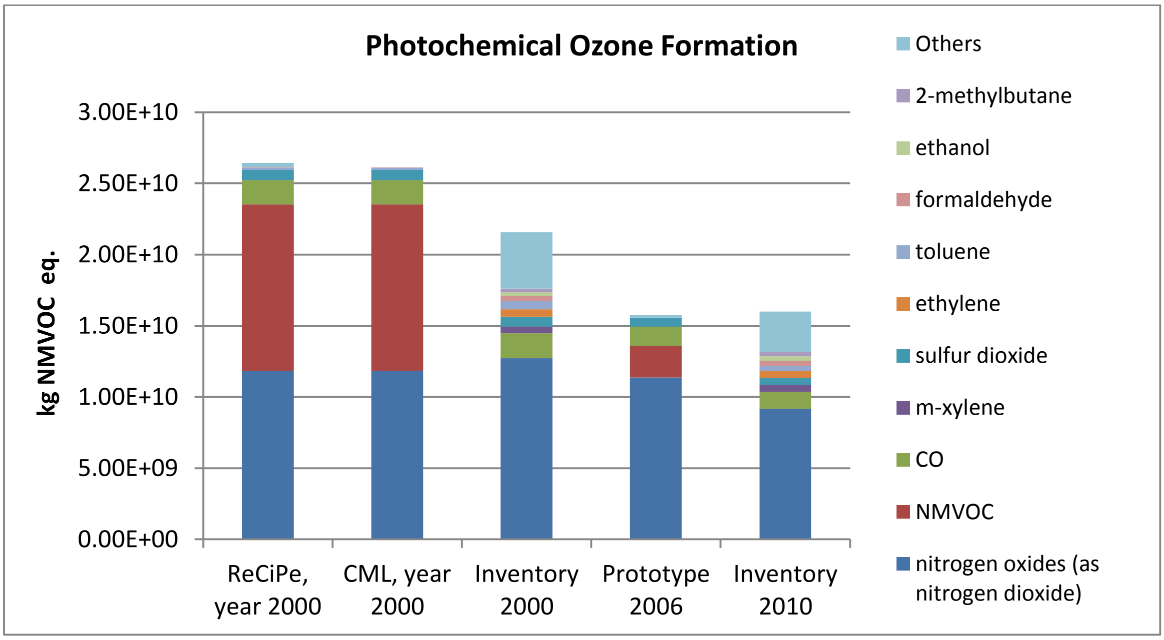


Figure 27 Comparison between normalisation factors for photochemical ozone formation calculated with ILCD CFs

3.8.3 Contribution to the impact

In the inventory 2010, the relative contribution is as follows: 58% nitrogen dioxide, followed by carbon monoxide at 7%, m-xilene at 4% , sulphur dioxide at 3% and ethylene at 3%. Other compounds, mostly NMVOC, cover up to 18% of the total (Figure 28).

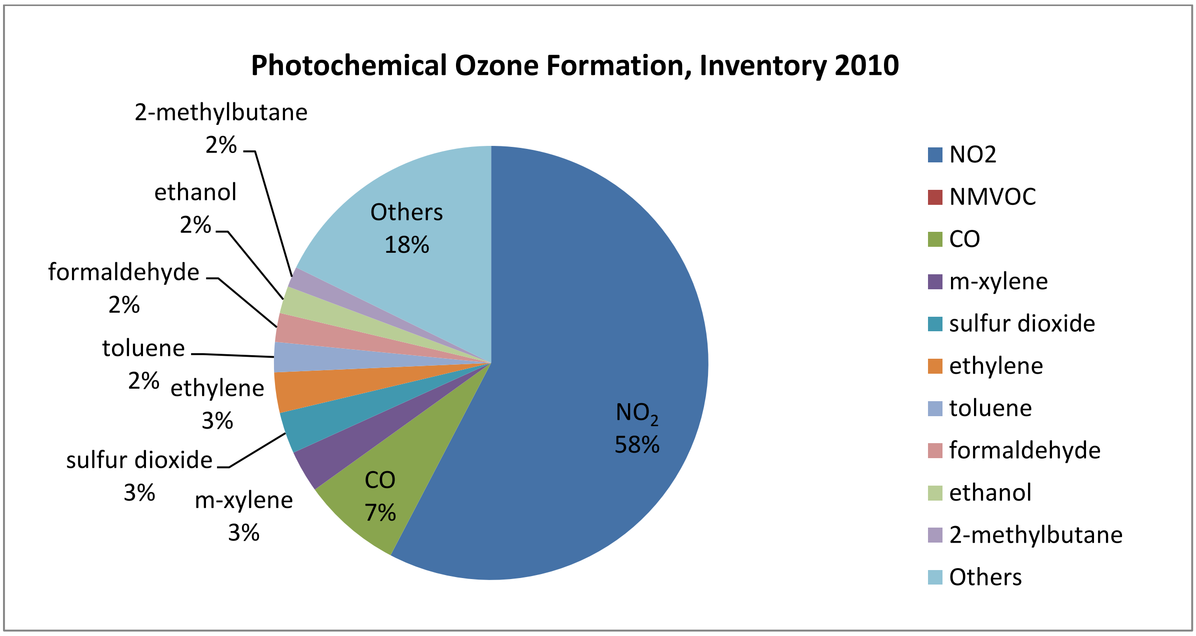


Figure 28 Contribution to the total photochemical ozone formation impact in Inventory 2010 normalisation dataset

3.8.4 Uncertainty sources and limitations

The Inventory 2010 dataset seems consistent as a whole. A number of potential outliers should be double checked, in particular where for some specific substances only one country contributes significantly to the overall value for EU-27. However due to their low relevance, even revised figures for these substances are unlikely to significantly change the overall picture.

3.9 Terrestrial eutrophication

Impact category	Unit	DOMESTIC	NF per person	ILCD recommendation level for characterisation method
Terrestrial eutrophication	mol N eq	8.76E+10	1.76E+02	II

3.9.1 Completeness of the dataset

The flows that contribute to terrestrial eutrophication, as estimated within the domestic inventory for 2010, are ammonia and nitrogen dioxide emitted to air. The original data sources are UNFCCC for NOx (reported as NO_2) and the EMEP/CEIP 'modeled' database for NH_3 (EMEP/CEIP, 2013b). The flows of NO_x as retrieved from the statistics have been mapped into the respective ILCD flow i.e. nitrogen dioxide (NO_2); as a consequence the corresponding characterization factor has been used for calculating the midpoint impact indicator. The ILCD flows include 6 emissions to air that contribute to this impact category (Table 13).

Table 13 Number and share of flows (related to ILCD flows) in different normalisation datasets for terrestrial europhication

	ReCiPe - year 2000, EU25+3	CML - year 2000, EU25+3	Inventory 2000	Prototype 2006	Inventory 2010
Number of flows reported within the normalisation dataset:					
- air	NA	3	2	2	2
- freshwater	NA	1	0	0	0
- soil	NA	2	0	0	0
Share of ILCD flows covered* [a]					
- air	NA	50%	33%	33%	33%

*CML covers flows to freshwater and soil which are not included within the ILCD

3.9.2 Comparison to other normalisation datasets

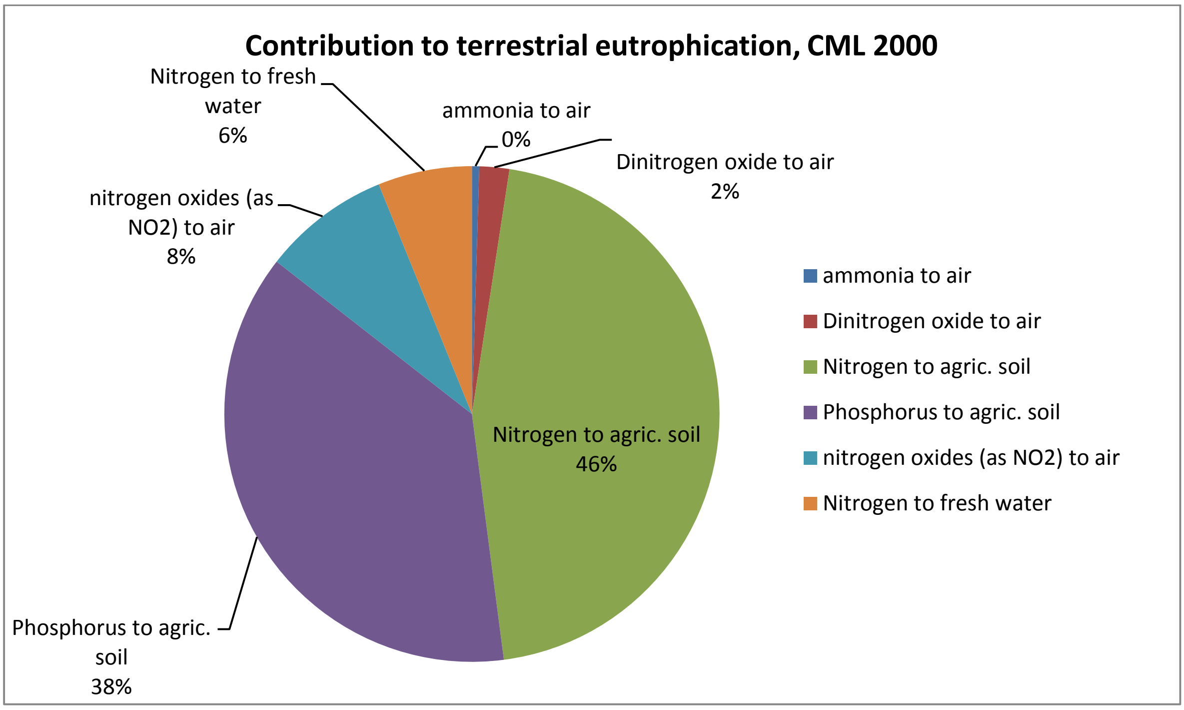


Figure 29 Contribution to the total acidification impact in CML normalisation dataset (year 2000)

The CML data values in Figure 29 are dominated by the emission of nitrogen and phosphorus to agricultural soil. Together they account for 83 % of the terrestrial eutrophication impact category, as calculated using the CML method. By also including emissions of nitrogen to fresh water (6.1 %) the values rises to almost 90%. Emissions of ammonia to air contribute only to a lesser extent (0.5 %), whereas nitrogen dioxide emitted to air contributes to the remaining 8.3%. The ReCiPe methodology does not provide a terrestrial eutrophication impact assessment method among listed within its set of impact categories as only impacts due to eutrophication of freshwater and marine are accounted for.

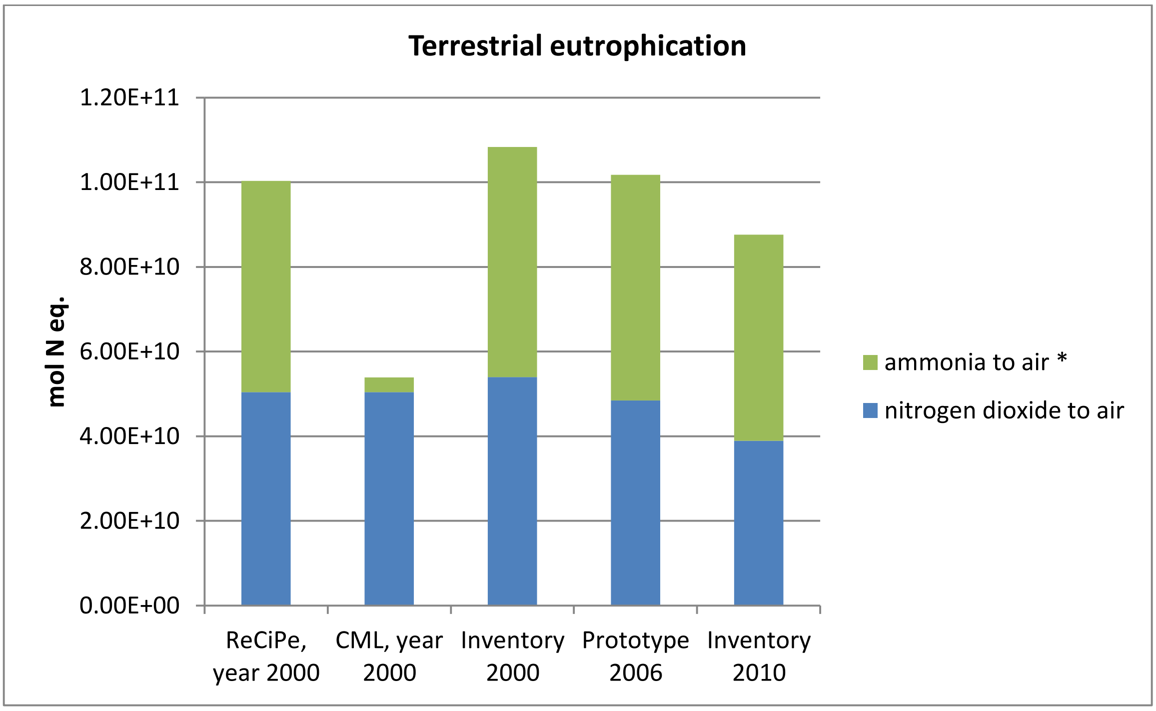


Figure 30 Comparison between normalisation factors for terrestrial eutrophication calculated with ILCD CFs ammonia

* values include also secondary volatilization from fields so to take into account also the contribution of manure and fertilizers as reported by the authors (Wegener Sleeswijk et al., 2010)

As it is possible to see from Figure 30, nitrogen dioxide is an important contributor to terrestrial eutrophication in all estimations. According to the authors of the dataset (Wegener Sleeswijk et al., 2010) used by ReCiPe, manure and fertiliser are responsible for an additional (secondary) ammonia emissions of 3.45E+09 kg for Europe; hence, this value has been added to the original ammonia data for the sake of comparability with the other methods. The estimations done within the domestic inventory are consistent with those reported by ReCiPe, CML and Prototype – 2006, in terms of overall emissions and main contributors.

3.9.3 Contribution to the impact

Overall, emissions of ammonia to air contribute to the 55% of the observed impacts and the remaining 45% is covered by emissions of NO_2 to air.

3.9.4 Uncertainty sources and limitations

Uncertainties and limitations are to be found in the original data source (UNFCCC, 2013 and EMEP/CEIP, 2013b) and in the estimations carried out for missing countries (Luxembourg) as documented in Sala et al. (2014).

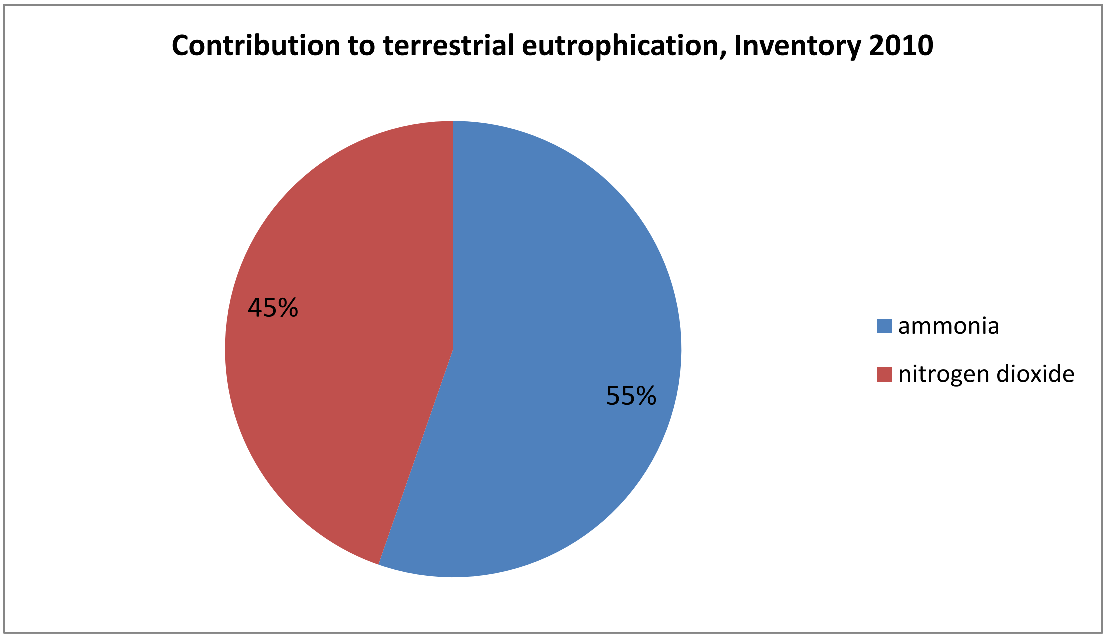


Figure 31 Contribution to the terrestrial eutrophication impact in Inventory 2010 normalisation dataset

3.10 Freshwater eutrophication and Marine eutrophication

Impact category	Unit	DOMESTIC	NF per person	ILCD recommendation level for characterisation method
Freshwater eutrophication	kg P eq	7.41E+08	1.48E+00	II
Marine eutrophication	kg N eq	8.44E+09	1.69E+01	II

3.10.1 Completeness of the dataset

The values for emissions to water, both for Ntot and Ptot, are estimated on the basis of the methodology developed by Van Drecht et al. (2009). The key data sources underlying such estimates are Eurostat (2013h), UNFCCC (2013), Faostat, (2013b and 2013f). However, some of the statistics used for modelling the emissions of nitrogen and phosphates to water bodies, such as share of population connected to waste water treatment (by typology) (Eurostat, 2013h; OECD, 2013a) do not have a good coverage over time within the EU-27. Such lack has been assessed through the analysis of correlation with time. As many of the observed correlations where not significant, it is likely that the estimation procedure might lead to errors in the results. Another issue is represented by the fact that the original equation for estimating Ntot and Ptot covers only partially the industrial emissions to water, leading to a potential underestimation of the overall figures. Hence, such uncertainty sources represent the main limitation of the robustness of the normalization factors for both marine and freshwater eutrophication-related impacts.

Table 14 Number and share of flows (related to ILCD flows) in different normalisation datasets for Freshwater eutrophication

	ReCiPe - year 2000, EU25+3	CML - year 2000, EU25+3	Inventory 2000	Prototype 2006	Inventory 2010
Number of flows reported within the normalisation dataset:					
- water	1	0	1	1	1
- freshwater	0	0	0	0	0
- soil	1	1	1	0	1
Share of ILCD flows covered:					
- water	33%	0%	33%	33%	33%
- freshwater	0%	0%	0%	0%	0%
- soil	33%	33%	33%	0%	33%

Table 15 Number and share of flows taken into account in different normalisation datasets with respects to the ILCD flows, for Marine eutrophication

	ReCiPe - year 2000, EU25+3	CML - year 2000, EU25+3	Inventory 2000	Prototype 2006	Inventory 2010

Number of flows reported within the normalisation dataset:					
- air	2	2 (+1)*	2	2	2
- water	0	1	1	1	1
- soil	22**	2	0	0	0
Share of ILCD flows covered:					
- air	40%	40%	40%	40%	40%
- water	0%	20%	20%	20%	20%
- soil	NA	NA	NA	NA	NA

* CML includes also emissions of N2O to soil which is not included in the ILCD.

**the emissions to soil covered by ReCiPe are relative to fertilizers and manure. The ILCD does not cover such flows.

3.10.2 Comparison to other normalisation datasets

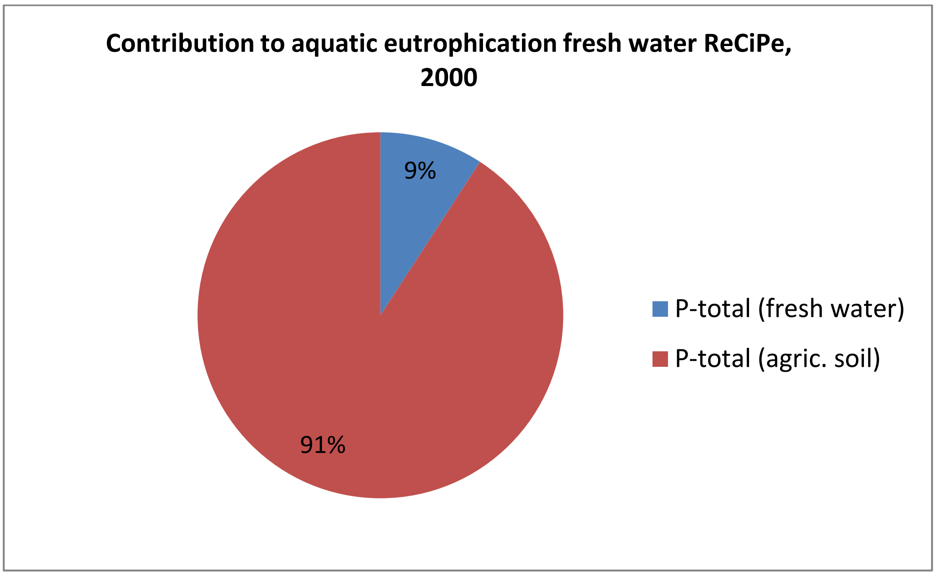


Figure 32 Contribution to the Aquatic eutrophication fresh water total impact in ReCiPe normalisation dataset (year 2000)

The CML methodology does cover eutrophication to terrestrial/freshwater and does not provide an impact assessment method to assess marine water eutrophication. The results for CML of the terrestrial/freshwater eutrophication are reported in the section above. ReCiPe covers both freshwater and marine water eutrophication. In ReCiPe only emissions of P-total to fresh waters and agricultural soils are estimated to contribute to aquatic freshwater (EU25+3, year 2000), as reported in figure below. The vast majority of the impact derives from the emissions to agricultural soils (91%), whereas emissions to agricultural soils contribute only to 9% of the total (Figure 32).

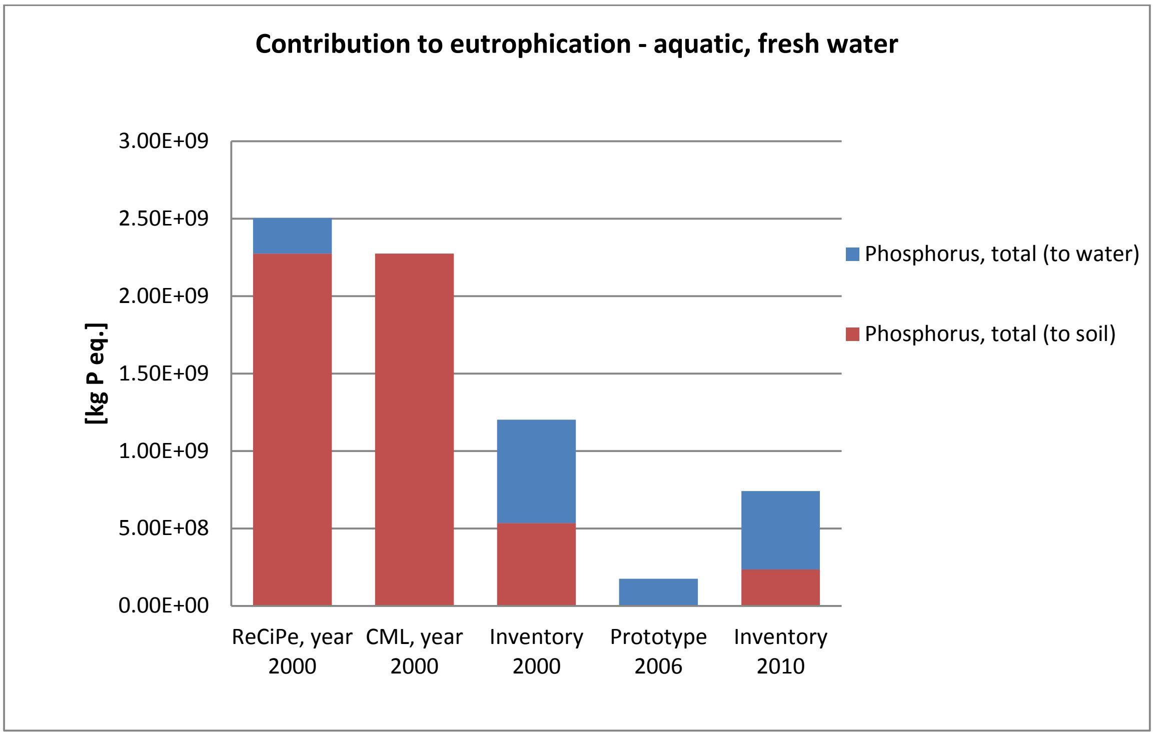


Figure 33 Comparison between normalisation factors for eutrophication, fresh water, calculated with ILCD CFs

The values for total phosphorus emitted to soils are a factor 10 lower in the inventory 2010 than the CML and ReCiPe year 2000 (Figure 33). This can only partially be explained by a reduction from 2000 to 2010, as the Inventory 2000 shows a factor 4 lower than the ReCiPe and CML for the same year. The reason of such discrepancy is likely to stem from different data sources used between ReCiPe, CML, Prototype 2006 and the domestic inventory, both for 2000 and 2010. For the latter dataset, the data on Ptot emissions to soils are taken from Eurostat (2013g) and data-gap filled through the emissions of Ntot to soil, used as proxy variable, assuming that there is correlation between total phosphorous and total nitrogen, both for inputs and outputs.

3.10.3 Contribution to the impact

Overall, 68% of the impact on freshwater is due to emissions of phosphorous to water and the remainder to emissions of phosphorous to soil.

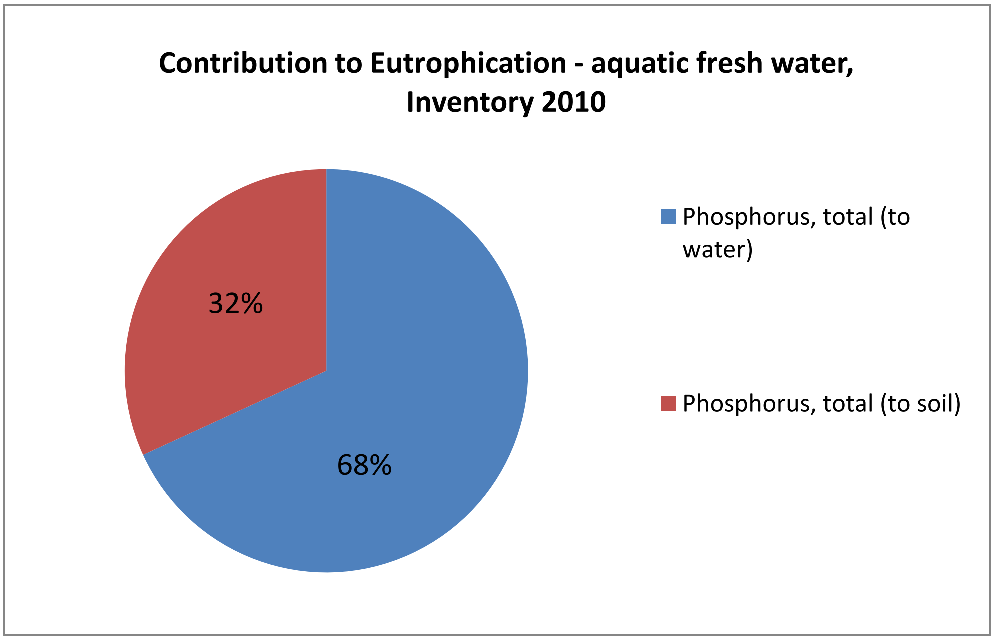


Figure 34 Contribution to freshwater eutrophication impact in Inventory 2010 normalisation dataset

3.10.4 Uncertainty sources and limitations – Freshwater eutrophication

The main difference with ReCiPe and CML consists in the fact that the statistics used in the domestic inventory are relative to the balance of nutrients in the soil, which is the result of overall inputs and output processes, such as the losses to water, the removal of nutrients through harvest and grazing, as well as from removal of crop residues from the field. Whereas, the ReCiPe and CML datasets are based on the total input of Ptot to soils and do not take into account the output processes. Because of the relevance of the output processes within the balance equation of phosphorous in soils, the choice in the modelling of the domestic inventory was to use the actual balance rather than the overall input to soil.

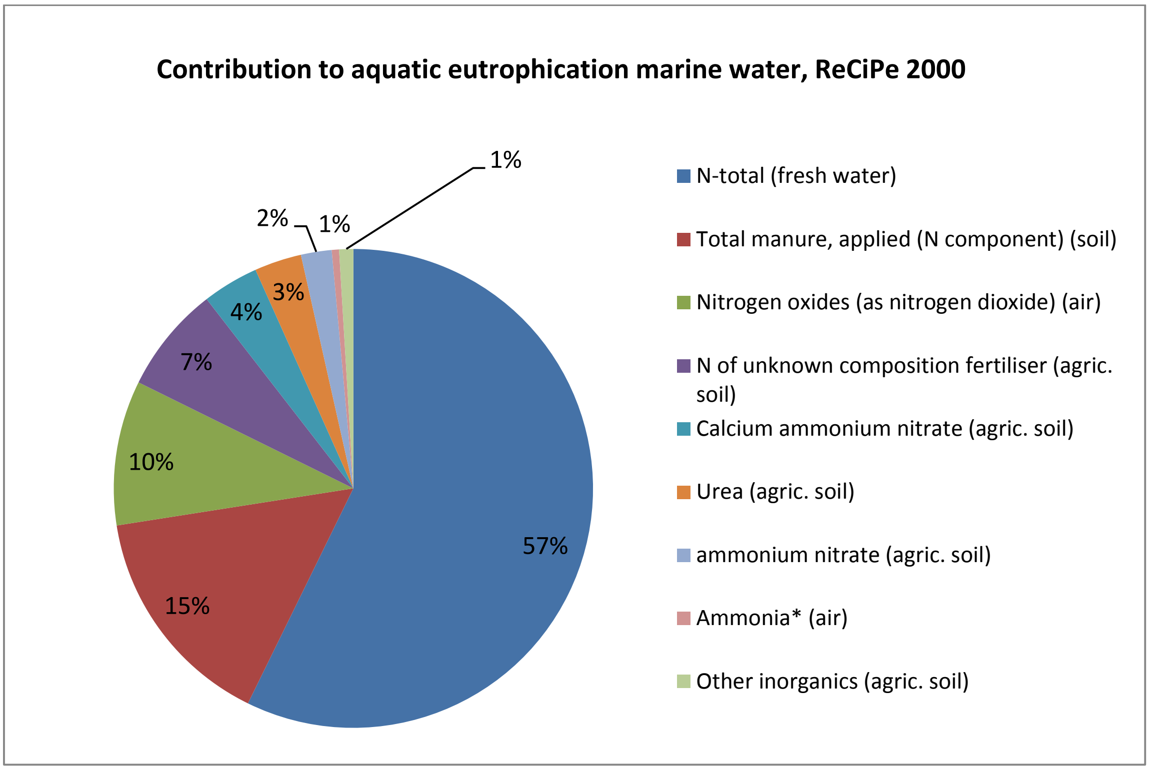


Figure 35 Contribution to the eutrophication marine water total impact in ReCiPe normalisation dataset (year 2000)

For what concerns the eutrophication of marine water, the ReCiPe (Figure 35) normalisation factor for the impact category is dominated by the emissions of N-total to fresh water 57%, with relevant contributions from total manure applied to soil (15%) and nitrogen oxides emitted to air (10%). Except for ammonia to air, the other normalisation data for this impact category are emissions to agricultural soil.

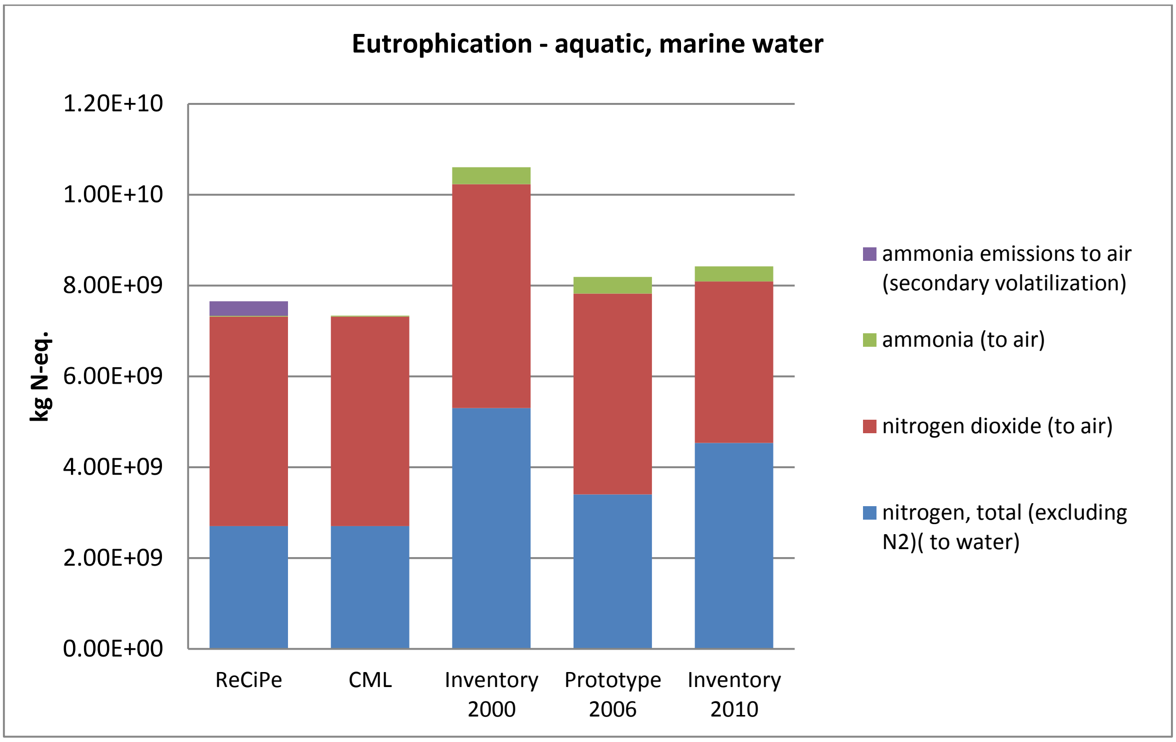


Figure 36 Comparison between normalisation factors for eutrophication, marine water, calculated with ILCD CFs

The domestic inventory does not include emissions to soil (such as fertilizers or manure) because there are no ILCD flows which have a corresponding characterization factor leading to marine water eutrophication. On the contrary, ReCiPe accounts for these flows in its impact assessment methodology. In order to be consistent, as in the case of terrestrial eutrophication, the secondary volatilization of ammonia from the application of fertilizers and manure to soil has been added to the totals so to allow for direct comparison among the datasets. Emissions of ammonia provide a minor contribution to the totals consistently among all the datasets. Emissions of nitrogen dioxide leaded to the highest contribution to marine eutrophication in 2000, for ReCiPe, CML and the domestic inventory; whereas in the domestic inventory 2010 the emissions of Ntot to water became the first contributor (Figure 36).

3.10.5 Contribution to the impact

Overall, 54% of the impact on freshwater is due to emissions of nitrogen to water, 42% to emissions of nitrogen dioxide to air and the remainder 4% to emissions of ammonia to air.

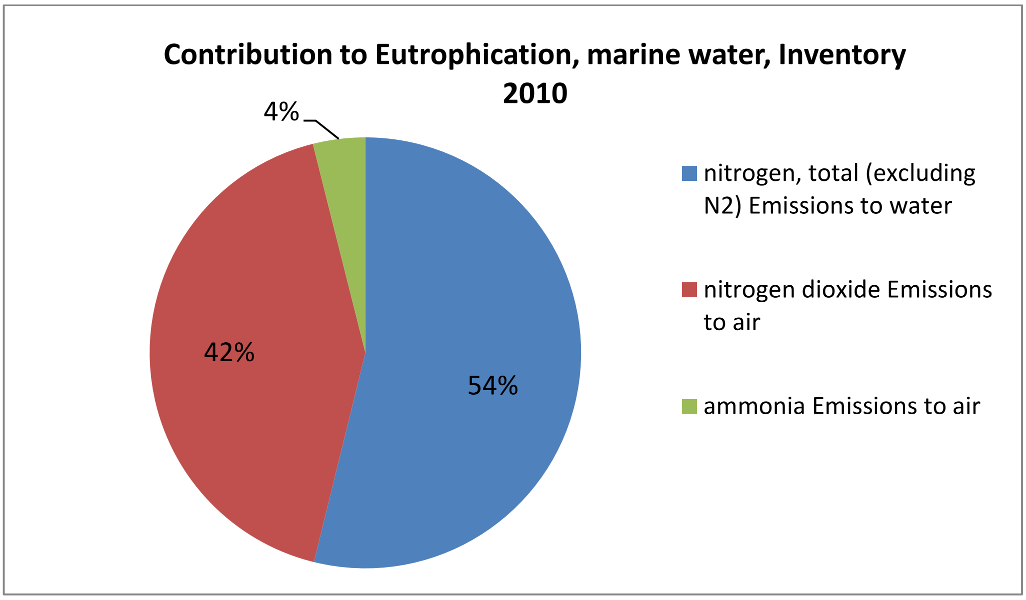


Figure 37 Contribution analysis, eutrophication - marine water, Inventory 2010

3.10.6 Uncertainty sources and limitations – Marine eutrophication

Overall, the values reported by ReCiPe and CML are lower than those reported by the domestic inventory, both for the years 2000 and 2010. Such difference is due to the different approaches adopted to estimate the emissions of Ntot to water among the domestic inventory, ReCiPe and CML. Concerning ReCiPe and CML, the estimation of nitrogen emissions to water is based on two proxies: GDP and population, as suggested in Van Drecht et al. (2003). For what concerns the domestic inventory (both 2000 and 2010) the emissions of Ntot to water are derived from the nutrient mass balance in soil provided by Eurostat (2013g) (i.e. the share of Ntot emissions to soil that is lost to water) and from an estimation of emissions from wastewater. In turns, emissions from wastewater are estimated on the basis of food balance sheets (FAO, 2013f), households' connection to wastewater treatment plants (Eurostat, 2013h) and removal efficiency rates as reported in Van Drecht et al. (2009). Hence, the difference observed between the datasets can be explained by a finer estimation technique adopted in the development of the domestic inventory, which leaded to a more comprehensive assessment. In addition to that, it is noteworthy that the domestic inventory covers also the share of Ntot emissions to soil that are lost to water after the on-field application of nutrients, leading to a higher quantification of nutrients emissions to water and to a lower value of nutrients emitted to soils in comparison to ReCiPe and CML. Hence, similarly to what discussed in the case of the emissions of Ptot (see above), it is likely that the domestic inventory estimates higher emissions to water and lesser emissions to soil than ReCiPe and CML, for both Ntot and Ptot, as only the amount of nutrients remaining in the field are accounted as actual emissions to soils, whereas nutrients lost to water are included among overall emissions to water, consistently with the underlying statistics (Eurostat, 2013g).

3.11 Land use

Impact category	Unit	DOMESTIC	NF per person	ILCD recommendation level for characterisation method
Land use	kg C deficit	3.74E+13	7.48E+04	III

The ILCD recommended method for land use impact assessment (Milà i Canals, Romanyà, & Cowell, 2007) accounts for impacts due to two different classes of elementary flows: land occupation and land transformation. Land occupation flows refer to the actual occupation of a square meter of land for one year, whereas land transformation refers to the process of land conversion from one typology of land use to another and is expressed in square meters of land converted. The original dataset from which the statistics are taken is the LULUCF dataset from the national GHGs inventories (UNFCCC, 2013) submitted by countries to the United Nations Framework Convention on Climate Change (UNFCCC). Existing data-gaps (mainly for Cyprus and Malta) have been filled by using the CORINE land cover maps (EEA, 2012b) and subsequent interpolation and extrapolations.

3.11.1 Completeness of the dataset

In Table 16, the overall coverage of ILCD flows for each of the inventory dataset used for comparison is presented. As it is possible to see, the domestic inventory for the year 2010 covers only 8% of the flows which have a characterization factors within the ILCD contributing to land use impacts. This lack of completeness is due to the inconsistency between the UNFCCC and the ILCD nomenclatures, which are, indeed, meant with two different purposes. The flows covered within the UNFCCC, although having a good coverage of the total land uses and land use changes, have a very coarse resolution. Despite that, it is reasonable to assume that the domestic inventory (both 2000 and 2010) is representative of the current land use occupation and transformation values observed at the level of the EU-27 because of the high quality of the UNFCCC datasets on GHGs and LULUCF reported by countries and checked through a quality assurance and review procedure within the UNFCCC convention.

3.11.2 Comparison to other normalisation datasets

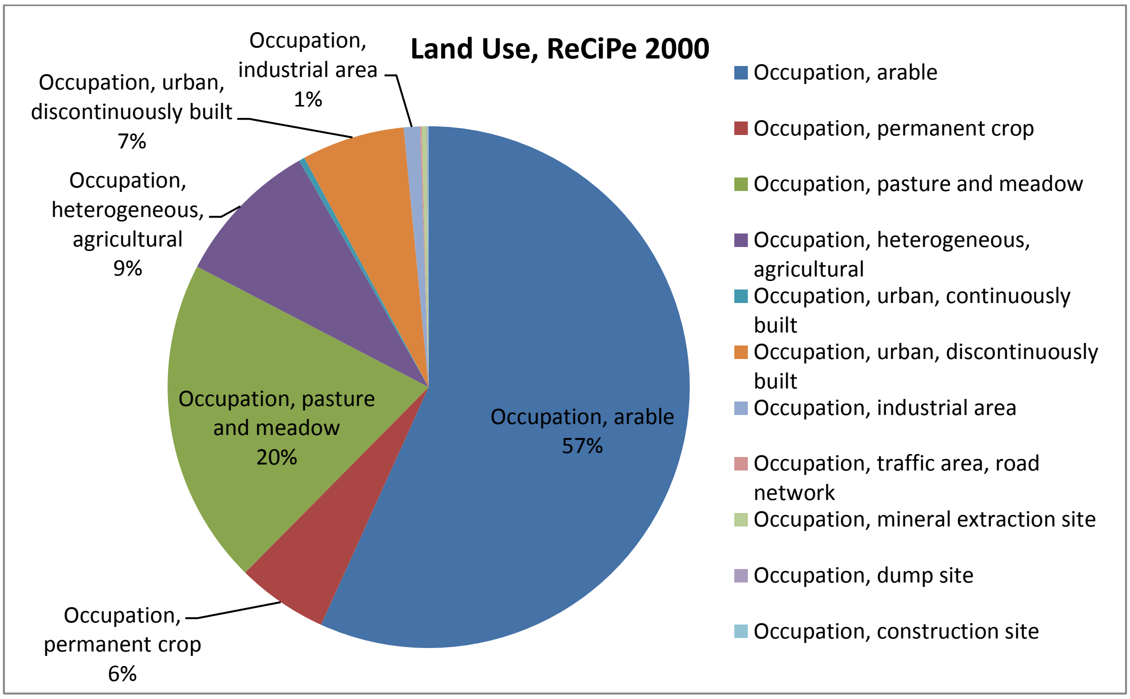


Figure 38 Contribution to the Land use total impact in ReCiPe normalisation dataset (year 2000)

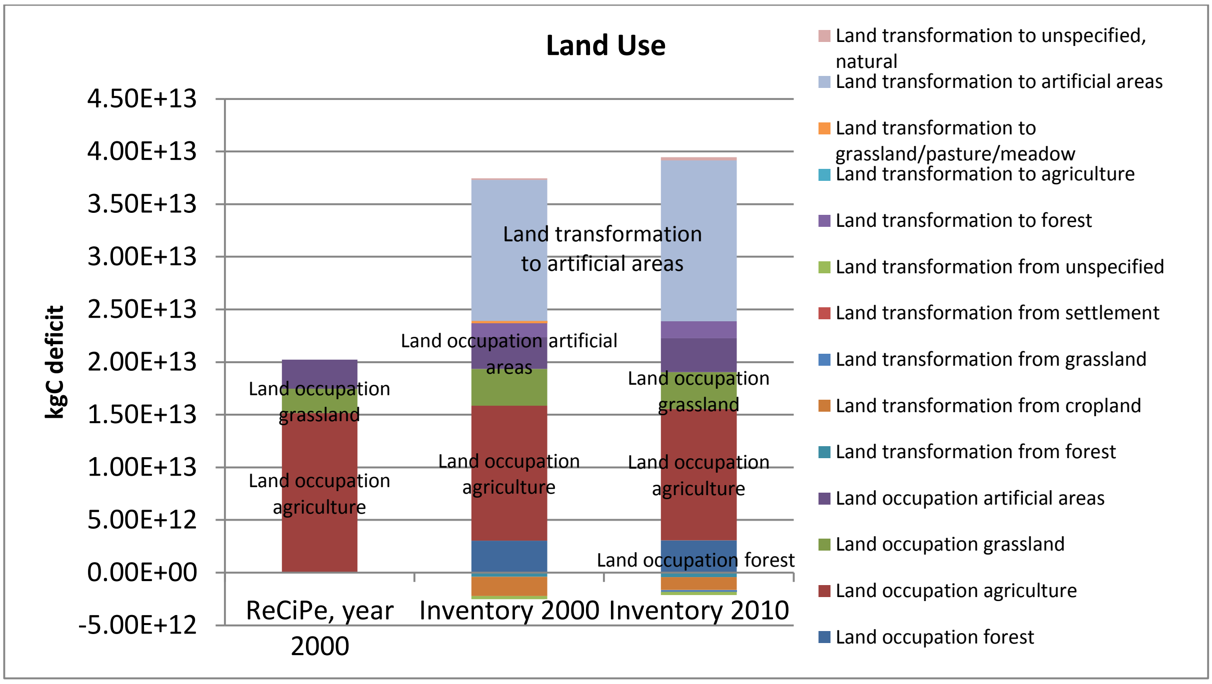


Figure 39 Comparison between normalisation factors for land use calculated with ILCD CFs

As it is possible to see from the pie-chart in Figure 38, the land uses that contribute the most to the overall impact in ReCiPe are: arable land, pastures and 'other agricultural areas'. The impact assessment method used within ReCiPe accounts only for those flows related to occupation and does not include flows related to transformation. By looking at Figure 39, it is possible to see that, despite the different data sources used among the datasets, there is overall consistency among ReCiPe and the domestic inventory, for those flows (Table 16) related to land occupation (i.e. land occupation from agricultural and artificial areas).

Table 16 Number and share of flows (related to ILCD flows) in different normalisation datasets for land use

	CML - year 2000, EU25+3	ReCiPe - year 2000, EU25+3	Inventory 2000	Prototype 2006	Inventory 2010
Number of flows included in the normalisation dataset:					
- occupation	NA	11	4	NA	17
- transformation	NA	0	13	NA	13
Share over ILCD flows:					
- occupation	NA	15%	5%	NA	23%
- transformation	NA	0%	17%	NA	17%

3.11.3 Contribution to the impact

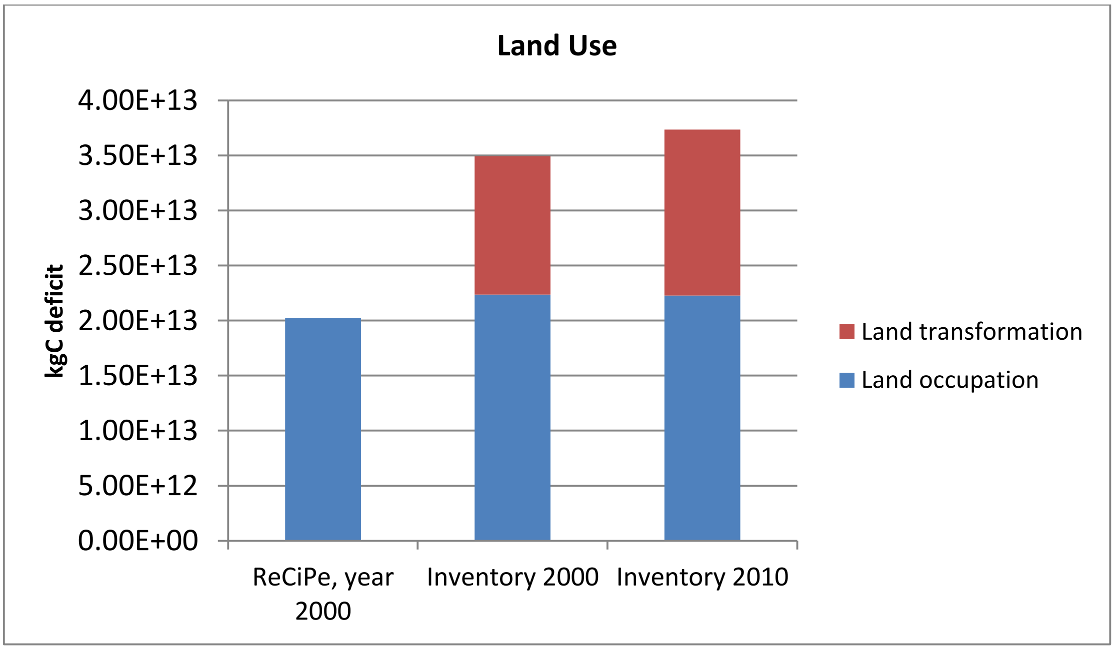


Figure 40 Contribution to the total land use impact from different datasets calculated with ILCD CFs

The flows contributing the most to the land use impacts in the domestic inventory 2010 are those related to land occupation; all together cover around 60% of the total impact in the EU-27 (Figure 40), while the remaining 40% is due to land transformation. The impacts associated to land occupation account for one dime of the land transformation. However, taken singularly, the land transformation to artificial areas is the flow which contributes the most to the impacts, followed by land occupation due to agriculture, artificial areas, grassland and forests.

3.11.4 Uncertainty sources and limitations

The uncertainty factors affecting the estimation are due to the source of the dataset, the mapping from the original dataset to the ILCD flows, as well as the use of default site-independent characterization factors. The latter factor refers to a limitation of the recommended impact assessment method, thus it is not addressed in this document. On the contrary, a set of choices has been done in this assessment in order to mapping the UNFCCC dataset into ILCD flows. Such choices are subject to limitations and may affect the robustness of the results. Due to the lack of details in the land use categories reported within the UNFCCC (e.g. 'from forest to agriculture' or 'from forest to unspecified areas, used') some assumptions have been made in matching them into ILCD flows. However in some cases the choice was not straightforward, due to the coarse resolution of the original dataset. In most of the cases such choices do not lead to changes in the final results (i.e. all the ILCD flows related to arable lands lead to the same characterization factor); whereas the assumptions made for land use transformation from and to 'unspecified' show high variability among the characterization factors, as reported in Table 17. A correction of the previous normalisation factors set is done in this version by means of mapping the flow 'from other land' (UNFCCC dataset) to the ILCD flow 'from unspecified, natural'. In addition to that, several errors which affected land transformations statistics (especially 'transformation to artificial areas') spotted within the UNFCCC dataset has been corrected. As a result, the normalisation reference for land use had been changed from 3.41E+14 to 3.74E+13 kg C deficit.

Table 17 Mapping of UNFCCC flows into ILCD flows and relative characterization factors for land use

Statistical dataset (UNFCCC, 2013)	ILCD flow	Characterization factor
from 'other land'	'from unspecified, natural'	-20 kgC
from 'other land'	'from unspecified, artificial'	-7400 kgC
from 'other land'	'from unspecified'	-1720 kgC

3.12 Resource depletion, water

Impact category	Unit	DOMESTIC	NF per person	ILCD recommendation level for characterisation method
Resource depletion water	m^3 water eq.	4.06E+10	8.14E+01	III

The total domestic resource depletion impact has been calculated considering the gross freshwater abstraction from river and from the ground, for which characterization factors are available for EU-27. The ILCD recommended impact assessment method – Swiss Ecological Scarcity 2006 (Frischknecht et al., 2009) accounts the water use related to local scarcity of water. Accordingly with other impact categories, the generic CF for “freshwater, OECD average scarcity” has been used for the calculation; hence, no country-specific CF has been used.

Data on water abstractions are from Eurostat (2013i), and have been supplemented with OECD (2013b) and FAO-Aquastat (2013). Missing data were estimated using sector-specific coefficients of water withdrawals as reported in Sala et al. (2014). Data on water withdrawals for hydropower generation are not accounted within the normalization factors, consistently with the Swiss Ecological Scarcity 2006 (p 155, reported below) impact assessment method.

"In accordance with the OECD (2004) and FAO (2005) we understand water consumption to mean all extractions of freshwater for production or consumption processes.
Water consumption does not include water used by hydroelectric facilities to generate electricity *(cf. also Section 2.1.4)."*

Nor CML, ReCiPe neither prototype 2006 provides normalisation values for water. A comparison of the results can be performed using data on water abstractions reported in Vandecasteele et al. (2013). In this study pan-European public/municipal water withdrawals and consumption were mapped for 2006. The average sectorial water withdrawals from Eurostat were supplemented by the 2003-2007 average from FAO-AQUASTAT (2012) in case of missing or inconsistent data. Using this dataset and applying the same CF the resulting normalisation factor would be 3.02E+10 m^3 water eq. The difference of 30% between the two results stem from the estimation methods used to derive missing data, and reflects the difference in the inventory data of water abstractions (Table 18).

The main source of uncertainty for this impact category concerns the estimation methods used to derive missing values from official statistics. It is important to note that in the implementation of the normalisation factor for water depletion practitioners should verify that the characterization is performed accordingly to the recommended IA method. In particular, some LCA software applies a CF for the flow “water, turbine use”[7], that is not considered as water consumption in the LCIA method by Frischknecht et al. (2009). Therefore, the impact derived by this flow wasn’t included in the calculation of the Normalisation factor. Accounting the impact derived by the turbine use of

[7] It is known that some commercial LCA softwares do report net water consumption only and this is not consistent with the Swiss Ecological Scarcity 2006 method which requires total water withdrawals instead. For a consistent use of the NFs calculated in this document it is suggested to LCA practitioners to account for all water withdrawals associated to the product under investigation, but hydropower generation (i.e. water turbine use), thus not to focusing only on net water consumption.

water at IA stage and using the NF provided by this study would therefore result in an overestimation of the normalized water depletion impact values over the normalized impact categories. Moreover, it should be noticed that the NF calculated at EU level is based on an "average scarcity" CF for OECD countries. If the datasets used in the LCIA phase contain processes with water abstraction in extra-EU countries with severe water scarcity and country specific CFs are applied in the characterization phase, this could result in a very high water depletion impact, relatively to the other impacts.

Table 18 Comparison of results for water depletion using different datasets

	Data sources	
	EC – JRC, 2013	**Vandecasteele et al., 2013**
Total water abstractions (m^3)	2.44E+11	1.87E+11
Water depletion (m^3 water eq.)	3.95E+10	3.02E+10

3.13 Resource depletion, minerals and fossil

Impact category	Unit	DOMESTIC	NF per person	ILCD recommendation level for characterisation method
Mineral, fossil & renewable resource depletion	kg Sb eq.	5.03E+07	1.01E-01	II

The impact on resource depletion has been calculated using the CML method (Guinee, 2002) recommended by the ILCD and applying the characterization factors to the metal content data. The British Geological Survey is the main data source for metals (BGS, British Geological Survey, 1995, 2000, 2002, 2012), Raw Material Group (RMG) (2013) and World Mining Data (WMD) (2014) while data on minerals are from PRODCOM (PRODCOM/Eurostat, 2013). Data for energy carries are from Eurostat (2013l; 2013m; 2013n; 2013o; 2013p; 2013q), with the exception of uranium, that is again from BGS. Biotic materials are not covered by this method; minerals & metals are assessed separately from energy.

Fossil fuels are considered as a group, thus all the flows have the same characterization factor (7.79E-09 kg Sb eq.).

3.13.1 Completeness of the dataset

Inventory data on mineral resources covers 37% of the elementary flows for abiotic resources in the ILCD. Conversely, ten metals have a characterization factor, but don't have available data for the metal contents. The six energy resource flows having a CF are all taken into account.

3.13.2 Comparison to other normalisation datasets

The ReCiPe normalisation dataset does not include the impact category resource depletion of minerals; for fossil fuels ReCiPE and CML uses the same inventory data (Wegener Sleeswijk et al., 2008). Therefore, our results are compared with the CML normalisation dataset and with Prototype 2006, even though a different method was used there for the impact assessment (EDIP). In terms of coverage of flows, the different datasets cover 21 to 37% of minerals flows and up to 100% of the energy flows (Table 19).

Table 19 Number and share of flows (related to ILCD flows) in different normalisation datasets for resource depletion

	CML - year 2000, EU25+3	Inventory 2000	Prototype 2006	Inventory 2010
Number of flows included in the normalisation dataset				
Minerals & metals	13	22	13	23
Energy	4	6	6	6
Share of ILCD flows covered				
Minerals & metals	21%	37%	21%	37%
Energy	67%	100%	100%	100%

In CML 98% of the impact of minerals is due to four metals: silver, lead, zinc and copper (Figure 41). The total impact is approximately half of the value calculated from the inventory 2010 (2.32E+07 vs. 4.71E+07 kg Sb eq). This can be attributed to the lower coverage of flows in CML 2000 (21% of the flows mapped in the ILCD vs. 37%). Assessment from the prototype 2006 and inventory 2000 confirm the predominant role of strontium in composing the total impact of mineral depletion; this element is not covered in the CML inventory; while silver, that is included in all the datasets, is the second main contributor to the total impact (Figure 43).

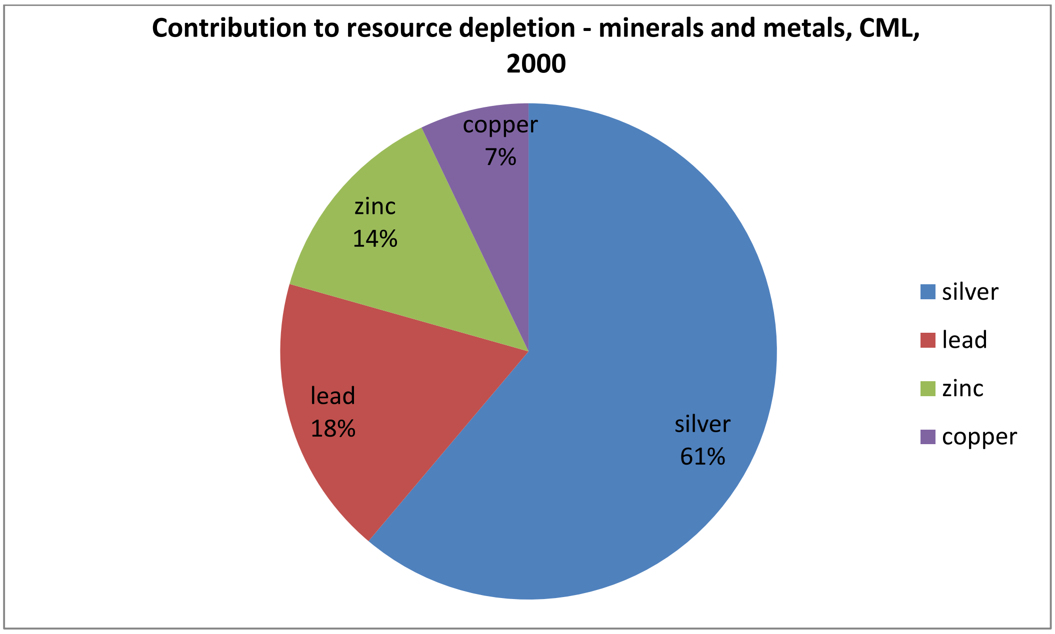


Figure 41 Contribution to the resource depletion – minerals and metals total impact in CML normalisation dataset (year 2000)

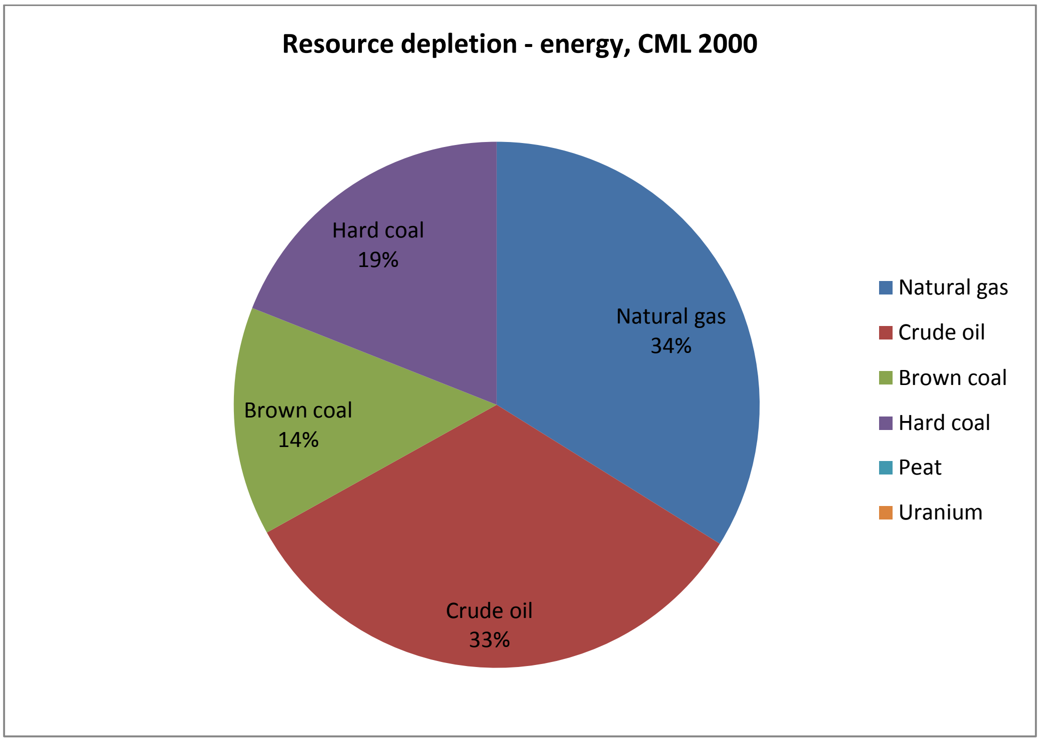


Figure 42 Contribution to the resource depletion – energy total impact in CML normalisation dataset (year 2000)

Concerning energy (Figure 44), results from 2010 are consistent with results from inventories 2000 and the prototype 2006, while CML total result is lower (as it does not include uranium and peat). However, excluding uranium, the total impact due to other fossil fuels is 30% higher in CML. Such difference is partly attributable to the different territorial coverage of the two datasets – that in CML has 25+3 countries, as explained in chapter 3.1.1. Indeed, the CML assessment includes also Norway that is the larger oil producer and exporter in Western Europe. Given that the used CFs are the same – with the exception of uranium - and the same figure is used for all fossil fuels the difference between the assessment is attributable to the different statistics used to compose the inventories (Eurostat and USGS). Uranium is the main contributor to the depletion impact for energy carriers in Inventories 2000 and 2010 and in Prototype 2006.

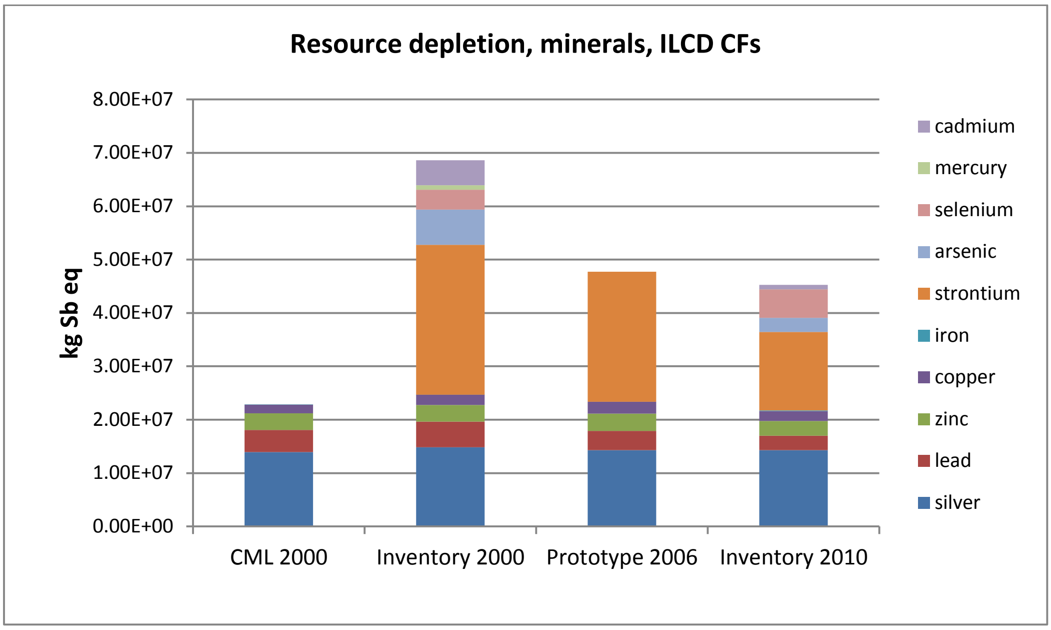


Figure 43 Comparison between normalisation factors for resource depletion of minerals and metals extracted in EU calculated with ILCD CFs

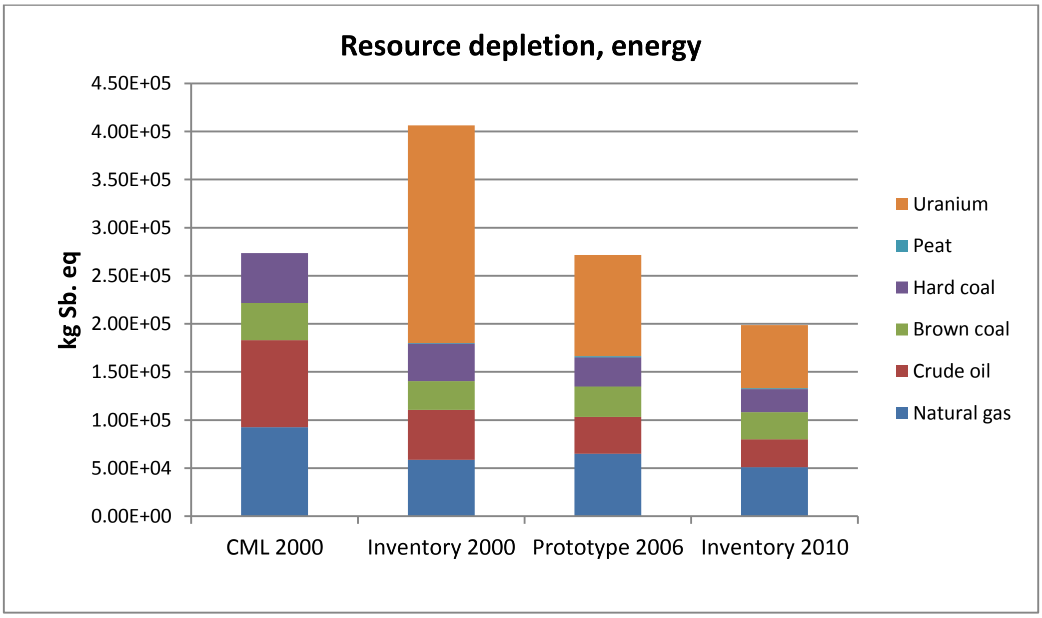


Figure 44 Comparison between normalisation factors for resource depletion, energy, calculated with ILCD CFs

3.13.3 Contribution to the impact

Six materials contribute to 90% of the total impact on resource depletion in the results from the inventory 2010: strontium, silver, selenium, zinc, lead and arsenic (Figure 45). Concerning energy, uranium has the highest share of the impact (33%) followed by natural gas and crude oil (Figure 46).

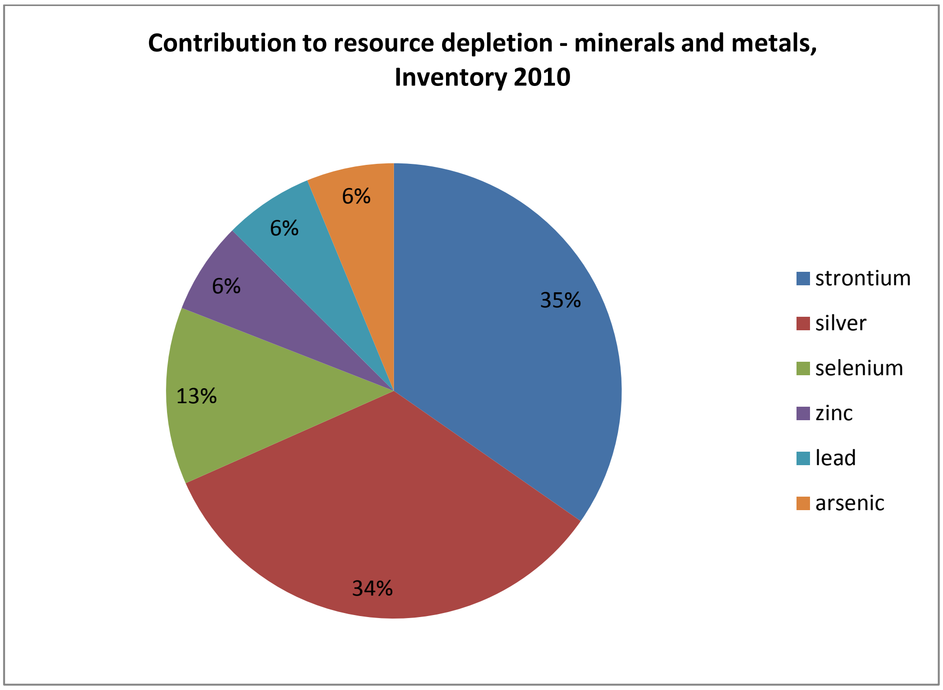


Figure 45 Contribution to resource depletion, metals and minerals total impact in Inventory 2010

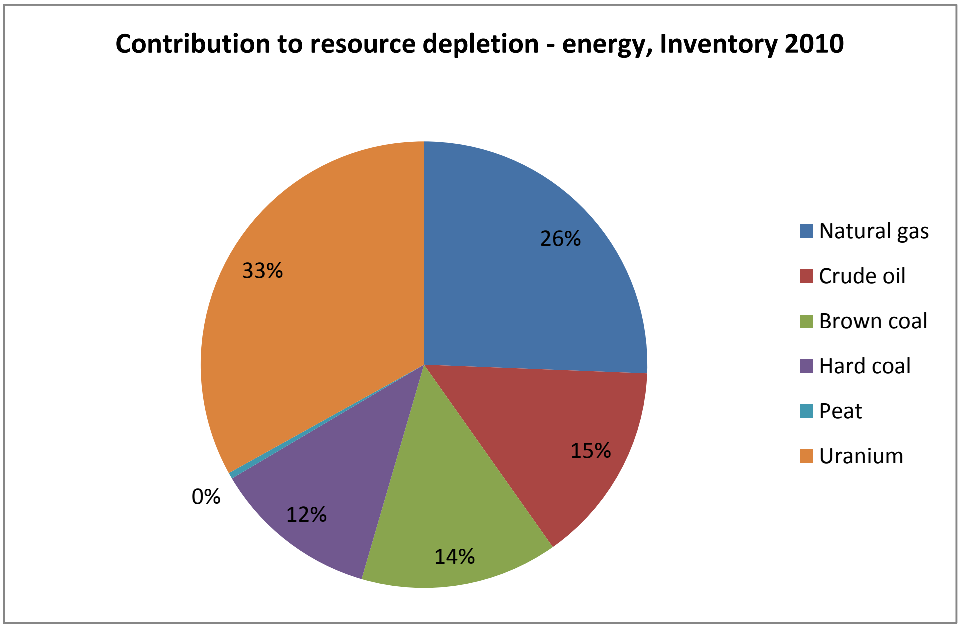


Figure 46 Contribution to resource depletion, energy total impact in Inventory 2010

3.13.4 Uncertainty sources and limitations

The lack of inventory data for some mineral resources implies a potential underestimation of the total depletion impact. Even though the data source used for the assessment (BGS) is reliable, it can happen that different data sources provide different values of resource extractions due to different computing systems or the use of different coefficient to derive the element content from the mineral extracted. This is the case of the strontium: according to BGS the EU extractions of this element in 2010 were 8.3E+04 tonnes, while USGS reports a production of 1.4E+05 tonnes. Using the USGS data the contribution of the strontium to the total impact would rise to 41%. Indium was not accounted in the inventory because the EU production of this material (mainly in Belgium, Italy, Germany and the Netherlands) is only at refinery stage (Polinares, 2012) and therefore was not considered as a resource extraction. Indium, indeed, is a typical byproduct of smelting polymetallic ores of base metals such as lead, zinc, copper and tin. Including the EU production of indium (55 tonnes in total) in the impact assessment would raise the overall result of resource depletion to 8.10E+07 kg of Sb equivalents and the contribution of indium would be 37.7%, due to the high CF of this element.

No estimations methods for data-gap filling have been applied for this impact category.

Concerning the results for fossil fuels, the different data sources used in the assessments (EUROSTAT in our study, IEA and USGS country statistics in CML) provide different figures on energy production. The use of different calorific power factors (in order to convert data on mass into energy values) is also one reason for the difference in the results.

4 Methodology and results for trade

The estimation of the environmental impacts arising from European (intended as EU-27) trade (i.e. imports and exports) in year 2010 has been approached in two ways:

- Method A - Calculation based on a sample of selected product groups at HS6 aggregation level for imports, and CN8 aggregation level for outputs (chapter 4.1)
- Method B - Calculation based on an update of the environmental impacts from European trade calculated for 2006 (which was based on product groups at the CN8 aggregation level), i.e. recalculating the impact assessment using 2010 data of European trade but keeping the same representative products and life cycle inventories used in the 2006 calculations (chapter 4.2)

4.1 Estimation of impacts from European trade: Method A

This calculation makes use of statistical data on European traded quantities (imports and exports) for year 2010 (taken from the ComExt database provided by Eurostat[8]). These are combined with relevant cradle-to-gate LCI datasets taken from the EcoInvent database, versions 2.2 and 3.0. The most important product groups in terms of traded quantities were considered for the calculation. From these, the product groups that have actually been used in the calculation are those for which a suitable LCI dataset is available in EcoInvent. In order to maximise the mass-representativeness of the sample of modelled product groups based on the datasets available in the EcoInvent database, HS6 aggregation level was considered for imports, while the CN8 level was considered for exports (Table 20). Overall, the modelled sample is composed of:

- Imports: 19 HS6 product groups modelled, which belong to 9 HS2 product groups
- Exports: 35 CN8 product groups modelled, which belongs to 21 HS2 product groups

The reference year for the calculation of the environmental impacts is 2010, i.e. all data related to the traded quantities (both imports and exports) refer to 2010. Due to limited data availability, the individual datasets used to model each traded product-group do not always refer to 2010 but are sometimes older.

As mentioned, the approach adopted to gather LCI datasets for modelling of the indicators has been the maximisation of the cumulative mass of the modelled product groups compared to overall mass of traded products (imports and exports). This inherently assumes that having a mass-representative sample of the overall EU-27 trade allows obtaining a representative estimate of the overall environmental impact from European trade. A different approach could have been used, e.g. a mixed approach that considers both the traded mass and the traded monetary values. However, it seems questionable that monetary trade value can be seen as a representative parameter for environmental impact estimation.

[8] http://epp.eurostat.ec.europa.eu/portal/page/portal/international_trade/data/main_tables

Up-scaling of the emissions and use of resources had to be conducted (as explained next), though it also adds to the uncertainty of the final results. Up-scaling was conducted at three levels:

1. At the level of the individual cradle-to-gate data-sets for each specific product group, in order to obtain LCIs that account for 100% of the traded mass of each product groups. This is needed for imported products because, for simplicity, only the 3 major source countries were actually modelled, which in general do not provide the entire EU-27 import of a certain product. For instance, if the 3 source countries count for 60% of the total EU-27 import of a certain product, then an up-scaling factor of 1/0.6=1.67 has been applied.
2. At the level of the estimated overall inventory for HS6 product groups (for imports) and CN8 product groups (for exports), in order to estimate the overall inventory at HS2 level.
3. At the level of the previously estimated inventory at HS2 level, in order to estimate the total LCIs of EU-27 imports and of EU-27 exports. E.g., with respect to the imported products, the overall mass of the modelled products at HS2 level was $1.05*10^9$ tons, compared to an overall import (in 2010) of $1.63*10^9$ tons. Thus, an up-scaling factor of $1.63*10^9 / 1.02*10^9 = 1.55$ has been applied. With respect to the exports, the resulting up-scaling factor is 1.28.

Table 20 Method A: selected product groups used for the calculation of the environmental impacts for European trade in year 2010

IMPORT		EXPORT	
HS6 code	**product**	**CN8 code**	**product**
120100	Soya beans	10019099	Spelt, common wheat and meslin
170111	Raw Cane Sugar	10030090	Barley
250100	Salts and pure sodium chloride	10059000	Maize (excl. Seed for sowing)
251710	Pebbles, gravel, broken or crushed stone	11081300	Potato starch
252329	Portland Cement	22011011	Mineral waters, natural, not carbonated
260111	Non agglomerated iron ores and concentrates	25171010	Pebbles and gravel for concrete aggregates
260112	Agglomerated iron ores and concentrates	25231000	Cement clinkers
270112	Bituminous coal	25232900	Portland cement (excl. White, whether or not artificially coloured)
270119	Coal	27101969	Fuel oils obtained from bituminous materials
270900	Petroleum oils	28070010	Sulphuric acid
271011	Light oils of petroleum	28362000	Disodium carbonate
271111	Natural Gas, liquefied	29091990	Acyclic ethers & their halogenated/sulphonated/nitrated/nitrosated
271112	Propane, liquefied	31022100	Ammonium sulphate
271121	Natural gas in gaseous state	31052010	Mineral or chemical fertilisers containing n, p, k
271311	Petroleum coke	38160000	Refractory cements, mortars, concretes and similar compositions

290511	Methanol, methylic alcohol	39012090	Polyethylene with specific gravity >0.94, in primary forms
310420	Potassium Chloride	40021100	Styrene-butadiene rubber latex "sbr"
440122	Wood Chips	44101130	Particle board of wood
720712	Semi-finished products of iron or non-alloy steel	47071000	Recovered "waste and scrap" paper or paperboard
		47079090	Sorted, recovered "waste and scrap" paper or paperboard
		48010000	Newsprint paper
		48102210	Coated paper used for writing, printing or other graphic purposes
		48101990	Paper & paperboard used for writing, printing or other graphic purposes
		68091100	Boards, sheets, panels, tiles of plaster
		68109190	Structural components for building, of cement, concrete or stone
		69051000	Roofing tiles
		70109053	Coloured glass used for packing of foodstuffs and beverages
		73051100	Oil or gas pipeline with diameter >406mm
		87032319	Motor cars and other motor vehicles principally designed for the transport of 1 to 9 persons
		26011100 + 26011200	Agglomerated and non-agglomerated iron ores
		27101141 + 27101145	Motor spirit, with a lead content < 0.013 g/l
		70052935 + 70052980	Float glass and surface ground and polished glass, in sheets

4.2 Estimation of impacts from European trade: Method B

As anticipated, this calculation is based on an updated of the estimation of the environmental impacts from European trade conducted for year 2006. In the LC-indicators framework for year 2006, 15 major import and export product groups (as HS2 level) were selected in order to assess impacts from international traded product (Table 21). One representative product (at CN8 level) was chosen and modelled for each HS2 product group, using LC inventories associated to the product. The selection of the product groups was based on a pre-selection of the 50 most important product groups by mass, and a final selection based on life cycle inventory data on important products within these 50 product groups. A mass-based upscaling was applied to obtain the overall impact of import and export (EC - JRC, 2012a). The traded quantities (imports and exports) for year 2006 are taken from the ComExt database provided by Eurostat[9]. Up-scaling has been applied similarly to the 2010 calculations described in the previous sub-chapter.

Based on this estimation, the 2010 calculation of the impacts from European trade was conducted by using the 2010 update on European traded quantities (again taken from the ComExt database),

[9] http://epp.eurostat.ec.europa.eu/portal/page/portal/international_trade/data/main_tables

while keeping the same representative products at CN8 level and product groups at HS2 level (again, one representative CN8 product per each HS2 product group) and the same life cycle inventories used for 2006 calculation.

Table 21 Method B: product groups (HS2) and representative products (CN8) chosen for calculation of 2006 impacts from European trade

IMPORT		EXPORT	
CN8 code	**product**	**CN8 code**	**product**
27090090	Crude oil	72085120	Hot-rolled non-alloyed steel
72071210	Non-alloyed steel slaps or coils	27090090	Crude oil
76011000	Unwrought aluminium	87032319	Passenger car
61091000	T-shirts (cotton)	39021000	Propylene
87032319	Passenger car	84295210	Self-propelled excavators
39232100	Polyethylene bags	84714990	Data processing machines
84158190	Air conditioning	76061291	Alloyed aluminium sheets
84713000	Computer/laptop	25232900	Portland cement
85219000	Video recording or reproducing apparatus	48101990	Paper and paperboard
26011100	Iron ore	85030099	Electric motor parts
28182000	Aluminium oxide	31052010	NPK fertilisers
31021010	urea	17019910	White sugar
29051100	methanol	04021019	Milk and cream in solid forms
17011110	Cane sugar	02032955	Frozen boneless swine meat
23040000	Soya oil cake	28182000	Aluminium oxide
02013000	Bovine meat boneless	29337100	Caprolactam

4.3 Comparison of results among methods A and B

Table 22 provides an overview of the environmental impacts from European trade calculated with method A (2010) and method B (2006 and 2010)

It has to be stressed, that the estimations are affected by a significant degree of uncertainty which depends e.g. on:

- The choice of the representative product-groups (method A: one CN8 product per each HS2 group – method B: as many representative products at HS6 level for imports and CN8 level for outputs). In method A, as only one CN8 representative product is chosen per each HS2 product group, the estimated impacts are strongly influenced by this chosen CN8 product. In method B, the logic has been to maximize of the cumulative mass of the modelled product groups compared to overall mass of traded products (imports and exports). This inherently assumes that having a mass-representative sample of the overall EU-27 trade allows obtaining a representative estimate of the overall environmental impact from European trade. A different approach could have been used, e.g. a mixed approach that considers both the traded mass and the traded monetary values. However, it seems questionable that monetary trade value is a representative parameter for environmental impact estimation.

- The 3 levels of up-scaling conducted to determine the overall impacts adds a lot to the overall uncertainty, as they amplify all uncertainty proportionally to the up-scaling factors applied.
- The reference year for the calculation of the environmental impacts is 2010, i.e. all data related to the traded quantities (both imports and exports) refer to 2010. However, the individual data-sets used to model each traded product-group do not necessarily refer to 2010, i.e. the datasets available do not always have a good temporal representativeness.
- Also, the chosen LCI datasets may not be fully relevant in terms of their technological and geographical representativeness: e.g. they may represent a similar technology/process, but not the exact one that should be used; or, may represent a European average, but not the exact process of the country from which a given product is imported. In addition, they do not always include to exact cradle-to-gate inventory, i.e. some processes that are part of the cradle-to-gate life cycle may not be included. Whenever this issue was identified, other datasets were added – if available and relevant - to fill the gap.

Table 22 Impacts from European trade in year 2010 and year 2006 from methods A and B

LCIA Indicator		Method A 2010	Method B 2006	Method B 2010
Climate change midpoint [kg CO_2 eq.]	Import	3.12E+11	1.15E+12	9.40E+11
	Export	2.24E+11	7.85E+11	8.45E+11
Ozone depletion midpoint [kg CFC11 eq.]	Import	1.04E+05	1.47E+05	1.27E+05
	Export	3.55E+04	4.91E+04	4.96E+04
Human Toxicity midpoint, cancer effects [CTUh]	Import	2.78E+05	4.39E+03	4.18E+03
	Export	3.37E+04	1.28E+03	1.32E+03
Human Toxicity midpoint, non-cancer effects [CTUh]	Import	2.21E+05	3.57E+04	7.43E+03
	Export	4.48E+04	7.80E+04	6.79E+04
Particulate matter/Respiratory inorganics midpoint [kg PM2.5 eq.]	Import	2.53E+08	9.58E+08	7.38E+08
	Export	1.48E+08	2.16E+08	2.29E+08
Ionizing radiation midpoint, human health [kBq U235 eq.]	Import	5.15E+10	4.08E+10	3.13E+10
	Export	4.47E+10	3.28E+10	3.35E+10
Ionizing radiation midpoint, ecosystems [CTUe]	Import	1.57E+05	5.98E+05	4.61E+05
	Export	1.37E+05	4.75E+05	4.85E+05
Photochemical ozone formation midpoint, human health [kg NMVOC eq/ kg C_2H_4 eq.]*	Import	1.88E+09	4.61E+09	3.72E+09
	Export	9.04E+08	1.94E+09	2.08E+09
Acidification midpoint [mol H^+ eq.]	Import	3.76E+09	9.08E+09	1.12E+10
	Export	1.39E+09	5.51E+09	5.00E+09
Eutrophication terrestrial midpoint [mol N eq.]	Import	5.96E+09	1.66E+10	1.30E+10
	Export	3.14E+09	1.24E+10	1.44E+10
Eutrophication freshwater midpoint [kg P eq.]	Import	2.12E+08	1.81E+07	1.97E+07
	Export	7.68E+07	6.64E+06	5.87E+06
Eutrophication marine midpoint [kg N eq.]	Import	6.00E+08	1.27E+09	9.88E+08
	Export	4.04E+08	5.76E+08	6.24E+08

Ecotoxicity freshwater midpoint [CTUe]	Import	3.01E+12	2.71E+11	2.39E+11
	Export	5.71E+11	1.14E+11	1.11E+11
Land use midpoint [kg C deficit]	Import	4.88E+12	0.00E+00	0.00E+00
	Export	1.20E+12	0.00E+00	0.00E+00
Resource depletion water midpoint [m^3 water eq.]	Import	3.81E+08	0.00E+00	0.00E+00
	Export	3.91E+08	0.00E+00	0.00E+00
Resource depletion minerals, fossil and renewables midpoint [Sb eq/Person Reserve - PR]**	Import	1.48E+06	5.38E+08	3.39E+08
	Export	1.32E+07	3.99+08	3.99E+08

*results for photochemical ozone formation according to Method B are expressed in kg C_2H_4 eq. and therefore cannot be directly compared with Method A.

**results for Resource Depletion minerals, fossil and renewables according to Method B have been calculated using a different impact assessment method (Person Reserves, PR as in EDIP) and therefore cannot be directly compared with Method A.

4.4 Comparison of results with environmentally extended input output tables

As it is possible to see from Table 23 below, the different approaches (method A and method B) to the estimation of the environmental impacts embodied in trade lead to substantially different results. The comparison below includes three different methodologies: multi-regional input output tables, single region input output table and up-scaling from bottom-up LCI modelling (this work). The three methodologies are based on different theoretical approaches, as explained in EC-JRC (2010). For what concerns climate change it is possible to note that the ratio between import and domestic changes substantially, ranging from 0.63 to 0.07 according to the results provided respectively by the World Input Output database (EC-JRC, 2012e) and the of the bottom-up modelling approach developed in this work, method A. A similar pattern can be observed for all the impact categories included in the table below; input output tables (both multi-regional and single region) estimate a higher contribution from imports than the bottom-up LCI modelling. Such aspect raises questions on the robustness of the currently available bottom-up estimations associated with trade. The bottom-up LCI modelling can be considered a powerful technique when the sample of products used for modelling trade can be seen as representative of the basket of products imported into an economy. In order to reach such representativeness a high number of representative traded products would be required. In the current version only a limited number of products could be included in the analysis; hence it is likely that the set of products is not sufficiently representative of the imports that occur within the EU-27. This might explain why the bottom-up exercises reported in the table are always underestimating the contribution of trade if compared to the input output tables. Another possible source of difference is the completeness of the LC inventories used for modelling the products in import. However, even if some life cycle inventories would lack a range of elementary flows because of e.g. the level of technological, time and geographical representativeness of the inventory, such error should not have affected the results to such an extent. Another possibility is that the monetary estimations of environmental impacts used in input output tables are biased towards higher values because of their inability to differentiate between products within the same sector. However currently this is a hypothesis that needs further investigation.

Table 23 Comparison between the relative importance of import as calculated in this study with input/output tables

Impact category	Methodology	additional details	Unit of measurement	Embodied emissions [2] in import	Domestic emissions[2]	Ratio Import/ Domestic	Year	Cover-age	Data source
Emissions									
Climate change	Multi-Regional Env.Ext. Input Output table		kg CO_2 eq.	3.21E+03	5.08E+12	0.63	2008	EU-27	EC-JRC (2012e)
	Multi-Regional Env.Ext. Input Output table	only CO_2	kg CO_2	1.17E+03[1]	3.96E+12	0.30	2008	EU-27	Peters et al. (2011)
	bottom-up LCI and upscaling	import - method B*	kg CO_2 eq.	9.40E+11	4.60E+12	0.20	2010	EU-27	this work
	bottom-up LCI and upscaling	import - method A**	kg CO_2 eq.	3.12E+11	4.60E+12	0.07	2010	EU-27	this work
Acidification	Multi-Regional Env.Ext. Input Output table		kt acid-eq	6.01E+02	7.24E+02	0.83	2008	EU-27	EC-JRC (2012e)
	bottom-up LCI and upscaling	import - method B	mol H+ eq	1.12E+10	2.36E+10	0.47	2010	EU-27	this work
	bottom-up LCI and upscaling	import - method A	mol H+ eq	3.76E+09	2.36E+10	0.16	2010	EU-27	this work
Ozone precursors emissions	Multi-Regional Env.Ext. Input Output table		kt NMVOC-eq	3.22E+04	2.90E+04	1.11	2008	EU-27	EC-JRC (2012e)
	bottom-up LCI and upscaling	import - method B	kg NMVOC eq	3.72E+09	1.59E+10	0.23	2010	EU-27	this work
	bottom-up LCI and upscaling	import - method A	kg NMVOC eq	1.88E+09	1.59E+10	0.12	2010	EU-27	this work
Resources									
Land Use	Multi-Regional Env.Ext. Input Output table		1000 km^2	4.77E+03	3.04E+03	1.57	2008	EU-27	EC-JRC (2012e)
	bottom-up LCI and upscaling	import - method B	kg C deficit	n.a.	3.74E+13	n.a.	2010	EU-27	this work
	bottom-up LCI and upscaling	import - method A	kg C deficit	4.88E+12	3.74E+13	0.13	2010	EU-27	this work
Water Use	Multi-Regional Env.Ext. Input Output table		km3	8.02E+02	7.32E+02	1.10	2008	EU-27	EC-JRC (2012e)
	bottom-up LCI and upscaling	import - method A	m^3 water eq	3.81E+08	4.06E+10	0.01	2010	EU-27	this work
Material extraction	Multi-Regional Env.Ext. Input Output table		Mt	4.99E+03	6.99E+03	0.71	2008	EU-27	EC-JRC (2012e)
	Single region Env.Ext. Input Output table	Energy carriers only	t	1.63E+09	8.12E+08	2.01	2010	EU-27	Schoer et al.(2012), Eurostat (2013k)
	Single region Env.Ext. Input Output table	Metals only	t	1.30E+09	1.55E+08	8.39	2010	EU-27	Schoer et al. (2012), Eurostat (2013k)
	Single region Env.Ext. Input Output table	All materials	t	3.52E+09	5.93E+09	0.59	2010	EU-27	Schoer et al. (2012), Eurostat (2013k)
Mineral, fossil & renewable resource depletion	Single region Env.Ext. Input Output table	Energy carriers only	kg Sb eq.	2.14E+05	2.14E+05	18.5	2010	EU-27	EC-JRC est. on Schoer et al. (2012)
	Single region Env.Ext. Input Output table	Metals only	kg Sb eq.	1.03E+08	3.36E+07	3.1	2010	EU-27	EC-JRC est. on Schoer et al. (2012)
	Single region Env.Ext. Input Output table	All materials	kg Sb eq.	3.36E+07	3.38E+07	3.07	2010	EU-27	Schoer et al. (2012), Eurostat
	bottom-up LCI and upscaling	import - method A	kg Sb eq.	1.48E+06	5.03E+07	0.03	2010	EU-27	this work

* ‘import - method B’ refers to the LCI bottom-up modelling as estimated in EC-JRC (2012a) for 2006 but updated to reflect trade flows in 2010; ** ‘import - method A’ refers to the LCI bottom-up modelling as estimated in the current version of the trade inventory; [1] this value is relative to the year 2006 ; [2] emissions (or resources extracted)

5 Recommendations

At present level of methodological development and data availability, the results of impacts associated with trade are deemed not sufficiently mature to be recommended for use as normalisation values in Environmental Footprints or Life Cycle Assessments. The main reasons are: i) significant variability in the results applying different methods for selection and up-scaling of products; ii) ratio import to domestic seems to be underestimated.

5.1 Overview of results for EU 27, year 2010

Normalisation factors based on territorial/domestic inventory and on apparent consumption for EU-27 (calculated with different methods) are presented in Table 24 and Table 25. Per person Normalisation factors have been also calculated using Eurostat data on EU-27 population in 2010 (Eurostat, 2013a).

Table 24 Apparent consumption based Normalisation Factors (NF) for EU-27, trade calculated with method A (2010)

Impact category	Unit	Domestic	Import	Import (% of Domestic)	Export	Export (% of Domestic)	Apparent Consumption NF	Apparent consumption NF per person	Domestic NF per person
Climate change	kg CO_2 eq.	4.60E+12	3.12E+11	7%	2.24E+11	5%	4.69E+12	9.39E+03	9.22E+03
Ozone depletion	kg CFC-11 eq.	1.08E+07	1.04E+05	1%	3.55E+04	0.3%	1.09E+07	2.18E-02	2.16E-02
Human toxicity - cancer effect	CTUh	1.84E+04	2.78E+05	1511%	3.37E+04	183%	2.63E+05	5.26E-04	3.69E-05
Human toxicity- non -cancer effect	CTUh	2.66E+05	2.21E+05	83%	4.48E+04	17%	4.42E+05	8.86E-04	5.33E-04
Acidification	mol H^+ eq.	2.36E+10	3.76E+09	16%	1.39E+09	6%	2.60E+10	5.20E+01	4.73E+01
Particulate matter/Respiratory Inorganics	kg $PM_{2.5}$ eq.	1.90E+09	2.53E+08	13%	1.48E+08	8%	2.00E+09	4.01E+00	3.80E+00
Ecotoxicity for aquatic fresh water	CTUe	4.36E+12	3.01E+12	69%	5.71E+11	13%	6.80E+12	1.36E+04	8.74E+03
Ionising radiations – human health effects	kBq U^{235} eq. (to air)	5.64E+11	5.15E+10	9%	4.47E+10	8%	5.71E+11	1.14E+03	1.13E+03
Photochemical ozone formation	kg NMVOC eq.	1.58E+10	1.88E+09	12%	9.04E+08	6%	1.68E+10	3.36E+01	3.17E+01
Eutrophication - terrestrial	mol N eq.	8.76E+10	5.96E+09	7%	3.14E+09	4%	9.04E+10	1.81E+02	1.76E+02
Eutrophication - freshwater	kg P eq.	7.41E+08	2.12E+08	29%	7.68E+07	10%	8.76E+08	1.76E+00	1.48E+00
Eutrophication - marine	kg N eq.	8.44E+09	6.00E+08	7%	4.04E+08	5%	8.64E+09	1.73E+01	1.69E+01
Land use	kg C deficit	3.74E+13	4.88E+12	13%	1.20E+12	3%	4.10E+13	8.22E+04	7.48E+04
Resource depletion - water	m^3 water eq.	4.06E+10	3.81E+08	1%	3.91E+08	1%	4.06E+10	8.13E+01	8.14E+01
Resource depletion - mineral, fossil & renewable	kg Sb eq.	5.03E+07	1.48E+06	3%	1.32E+07	26%	3.86E+07	7.73E-02	1.01E-01

Table 25 Apparent consumption based Normalisation Factors (NF) for EU-27, trade calculated with method B (2010)

Impact category	Unit	Domestic	Import	Import (% of Domestic)	Export	Export (% of Domestic)	Apparent Consumption NF	Apparent consumption NF per person	Domestic NF per person
Climate change	kg CO_2 eq.	4.60E+12	9.40E+11	20%	8.45E+11	18%	4.70E+12	9.41E+03	9.22E+03
Ozone depletion	kg CFC-11 eq.	1.08E+07	1.27E+05	1%	4.96E+04	0%	1.09E+07	2.18E-02	2.16E-02
Human toxicity - cancer effect	CTUh	1.84E+04	4.18E+03	23%	1.32E+03	7%	2.13E+04	4.26E-05	3.69E-05
Human toxicity- non -cancer effect	CTUh	2.66E+05	7.43E+03	3%	6.79E+03	3%	2.67E+05	5.34E-04	5.33E-04
Acidification	mol H^+ eq.	2.36E+10	9.08E+09	38%	5.51E+09	23%	2.72E+10	5.44E+01	4.73E+01
Particulate matter/Respiratory Inorganics	kg $PM_{2.5}$ eq.	1.90E+09	7.38E+08	39%	2.29E+08	12%	2.41E+09	4.82E+00	3.80E+00
Ecotoxicity for aquatic fresh water	CTUe	4.36E+12	2.39E+11	5%	1.11E+11	3%	4.49E+12	8.99E+03	8.74E+03
Ionising radiations – human health effects	kBq U^{235} eq. (to air)	5.64E+11	3.13E+10	6%	3.35E+10	6%	5.62E+11	1.13E+03	1.13E+03
Photochemical ozone formation	kg NMVOC eq.	1.58E+10	3.72E+09	24%	2.08E+09	13%	1.74E+10	3.49E+01	3.17E+01
Eutrophication - terrestrial	mol N eq.	8.76E+10	1.30E+10	15%	1.44E+10	16%	8.62E+10	1.73E+02	1.76E+02
Eutrophication - freshwater	kg P eq.	7.41E+08	1.81E+07	2%	6.64E+06	1%	7.52E+08	1.51E+00	1.48E+00
Eutrophication - marine	kg N eq.	8.44E+09	9.88E+08	12%	6.24E+08	7%	8.80E+09	1.76E+01	1.69E+01
Land use	kg C deficit	3.74E+13	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	7.48E+04
Resource depletion - water	m^3 water eq.	4.06E+10	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	8.14E+01
Resource depletion - mineral, fossil & renewable	kg Sb eq.	5.03E+07	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1.01E-01

6 Conclusions

The goal of the study described in this report was to develop normalisation factors (NFs) for the implementation of the EU Environmental Footprint methodology (EC - European Commission, 2013). The NFs were initially meant to adopt the apparent consumption approach as defined in the life cycle indicators framework (EC-JRC, 2012a; 2012b). In order to obtain a more comprehensive picture of the actual environmental impacts due to EU consumption processes, it was postulated that the environmental lifecycle impacts related to imported goods should be added to, and the impacts related to exported goods deducted from, the EU-27 domestic inventory.

The study results indicate that the currently available methodologies and data are not sufficiently mature for the results of impacts associated with trade to be recommended for use in calculating normalisation values within the context of Environmental Footprint or Life Cycle Assessments. The main reasons are: i) significant variability in the results obtained using different methods to select and upscale products; ii) the ratio of imports to domestic inventories seems to be underestimated. The recommendation for normalisation factors in the Environmental Footprint context is to rely on domestic figures for 2010, as they have been identified as the most robust basis for this kind of application. Table 26 presents the recommended normalisation factors for the EU-27 related domestic inventory in 2010. Per person normalisation factors have been calculated using Eurostat data on the EU-27 population in 2010; 499 million inhabitants (Eurostat, 2013a).

Table 26 Normalisation factors (NF) for EU-27 (2010) using domestic inventories

Impact category	Unit	Domestic	Normalisation Factor per Person (domestic)	Overall Robustness
Climate change	kg CO_2 eq.	4.60E+12	9.22E+03	Very High
Ozone depletion	kg CFC-11 eq.	1.08E+07	2.16E-02	Medium
Human toxicity - cancer effect	CTUh	1.84E+04	3.69E-05	Low
Human toxicity- non -cancer effect	CTUh	2.66E+05	5.33E-04	Low
Acidification	mol H^+ eq.	2.36E+10	4.73E+01	High
Particulate matter/Respiratory Inorganics	kg $PM_{2.5}$ eq.	1.90E+09	3.80E+00	Very High
Ecotoxicity for aquatic fresh water	CTUeq.	4.36E+12	8.74E+03	Low
Ionising radiations – human health effects	kBq U^{235} eq.	5.64E+11	1.13E+03	Medium
Photochemical ozone formation	kg NMVOC eq.	1.58E+10	3.17E+01	Medium
Eutrophication - terrestrial	mol N eq.	8.76E+10	1.76E+02	Medium
Eutrophication - freshwater	kg P eq.	7.41E+08	1.48E+00	Medium to Low
Eutrophication - marine	kg N eq.	8.44E+09	1.69E+01	Medium to Low
Land use	kg C deficit	3.74E+13	7.48E+04	Medium
Resource depletion - water	m^3 water eq.	4.06E+10	8.14E+01	Medium to Low
Resource depletion - mineral, fossil & renewable	kg Sb eq.	5.03E+07	1.01E-01	Medium

With regard to the domestic inventory, the main sources of uncertainty found in this study for calculating the normalisation factors are:

- Data gaps,
- Extrapolation strategies,
- Coverage of flows compared to the impact assessment method,
- Coverage of flows compared to the overall actual emissions (e.g. a limited number of substances in E-PRTR compared to over 100 000 chemicals used and possibly emitted).

Although it is the recommended approach, adopting a purely domestic approach to normalisation also has inherent disadvantages that should not be overlooked. For example, normalisation factors based on domestic inventories can lead to significant over- or underestimation of actual impacts, such as in the case of resource depletion, because of the substantial amounts of raw materials imported by the EU for use as energy carriers and minerals/metals. Thus, using the domestic EU-27 normalisation factors as the reference values against which to compare the impacts associated with resource consumption in products and services can lead to an overestimation of the relevance of this impact category over others. . This limitation may also apply to impact categories other than resource depletion.

References

AFEAS (2006). AFEAS Data Download. Alternative Fluorocarbons Environmental Acceptability Study (AFEAS), Arlington, VA, USA, 2006.

ANU Uranium, Energy, Security: Australia & Its Region (2006). Background Information. Nuclear Power Industry. Status of the nuclear industry, 25 May 2006. The Australian National University (ANU), Canberra, Australia, 2006. Downloadable from: http://www.anu.edu.au/asianstudies/data/uranium/uranium_industry_background_info.pdf

Benini L., Sala S., Manfredi S., Góralczyk M. (2014) Overall environmental impact (resource) indicators. Deliverable 3 of the AA with DGENV '*Scientific support for screening and development of potential resource efficiency and product-group indicators as well as targets for the reduction of the overall environmental impact of EU consumption*'.

British Geological Survey (BGS) (1995). World Mineral Statistics 1990-1994. Keyworth Nottigham: British Geological Survey.

British Geological Survey (BGS) (2000). World Mineral Statistics 1994-1998. Keyworth Nottigham: British Geological Survey.

British Geological Survey (BGS) (2002). World Mineral Statistics 1996-2000. Keyworth Nottigham: British Geological Survey.

British Geological Survey (BGS) (2012). European Mineral Statistics 2006-10. Keyworth Nottigham: British Geological Survey.

CML (2013) CML-IA Characterisation Factors. Update information version 4.2, released april 2013. http://cml.leiden.edu/software/data-cmlia.html#downloads

CORINAIR/EEA (2007) EMEP/CORINAIR Emission Inventory Guidebook – 2007; Technical report No 16/2007. Published by the European Environmental Agency. Available at the EEA website: http://www.eea.europa.eu/publications/EMEPCORINAIR5/. Access to information for each (sub-) sector can be retrieved therein. Accessed on 10 December 2013.

CORINAIR/EEA (2009) EMEP/CORINAIR Air Pollutant Emission Inventory Guidebook – 2009; Technical report No 9/2009. Published by the European Environmental Agency. Avaialble at the EEA website: http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009. Accessed on 10 December 2013.

EA (2006). Pollution Inventory Data Trends Spreadsheet. Environment Agency (EA), London, United Kingdom, 2006. At: http://www.environment-agency.gov.uk/commondata/103601/pi_summ_proc_05v3prot_862571.xls

EC - European Commission. (2013). Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations (2013). ANNEX II : Product Environmental Footprint (PEF) Guide.

EC – JRC & PBL (Netherlands Environmental Assessment Agency) (2011). Emission Database for Global Atmospheric Research (EDGAR), release version 4.2. http://edgar.jrc.ec.europa.eu Accessed on 10 December 2013

EC - JRC (2011). Recommendations based on existing environmental impact assessment models and factors for life cycle assessment in European context. First edition EUR24571EN. ISBN 978-92-79-17451-3. Available at http://eplca.jrc.ec.europa.eu/

EC - JRC (2012a). Life cycle indicators framework: development of life cycle based macro-level monitoring indicators for resources, products and waste for the EU-27. European Commission, Joint Research Centre, Institute for Environment and Sustainability.

EC - JRC (2012b). Life cycle indicators for resources: development of life cycle based macro-level monitoring indicators for resources, products and waste for the EU-27. European Commission, Joint Research Centre, Institute for Environment and Sustainability.

EC- JRC (2012c). EDGAR-HTAP: a harmonized gridded air pollution emission dataset based on national inventories. JRC Scientific and Technical reports. European Commission, Joint Research Centre, Institute for Environment and Sustainability.

EEA (2012a) Air quality in Europe – 2012 report. EEA Report No. 4/2012. ISSN 1725-9177. Office for Official Publications of the European Union. European Environment Agency, Copenhagen, DK.

EEA (2012b) Land accounts data viewer 1990, 2000, 2006. http://www.eea.europa.eu/data-and-maps/data/data-viewers/land-accounts

EEA (2013a) European Pollutant Release and Transfer Register (E_PRTR) – Version 5 (17/05/2013) European Environmental Agency (EEA), Copenhagen, DK http://prtr.ec.europa.eu/ Accessed on 10 December 2013

EEA (2013b) Waterbase version 4 (19/06/2013). Available at: http://www.eea.europa.eu/data-and-maps/data/waterbase-emissions-3. Accessed 03/07/2013.

EEA (2013c). Consolidated table for all countries in the NFR09 format. National emissions reported to the Convention on Long-range Transboundary Air Pollution (LRTAP Convention). http://www.eea.europa.eu/data-and-maps/data/national-emissions-reported-to-the-convention-on-long-range-transboundary-air-pollution-lrtap-convention-7

EnvCanada (2006) National Pollutant Release Inventory (NPRI). Environment Canada, Ottawa, Ontario, Canada, 2006

EMEP/CEIP (2009) Comparisons of emissions reported to CEIP with emissions calculated by GAINS. Centre on Emission Inventories and Projections (CEIP). http://www.ceip.at/ms/ceip_home1/ceip_home/review_results/

EMEP/CEIP (2013a) Present state of emission data. Available at: http://www.ceip.at/webdab_emepdatabase/reported_emissiondata/ or http://www.ceip.at/status_reporting/2012_submissions/.

EMEP/CEIP (2013b) Present state of emissions as used in EMEP models. Available at http://www.ceip.at/webdab_emepdatabase/emissions_emepmodels/

Eurostat (2013a) Gross value added - Industry, including Energy [tec00004] Eurostat Statistics Database; Available at: http://ec.europa.eu/eurostat. Accessed July 2013.

Eurostat (2013b) Demographic data. Eurostat Statistics Database; Available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/population/introduction

Eurostat (2013c) use of sewage sludge applied to agricultural land – table [ten00030]. Eurostat Statistics Database; Available at: http://ec.europa.eu/eurostat http://epp.eurostat.ec.europa.eu/tgm/refreshTableAction.do?tab=table&plugin=0&pcode=ten00030&language=en . Accessed June 2013.

Eurostat (2013d). Land use - 1 000 ha - annual data [apro_cpp_luse] and Crops products - annual data [apro_cpp_crop] Eurostat European Statistical Database. http://ec.europa.eu/eurostat

Eurostat (2013e). Certified organic crop area by crops products [food_in_porg1] Eurostat European Statistical Database. http://ec.europa.eu/eurostat

Eurostat (2013f). Sales of pesticides – Fungicides Code: tag00085 Eurostat European Statistical Database. http://ec.europa.eu/eurostat

Eurostat (2013g) Gross Nutrient Balance [aei_pr_gnb] http://epp.eurostat.ec.europa.eu/portal/page/portal/product_details/dataset?p_product_code=AEI_PR_GNB. European statistical database. Accessed May 2013.

Eurostat (2013h) Population connected to wastewater treatment plants [env_ww_con] European statistical database. http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/ Accessed may 2013.

Eurostat (2013i) Annual water abstraction by source and by sector [env_watq2] http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/ Accessed may 2013.

Eurostat (2013k) Material flow accounts - table [env_ac_mfa]. Available at: http://ec.europa.eu/eurostat. Accessed July 2013.

Eurostat (2013l) Supply, transformation, consumption - solid fuels - annual data (nrg_101a). http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. Accessed Dec 2013

Eurostat (2013m) Supply, transformation, consumption - oil - annual data (nrg_102a). http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. Accessed Dec 2013

Eurostat (2013n) Supply, transformation, consumption - gas - annual data (nrg_103a). http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. Accessed Dec 2013

Eurostat (2013o) Supply, transformation - nuclear energy - annual data (nrg_104a). http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. Accessed Dec 2013

Eurostat (2013p) Supply, transformation, consumption - renewables and wastes (total, solar heat, biomass, geothermal, wastes) - annual data (nrg_1071a). http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. Accessed Dec 2013

Eurostat (2013q) Supply, transformation, consumption - renewables (hydro, wind, photovoltaic) - annual data (nrg_1072a). http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. Accessed Dec 2013

Eurostat (2013r) Supply, transformation, consumption - electricity - annual data (nrg_105a) http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database. Accessed Dec 2013

Fahey, D.W., and M.I. Hegglin (Coordinating Lead Authors) (2011) Twenty questions and answers about the ozone layer: 2010 Update, in Scientific Assessment of Ozone Depletion: 2010, Global Ozone

Research and Monitoring Project – Report No. 52, 516 pp., World Meteorological Organization, Geneva, CH.

FAO-Aquastat (2013) The Food and Agriculture Organization of the United Nations http://www.fao.org/nr/water/aquastat/main/index.stmFAOstat (2013a) Manure applied to Soils.. http://faostat3.fao.org/home/index.html#DOWNLOAD. Accessed June 2013.

FAOstat (2013a) Manure applied to Soils.. http://faostat3.fao.org/home/index.html#DOWNLOAD. Accessed June 2013.

FAOstat (2013b) Crop production quantities by country. The Food and Agriculture Organization of the United Nations; Link to database: http://faostat.fao.org/site/567/default.aspx#ancor

FAOstat (2013c). Agricultural area certified organic. The FAO (Food and Agriculture Organization of the United Nations) Statistical Database. http://faostat.fao.org

FAOstat (2013d). Agri-Environmental Indicators - Pesticides. The FAO (Food and Agriculture Organization of the United Nations) Statistical Database. http://faostat.fao.org

FAOstat (2013e). Pesticide Use - Triazoles, Diazoles. The FAO (Food and Agriculture Organization of the United Nations) Statistical Database. http://faostat.fao.org

FAOstat (2013f) Average protein supply (g/capita/day) (3-year average). The Food and Agriculture Organization of the United Nations; provides food security indicators. Link to database: http://www.fao.org/

Forwood M. (2008) The legacy of reprocessing in the United Kingdom - A Research report of the International Panel on Fissile Materials. Downloaded at: http://fissilematerials.org/library/rr05.pdf

Frischknecht R., Braunschweig A., Hofstetter P., Suter P. (2000) Human health damages due to ionising radiation in life cycle impact assessment. Environmental Impact Assessment Review 20 159–189

Frischknecht R., Steiner R., Jungbluth N. (2009) The Ecological Scarcity Method Eco-Factors 2006. A method for impact assessment in LCA. Bern

Greco, S.L., Wilson, A.M., Spengler J.D., and Levy J.I., (2007). Spatial patterns of mobile source particulate matter emissions-to-exposure relationships across the United State. Amospheric Environment (41), 1011-1025.

Guinee, J. (2002). Handbook on life cycle assessment operational guide to the ISO standards. The International Journal of Life Cycle Assessment, 7(5), 311–313. doi:10.1007/BF02978897

Huijbregts, M. (1999) Life-cycle impact assessment of acidifying and eutrophying air pollutants. Calculation of equivalency factors with RAINS-LCA. http://media.leidenuniv.nl/legacy/Life-cycle%20impact%20assessment.pdf Accessed on 10 December 2013

IAEA (2013). "Nuclear Share of Electricity Generation in 2011". International Atomic Energy Agency IAEA. 203-04-13. Retrieved 2013-04-14.

IIASA. (2013). GAINS - An interactive tool for assessing international GHG mitigation regimes. http://gains.iiasa.ac.at/gains/EUN/index.login?logout=1.

ISO 14044. (2006). Environmental management - Life cycle assessment - Principles and framework. Organization for Standardization.

Laurent A, Olsen S, Hauschild M (2011). Normalization in EDIP97 and EDIP2003: updated European inventory for 2004 and guidance towards a consistent use in practice. Int J Life Cycle Assess 16:401–409. doi: 10.1007/s11367-011-0278-6

Laurent A., Hauschild M.Z. (2014). Impacts of NMVOC emissions on human health in European countries for 2000-2010: Use of sector-specific substance profiles. Atmospheric Environment 85:247-255

Laurent, A., Hauschild, M. Z., Golsteijn, L., Simas, M., Fontes, J., & Wood, R. (2013). Normalisation factors for environmental, economic and socio-economic indicators. Deliverable 5.2 of PROSUITE (FP7 project) Retrieved from http://prosuite.org/c/document_library/get_file?uuid=750ef6d0-4e9d-4a00-913c-3f4cfd632782&groupId=12772

Milà i Canals, L., Romanyà, J., & Cowell, S. J. (2007). Method for assessing impacts on life support functions (LSF) related to the use of “fertile land” in Life Cycle Assessment (LCA). Journal of Cleaner Production, 15(15), 1426–1440.

NITE (2006) PRTR data 2011. National Institute of Technology and Evaluation (NITE), Japan, 2006.

OECD (2013a) Wastewater treatment (% population connected) Organisation for Economic Co-operation and Development. http://www.oecd.org/statistics/ Accessed May 2013

OECD (2013b) OECD Factbook 2013: Economic, Environmental and Social Statistics- Water consumption. http://www.oecd-ilibrary.org/sites/factbook-2013-en/09/01/01/index.html?itemId=/content/chapter/factbook-2013-68-en

OSPAR (2013a) Liquid Discharges from Nuclear Installations. Commission of the Convention for the Protection of the marine Environment of the North-East Atlantic (OSPAR). http://ospar.org/content/content.asp?menu=01511400000000_000000_000000

OSPAR (2013b) Discharges of Radionuclides from the non-nuclear sectors. Commission of the Convention for the Protection of the marine Environment of the North-East Atlantic (OSPAR). http://ospar.org/content/content.asp?menu=01511400000000_000000_000000

OSPAR (2013c) Discharges, Spills and Emissions from Offshore Oil and Gas Installations. Commission of the Convention for the Protection of the marine Environment of the North-East Atlantic (OSPAR). http://ospar.org/content/content.asp?menu=01511400000000_000000_000000

Polinares (2012) Fact Sheet: Indium POLINARES working paper n. 39. http://www.polinares.eu/docs/d2-1/polinares_wp2_annex2_factsheet5_v1_10.pdf

PRODCOM/Eurostat (2013). Survey on production of manufactured goods. http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/data/database

Rabl, A., and Spadaro, J.V. 2004. The RiskPoll software, version 1.051 (August 2004). www.arirabl.com Accessed on 10 December 2013

Raw Material Group (RMG) (2013) Raw Materials Data and IntierraLive database, http://www.intierrarmg.com/Products/SNL_MnM_Databases.aspx

Rosenbaum, R., Bachmann, T., Gold, L., Huijbregts, M. J., Jolliet, O., Juraske, R., … Hauschild, M. (2008). USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. The International Journal of Life Cycle Assessment, 13(7), 532–546.

Sala S, Wolf M, Pant R. (2012). Characterisation factors of the ILCD Recommended Life Cycle Impact Assessment methods. Database and Supporting Information. EUR 25167 EN. Luxembourg (Luxembourg): Publications Office of the European Union; 2012. JRC68250

Sala S, Benini L, Mancini L, Ponsioen T, Laurent A, Van Zelm R, Stam G, Goralczyk M, Pant R. Methodology for building LCA-compliant national inventories of emissions and resource extraction. EUR 26871. Luxembourg (Luxembourg): Publications Office of the European Union; 2014. JRC92036

Schneider and Marignac (2008) Spent nuclear fuel reprocessing in France - A Research report of the International Panel on Fissile Materials. Downloaded at: http://fissilematerials.org/library/rr04.pdf

Schoer K, Giegrich J, Kovanda J, et al. (2012) Conversion of European Product Flows into Raw Material Equivalents. IFEU Institut für Energie- und Umweltforschung, Heidelberg

UNEP. 2002. Production and Consumption of Ozone Depleting Substances under the Montreal Protocol 1986-2000. United Nations Environment Programme (UNEP), Ozone Secretariat, Nairobi, Kenya, 2002

UNFCCC (2013) United Nations Convention on Climate Change http://unfccc.int/ghg_data/ghg_data_unfccc/time_series_annex_i/items/3814.php Accessed on 10 December 2013

UNSCEAR (2008). UNSCEAR 2008 REPORT Vol. I. SOURCES OF IONIZING RADIATION. United Nations Scientific Committee on the Effects of Atomic Radiation. UNSCEAR 2008 Report to the General Assembly, with scientific annexes. Volume I: Report to the General Assembly, Scientific Annexes A and B

US-EPA (2006). Toxics Release Inventory (TRI) program. TRI Explorer. United States Environmental Protection Agency (US-EPA), Washington DC, USA, 2006. At http://www.epa.gov/triexplorer

Van Drecht, G., Bouwman A. F., et al. (2003). Global modelling of the fate of nitrogen from point and nonpoint sources in soils, groundwater and surface water. Global Biogeochem. Cycles 2003; 17 (4): 26-1 -26-20 DOI: http://dx.doi.org/10.1029/2003GB002060

Van Drecht, G., Bouwman A. F., et al. (2009). "Global nitrogen and phosphate in urban wastewater for the period 1970 to 2050." Global Biogeochem. Cycles23: GB0A03.

Vandecasteele I, Bianchi A, Batista e Silva F, Lavalle C, Batelaan O, (2013), Mapping Current and Future European Public Water Withdrawals and Consumption, Hydrology and Earth System Sciences Discussions, 10, 1-26, doi: 10.5194/hessd-10-1-2013.

Wegener Sleeswijk AW, van Oers LFCM, Guinée JB, et al. (2008) Normalisation in product life cycle assessment: An LCA of the global and European economic systems in the year 2000. Sci Total Environ 390:227–240.

Wegener Sleeswijk A. and Huijbregts M. (2010). LCA ReCiPe normalisation 2000 version 1.1 REVISED LCA NORMALISATION FACTORS FOR THE YEAR 2000. Revised September 2010 by Anneke Wegener Sleeswijk and Mark Huijbregts, last modified 23-09-2010. http://www.lcia-recipe.net/normalisation

World Mining Data (WMD) (2014). WORLD-MINING-DATA volume 29. Vienna. http://www.wmc.org.pl/sites/default/files/WMD2014.pdf

World Nuclear Association (WNA) http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Fuel-Recycling/Processing-of-Used-Nuclear-Fuel/

Annex 1

Table Annex 1: List of data sources used in this study, per impact category

Substance groups	**Data sources**	**Coverage estimate**	**Uncertainties and/or limitations**	**Added value compared to existing inventories**
		Climate Change		
CO_2, CH_4, N_2O, HCFC both from direct emissions and LULUCF	- UNFCCC (2013)	Good	Uncertainties arise from the different tiered approaches to the compilation of the inventories under the UNFCCC by countries; however are not quantified in the original datasets. Quality checks and reviews are done systematically under this framework through international panels of experts, ensuring high quality of the final dataset.	-
Other substances (incl. 1,1,2-trichloro-1,2,2-trifluoroethane, methylenchloride, chloroform, tetrachloromethane, chlorodifluoromethane, dichlorofluoromethane, CFCs, Dichloromethane)	- Total NMVOC per sector from EMEP/CEIP (2013a) and CORINAIR/EEA (2007; 2009) - CLTAP/EMEP (EMEP/CEIP 2013a)	Fair Good	High heterogeneity among data sources, mixing reporting datasets (EMEP, E-PRTR) and bottom-up modelling exercises (EDGAR). Gaps for few countries	-
		Ozone Depleting Potential		

CFC, HCFC, etc.	- Total NMVOC per sector from EMEP/CORINAIR (EMEP/CEIP 2013a; CORINAIR/EEA 2007; 2009) Literature sources (speciation per sectors) - Databases + CORINAIR for sector activity modelling - E-PRTR database (EEA, 2013a) - EDGAR (EC-JRC&PBL, 2011)	Fair	High heterogeneity among data sources, mixing reporting datasets (EMEP, E-PRTR) and bottom-up modelling exercises (EDGAR). Moreover, limited coverage of E-PRTR as reporting obligations apply only above activity thresholds Brominated substances are not accounted for in the inventory	- Figures are updated to EU-27, year 2010. However, Wegener Sleeswijk et al. (2008) made use of a currently dismissed dataset on ODP substances, which was more refined than the current one.
Human toxicity (cancer, non-cancer) and ecotoxicity				
- *Air emissions:*				
Heavy metals (HM)	CLTAP/EMEP (EMEP/CEIP 2013a)	Good	- Gaps for few countries	- Similar to previous works, except for some heavy metals (e.g. V, Al, Tl...) included in Wegener Sleeswijk et al. (2008) using data from regions outside EU.
Organics (non-NMVOC): e.g. dioxins, PAH, HCB, etc.	- CLTAP/EMEP (EMEP/CEIP 2013a) - E-PRTR (EEA 2013a)	Good (EMEP) Medium/Poor (E-PRTR)	- Gaps for some countries (substance-specific coverage)	- Similar to previous works, except for substances from E-PRTR not covered in Laurent et al. (2011a; 2011b). - Substance form E-PRTR used in LC Indicator project (EC-JRC 2012 a,b,c) but accounting for fewer substances (as the coverage for 2006 was limited).
NMVOC	Total NMVOC per sector from EMEP/CORINAIR (EMEP/CEIP 2013a; CORINAIR/EEA 2007; 2009)	Good	No major uncertainties identified (see further details in Annex I)	- Not existing in earlier works with such consistency and completeness - Reference year: (Different assumptions/ sources for speciation profiles) and 2010 (sector activity data)

	- Literature sources (speciation per sectors) - Databases + CORINAIR for sector activity modelling	Good		-
- *Water emissions:*				
Industrial releases of HM + organics	- E-PRTR (EEA 2013a) - Waterbase (EEA 2013b)	Good (HM) Fair/Poor (Organics)	- Gaps for many countries (organics mainly) - Existence of minimum thresholds for reporting industrial releases, leading to underestimations (partly filled in using the Waterbase data)	- Less completeness and consistency in previous inventories: - Raw data from EPER (very incomplete) used in Wegener Sleeswijk et al. 2008 - Riverine inputs to seas (very uncertain) used in Laurent et al. (2011a) - No inclusion of industrial releases in LC Indicator project. - Reference year : 2010 (E-PRTR); 2009 (Waterbase)
Urban WWTP (HM + organics)	- Waterbase, OECD (2013a), EUROSTAT (2013b)	Poor (EU covered via extrapolations from few countries)	- Raw data only available for few countries, with NL and RO being the most documented - Extrapolation based on emission archetype per inhabitant	- See above cell for treatment in Wegener Sleeswijk et al. 2008 (EPER) and Laurent et al. 2011a (riverine inputs). - Use of similar approach based on shares of population connected to WWTP and Waterbase emission data in LC Indicator project - Reference year. 2009
- *Soil emission:*				
Industrial releases (HM, POPs)	- E-PRTR (EEA, 2013a)	Poor	Territorial coverage very limited (total of 8 countries)	- Not covered in Laurent et al. (2011a). In LC Indicator project (EC-JRC 2012 a, b, c) emission to soil are related to imported products only. Included in Wegener Sleeswijk et al. 2008 from raw data for The Netherlands and Canada - Reference year: 2010/2009

Sewage sludge (containing organics and metals)	- EEA (2012) + EUROSTAT (2013c) for usage - EC (2010) for HM composition - EC-JRC (2001) for dioxins	Good (HM)	- None for HM. - Substance groups are typically reported for organics (EC 2001) - Out-of-date data for organics	- Heavy metals covered in Laurent et al. (2011a) with same approach; no organics covered. - Not covered in Wegener Sleeswijk et al. (2008) - Reference years: 2009/2010 for sewage sludge applied to agriculture; HM speciation: 2006/5; Mid – 90s for dioxins composition
Manure	FAOSTAT(2013a), Amlinger et al. (2004), Chambers et al. (2001)	Good (HM)	- Out-of-date composition data - Composition data provided as ranges covering several European countries - Organics missing - Calculation for estimating dry matter (dm) applied to land	- Heavy metals covered in Wegener Sleeswijk et al. (2008) from data for the Netherlands - Not covered in Laurent et al. (2011a) nor in LC Indicator project - Reference year: 2010 for manure use - Older than 2004 for composition
- *Pesticides:*				

Active ingredients (AI) breakdown	- Pesticide usage data: FAOstat (2013d, 2013e) (F, H, I, O + chemical classes) + EUROSTAT (2013f) for second check - Use of extrapolations for AI differentiations - EUROSTAT (2013d) for crop harvested areas - FAOstat (2013c) for organic areas	Poor/Fair	- Incomplete data because only top-5 AI per crop reported (when not confidential) - Substantial category “Others” (>25w% total); some a.i. with low dosage but high toxicity may thus not appear in inventory - Extrapolations from 2003 to 2010 only based on harvested area - Inconsistencies with pesticide use reported by FAO	- breakdowns of AI in Laurent et al. (2011a) extrapolated from data in DK only (very uncertain) - Breakdowns in Wegener Sleeswijk et al. (2008) from data in The Netherlands, UK and USA (very uncertain) - Use of similar approach (combination of AI data with PestLCI1.0 or 2.0 with crude assumptions) in Laurent et al. (2011a) and LC Indicator project; Wegener Sleeswijk et al. (2008) considered the emissions to agricultural soil equal to total pesticides applied on land. - Reference year: Usage stats: 2009-2010 for many EU countries (FAOSTAT/EUROSTAT data); Dosages taken for 2003 (assumed applicable to 2010); Crop data from 2010
Particulate matter/respiratory inorganics				
CO, NOx	- UNFCCC (2013)	Good	Uncertainties arise from the different tiered approaches to the compilation of the inventories under the UNFCCC by countries; however are not quantified in the original datasets. Quality checks and reviews are done systematically under this framework through international panels of experts, ensuring high quality of the final dataset. Data for Luxembourg have been taken from EMEP.	- Figures are updated to EU-27, year 2010. - Wegener Sleeswijk et al. (2008) made use of the EMEP data for NOx

SO_2, PM10, PM2.5, NH_3	- EMEP/CORINAIR (EMEP/CEIP 2013b) - EEA (2013c) - EDGARv4.2 (EC-JRC&PBL, 2011)	Good	Uncertainties are related to the level of completeness of the reported/modelled inventories to EMEP. No major gaps are found, however different tiered approaches among reporting countries may limit the accuracy of the dataset.	- Figures are updated to EU-27, year 2010. - Wegener Sleeswijk et al. (2008) - used in practice current practice by CML and ReCiPe - is updated to 2000 and does not include PM2.5 (covered by the current inventory)
Ionizing Radiations				
emissions of radionuclides to air and water from energy production (nuclear and coal);	- UNSCEAR data on emissions factors (2008) for 14C, 3H, 131I; - nuclear energy production (Eurostat, 2013b) - Ecoinvent 3.01 (Weidema et al., 2013)	Good/Fair	Ecoinvent 3.01 emission factors have been used to upscale emissions which were not covered from the UNSCEAR data. Because of potential differences among technologies, such assumption might be weak and limit the robustness of the assessment	- Figures are updated to EU-27, year 2010. - The combination of UNSCEAR data and Ecoinvent 3.01 provides a good estimation. - Wegener Sleeswijk et al. (2008) relied on rough emission factors (average UK's ionizing radiations emission factors), which did not reflect the existing differences in technology among nuclear plants in the EU.
emissions of radionuclides to air and water from nuclear spent-fuel reprocessing;	- fuel reprocessing is estimated on UNSCEAR data (2008) on emissions of 3H, 14C, 60Co, 90Sr, 99Tc, 129I, 106Ru, 137Cs and 241Pu - spent-fuel processing statistics are from the International Panel on Fissile Materials (IPFM) (2008a, 2008b). - nuclear energy production (Eurostat, 2013r)	Good/Fair	Some gaps in data availability are found and filled through extrapolation. However, the contribution of these emissions to the totals is minimal.	- Figures are updated to EU-27, year 2010. - No other normalization datasets have included these emissions (see Wegener Sleeswijk et al., 2008; EC, 2012)

discharge of radionuclides from non-nuclear activities (radio-chemicals production and research facilities)	- OSPAR Commission database (OSPAR, 2013b, 2013c) covering the following activities: radio-chemicals production and research facilities	Fair/Poor	The OSPAR Commission collects very detailed data at Country level, however the OSPAR countries are only a fraction of EU-27. Extrapolations for radiochemical productions and RTD were not done.	- Figures are updated to EU-27, year 2010. - No other normalization datasets have included these emissions (see Wegener Sleeswijk et al., 2008; EC, 2012)
discharge of radionuclides from offshore oil&gas industry	- OSPAR Commission database (OSPAR, 2013) - overall oil production figures (Eurostat, 2013r)	Fair	The emission factors from OSPAR have been used to estimate overall EU-27 emissions related to oil production. However, due to differences in technologies in extraction processes and refining, it is likely that the extrapolations are not accurate.	- Figures are updated to EU-27, year 2010. - No other normalization datasets have included these emissions (see Wegener Sleeswijk et al., 2008; EC, 2012)
emissions to air and water from the end-of-life scenario of gypsum boards	- Ecoinvent (v 3.01) unit processes; - PRODCOM data (Eurostat, 2013).	Poor	Data on wasted gypsum boards are not directly available; hence PRODCOM data have been used as proxy. The results are highly uncertain; however the contribution of this dataset to the totals is negligible.	- Figures are updated to EU-27, year 2010. - No other normalization datasets have included these emissions (see Wegener Sleeswijk et al., 2008; EC, 2012)
Acidification				

NOx	- UNFCCC (2013)	Good	Uncertainties arise from the different tiered approaches to the compilation of the inventories under the UNFCCC by countries; however are not quantified in the original datasets. Quality checks and reviews are done systematically under this framework through international panels of experts, ensuring high quality of the final dataset. Data for Luxembourg have been taken from EMEP.	- Figures are updated to EU-27, year 2010. - Wegener Sleeswijk et al. (2008) and EC (2012) made use of the EMEP data (2006; 2010) for NOx; - A joint effort between UNFCCC, EMEP, EC-JRC and PBL leaded to the creation of an extended emissions database (EC- JRC, 2012c), resolved at grid level. The same hierarchical approach used in that work for attributing priority to the emission' datasets (among UNFCCC, EMEP and EDGAR) has been adopted in this work. Hence, the priority is as foloows: UNFCCC > EMEP > EDGAR
SO_2, NH_3	- EMEP/CORINAIR (2013) - modelled dataset for SO2, NH3; - EMEP/CEIP (2013b)	Good	Uncertainties are related to the level of completeness of the reported/modelled inventories to EMEP. No major gaps are found, however different tiered approaches among reporting countries may limit the accuracy of the dataset.	- Figures are updated to EU-27, year 2010. - Wegener Sleeswijk et al. (2008) made use of the same data sources
Terrestrial eutrophication				

NOx	- UNFCCC (2013)	Good	Uncertainties arise from the different tiered approaches to the compilation of the inventories under the UNFCCC by countries; however are not quantified in the original datasets. Quality checks and reviews are done systematically under this framework through international panels of experts, ensuring high quality of the final dataset. Data for Luxembourg have been taken from EMEP.	- Figures are updated to EU-27, year 2010. - Wegener Sleeswijk et al. (2008) and EC (2012) made use of the EMEP data (2006; 2010) for NOx; - A joint effort between UNFCCC, EMEP, EC-JRC and PBL leaded to the creation of an extended emissions database (EC- JRC, 2012c), resoled at grid level. The same hierarchical approach used in that work for attributing priority to the emission' datasets (among UNFCCC, EMEP and EDGAR) has been adopted in this work. Hence, the priority is as foloows: UNFCCC > EMEP > EDGAR
NH_3	- EMEP/CORINAIR EMEP/CEIP (2013b) - modelled dataset for NH3;	Good	Uncertainties are related to the level of completeness of the reported/modelled inventories to EMEP. No major gaps are found, however different tiered approaches among reporting countries may limit the accuracy of the dataset.	- Figures are updated to EU-27, year 2010. - Wegener Sleeswijk et al. (2008) made use of the same data sources
Freshwater eutrophication				
Phosphorous (total) to soil and water, from agriculture	- Eurostat (2013g) for phosphorous Input and Output data - UNFCCC (2013) for nitrogen input - FAOstat (2013b) for cultivated cereal surfaces - Bouwman et al. (2009) 10% loss of P to water as global average	Fair	- the P input values missing from Eurostat are extrapolated from N input UNFCCC data. Missing P output values are extrapolated from N output data from Eurostat	- Figures are updated to EU-27, year 2010. - Wegener Sleeswijk et al. (2008) made use of FAO data (2006) on P-total to agricultural soils limiting the inventory to permanent crop areas

Phosphorous (total) to soil and water, from sewages	- removal efficiency of Phosphorous Van Drecht et al (2009) - Use of laundry detergents Risk and Policy Analysts (RPA) 2006 - Use of dishwasher detergents Risk and Policy Analysts (RPA) 2006 - Fraction of P-free laundry detergents Risk and Policy Analysts (RPA) 2006 - Percentage of people connected to wastewater treatment (no treatment/primary/secondary/tertiary) OECD (2013a) / Eurostat (2013h)	Fair/good	Simple data gap-filling techniques, such as correlation over time, have been adopted for estimating people's connection rate to wastewater plants, by typology of treatment. Fixed removal efficiency rates have been applied with no distinction among countries. Overall, the assumptions made limit the robustness of the estimates	- Figures are updated to EU-27, year 2010. - Wegener Sleeswijk et al. (2008) did not include emissions from sewages
		Marine Eutrophication		
NOx	- UNFCCC (2013)	Good	Uncertainties arise from the different tiered approaches to the compilation of the inventories under the UNFCCC by countries; however are not quantified in the original datasets. Quality checks and reviews are done systematically under this framework through international panels of experts, ensuring high quality of the final dataset. Data for Luxembourg have been taken from EMEP.	- Figures are updated to EU-27, yeagr 2010. - Wegener Sleeswijk et al. (2008) and EC (2012) made use of the EMEP data (2006; 2010) for NOx; - A joint effort between UNFCCC, EMEP, EC-JRC and PBL leaded to the creation of an extended emissions database (EC, 2012d), resoled at grid level. The same hierarchical approach used in that work for attributing priority to the emission' datasets (among UNFCCC, EMEP and EDGAR) has been adopted in this work. Hence, the priority is as foloows: UNFCCC > EMEP > EDGAR

NH_3	- EMEP/CORINAIR- EMEP/CEIP (2013b); modelled data for SO2, NH3;	Good	Uncertainties are related to the level of completeness of the reported/modelled inventories to EMEP. No major gaps are found, however different tiered approaches among reporting countries may limit the accuracy of the dataset.	- Figures are updated to EU-27, year 2010. - Wegener Sleeswijk et al. (2008) made use of the same data sources
Nitrogen (total) to water, from agriculture	- national inventories delivered to the UNFCCC (2013), for Ntot input data, losses to water, synthetic fertilizers, manure, losses to air. - N output is calculated by using the ratios (by country, by year) between Input and Output provided by Eurostat (2013g), then multiplied to Inputs from UNFCCC	Fair	average nitrogen Input/Output ratios were used to gap-filling for some missing data points	- Figures are updated to EU-27, year 2010. Wegener Sleeswijk et al. (2008) made use of FAO data for N-total emissions to agricultural soils (2006)
Nitrogen (total) to soil and water, from sewages	- protein intake FAO –Faostat (2013f) - removal efficiency of Nitrogen Van Drecht et al 2009 - Percentage of people connected to wastewater treatment (no treatment/primary/secondary/tertiary) OECD (2013a) / Eurostat (2013h)	Fair	Simple data gap-filling techniques, such as correlation over time, have been adopted for estimating people's connection rate to wastewater plants, by typology of treatment. Fixed removal efficiency rates have been applied with no distinction among countries. Overall, the assumptions made limit the robustness of the estimates	- Figures are updated to EU-27, year 2010. - Wegener Sleeswijk et al. (2008) did not include emissions from sewages
Water depletion				

Gross freshwater abstraction (freshwater + groundwater)	- Eurostat (2013i), - OECD (2013b) - FAO-Aquastat (2013)	Fair/Poor	The datasets have big data gaps, especially for the year 2010. Estimations were done on the basis of time trends and other proxies. The overall robustness of the estimates for 2010 is low.	- Figures are updated to EU-27, year 2010. - No other LCA normalization datasets have provided such figures. - The Water Footprint network has published data on water abstraction by country for the year 2005.
Land Use				
"land occupation" and "land transformation" flows: forest, cropland, grassland, settlements, unspecified	- UNFCCC (2013) national inventories Corine Land Cover (2000, 2006) (EEA, 2012b)	Fair/Poor	The coverage of flows is limited to 5 land use classes. Some gaps have been filled through extrapolations and assumptions. Data for Malta and Cyprus were not reported to UNFCCC and then have been estimated through interpolation and extrapolation of CLC data (2000, 2006).	- Figures are updated to EU-27, year 2010. - Only "land occupation" flows were reported in ReCiPe; hence, no "land transformation" flows were included in that normalization dataset.
Resource depletion				
minerals & metals	- British Geological Survey, (1995, 2000, 2002, 2012)	Fair	Data gaps have been filled using data from Raw Materials Group	- The number of metals considered in this assessment has enlarged from 13 to 23 - Figures are updated to EU-27, year 2010
energy carriers	- EUROSTAT (2013l; 2013m; 2013n; 2013o; 2013p; 2013q)	Good		- Uranium and peat, dismissed in other normalisation datasets, are included in this assessment

European Commission
EUR 26842 EN – Joint Research Centre – Institute for Environment and Sustainability
Title: Normalisation method and data for Environmental Footprints

Authors: Lorenzo Benini, Lucia Mancini, Serenella Sala, Simone Manfredi, Erwin M. Schau, Rana Pant

Luxembourg: Publications Office of the European Union

2014 – 109 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424 (print)

ISBN 978-92-79-40847-2

doi:10.2788/16415

LB-NA-26842-EN-N

JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

Serving society
Stimulating innovation
Supporting legislation

doi: 10.2788/16415

ISBN: 978-92-79-40847-2

Publications Office