Methodology for Building LCA-compliant National Inventories of Emissions and Resource Extraction

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Publication date:
2014

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Sala, S., Benini, L., Mancini, L., Ponsioen, T., Laurent, A., Zelm, R. V., ... Pant, R. (2014). Methodology for Building LCA-compliant National Inventories of Emissions and Resource Extraction. European Commission.

European
Commission

JRC SCIENCE AND POLICY REPORTS

Methodology for building LCA-compliant national inventories of emissions and resource extraction

Background methodology for supporting calculation of Product Environmental Footprint normalisation factors and resource efficiency indicators for EU

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2014

Report EUR 26871

Joint
Research
Centre

European Commission
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JRC92036

EUR 26871

ISBN 978-92-79-43262-0 (PDF)
ISBN 978-92-79-43263-7 (print)

ISSN 1831-9424 (online)
ISSN 1018-5593 (print)

doi: 10.2788/18238

Luxembourg: Publications Office of the European Union, 2014

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

This document provides the background methodology for building emission and resource inventories for calculating normalisation factors (NFs). The inventory is primarily based on extensive data collection at EU level. For missing flows, extrapolation strategies have been adopted and gap filling activities undertaken for their calculation. We present underpinning methodology for database population and we present and discuss possible source of outliers/ uncertainties

Executive summary

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

This document provides the background methodology for building inventories of emissions to air, water and soil occurring in the territory of the EU ("domestic") as well as resource extraction in EU to be used as input data for calculating normalisation factors (NFs) for Environmental Footprint (EC - European Commission, 2013) and life cycle based indicators for resource efficiency (EC-JRC, 2012a and b)

The inventory is primarily based on extensive data collection at EU level, from different sources. For missing flows, extrapolation strategies have been adopted and gap filling activities undertaken for their calculation. We present underpinning methodology for database population and we present and discuss possible source of outliers/ uncertainties

The Environmental Footprint (EF) guides, i.e. the Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF) provide a method for modelling the environmental impacts of the flows of material/energy and the emissions and waste streams associated with a product or organisation throughout its life cycle. The methodology for building LCA-compliant national inventories of emissions and resource extraction contributes to the EF implementation, especially during the three year pilot phase of developing Product Environmental Footprint Category Rules (PEFCRs) and Organisation Environmental Footprint Sector Rules (OEFSRs). With that the work also contributes to the related COM (2013) 196 final Building the Single Market for Green Products.

Contents

1 Introduction

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

This document provides the background methodology for building inventories of emissions to air, water and soil occurring in the territory of the EU ("domestic") as well as resource extraction in EU to be used as input data for calculating normalisation factors (NFs) for Environmental Footprint (EC - European Commission, 2013) and life cycle based indicators for resource efficiency (EC-JRC, 2012a and b).

Direct use of raw data from several sources as well as estimation methodology for data gap filling has been implemented, as described in the methodological section. Data spanning from 1990 to 2010 were collected (Benini et al 2014a) and mapped with ILCD elementary flows.

The methodological development and the related indicators in this report are contributing to the European Commission's "Europe 2020 Strategy", as described in the "Roadmap to a Resource Efficient Europe" (COM(2011)0571), which as one objective has to increase resource productivity and to decouple economic growth from resource use and its environmental impact.

It supports several strategies linked to "*transforming the economy onto a resource-efficient path that will bring increased competitiveness and new sources of growth and jobs through cost savings from improved efficiency, commercialisation of innovations and better management of resources over their whole life cycle*", including "*sustainable consumption and production*" and "*turning waste into a resource*" (COM(2011)0571).

More specifically, in the context of the Environmental Footprint work it contributes to fulfilling the policy commitment to "*Establish a common methodological approach to enable Member States and the private sector to assess, display and benchmark the environmental performance of products, services and companies based on a comprehensive assessment of environmental impacts over the life-cycle ('environmental footprint')*" (COM(2011)0571) p.7).

The Environmental Footprint (EF) guides, i.e. the Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF) provide a method for modelling the environmental impacts of the flows of material/energy and the emissions and waste streams associated with a product or organisation throughout its life cycle. The methodology for building LCA-compliant national inventories of emissions and resource extraction contributes to the EF implementation, especially during the three year pilot phase of developing Product Environmental Footprint Category Rules (PEFCRs) and Organisation Environmental Footprint Sector Rules (OEFSRs). With that the work also contributes to the related COM (2013) 196 final Building the Single Market for Green Products.

In the context of PEF, data referring to 2010 were taken for EU 27 at country level and then aggregated as EU figures to be multiplied by characterisation factors in order to calculated normalisation factors. In the context of Life Cycle Assessment (LCA), according to ISO 14044 (ISO 2006), normalisation is an optional step of Life Cycle Impact Assessment (LCIA) which allows the practitioner expressing results after characterization using a common reference impact. This supports the comparison between alternatives using reference numerical scores. The normalisation factors express the total impact of a reference region for a certain impact category (e.g. climate change, eutrophication, etc.) in a reference year.

For what concern Life Cycle Indicators, the full time series have been used as reported in Benini et al 2014 to provide information on time trends of environmental impacts linked to European domestic emission and resource extraction.

Both for the PEF and the domestic part of Life cycle indicators, the ILCD set of impact assessment methods (EC-JRC, 2011) and related characterisation factors (Sala et al 2012) have been applied for calculating the normalisation factors.

In the following sections, the main methodological steps for building the domestic inventories are described and discussed.

Chapter 2 explains the overall methodology implemented for building the inventory. Chapter 3 presents in details the different estimation strategies and methods adopted.

2 Methodology for building the inventory

Increasingly, over the years, data on emissions and resource extraction has been monitored, modelled and reported by different sources as result of national and international efforts and initiatives to collect better environmental data. However, significant efforts are still needed when confronted with the need of building inventories of emission and resource extraction covering the macro scale, e.g. covering EU countries over a time series of 20 years.

This is mainly due to the need of selecting data from different sources and to complement those sources with proxies when data are missing.

In the present report, we describe the methodological choices adopted for building a domestic inventory of emission and resource extraction in EU 27, ranging from 1990 to 2010.

Basically two approaches have been followed:

1. Collection of data from statistical data sources, implementing a hierarchy criterion for selecting the source when more options where available.
2. Development and application of estimation strategies for populating the inventory in case of data gaps.

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 inventories developed for calculating normalisation factors (e.g. CML, 2013), 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 toward increasing the coverage of substances monitored and reported.

Nonetheless, several assumptions were needed in order to estimate missing values and to map territorial statistics to the elementary flows in the ILCD format.

In fact, the statistical datasets have 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 the next chapter.

2.1 Data sources

The so-called 'domestic inventory' of emissions and resources extraction is mostly composed of datasets provided by international and European statistical agencies (Table 1), complemented by extrapolation methods, as reported in the last column.

The 'domestic inventory' includes all the emissions, as well as the extraction of resources, occurring within the territorial boundaries of EU27 member states. Instead, the resources consumed in the EU (e.g. natural gas imported from Russia and consumed in the UE) and the emissions released to produce a product that is then shipped and consumed in the EU (e.g. emissions of greenhouse gases emitted in China to manufacturing a laptop imported in the EU) are not accounted for in this inventory, as they are accounted, via estimation, in the trade inventory (see Benini et al. 2014a; section 2.4).

The domestic inventory has been compiled, when possible, by making use of the officially reported statistics on emissions- into air, water and soil- and resources extracted in EU 27 territory, relying on the data reported by Eurostat and other international and national statistical bodies. Nonetheless, several estimations were needed in order to estimate missing values within the time series or to estimate, for instance, emissions of pollutants that are not currently reported in official statistics. However, in general, official statistics were preferred for those statistics that guarantee a high degree of robustness, by means of standardized protocols, metadata, recalculation and quality assessment checks.

Below, the hierarchical approach applied to the selection of the dataset to be used for building the domestic inventory:

- **1st choice → officially reported data**. EU and international bodies (Eurostat, FAO, OECD, BGS), based on agreed models/methods/standards, with documented metadata and periodical quality checks. Better if the dataset is already used in EU monitoring/policy making (e.g. IPCC, EEA/EMEP, Eurostat, E-PRTR) and providing consistent time-series;

- **2nd choice → activity-based estimations**. Based on the following equation: Activity data * Emission factor Activity data are taken from officially reported data; Emission factors are based on scientific literature, grey literature (e.g. sectoral reports), life cycle inventories (LCIs);
- **3rd choice → statistical proxies (time, flows).** Better when the correlation is proved statistically significant. When possible, consistency rules have been applied (e.g. the sum of the relative shares estimated must sum-up to 1);
- **4th choice → speculative assumption(s).** Assumptions based on reasonable correlation and/or cause-effect models, not statistically tested. Very often used for filling-in punctual data gaps (e.g. figure available for 2009 not for 2010 and no evident underlying trend).

In general, the domestic inventory is composed of raw data provided by third parties (e.g. national or international statistical offices) and data derived from estimations carried out in order to complement the available dataset with additional information (from the 2nd to the 4th strategy). An example of **raw data** is the emission of *x* tons of CO_2 occurring in a given country for a given year, as reported by the dataset of UNFCCC (2013), which is the international body deputed to the collection of data on greenhouse gases (GHGs) emissions. When more than one international or EU statistical agency collected datasets related to the same emission of a given pollutant, the choice has been made on a set of additional rules that has been put in place in order to provide a justification to the selection. For instance, for what concerns NOx, NH3, SOx, CO 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 has been set as follows: UNFCCC (2013)> EMEP_modeled (EMEP/CEIP, 2013b) > EMEP_reported (EMEP/CEIP, 2013a) > EDGARv4.2 (EC – JRC & PBL, 2011). The original data sources for those substances are then: UNFCCC for CO and NOx (reported as NO_2) and the EMEP/CEIP database for NH3, and SO_x (reported as SO_2) (EMEP/CEIP, 2013b).

An example of an **estimated inventory data** is the amount of nitrogen (total) discharged into freshwater bodies from wastewater plans. This value has been estimated for each of the countries and for each year by applying scientific literature (Van Drecht et al., 2009) and data taken from Eurostat (statistics on population connection to wastewater plants, by plant typology) and FAOstat (statistics on yearly average intake of proteins per EU inhabitant). An in-depth presentation of the methodologies developed to estimate missing substances and punctual values is given in the following section.

In table 1, the list of data sources as well as methods applied to estimate additional flows by group of substance, is presented by impact category.

The dataset which has been used for calculating PEF normalisation factors covers, in its current form, the EU27 for the year 2010, by including the inventory of emissions and resource flows occurring within the EU27 boundaries (domestic inventory).

Table 1 Data sources used to compile the domestic inventory, by impact category.

Impact category	Substance groups	Data sources	Estimation technique[1]	Coverage estimate[2]	Uncertainties and/or limitations	Added value [3]
Climate change	CO_2, CH_4, N_2O both from direct emissions and LULUCF	- UNFCCC (2013)	- Method S1	- 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.	-
	HFCs, PFCs and SF_6	- UNFCCC (2013)	- Method S2	- Good	- In addition to the uncertainties reported above, for these groups of chemicals it had not been possible to disaggregate by substance	-
	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)	- Methods A	- Fair	High heterogeneity among data sources, mixing reporting datasets (EMEP, E-PRTR) and bottom-up modelling exercises (EDGAR).	-
	HCFC-141b, HCFC-142b	- EDGARv4.2 (EC – JRC & PBL, 2011)	- Method B	- Fair/Good	- Data are from bottom-up modelling (EDGARv4.2 database) overall the database showed higher values than other databases for different substances; this could be the case also for HCFC-141b and 142b.	-
	1,1,1-trichloroethane	- E-PRTR database (EEA, 2012a)	- Method C	-	- E-PRTR is characterized by some degree of incompleteness because facilities are asked to report only above certain thresholds	-

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[1] Chapter 3 reports the description of each method

[2] Coverage referring to number of flows for which a data is available compared to total number of flows for which a characterisation factors is available in the impact assessment method.

[3] Added value of current inventory if compared to existing inventories

Impact category	Substance groups	Data sources	Estimation technique[1]	Coverage estimate[2]	Uncertainties and/or limitations	Added value [3]
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	- 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 EU27, 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.
	HCFC-141b, HCFC-142b	- EDGARv4.2 (EC – JRC & PBL, 2011)	- Method B	- Fair/Good	- Data are from bottom-up modelling (EDGARv4.2 database) overall the database showed higher values than other databases for different substances; this could be the case also for HCFC-141b and 142b.	-
	1,1,1-trichloroethane	- E-PRTR database (EEA, 2013a)	- Method C	- Fair	- E-PRTR is characterized by some degree of incompleteness because facilities are asked to report only above certain thresholds	-
Human toxicity (cancer, non-cancer) and ecotoxicity	*Air emissions*					
	Heavy metals (HM)	- EMEP/CEIP (2013a) 'EMEP_reported'	- Method C	- 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.	- EMEP/CEIP (2013a) 'EMEP_reported', - E-PRTR (EEA 2013a)	- Method C	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: ○ CORINAIR/EEA (2007; 2009)	- Method A	- 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)

Impact category	Substance groups	Data sources	Estimation technique[1]	Coverage estimate[2]	Uncertainties and/or limitations	Added value [3]
		○ EMEP/CEIP (2013a) for sector activity modelling ○ Literature sources (speciation per sectors)				
	Water emissions					
	Industrial releases of HM + organics	- E-PRTR (EEA, 2013a) - Waterbase (EEA, 2013b) - Eurostat (2013a)	- Method D	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 (EEA, 2013b), OECD (2013a), Eurostat (2013b)	- Method D	- 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)	- Method E	- 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 (2013b, 2013c) + Eurostat (2013c) for usage - EC (2010) for HM composition - EC (2001) for dioxins	- Method E	- 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)

Impact category	Substance groups	Data sources	Estimation technique[1]	Coverage estimate[2]	Uncertainties and/or limitations	Added value [3]
						- 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)	- Method E	- 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 (2013b) - FAOstat (2013c) for organic areas	- Method F	- 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/EurostatT data); Dosages taken for 2003 (assumed applicable to 2010); Crop data from 2010
Particulate matter/respiratory inorganics	CO, NO_X (as NO_2)	- UNFCCC (2013)	- Method T1 and T2	- 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.	-

Impact category	Substance groups	Data sources	Estimation technique[1]	Coverage estimate[2]	Uncertainties and/or limitations	Added value [3]
					- Data for Luxembourg have been taken from an average between EMEP and EEA.	
	SO$_2$, NH$_3$	- EMEP/CEIP (2013b) – 'EMEP_modeled' dataset	- Method T1	- Good	- Uncertainties arise from the different approaches adopted in the compilation of the inventories under EMEP; however are not quantified in the original datasets. Quality checks and reviews are done systematically on the datasets ensuring high quality	- Figures are updated to EU27, year 2010. - Wegener Sleeswijk et al. (2008) made use of the same data sources
	PM10, PM2.5	- EEA (2013c)	- Methods T1 and T3	- Good	- Uncertainties arise from those associated to EMEP data with the addition of estimations carried out by EEA to consolidate the EMEP dataset. Risk of double-counting in the impact assessment phase	- PM2.5 is generally not included in other normalization datasets.
	PM0.1	- EDGARv4.2 (EC-JRC/PBL, 2011)	- Method T4	- Fair	- The method builds on data of PM10 from EDGARv2.4 and speciation profiles; it is not consistent with the EEA database. PM0.1 lacks the characterization factor in ILCD	-
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) - Ecoinvent 3.01 (Weidema et al., 2013)	- Method M1	- 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 EU27, 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	- 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) (Forwood,	- Method M2	- 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 EU27, year 2010. - No other normalization datasets have included these emissions (see Wegener Sleeswijk et al., 2008; EC, 2012)

Impact category	Substance groups	Data sources	Estimation technique[1]	Coverage estimate[2]	Uncertainties and/or limitations	Added value [3]
		2008; Schneider and Marignac, 2008).				
	discharge of radionuclides from non-nuclear activities (radio-chemicals production and research facilities)	- OSPAR Commission database (OSPAR, 2013b) covering the following activities: radio-chemicals production and research facilities	- Method N	- Fair/Poor	- The OSPAR Commission collects very detailed data at Country level, however the OSPAR countries are only a fraction of EU27. Extrapolations for radiochemical productions and RTD were not done.	- Figures are updated to EU27, year 2010. - No other normalization datasets have included these emissions (see Wegener Sleeswijk et al., 2008; EC, 2012) -
	discharge of radionuclides from oil&gas industry	- OSPAR Commission database (OSPAR, 2013c) - overall oil production figures (Eurostat, 2013r)	- Method N	- Fair	- The emission factors from OSPAR have been used to estimate overall EU27 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 EU27, 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 (Weidema et al., 2013); - PRODCOM data (PRODCOM/Eurostat 2013).	- Method O	- 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 EU27, year 2010. - No other normalization datasets have included these emissions (see Wegener Sleeswijk et al., 2008; EC, 2012)
Acidification	NO_X (as NO_2)	- UNFCCC (2013)	- Method T1 and T2	- 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 an average of EMEP and EEA.	- Figures are updated to EU27, 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, 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 follows: UNFCCC > EMEP > EDGAR
	SO_2, NH_3	- EMEP/CEIP (2013b) – EMEP_modeled dataset	- Method T1	- Good	- Uncertainties are related to the level of completeness of the reported/modelled inventories to EMEP. No major gaps are found, however different tiered	- Figures are updated to EU27, year 2010. - Wegener Sleeswijk et al. (2008) made use of the same data sources

Impact category	Substance groups	Data sources	Estimation technique[1]	Coverage estimate[2]	Uncertainties and/or limitations	Added value [3]
					approaches among reporting countries may limit the accuracy of the dataset.	
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	- Fair/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. - Speciation per sectors may omit some substances	- Other normalization datasets reported NMVOC as aggregated figures
	NO$_X$ (as NO$_2$)	- UNFCCC (2013)	- Method T1 and T2	- 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 an average of EMEP and EEA.	- Figures are updated to EU27, 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, 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 follows: UNFCCC > EMEP > EDGAR
	SO$_2$	- EMEP/CEIP (2013b) – 'EMEP_modeled' dataset	- Method T1	- 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 EU27, year 2010. - Wegener Sleeswijk et al. (2008) made use of the same data sources
Terrestrial eutrophication	NO$_X$ (as NO2)	- UNFCCC (2013)	- Method T1 and T2	- 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 EU27, 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, 2012d), resoled at grid level. The same hierarchical approach used in that work for attributing priority to the emission' datasets (among UNFCCC, EMEP and

Impact category	Substance groups	Data sources	Estimation technique[1]	Coverage estimate[2]	Uncertainties and/or limitations	Added value [3]
						EDGAR) has been adopted in this work. Hence, the priority is as follows: UNFCCC > EMEP > EDGAR
	NH_3	- EMEP/CEIP (2013b) – 'EMEP_modeled' dataset	- Method T1	- 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 EU27, 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	- Methods I	- 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 EU27, 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 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	- 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 EU27, year 2010. - Wegener Sleeswijk et al. (2008) did not include emissions from sewages
Marine Eutrophication	NOx (as NO_2)	- UNFCCC (2013)	- Method T1 and T2	- Good	- Uncertainties arise from the different tiered approaches to the compilation of the inventories under the UNFCCC	- Figures are updated to EU27, year 2010.

Impact category	Substance groups	Data sources	Estimation technique[1]	Coverage estimate[2]	Uncertainties and/or limitations	Added value [3]
					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.	- 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 follows: UNFCCC > EMEP > EDGAR
	NH_3	- EMEP/CEIP (2013b) – 'EMEP_modeled' dataset	- Method T1	- 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 EU27, year 2010. - Wegener Sleeswijk et al. (2008) made use of the same data sources
	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	- Fair	- average nitrogen Input/Output ratios were used to gap-filling for some missing data points	- Figures are updated to EU27, 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 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)	- Methods I	- 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 EU27, year 2010. - Wegener Sleeswijk et al. (2008) did not include emissions from sewages

Impact category	Substance groups	Data sources	Estimation technique[1]	Coverage estimate[2]	Uncertainties and/or limitations	Added value [3]
Resource depletion, water	Gross freshwater abstraction	- Eurostat (2013i) - OECD (2013b) - FAO-Aquastat (2013)	- Methods J	- 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 EU27, year 2010. - The Water Footprint network has published data on water abstraction by country only for the year 2005.
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	- 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 EU27, year 2010. - Only "land occupation" flows were reported in ReCiPe; hence, no "land transformation" flows were included in that normalization dataset.
Resource depletion, minerals and fossils	metals	- BGS (1995, 2000, 2002, 2012) - RMG (2013) - WMD (2014)	- Method K3	- Fair/Poor	- Data gaps are very frequent in these datasets, moreover the figures are based on approximate estimations	-
	minerals	- PRODCOM (PRODCOM/Eurostat, 2013)	- Method K3	- Poor	- Volumes sold is used to monitor production and hardly reflects real extraction of materials	-
	energy carriers	- Eurostat (2013l; 2013m; 2013n; 2013o; 2013p; 2013q)	- Method K2	- Fair/Good	- The Eurostat/OECD joint questionnaire provides guidance to data collection, along with definitions and metadata. Anyhow an explicit quality assessment procedure is not mentioned in the data documentation	-
Domestic biomass production	crop residues, wood and fish, For fodder crops and grazed biomass	- Eurostat (2013d; 2013k)	- Method K1	- Fair/Poor	- Eurostat and FAO data are often non compatible, moreover yields calculated on the basis of produced biomass and cultivated lands lead to unrealistic figures	-
	crop production	- FAOstat (2013b)	- Method Q	- Fair/Poor	- Eurostat and FAO data are often non compatible, moreover yields calculated on the basis of produced biomass and cultivated lands lead to unrealistic figures	-

2.2 Uncertainty sources and limitations of present inventory

An evaluation of the robustness of the inventory is beyond scope of this document and will be provided in the documents applying this inventory in specific contexts, namely LC –indicators (Benini et al 2014a) and PEF (Benini et al 2014b) .

Nonetheless, main sources of limitations and uncertainties affecting the inventory could be listed as follows:

i. Methodological choices - both related to the data sources to be used and to the techniques to be adopted for the estimation.
ii. 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.
iii. Inconsistency between data sources, need of hierarchical approach in selecting sources, (e.g. for NOX----UNFCC (2013), EMEP reported, EMEP modelled, EDGAR etc)
iv. Data gaps/country gaps etc

In order to present an overview of the completeness of the actual inventory (coverage) and the main sources of uncertainties for each group of flows, we provide a description of main sources of uncertainty in table 1 (last column).

3 Estimation strategies and methods for data gap filling in the inventory

To overcome data limitation in existing sources, a set of methods has been defined for data gap filling. These extrapolation methods has been used for building a database ranging from 1990 to 2010 in the context of the project “Life Cycle Indicators for resource efficiency” (EC - JRC, 2012a; 2012b).

- A. NMVOC breakdown estimates
- B. Ozone-depleting substances
- C. Toxic air borne emissions
- D. Toxic water borne emissions
- E. Toxic soil borne emissions
- F. PesticidesI. Total N and total P to water
- J. Water Consumption
    - J1. Total gross freshwater abstraction
    - J2. Desalinated water production
- K. Time interpolation
    - K1. Domestic biomass production
    - K2. Resource depletion – energy
    - K3 Resource depletion – minerals and metals
- M. Ionising radiation related to energy production
    - M1. Upscaling ionizing radiation from electricity production
    - M2. Emissions of radionuclides to air and water from nuclear spent-fuel reprocessing
- N. Extrapolation of ionizing radiation discharges of radionuclides from the non-nuclear sectors
- O. Ionizing radiation emissions from gypsum plaster and ceramics end of life
- Q. Crops
- R. Land use & land use change
- S. GHG emissions
    - S1. GHG emissions - CO2, CH4, N2O
    - S2. GHG emissions - HFCs, PFCs and SF6
- T. Emissions into air
    - T1. emissions of NH3, NOx, SOx, CO, PM10, PM2.5
    - T2. estimation of missing emissions of NOx and CO
    - T3. estimation of missing emissions of PM10, PM2.5
    - T4. PM0.1 emissions

Method A – NMVOC breakdown estimates

Non-methane volatile organic compounds (NMVOC) are known to cause important damages to human health via two main pathways, viz. the direct toxic effects exerted by certain substances (i.e. human toxicity) and their indirect effects related to photochemical ozone formation (POF). To comprehensively assess the damages at national level and thus define adequate air pollution abatement policies, substance breakdowns are needed. However, these are not readily available as total NMVOC emissions are reported at sector level in available monitoring reports. A reproducible methodology for the breakdown was thus developed (see Laurent and Hauschild, 2014). 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. Details of the methodology and the resulting inventories for the years 2000-2010, performed within this project, are fully documented in Laurent and Hauschild (2014).

The total NMVOC emission data were retrieved from the European Monitoring and Evaluation Programme (EMEP) – Centre on Emission Inventories and Projections (CEIP) (EMEP/CEIP, 2013a) using “Officially reported emission data”. Data were extracted at country- and sector-disaggregated levels. 117 sectors (NFR09 codes[4]) are distinguished. Ten sectors were disregarded because they either relate to NMVOC emissions from natural

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[4] NFR09 is a Nomenclature for Reporting (NFR) format, i.e. sector classification, commonly used in Europe (United Nations Economic Commission for Europe/European Monitoring and Evaluation Programme).

sources (e.g. forest fires) or because no emissions of NMVOC are reported for any countries (10-yr time series were also checked for potential occurrences; e.g. road abrasion or tyre and break wear). Emissions in the category "7 B - Other not included in national total of the entire territory" were also disregarded.

Speciation profiles (i.e. breakdown of NMVOC single substances) were assigned to each of the 107 sectors. Speciation profiles were retrieved from different literature sources as well as from CORINAIR emission inventory reports (2007, 2009), which provide very detailed documentation on a sector basis for a number of pollutants (e.g. see CORINAIR Guidebook 2007 and 2009). Theloke and Friedrich (2007) provided a database of 86 speciation profiles for Europe using the SNAP97 code nomenclature; it was used for all sectors NFR09 1, NFR09 2 and NFR09 3. Other literature sources were used for the sectors NFR09 4 and NFR09 6.

Most of the available speciation profiles are source-oriented, e.g. for "coal combustion" processes, and do not always match the scope of the sector activities, e.g. "public electricity and heat production". A substantial number of NFR09-coded sectors thus did not link to the availability of the speciation profiles, e.g. reported in Theloke and Friedrich (2007). A framework was developed to assign combinations of several available speciation profiles based on specific activity data within the concerned sectors. Additionally, in some relevant sectors, for which activities vary considerably across countries, the generic NMVOC speciation profiles provided by Theloke and Friedrich were differentiated at country level and made time-dependent. Such regionalisation of the speciation profiles was performed on energy production sectors and on road transport-related sectors, which are important contributors to total national NMVOC emissions. Details of the methodology are available in Laurent and Hauschild (2014).

The data sets reports emission data for 11 years (2000-2010) and for each of the 27 European countries. For the new EU members, e.g. Poland, only the years after the entry into the EU are indicated. Each inventory includes 270 single substances, 52 unrefined groups of substances, "other aldehydes" or "xylenes, unspecified", and 1 category of unspecified VOCs. One correction was made to the final data sets: emissions of 1,2-dichloroethane (EDC), which were equal to zero after the inventory computation, were substituted with the available emission data from the E-PRTR database (EEA, 2013a; see Method C) as these were not null. No adjustment of the total NMVOC emissions was made following this correction (negligible impact as these emissions would represent ca. 0.01% of the total NMVOC emissions in 2010 in EU-27). Out of the recommended substances, five are not provided, viz. 2-methyl-1-propene, HCFC-140, methyl formate, R40 and tertbutyl methyl ether. No data were retrieved for them.

Method B – Ozone-depleting substances (ODS)

Emissions of ozone-depleting substances are derived using atmospheric observations. As a result, they are nearly always expressed as global emissions with no further differentiation into countries or regions, which require the use of sophisticated model accounting for the atmospheric transport of ODS. Some works have been undertaken to determine emissions of single substances for some regions or countries. The US-EPA has thus developed a bottom-up methodology relying on a vintaging model that considers market size, amount of ODS in different equipments and ODS substitution trends to estimate ODS annual emissions in the US (US-EPA 2012). Other studies have also used top-down approaches (e.g. Millet et al. 2009 for US and China, Keller et al. 2012 for some European countries), but they typically encompass a limited number of substances (for a limited period of time, e.g. one single year). "In general, estimating emissions of individual ozone-depleting substances at a country level and for individual years is highly challenging because of the inherent uncertainties in the ODS production and consumption rates that underlie these estimates. By using atmospheric observations, this problem can be circumvented. However, the currently established measurement network is not dense enough to permit top-down emission estimations at a country level (Keller, 2013). In the absence of comprehensive, readily-available sets of data, production figures from the UNEP Ozone Secretariat can thus be used to report country-specific data on ODS. These production figures are defined as the "amount of controlled substances produced, minus the amount destroyed by technologies to be approved by the Parties and minus the amount entirely used as feedstock in the manufacture of other chemicals" (paragraph 5 of Article 1 in the Montreal Protocol). Production and consumption figures are the ones used for reporting official emission inventories to the UNFCCC. Because the production of ODS has dropped dramatically to a nearly zero level whereas the ODS contained in ODS banks are still being destroyed, the balance for production figures in many European countries tend to be negative. Based on the results for

USA, in which emission-based figures determined by the US-EPA from activity data are about twice larger than consumption figures in the period 2000s (Montzka et al. 2008), an underestimation of the results can be expected (i.e. positive emissions can be expected, as indicated by e.g. Keller et al. 2012, Brunner et al. 2013).

Because the available production data from the UNEP Ozone Secretariat (negative) do not reflect actual emission data (positive), this data source was not retained. From the work undertaken in Theme 1.2 “photochemical ozone formation”, emissions of 12 ODS were determined. Emissions of 1,1,1-trichloroethane (from E-PRTR database (EEA, 2013a) see Method C) were separately reported although total emissions of trichloroethane isomers are also indicated (extracted from Method A). This will have to be considered in the impact assessment phase. For the years 1990-1999, linear regression analyses were performed based on the data sets for the years 2000-2010 for each country (see Section 2.1 for discussion on statistics). Two additional substances, i.e. HCFC-141b and HCFC-142b, were retrieved from the EDGARv4.2 database (EU-JRC/PBL (2011). Emissions span the years 1990-2008 with some gaps in 2007 and 2008. These gaps as well as the years 2009 and 2010 were extrapolated using quadratic regression (negative values obtained for DE in 2009-2010 for HCFC-141b were transformed into zero emissions). Emissions of HCFC-141b and HCFC-142b were indeed found to be parabola-like shaped, which is reflected by the regression statistics –see Table B-1. According to Fahey and Hegglin (2011), who report the global distribution of anthropogenic ODS entering the stratosphere in 2008, it can be estimated that more than 90% of the chlorine source emissions are covered by the present inventory (e.g. CFC-12, CFC-11, carbon tetrachloride, HCFC-22, CFC-113). On the other hand, a gap lies with the unreported emissions of bromine source gases (e.g. halon-1211, halon-1301, methyl bromide). Based on expert’s knowledge, about 70% of the ozone depletion potential is expected to be covered by the currently-defined emission inventory.

Table B-1. Statistical results for the quadratic regressions for HCFC-141b and HCFC-142b.

Countries	**HCFC-141b [a]**		**HCFC-142b [a]**	
	r2	**p-value**	**r2**	**p-value**
AT	0,970	1,18E-10	0,940	1,79E-10
BE	0,789	1,86E-05	0,932	4,32E-10
BG	0,784	1,03E-05	0,819	1,17E-06
CY	0,853	1,46E-06	0,892	1,90E-08
CZ	0,878	3,92E-07	0,907	5,53E-09
DK	0,786	2,05E-05	0,936	2,91E-10
EE	0,726	3,17E-05	0,950	3,85E-11
IE	0,805	1,07E-05	0,881	4,08E-08
FI	0,788	1,94E-05	0,910	4,13E-09
FR	0,789	1,84E-05	0,927	8,09E-10
DE	0,969	1,68E-10	0,943	1,16E-10
EL	0,820	6,15E-06	0,896	1,33E-08
HU	0,897	1,25E-07	0,937	2,38E-10
IT	0,969	1,49E-10	0,937	2,42E-10
LV	0,759	1,15E-05	0,945	8,26E-11
LT	0,693	7,79E-05	0,902	8,57E-09
LUXE	0,794	1,58E-05	0,926	9,45E-10
MT	0,830	4,14E-06	0,920	1,69E-09
NL	0,969	1,52E-10	0,935	3,34E-10
PL	0,969	1,52E-10	0,939	1,90E-10
PT	0,872	5,63E-07	0,898	1,21E-08
RO	0,810	3,93E-06	0,761	1,05E-05
SK	0,716	7,88E-05	0,941	1,39E-10
SI	0,866	7,84E-07	0,942	1,32E-10
ES	0,813	8,14E-06	0,894	1,62E-08
SE	0,791	1,73E-05	0,925	1,03E-09
UK	0,797	1,43E-05	0,929	6,47E-10

[a] N=16-18 data points (dependent on countries) for HCFC-141b; N=18 for HCFC-142b

Method C – Toxic airborne emissions

This method was used to determine the inventory of airborne emissions, including both organics and heavy metals (HM). Pesticides used in agriculture and ending up to air are excluded from this method (separately treated in Section 2.6, which co-jointly provide the fractions of pesticides reaching the water, air and soil compartments as well as plant surface).

The mandatory substances were reported following the figures provided by EMEP/CEIP (2012a). Emission data were retrieved for 9 HM (As, Pb, Hg, Cu, Cd, Cr, Ni, Se, Zn) and 20 organics, including PAHs, PCBs and dioxins (see Table C-1). 11 compounds, primarily pesticides such as endrin or DDT, were set to 0 as their emissions were reported either as "not applicable", "not occurring" or "not relevant"; in fact, the use of most of these compounds has been banned in Europe. Additional emission reports for a number of substances, i.e. pentabromodiphenyl ether (PentaBDE), perfluorooctane sulfonate (PFOS), polychlorinated naphthalenes (PCN), pentachlorobenzene (PeCBz), hexachlorobutadien (HCBD), octabromodiphenyl ether (OctaBDE) and short chain chlorinated paraffins (SCCP), are foreseen to be made available via the amended Protocol on Persistent Organic Pollutants (not yet entered into force; UNECE, 2010).

The EMEP/CEIP Centre provides 2 sets of emission data: the "Officially reported emission data", which are emission data that each Party is committed to report, and "emissions as used in EMEP models", where official reports undergo a 3-step gap-filling procedure[5]. In the latter, only the major pollutants are treated, i.e. 3 main heavy metals (Cd, Hg and Pb) and 3 POPs (PAH or benzo(a)pyrene, PCDD/PCDF and HCB). Some inconsistencies between the 2 sets may arise because Parties submit recalculations of their inventories, including of the previous years, each year whereas the gap-filling procedure is only applied once to the latest reporting year and thus is not updated with the most recent recalculations. For these 2 reasons, official reports were used. The completeness of "Officially reported emission data" differs from one country to another and from one sector to another (reports are provided using the NFR09 sectors nomenclature[6]). Uncertainties are strongly dependent on which aggregation level is used. Because only totals for each country are used, without further sector disaggregation, these uncertainties are believed to be negligible.

The data are provided for each year within the 2000-2010 period and for each country (for new EU members, data sets start at their date of entry to the EU). No emission data was reported for Luxembourg for the following substances: Cd, Cr, Cu, Hg, Ni, Pb, PCP, SCCP, Se and Zn. For the other substances, emissions were null. Therefore, it was assumed that emissions for those substances were also equal to zero.

Table C-1. Coverage of airborne emissions of HM and POPs in 2010 (EMEP/CEIP, 2013a)

HM	POPs covered	Banned substances (pesticides)
Arsenic	benzo(b) fluoranthene	Chlordecone
Lead	PAH	Endrin
Mercury	Polychlorinated biphenyl (PCB)	DDT
Copper	benzo(a) pyrene	PCP
Cadmium	benzo(k) fluoranthene	Toxaphene
Chromium	Dioxins	Chlordane
Nickel	Hexachlorobenzene (HCB)	Aldrin
Selenium	Hexachlorocyclohexane (HCH)	Heptachlor
Zinc	Indeno (1,2,3-cd) pyrene	Mirex
		Dieldrin
		Hexabromobiphenyl

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[5] The procedure involves the Task Force on Emission Inventories and Projections (TFEIP), the European Environmental Agency (EEA), the Centre on Emission Inventories and Projections (CEIP), and the European Topic Centre on Air and Climate Change (ETC ACC), and includes (1) an initial check of the timeliness and completeness of the Party submissions, (2) a synthesis and assessment of the consistency and comparability of the national reports followed by recommendations for data quality improvement, (3) an in-depth review at pollutant and sector levels of emissions from selected Parties.

[6] Nomenclature for Reporting (NFR09) reporting format agreed by UNECE/EMEP is documented in the 2009 UNECE/EMEP Emission Reporting Guidelines (HHUUECE/EB.AIR/97UUHH)

Excluding the pesticides (see Method F), a number of recommended/optional substances were added based on the data sets for the NMVOC and on the data from the E-PRTR database[7] (EEA, 2013a). For details on NMVOC, the reader is referred to Method B.

The additional substances from the E-PRTR database are given in Table C-2. The scope of the EMEP, which covers all industrial and non-industrial activities and transport sectors, is larger than that of the E-PRTR, which only reports chemical emissions due to specific sectors (as reported in annex I of the EU regulation 166/2006) and when those emission are above certain thresholds, as reported in Annex II of the mentioned regulation. On the other hand, the EMEP reports are related to substances having a long-range transport potential whereas the E-PRTR database does not have such restrictions on substance coverage. Therefore, the EMEP database can be expected to provide more complete data on a limited number of substances, whereas the E-PRTR can be expected to document more substances, but with less completeness in their emission reports. As a result, the E-PRTR data were disregarded in the inventory of air emissions wherever the substance was already covered in the EMEP database (i.e. the substances identified in Table C-2 are not covered by the EMEP/CEIP database). An exception includes emissions of 1,1,1-trichloroethane, which were separately reported although total emissions of trichloroethane isomers are also indicated (extracted from Method A). This will have to be considered in the impact assessment phase in order to avoid double counting.

Table C-2. Coverage of airborne emissions of organic substances from industrial sources from E-PRTR (EEA, 2013a) and not reported in EMEP database

Substances	**Country coverage**
1,1,1-trichloroethane	FR, UK
1,1,2,2-tetrachloroethane	BE, GR, UK
1,2-dichloroethane (DCE)	AT, BE, CZ, DE, ES, FR, IT, NL, NO, PL, SE, SK, UK
Anthracene	BE, ES, IT, NL, NO, UK
Di-(2-ethyl hexyl) phthalate (DEHP)	BE, CZ, ES, HU, IT, PL, UK
Ethylene oxide	DE, ES, FR, PL, SK, UK
Fluoranthene	NO
Pentachlorobenzene	BE, LU
Trichlorobenzenes (TCBs) (all isomers)	CH, FR, UK
Hydrogen cyanide (HCN)	AT, BE, CZ, DE, DK, ES, FR, HU, IT, PL, RO, SK, UK

Because the reporting of emissions from industries in the E-PRTR database is triggered by the exceedance of emission thresholds, not all countries report emissions. In addition, the same country may report emissions one year when the threshold is exceeded but not another year when emissions remain below it. It shall also be mentioned that the E-PRTR database only provides emission reports for the years 2001, 2004, 2007, 2008, 2009 and 2010.

To fill in data gaps, a relationship between process outputs and their emissions could be 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 extrapolations were performed for 2000 and for the two periods 2002-2003 and 2005-2006. For the 2 periods, linear regression was used and applied only when emissions of a specific substance was reported in both years surrounding the periods. For example, emissions of 1,2-dichloroethane (DCE) in Austria (AT) in 2002 and 2003 were extrapolated using a linear regression based on the emissions reported in 2001 and 2004. Due to variations of emissions over time, the regressions did not include the report available for other years (e.g. 2007-2010 in the previous example of DCE in AT). For the year 2000, the same emission data as for 2001 were generally used. Exceptions include those substances, for which linear regressions were available for the period 2001-2004: for those cases, the same linear regression was applied to predict the emissions in 2000 (see list of cases in Table C-3). Negative values were converted

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[7] E-PRTR was established through Regulation (EC) No 166/2006. It contains data on the main pollutant releases to air, water and land of about 28,000 industrial facilities across the European Union and EFTA countries. These data represent the total annual emission releases during normal operations and accidents.

to zero emissions (hydrogen cyanide for BE and FR). No statistical results are provided as extrapolations were generally based on 2 data points.

For the years 1990-1999, linear regression analyses were performed based on the data sets derived for the years 2000-2010 for each country and for each substance (see Method P).

Table C-3. Substance emissions extrapolated to the year 2000 (linearity with emissions 2001-2004).

Substance	Countries extrapolated
1,1,1-trichloroethane	FR
1,2-dichloroethane (DCE)	BE, DE, FR, HU, IT, NL, NO, SE, UK
Hydrogen cyanide (HCN)	AT, BE, DE, ES, FR, IT, UK
Trichlorobenzenes (TCBs) (all isomers)	DE, FR

Method D – Toxic waterborne emissions

Method D addresses the waterborne emissions from industries and non-industrial releases (excl. pharmaceuticals). Emissions of pharmaceuticals are additionally inventorized. These 3 sources are kept separate in their treatment although some of the data sources are slightly overlapping. In all, raw data are extracted from large European emission databases or from available estimates, and gap-filling procedures are applied thereafter.

Industrial emissions

Data were extracted from the E-PRTR database (version 5.0 – June 2013; EEA, 2013a), which contains information on releases from industries. It is aiming at covering more than 90% of emissions (air, water, and soil emission compartments altogether; http://prtr.ec.europa.eu/pgFAQ.aspx). Taking waterborne emissions alone, the coverage is likely to be much lower than 90%. In addition, it is unclear whether this quantified coverage refers to all the actual industrial emissions in Europe or just the fraction that is to be reported under the E-PRTR regulation (i.e. only above threshold emissions).

The emission data from the E-PRTR (EEA, 2013a) cover the years 2001, 2004, 2007-2010. The year 2011 was recently released; although it is outside the scope of the project, it was kept to increase the robustness of the extrapolation parameters (see below). Important gaps however occur in terms of country and substance coverage. A gap-filling procedure was therefore developed:

- In the E-PRTR database, a large proportion of emissions are associated with their source sector (via the facility information stored in the database). Substance emissions were thus aggregated within each combination {year-country-sector}.
- To fill in the gaps over time, the gross economic output of the sector was used as an extrapolation parameter. The gross output reflects the total sales value from a sector, and accounts for the intermediate consumption (i.e. fraction of output of an industry used as inputs in production), hence it is believed to be a better indicator than GDP (equivalent to net output) in that context. As each sector is taken independently in the extrapolation procedure, the double counting resulting from the consideration of the intermediate consumption has no influence.
- The economic data were retrieved from Eurostat (2013a) and covers most years within 1990-2010 for all countries. Some countries are associated with gaps (e.g. no data for Belgium in the 90s). However, for all EU-27 countries but Ireland and Malta, economic data are complete within the 2000-2010. It is noteworthy that some sectors are associated with large gaps for some countries and years. No correction was made, assuming that these sectors were negligible in the industrial portfolio of these countries.
- It shall be mentioned that about half of the water emissions are not linked to any sector in the E-PRTR database. Therefore, although those emissions are included in the total of their reporting year, they are not considered in the extrapolation step, thus likely to lead to some underestimations in the data sets. For the years reported in the E-PRTR, these underestimations may be counterbalanced by the existence of double counting between the extrapolated data and the unallocated emission data (which may be attributable to an extrapolated sector). No such double counting exists for the years other than the 6 reported years. Similarly, wherever no economic data was available for a given country in a given year, extrapolations were not performed.

- The E-PRTR database sector nomenclature (NACE; 247 considered sectors) was matched with the Eurostat nomenclature (NACE rev. 2; 38 sectors), resulting in a total of 30 included sectors (8 sectors disregarded because not matched with the E-PRTR database).
- Each emission, for which sectoral information was available, was normalised against the total gross output of the sector, country and year, to which that emission related to. Statistics were investigated in terms of substance-specific variations of normalised values across years, sectors and countries (i.e. standard deviations of the geometric mean). However, more refined statistical analysis should be conducted in the future (i.e. correlation between substance-, country-, year- and sector-specific emission intensities and related gross outputs, consideration of trends over time, etc.). A rough analysis of the geometric means however shows that (i) for a same sector, the variability across countries is much larger than the variability across years within a given country (likely due to the different completeness of data sets for each country-year combinations); (ii) for a fixed year and country, large variations may occur between sectors (e;g. up to several orders of magnitude); and (iii) the generic geometric means (i.e. across all years and countries for a single substance emitted from a given sector) are associated with 95th confidence intervals typically ranging within 2-3 orders of magnitude (assuming log-normal distribution of uncertainty; some substance-sector combinations above that range). For example, it is observed that there is 95% confidence that the emission intensity of zinc released from the sector 'Manufacture of basic metals and fabricated metal products' falls within a factor of 27 from the generic geometric mean (N=115).
- In addition to taking the raw emission data that were existing, extrapolations were separately performed for each substance to obtain the emissions per country and per sector for a given year and substance. 3 situations may thus arise:
    - Case 1: the normalised value was not defined for the considered country and year, but normalised values could be defined for other years (same country). In those cases, the country-specific means were applied. The substance-, sector- and country-specific geometric means (time as only variable) were combined with the gross output data for the missing years to obtain sector- and country-specific emission estimates within the time series (minus years with unavailable economic data).
    - Case 2: the normalised value was not defined for the considered country and year, and normalised values could not be defined for any other years for the country. In those situations, means aggregated over countries were applied. The substance-, sector-specific geometric means (time and reported countries as variables) were combined with the gross output data for the missing countries to obtain sector-specific emission estimates within the time series (minus years with unavailable economic data).
    - Case 3: no geometric mean was defined for the sector for any country or year. In those situations, it was assumed that no emission occurred from that sector and emissions were set to zero.

Country-, substance- and year-specific inventories were obtained by aggregating the corresponding emissions over all sectors, including the unallocated emissions for the years 2001, 2004, 2007-2010. A total of 71 substances or groups of substances were inventorized for all 27 countries but Ireland, which was left out from the extrapolations (due to no available economic data). Indications "NA" were applied for years where no emissions were reported (also considering the assumptions made in the approach –see above). Some groups of substances like total organic carbon (TOC) and total phosphorus were kept as they appear in some LCIA methods.

The E-PRTR database (EEA, 2013a) has a unique focus on industrial activities. In parallel, the Waterbase (EEA, 2013b) is another database that reports emissions to water from a variety of sources, including some of the activities reported in E-PRTR. It is unclear how much overlaps exist between the two databases. The Waterbase is more comprehensive in its scope (including all activities and not having threshold values); however, its coverage in terms of country and year is currently very limited (i.e. BE, CH, CZ, EE, FI, LT, LV, NL, RO, SE, SI, SK reported for industrial emissions). Although it should theoretically be a first choice of data source, its incomplete coverage made it considered as a second data source with regard to releases from industries. Because of the gap-filling procedure applied to the E-PRTR data, the addition of emissions reported in the Waterbase for substances already covered in the E-PRTR might bring a risk of double counting, and was thus disregarded. Only emissions of substances not covered in the E-PRTR database were added to the totals. This referred to 9 substances (1,1,2,2-tetrachloroethene; 1,1,2-trichloroethene; 1,2-Dichloroethane; Benzo(a)pyrene; Benzo(b)fluoranthene; Benzo(g,h,i)perylene; Benzo(k)fluoranthene;

Indeno(1,2,3-cd)pyrene; Para-tert-octylphenol); in the absence of data on the source types, no extrapolations were performed on those substance emission data (see Table D-1).

Non-industrial emissions (excl. pharmaceuticals)

The Waterbase (version 4 – June 2013; EEA, 2013b) was used to estimate the releases into freshwater of heavy metals and organics via wastewater. The database also includes wastewater releases from industries covered in the E-PRTR; these were addressed with care to avoid double counting.

The Waterbase is structured according to releases from: (i) point sources and (ii) diffuse sources. Sources are differentiated into several types –these are reported in Tables D-1 and D-2. Risk of double counting was avoided wherever relevant, e.g. where data available for type U1 (as total for U1x), the values of sub-types U11, U12, U13, U14 were not reported.

Table D-1. Differentiation of point sources (Waterbase codes and definitions) [a]

Code	Definitions	Further description
D0	Direct Discharges to Coastal and Transitional Water total	
G7	Point Sources to Groundwater total	
I	Industrial Waste Water Discharges total	
I3	Industrial Waste Water Treated Discharges	Only discharge of treated industrial waste water from independently operated industrial WWTPs and not that discharged from municipal treatment plants
I4	Industrial Waste Water Untreated Discharges	Refers to discharges of industrial wastewater that remain untreated
O	Other Waste Water Discharges total	
O5	Other Waste Water Treated Discharges	
O6	Other Waste Water Untreated Discharges	
PT	Point Sources to Inland Surface Water total	
R	Riverine Input to Coastal Water	
U	Urban Waste Water Discharges total	
U1	Urban Waste Water Untreated Discharges total	Refers to municipal wastewater that is collected but discharged without treatment
U11	Urban Waste Water Untreated Discharges < 2 000 p.e.	
U12	Urban Waste Water Untreated Discharges 2 000 >= p.e. <= 10 000	
U13	Urban Waste Water Untreated Discharges 10 000 > p.e.<= 100 000	
U14	Urban Waste Water Untreated Discharges > 100 000 p.e.	
U2	Urban Waste Water Treated Discharges total	Discharge of municipal waste water following treatment in an UWWTP. Such wastewater may have come originally from domestic and industrial sources.
U21	Urban Waste Water Treated Discharges < 2 000 p.e.	
U22	Urban Waste Water Treated Discharges 2 000 >= p.e. <= 10 000	
U23	Urban Waste Water Treated Discharges 10 000 > p.e.<= 100 000	
U24	Urban Waste Water Treated Discharges > 100 000 p.e.	

[a] Source: EEA (2013b)

Table D2. Differentiation of diffuse sources (Waterbase codes and definitions) [a]

Code	Definitions	Further description
NP	Total Diffuse Emissions to Inland Waters	
NP1	Agricultural Emissions	
NP2	Atmospheric Deposition	
NP3	Un-Connected Dwellings Emissions	
NP4	Urban Diffuse Emissions	Refers only to those emissions of pollutants in urban runoff that are not connected to a collecting system
NP5	Storm Overflow Emissions	Refers to discharges/emissions to a receiving water following exceedance of the storage capacity of the collecting/treatment system during heavy 'storm' rainfall
NP6	Abandoned Industrial Site Emissions	
NP7	Other Diffuse Emissions	
NP8	Background Emissions	

[a] Source: EEA (2013b)

A framework was developed to estimate releases from households and institutional/commercial activities. It relies on the assumption that releases can be defined on a per-capita basis, accounting for a differentiation into: (i) countries, and (ii) percentage of population connected to waste water treatment plants (WWTP). The emissions reported in the Waterbase are aggregated at a country level and regarded as profiles, which are normalized with the population either connected or not to WWTP. These normalized numbers are used for extrapolating to unreported countries. Figure D-1 describes the developed framework. The assumptions and data treatments are further detailed in the following sub-sections.

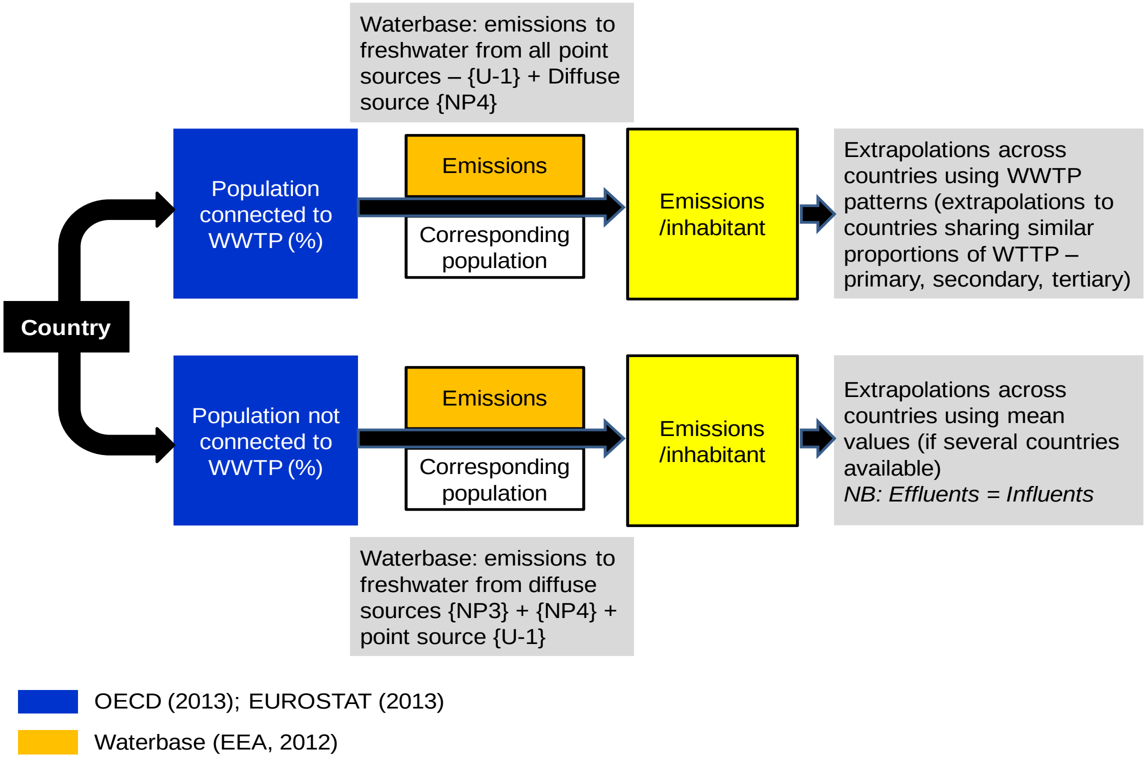

Figure D-1. Framework for estimating non-industrial waterborne emissions

Population data

Population data (mid-year) were extracted from Eurostat (2013b).

Data for the population connected to WWTP in each country and year were taken from Method I (Eurostat, 2013h). The proportions of populations connected to primary, secondary and tertiary were aggregated and regarded as the fraction of population connected to WWTP. When the totals exceeded 100% or were negative (due to extrapolations), they were brought down/up to 100% and 0%, respectively.

Waterbase raw data treatment

As Figure D-1 illustrates, emissions from the Waterbase need to be differentiated between those corresponding to the population connected to WWTP and those corresponding to direct discharges to the environment.

Using the information on the differentiation of sources, three groups of emissions were defined:

- Population connected to WWTP: emissions from all point sources U2 (treated discharges), G7 (groundwater), D0 (Coastal and Transitional Water) and O (Others; negligible). In addition the diffuse sources NP4 and NP5 (urban run-off) were included.
- Population not connected to WWTP – point sources: emissions from point sources U1 (untreated discharges).
- Population not connected to WWTP – diffuse sources: emissions from diffuse sources NP4 (urban run-off) and NP3 (unconnected population).

The rationale for dividing the emissions from unconnected population between point sources and diffuse sources stems from the paucity of data. Very few data are reported for those sources and no single country except BE reports both in the same year. An emission profile based on the aggregated data would thus result in significant gaps and lead to inconsistencies. For example, in Cucurachi et al. (2013), emission intensities for unconnected populations ended up being lower than emissions from connected population. To prevent such situations, separate profiles were therefore defined for each of these two types of sources before aggregation. Overview of data coverage is presented in Table D-3.

Table D-3. Data coverage per type of emissions sources

Type of sources	Number of substances	Covered years	Covered countries
Connected population	41	2000-2010	AT, BE, FI, EE, LT, LV, NL, RO, SK, SI, SE
Unconnected population – point sources	9	2000-2010	BE, RO, SK
Unconnected population – diffuse sources	28	2000-2008, 2010	BE, NL, SE

In the Waterbase, the report of an emission data in the E-PRTR is flagged as "Yes", "No", "Both" or with no indication. Without further knowledge, it was assumed that all flagged emissions but "Yes"-flagged ones were complementary to the E-PRTR data. Overestimations could be expected from this approach; the magnitude of the resulting bias is difficult to predict. To avoid double counting, the point sources U (as urban WW discharge total) were disregarded wherever the point sources U1 and U2 were available. The same applies to U1 and U2 for U1x and U2x (e.g. RO).

Extrapolations

All retrieved emission data were normalized by the population corresponding to each country-year combination. For example, only the population connected to WWTP was considered in the normalization of the emissions for wastewater treatment. The representativeness of the emissions was overall assumed, i.e. the emission data were considered to stem from the entire population fitting the scope of the data (e.g. population connected to WWTP). Normalised values were calculated for each of the 3 types of sources whenever emission data was available.

A similar approach to that applied to industrial emissions was defined. For each of the 3 types of sources, two sets of geometric means were calculated, viz. (i) over each individual country (considering data of all years of the given country); and (ii) over all countries considering all years (i.e. taking all data available for a substance). In addition to taking the raw emission data that were existing, extrapolations for each type of sources were performed with the following priority:

- Case 1: the normalised value was not defined for the considered country and year, but normalised values could be defined for other years (same country). In those cases, the country-specific means were applied. The substance- and country-specific geometric means (time as only variable) were combined with the population data for the missing years to obtain country-specific emission estimates within the time series.
- Case 2: the normalised value was not defined for the considered country and year, and normalised values could not be defined for any other years for the country. In those situations, means aggregated over countries and years (i.e. considering all available normalised value) were applied. The substance-specific geometric means (time and reported countries as variables) were combined with the population data for the missing countries to obtain sector-specific emission estimates within the time series.

As many countries did not report emissions, case 2, requiring the use of the overall geometric means, was the most common situation. Tables D-4, D-5, D-6 documents the different emission profiles (geometric means) used for cases 1 and 2.

With regard to unconnected population, most data points relate to heavy metals. A relatively low variability is observed for unconnected point sources (see Table D-4), with emission profiles falling within the same order of magnitude across countries. A larger variability across countries is observed for diffuse emissions of heavy metals (see Table D-5). Most organic emission profiles rely on one single data point each (i.e. NL; see Table D-5) and are hence largely uncertain. With respect to emissions from population connected to WWTP, more data are available, particularly for heavy metals (see Table D-6). However, large variability is observed across countries, with several orders of magnitude differences between the country-specific geometric means. Such large variability may be explained by important gaps in the reported emissions, e.g. if one country only covered 1% of their waterborne emissions from population connected to WWTP in their reports while another reported more than 90%. In the future, one can expect that data from more European countries and with an increasing quality and completeness should become available and should thus help strengthen the building of emission profiles. Meanwhile, it is difficult to assess to which extent the emission intensities vary across countries due to different waste water treatment structures and different geographical and societal (e.g. cultural) patterns.

When extrapolating the emissions to all countries and years, the emission profiles of unconnected population for both point and diffuse sources are summed. It can be observed from Tables D-4 to D-6 that all substances that are both reported as diffuse and point sources lead to emission intensities larger than that for connected population (e.g. see all reported heavy metals). For substances, for which only diffuse sources are reported, this is not always the case, thus resulting in underestimations. No correction was deemed suitable for mitigating these inconsistencies. Based on the emission profiles for heavy metals, more available data on direct discharges of untreated wastewater can be expected to contribute solving them.

Table D-4. Geometric means for unconnected sources – point sources [a]

Country	**BE**		**RO**		**SK**		**Total**		
Substance	**Geomean (kg/inh)**	**GSD**	**Geomean (kg/inh)**	**GSD**	**Geomean (kg/inh)**	**GSD**	**Geomean (kg/inh)**	**GSD**	**N**
Arsenic	3.6E-05	1.1	NA	NA	NA	NA	3.6E-05	1.1	9
Cadmium	1.5E-06	1.1	1.1E-05	2.1	NA	NA	2.4E-06	2.6	12
Chromium	1.4E-04	1.1	NA	NA	NA	NA	1.4E-04	1.1	9
Copper	5.8E-04	1.1	4.8E-04	1.1	NA	NA	5.6E-04	1.1	12
Cyanides (as total CN)	NA	NA	1.5E-04	1.5	NA	NA	1.5E-04	1.5	3
Lead	2.5E-04	1.1	2.4E-04	1.1	NA	NA	2.5E-04	1.1	12
Mercury	1.8E-06	1.1	9.3E-06	NA	NA	NA	2.1E-06	1.7	10
Nickel	1.2E-04	1.1	2.1E-04	1.1	1.3E-06	NA	9.4E-05	3.7	13
Zinc	1.2E-03	1.1	7.2E-03	1.5	NA	NA	1.9E-03	2.3	12

[a] Geomean: geometric mean; GSD: geometric standard deviation; N: number of data points.

Table D-5. Geometric means for unconnected sources – diffuse sources [a]

Country	**BE**		**NL**		**SE**		**Total**		
Substance	**Geomean (kg/inh)**	**GSD**	**Geomean (kg/inh)**	**GSD**	**Geomean (kg/inh)**	**GSD**	**Geomean (kg/inh)**	**GSD**	**N**
Anthracene	NA	NA	5,2E-07	NA	NA	NA	5,2E-07	NA	1
Arsenic	2,2E-05	1,2	4,6E-05	NA	NA	NA	2,4E-05	1,3	10
Benzene	NA	NA	1,9E-06	NA	NA	NA	1,9E-06	NA	1
Benzo(a)pyrene	NA	NA	5,3E-07	NA	NA	NA	5,3E-07	NA	1
Benzo(b)fluoranthene	NA	NA	1,6E-06	NA	NA	NA	1,6E-06	NA	1
Benzo(g,h,i)perylene	NA	NA	1,0E-06	NA	NA	NA	1,0E-06	NA	1
Benzo(k)fluoranthene	NA	NA	5,3E-07	NA	NA	NA	5,3E-07	NA	1
Cadmium	9,0E-07	1,2	1,4E-05	NA	5,3E-04	1,0	3,3E-06	12,3	12
Carbamazepin	NA	NA	2,6E-05	NA	NA	NA	2,6E-05	NA	1
Chromium	8,4E-05	1,2	4,6E-05	NA	NA	NA	7,9E-05	1,3	10
Copper	3,6E-04	1,2	1,6E-03	NA	3,8E-02	1,3	8,8E-04	6,2	12
Di (2-ethylhexyl) phthalate (DEHP)	NA	NA	2,7E-04	NA	NA	NA	2,7E-04	NA	1
Dichloromethane	NA	NA	1,4E-04	NA	NA	NA	1,4E-04	NA	1
Diclofenac	NA	NA	1,4E-05	NA	NA	NA	1,4E-05	NA	1
Fluoranthene	NA	NA	6,3E-06	NA	NA	NA	6,3E-06	NA	1
Hexachlorobenzene (HCB)	NA	NA	2,3E-07	NA	NA	NA	2,3E-07	NA	1
Indeno(1,2,3-cd)pyrene	NA	NA	5,3E-07	NA	NA	NA	5,3E-07	NA	1
Lead	1,5E-04	1,2	1,8E-04	NA	1,6E-02	NA	2,4E-04	4,1	11
Mercury	1,1E-06	1,2	3,8E-06	NA	6,9E-05	1,5	2,4E-06	5,0	12
Naphthalene	NA	NA	7,6E-06	NA	NA	NA	7,6E-06	NA	1
Nickel	7,1E-05	1,2	1,2E-04	NA	6,0E-03	NA	1,1E-04	3,8	11

Country	BE		NL		SE		Total		
Pentachlorophenol	NA	NA	1,6E-06	NA	NA	NA	1,6E-06	NA	1
Polyaromatic hydro-carbons (PAH) (sum)	NA	NA	3,1E-06	NA	NA	NA	3,1E-06	NA	1
Sulfamethoxazole	NA	NA	1,7E-05	NA	NA	NA	1,7E-05	NA	1
Tetrachloromethane	NA	NA	6,1E-06	NA	NA	NA	6,1E-06	NA	1
Toluene	NA	NA	4,4E-05	NA	NA	NA	4,4E-05	NA	1
Trichloromethane	NA	NA	3,4E-05	NA	NA	NA	3,4E-05	NA	1
Zinc	7,6E-04	1,2	2,3E-03	NA	1,1E-01	1,2	1,9E-03	6,8	12

[a] Geomean: geometric mean; GSD: geometric standard deviation; N: number of data points.

Table D-6. Geometric means for connected population (total means) [a]

Substance	Geomean (kg/inh)	GSD	N
1,1,2,2-tetrachloroethene	1,4E-04	27,3	4
1,1,2-trichloroethene	6,3E-06	13,3	5
1,2-dichloroethane	8,0E-06	2,0	4
Adsorbable organic halogens (AOX)	1,6E-04	9,9	10
Aldrin	1,2E-12	NA	1
Anthracene	9,2E-07	8,5	4
Arsenic	1,5E-05	7,8	19
Atrazine	2,7E-08	NA	1
Benzene	1,2E-04	1,2	3
Benzo(a)pyrene	1,6E-06	7,9	3
Benzo(b)fluoranthene	2,1E-06	4,9	3
Benzo(g,h,i)perylene	1,1E-06	10,9	3
Benzo(k)fluoranthene	1,1E-06	8,4	3
Cadmium	1,4E-06	19,7	37
Carbamazephin [b]	5,9E-05	1,0	2
Chromium	5,6E-05	5,2	23
Copper	1,3E-04	32,7	38
Cyanides (as total CN)	3,7E-05	19,8	7
Di (2-ethylhexyl) phthalate (DEHP)	1,9E-05	4,1	8
Dichloromethane	4,0E-05	1,7	4
Diclofenac [b]	2,0E-05	1,0	2
Dieldrin	1,5E-10	NA	1
Diuron	9,4E-09	13,9	2
Endrin	8,1E-11	NA	1
Fluoranthene	4,9E-06	9,4	4
Hexachlorobenzene (HCB)	1,3E-07	1,0	3
Hexachlorobutadiene (HCBD)	1,9E-08	1,4	3
Indeno(1,2,3-cd)pyrene	9,4E-07	5,2	3
Isoproturon	4,7E-07	NA	1
Lead	1,9E-05	17,2	38
Mercury	6,5E-07	18,9	32
Naphthalene	4,7E-06	34,9	5
Nickel	6,3E-05	23,0	38
Pentachlorophenol	7,3E-06	1,1	3
Polyaromatic hydro-carbons (PAH) (sum)	1,9E-07	32,0	6
Simazine	1,1E-07	1,1	2
Sulfamethoxazole [b]	1,6E-05	1,0	2
Tetrachloromethane	1,7E-06	1,1	4
Toluene	1,7E-05	1,8	3
Trichloromethane	3,4E-06	8,5	6
Zinc	7,7E-04	28,1	38

[a] Geomean: geometric mean; GSD: geometric standard deviation; N: number of data points.

[b] Emissions of Carbamazephin, Diclofenac and Sulfamethoxazole were disregarded here. Estimates from the method applied to pharmaceuticals were priviledged (see related section).

Emissions of pharmaceuticals

A similar approach as that applied to non-industrial emissions was used. The emissions of pharmaceuticals were estimated from sales data and assumptions with regard to the degradation in human body and removal rates in wastewater treatment plants. The obtained emissions were normalised by the population in the country and year reflected by the sales data. This led to generate normalised profiles, from which means could be calculated and used the same way as for non-industrial emissions.

Emissions of pharmaceuticals were estimated from sales data. These data were extracted from Larsen et al. (2009) and originally referred to Kümmerer (2008), Ternes and Joss (2006), and Williams (2003). Data were available for few countries (AT, FI, FR, DE, ES, SE, UK) in selected years (1995, 1997-1999, 2001-2003, 2005). A total of 19 substances are covered although not all countries reported their sales (and not every year). For example, for some substances, only sales for one country in a specific year could be retrieved. The sales data in a given year and country were assumed to be equal to the consumption data within the same year and country, thus disregarding any influence from stock use, carry-over and imports/exports.

No degradation in the human body was assumed, meaning that 100% of the consumed pharmaceuticals is assumed to end up in the sewage (Larsen et al. 2009). This of course is a conservative estimate and could be refined depending on the usage and action mode of each pharmaceutical. It also does not account for the fraction of pharmaceuticals that is unused, unwanted or expired, which may not enter the sewage system (Cook et al. 2012). Removal rates in WWTP were taken from a variety of literature sources –see Table D-7. It is noteworthy that large variations occur between removal rates for a given pharmaceutical depending on the type of wastewater treatment (Verlacchi et al. 2012). Therefore large uncertainties are expected from the removal rates considered in this study.

Table D-7. Removal rates and generic emission profile for pharmaceuticals in Europe

Substance	Input to sewage	Removal rates		Generic emission profile		
		Value or mean (%)	References	Geomean [a](kg/inh)	GSD [a]	N [a]
17α-ethynyl estradiol (EE2)	100%	71%	Habibi et al. 2009	7,28E-08	9,9	5
17β-estradiol (E2)	100%	88%	Habibi et al. 2009	2,09E-06	NA	1
Atenolol	100%	26%	Igos et al. 2012; Rosal et al. 2010	1,66E-04	3,1	2
Bezafibrate	100%	9%	Rosal et al. 2010	2,18E-04	2,6	5
Carbamazephin	100%	0%	Igos et al. 2012; Rosal et al. 2010; Miao et al. 2005; Gao et al. 2012	7,42E-04	1,4	6
Clarithromycin	100%	0%	Igos et al. 2012	8,69E-05	NA	1
Clindamycin	100%	0%	Verlicchi et al. 2012	1,95E-04	NA	1
Clofibric acid	100%	54%	Rosal et al. 2010	5,29E-05	1,3	2
Diclofenac	100%	15%	Rosal et al. 2010; Gros et al. 2012; Igos et al. 2012	3,47E-04	1,9	6
Erythromycin	100%	4%	Rosal et al. 2010	2,23E-04	NA	1
Ibuprofen	100%	93%	Rosal et al. 2010; Gros et al. 2012	2,53E-04	2,8	6
Iopamidol	100%	70%	Petrovic and Barcelo, 2007	1,57E-04	NA	1
Iopromid	100%	38%	Verlicchi et al. 2012	7,26E-04	1,4	3
Metoprolol	100%	7%	Rosal et al. 2010	1,28E-04	NA	1
Naproxen	100%	73%	Rosal et al. 2010; Gros et al. 2012	4,08E-04	NA	1
Propanolol	100%	1%	Rosal et al. 2010	1,87E-04	3,1	2
Roxithromycin	100%	20%	Verlicchi et al. 2012	2,25E-05	5,8	6
Sotalol	100%	50%	Verlicchi et al. 2012	7,21E-05	NA	1
Sulfamethoxazole	100%	49%	Rosal et al. 2010; Gros et al. 2012; Igos et al. 2012	1,32E-04	2,0	5

[a] Geomean: geometric mean; GSD: geometric standard deviation; N: number of data points.

Extrapolations to other countries and years were made by using the same priority order than that of non-industrial emissions (see above section). In short, normalised values were used wherever available. If not, the country-specific or otherwise the generic geometric means were considered. These emission profiles were combined with population data extracted from Eurostat (2013b).

As indicated in Table D-6, Carbamazephin, Diclofenac and Sulfamethoxazole were also reported in the Waterbase. However, the estimated releases using the latter data led to emissions about 1-2 orders of magnitude lower than that derived using the sales data. The data sets for these substances in the Waterbase are only limited to 2 data points each and are thus not believed to be representative. Therefore, the estimates from the sales data were privileged.

Future research will focus on including pharmacokinetic towards more realistic emission estimations.

Method E – Toxic soil borne emissions

Method E is applied to soil borne emissions, which primarily stem from use of sewage sludge and manure on agricultural land. Additional emissions to soil from industries are also documented here although the coverage impacts a few countries.

No comprehensive emission data are directly available for emissions from sludge and manure management. The core of the method thus consists in quantifying the flows of sewage sludge and manure that are used on agricultural land, and in coupling them with typical concentrations of specific substances to obtain emission figures. Details are separately provided for both sewage sludge and manure management.

Emissions from sewage sludge applied to agricultural soil

Quantity of sewage sludge applied to land

A number of countries allow the use of sewage sludge as soil amendment (after specific treatment as its direct use is banned in most EU countries). This can be a potential source of releases of organic chemicals and HM.

Three major sources were used to obtain raw data. A major part of the data on the use of sewage sludge applied to agricultural land between 1998 and 2009 was retrieved at country level from Eurostat (2013c). For 2009 and 2010, values from Waterbase (EEA, 2013b) were considered wherever available. When both Eurostat and Waterbase reported amounts of sewage sludge used on agricultural land for a same year and country, the value from Waterbase was privileged (a good match was typically obtained). Finally, these data were complemented by reported figures from the Global Atlas of Excreta, Wastewater sludge and biosolids management (LeBlanc et al., 2008). The use of the latter was limited to providing information for Hungary and Finland over the period 2004-2006.

Data collected from these three sources still left a number of gaps, i.e. missing combinations {country-year}, in the data set that aims to report emission data for the period 1990-2010. A gap-filling procedure was therefore applied.

No robust extrapolation parameter was found. For example, data on the total produced amount of sewage sludge, which could have been used as proxy by assuming a same or progressive proportion being applied on land every year, contain the same gaps {country-year} as the current data sets and are thus useless. Linear regression was therefore used.

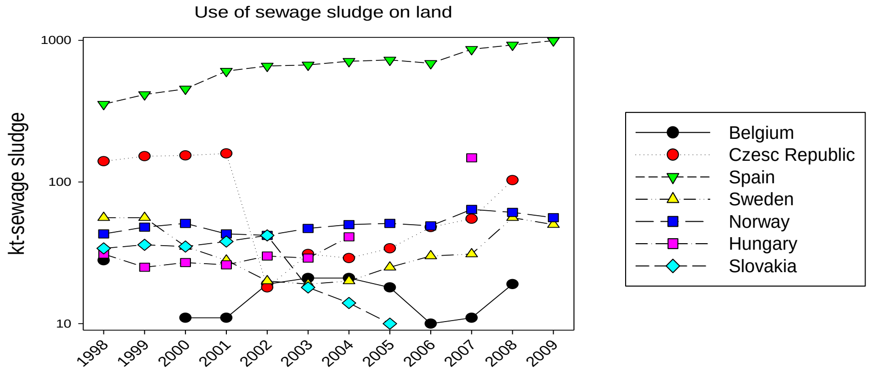

Figure E-1. Use of sewage sludge on agricultural land for selected European countries (raw data from Eurostat, 2013c)

The analysis of the available data shows that the amounts of sewage sludge applied to agricultural land can vary considerably from one year to another in a given country –see illustrative Figure E-1 (log-scale used). To limit the influence of the large variations over time, which may generate biases in the extrapolated figures, gaps were thus filled in by using truncated sets of data, and not the entire data sets available within the period 1998-2010. Gaps were classified in three groups: (1) gaps surrounded by years for which data were available (e.g. 2004 with data in 2003 and 2005), (2) gaps for which not data were available in preceding years (e.g. 1999, with no data in 1998), (3) gaps for which no data were available in following years (e.g. 2009, with no data in 2010).

- Case (1): gaps were filled in only assuming linearity over time with the borders of the gaps, i.e. between the last and the first year surrounding the gaps.
- Case (2): This case mainly refer to the years 1990-1997. For the linear regression, data limited to the time series 1998-2000 (3 data points) was used as first priority to capture trends representative of the use of sewage sludge in the 90s. Some regulations and/or voluntary measures on the use of sewage sludge were developed in the late 90s-beginning 2000 in several countries (e.g. UK, FR; EC, 2010) and may have impacted the quantities of sewage sludge used. When data were not available for those 3 years, the available time series was considered. See Table E-1 for details on statistics for linear regression.
- Case (3): Linear regression was used on the data available for the years within 2000-2010 –see Table E-1 for details on statistics.

A number of assumptions and specific treatments were also made in the data sets.

- For Malta and the Netherlands, the use of sewage sludge on agricultural land has been banned (e.g. 1991 for NL). In spite of uncertainties for some years, e.g. NL in 1990, zero values were reported for these 2 countries for the entire period 1990-2010. For Greece, reported values in the period 1998-2009 are also null; the entire period 1990-2010 was thus assumed to include no use of sewage sludge on agricultural land.
- In few cases, the use of linear regression led to negative values, e.g. in the 1990s. These negative values were substituted with zero values assuming no use of sewage sludge on agricultural land.
- For Italy and Portugal, only 2 values for each could be retrieved (2005 and 2010, and 2007 and 2009, respectively). The values for 2005 and 2007 were used as proxy for all other years.
- In Eurostat, data for the United Kingdom are reported as the sum of data for England and Wales, Scotland and North Ireland. Extrapolations were performed on each region individually and results were summed up to the UK level.

Table E-1. Linear regression parameters and statistical results for sewage sludge applied to agricultural land in 1990-2010 in Europe

Country	**Case (2)** [a]	**r2**	**p-value**	**Case (3)** [a]	**r2**	**p-value**
Belgium	1998-2000	NA	NA	2000-2010	NA	NA
Bulgaria	1998-2000	NA	NA	2006-2009	NA	NA
Czech Republic	1998-2000	0,9	0,249	2002-2008	NA	NA
Denmark	1998-2000	NA	NA	2004-2008	NA	NA
Germany	1998-2000	NA	NA	2000-2008	0,25	0,2
Estonia	2005-2008	0,6	0,225	Zero values	NA	NA
Ireland	1999-2001	1,0	0,091	2000-2007	1,00	<0.001
Greece	Zero values	NA	NA	Zero values	NA	NA
Spain	1998-2000	1,0	0,073	2000-2009	NA	NA
France	1998-2000	NA	NA	2000-2008	NA	NA
Italy	2005 value assumed every year	NA	NA	2005 value assumed every year	NA	NA
Cyprus	2004-2007	1,0	0,017	2004-2007	0,21	0,017
Latvia	2002-2007	0,3	0,238	2002-2007	0,29	0,238
Lithuania	2005-2009	0,0	0,704	2005-2009	0,00	0,704
Luxembourg	1999-2001	NA	NA	2003-2008	NA	NA
Hungary	1998-2000	0,4	0,546	2000-2007	0,66	0,042
Malta	Zero values	NA	NA	Zero values	NA	NA
Netherlands	Zero values	NA	NA	Zero values	NA	NA
Austria	1998-2000	NA	NA	2000-2008	NA	NA
Poland	2000-2002	0,7	0,398	2000-2009	NA	NA
Portugal	2007 value assumed every year	NA	NA	2007 value assumed every year	NA	NA
Romania	2005-2009	0,2	0,308	Zero values	NA	NA
Slovenia	1998-2000	0,8	0,333	Zero values	NA	NA
Slovakia	1998-2000	0,3	0,667	Zero values	NA	NA
Finland	1998-2000	0,6	0,454	2000-2005	0,65	0,004
Sweden	1998-2000	0,8	0,333	2000-2009	NA	NA
United Kingdom	Sum of England, Scotland and North Ireland	NA	NA	Sum of England, Scotland and North Ireland	NA	NA
England and Wales	1998-2000	0,7	0,340	2000-2008	0,93	<0.001
Scotland	1998-2000	NA	NA	2000-2005	0,03	0,75
Northern Ireland (UK)	1998-2000	NA	NA	2000-2009	0,39	0,055

[a] Numbers of data points for each country are reflected by the number of years in the indicated time period.

Concentrations of pollutants in sewage sludge applied to land

Typical concentrations of 7 heavy metals (Zn, Cu, Pb, Ni, Cr, Hg, Cd) were retrieved at a country level from a report by the EU Commission (EC, 2010). These heavy metals (HM) concentration profiles were collected for the reference year 2005/2006. It is assumed that they are valid for the entire time series. Profiles are missing for a number of countries (altogether representing 9.2% of the total sewage sludge applied in the EU-27 countries in 2009/2010); they were assumed similar to the profile of other countries that share similar regulations with regard to concentration thresholds of heavy metals in sewage sludge applied to agricultural land (data on thresholds also reported in EC 2010).

- Germany's profile was thus taken representative for Austria (same ranges of threshold and same policy towards banning the use of sewage sludge on land)
- Danish profile was assumed identical to Slovenia (Denmark has the most stringent regulations in the EU and Slovenia has overall the lowest thresholds among the reported countries)
- Cyprus's profile was taken representative of Greece and Luxembourg (thresholds are among the highest, and the poor state of the sludge policy in LU is confirmed in EC, 2010)
- Ireland is modelled as Spain (same regulations)
- Romania is modelled as Poland (closest regulations).

Up-to-date concentrations of organics in sewage sludge applied to land is more difficult to obtain and most available data are reported per group of substances (e.g. adsorbable organic halogens, AOX). Only dioxins were thus included based on the report by the EU Commission (EC, 2001) with an average value assumed to be 20 ng/kg-dry-matter. The used concentration is assumed the same in all countries and for all years; the original data referred to measurements in few countries, i.e. DE, DK, SE and UK, and referred to early-mid 90s investigations.

Use of manure on agricultural soil

Manure used as fertilizers on agricultural land can be a substantial source of heavy metals and other chemical compounds, in particular because of mineral additives in feedstock for animals. Pig manure and slurry is thus typically associated with high levels of zinc and copper (Amlinger et al. 2004).

The use of manure applied to agricultural land is documented at a country level by the FAOstat database (FAOstat 2013a). The soil manure figures are reported as ton N-content for 9 different animal types (see Table E-2). To match the available chemical composition data expressed per dry matter (dm) weight, the content of nitrogen needs to be evaluated. Data for solid manure retrieved from Chambers et al. (2001) on the management of livestock manures on land in the UK were used for that purpose; these data could be differentiated according to the 9 types of livestock considered. Heavy metals concentrations were extracted from Amlinger et al. (2004), who reported ranges of mean concentrations for 10 countries among the EU-27 (AT, BE, DK, FI, FR, DE, IT, LU, NL, UK). Without further specifications, averages of the ranges provided were taken. In the absence of data, no time differentiation was considered. Uncertainties may stem from this approach.

Manure is typically reported to contain residuals of veterinary pharmaceuticals that are used to prevent or control diseases as well as manage reproductive and growth processes. Many antibiotics, which are among the most widely used drugs for animals, are poorly absorbed or deteriorated in the animal body and a large fraction end up in the excretion, either as the parent compound or as metabolites (Sarmah et al., 2006). Several of these active substances are highlighted in Sarmah et al. (2006). However, only data for chlortetracycline (CTC) and tetracycline (TC) could be retrieved with respect to their concentrations in manure (Hamscher et al. 2002). These 2 substances were thus included in the inventory. No time or country differentiation in the concentration data was performed. The measurements reported by Hamscher et al. (2002) however show that the same concentrations in manure were obtained in the two separate tests conducted in 2000 and 2001.

Table E-2 provides an overview of the background data per type of livestock.

The combination of manure data and pollutant concentrations led to country-specific, year specific emission inventories. However, manure data were missing for a few countries in few years within the 90s –see Table E-3. To fill in the gaps, linear regressions on the inventory were performed for each substance based on the available data sets within 1990-2010. Relatively good statistical results were obtained for all countries/substances, except for Luxembourg.

Table E-2. Nitrogen content and concentrations of heavy metals and organics in manure

Animal types	**Nitrogen content (ton-N/ton-dm)**	**Concentrations (mg/kg-dm)**									
		Cd	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**	**As**	**CTC**	**TC**
Buffaloes	2.40E-02	0.49	30.5	46.5	0.21	25.5	11.5	228	1.22	0.1	4.0
Chickens	5.33E-02	1.52	8.7	99	0.085	19.05	16.2	469	0.69	0.1	4.0
Dairy cattle	2.40E-02	0.49	30.5	46.5	0.21	25.5	11.5	228	1.22	0.1	4.0
Ducks	2.60E-02	1.52	8.7	99	0.085	19.05	16.2	469	0.69	0.1	4.0
Goats	2.40E-02	0.345	33.15	33.5	0.17	11.4	15.7	155.5	1.82	0.1	4.0
Non-dairy cattle	2.40E-02	0.49	30.5	46.5	0.21	25.5	11.5	228	1.22	0.1	4.0
Pigs	2.80E-02	0.715	12.22	508	0.04	16.35	10.85	1091	*0.675*	0.1	4.0
Sheep	2.40E-02	0.345	33.15	33.5	0.17	11.4	15.7	155.5	1.82	0.1	4.0
Turkeys/broilers	5.00E-02	1.52	8.7	99	0.085	19.05	16.2	469	0.69	0.1	4.0

Table E-3. Statistical results for the linear regressions performed in the 90s for affected countries.

Countries	**Missing years**	**r-square [a]**									
		Cd	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**	**As**	**CTC**	**TC**
Belgium	1990-1999	0.765	0.842	0.653	0.854	0.822	0.799	0.698	0.829	0.800	0.800
Czech Republic	1990-1992	0.929	0.917	0.947	0.878	0.933	0.940	0.965	0.928	0.952	0.952
Estonia	1990-1991	0.614	0.669	0.405	0.688	0.655	0.635	0.488	0.658	0.630	0.630
Latvia	1990-1991	0.479	0.512	0.429	0.516	0.505	0.495	0.454	0.507	0.496	0.496
Lithuania	1990-1991	0.526	0.616	0.490	0.616	0.597	0.573	0.519	0.604	0.583	0.583
Luxembourg	1990-1999	0.117	0.133	0.002	0.132	0.131	0.127	0.080	0.132	0.130	0.130
Slovakia	1990-1992	0.844	0.924	0.966	0.896	0.915	0.898	0.956	0.918	0.923	0.923
Slovenia	1990-1991	0.810	0.748	0.383	0.750	0.799	0.803	0.548	0.777	0.781	0.781

[a] p-values were all below 0.005 except for Luxembourg (ranges: 0.270 – 0.900).

Industrial releases to soil

As indicated in Method C (airborne emissions), the reporting of emissions from industries in the E-PRTR database is triggered by the exceedance of emission thresholds, and not all countries thus report emissions (EEA, 2013a). In addition, the same country may report emissions one year when the threshold is exceeded but not another year when emissions remain below it. It shall also be mentioned that the E-PRTR database only provides soilborne emission reports for the years 2007, 2008, 2009 and 2010. A number of 28 substances or groups of substances are listed. Groups of substances, such as polycyclic aromatic hydrocarbons (PAHs) or polychlorinated biphenyls (PCBs), were kept in the inventory as some LCIA methods allow their impact assessment.

To fill in data gaps, the same approach as in Method C was applied. Although a relationship between process outputs and their emissions could be investigated, such correlation would be time-dependent because of continuous incentives to reduce pollution. As indicated in Table E-4, the scopes of the data sets are very limited in terms of covered countries and years, hence rendering the find of such a relationship even more uncertain. Large variations occur from year to another, often with emission intensities differing by more than one order of magnitude (e.g. chromium emissions from UK in 2007-2009). Linear regression was thus not considered (trials gave very poor statistical results; data not shown). As a substitute, the geometric means of the available data points (calculated per country and substance) were taken as proxy for the considered countries. These means were used to fill in the gaps within the period 1990-2010. By this procedure, it is assumed that the mean acts as a proxy for the sum of the unreported activities (below threshold) in the period 2007-2010 where data are not indicated. It is believed that the farther back in time from 2007, the larger the uncertainties are with respect to these proxies (because of, e.g., different regulations, closure/opening of new facilities or industrial activities, limited technology efficiencies, etc.). Unreported countries were disregarded from the inventory, and the specification 'NA' (data not available) was applied to those in the final data set.

Table E-4. Geometric means for industrial soilborne emissions in the period 2007-2010 [a, b]

Substances/Country	**BG**	**CZ**	**DE**	**ES**	**FR**	**PL**	**PT**	**SK**	**UK**
1,2-dichloroethane (DCE)	NA	NA	NA	NA	8.4E+02	NA	NA	NA	NA
1,1,1-trichloroethane	NA	NA	NA	NA	NA	NA	NA	NA	NA
Anthracene	NA	NA	NA	NA	NA	NA	NA	2.5E+00	NA
Arsenic and compounds (as As)	NA	1.5E+01	8.7E+01	NA	5.5E+02	NA	NA	4.5E+01	4.9E+01
Benzo(g,h,i)perylene	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cadmium and compounds (as Cd)	NA	NA	9.3E+00	5.2E+00	3.8E+02	7.1E+00	3.2E+01	2.3E+01	2.1E+02
Chlorides (as total Cl)	NA	NA	6.1E+08	NA	3.1E+06	NA	NA	NA	NA
Chromium and compounds (as Cr)	NA	6.2E+03	1.1E+02	5.3E+01	1.0E+04	2.0E+02	NA	2.1E+02	3.2E+02
Copper and compounds (as Cu)	NA	9.3E+02	2.6E+03	3.2E+02	6.5E+04	4.5E+02	NA	2.9E+02	6.2E+03
Dichloromethane (DCM)	NA	1.4E+04	NA	NA	NA	NA	NA	NA	NA
Diuron	NA	NA	NA	NA	4.8E+00	NA	NA	NA	NA
Fluoranthene	NA	NA	NA	NA	NA	NA	NA	NA	NA
Halogenated organic compounds (as AOX)	NA	NA	1.0E+03	NA	NA	NA	NA	2.9E+03	NA
Hexabromobiphenyl	NA	NA	NA	NA	4.1E+00	NA	NA	NA	NA
Lead and compounds (as Pb)	NA	1.9E+02	8.9E+01	6.3E+01	1.9E+04	1.1E+02	NA	6.4E+02	1.8E+03
Mercury and compounds (as Hg)	NA	NA	NA	NA	1.6E+02	1.1E+00	NA	3.7E+00	1.1E+01
Naphthalene	NA	NA	NA	NA	NA	NA	NA	1.5E+01	NA
Nickel and compounds (as Ni)	3.7E+01	2.9E+03	2.4E+02	5.2E+01	5.9E+03	9.0E+01	NA	1.0E+02	6.3E+02
Octylphenols and Octylphenol ethoxylates	NA	NA	NA	NA	NA	NA	NA	NA	NA
Organotin compounds (as total Sn)	NA	NA	NA	NA	NA	NA	NA	2.6E+03	NA
PCDD + PCDF (dioxins + furans) (as Teq)	NA	NA	NA	NA	NA	NA	NA	2.0E-02	NA
Phenols (as total C)	NA	NA	NA	NA	NA	NA	NA	8.3E+01	3.7E+02
Polychlorinated biphenyls (PCBs)	NA	3.9E-01	NA	NA	4.5E+01	NA	NA	1.0E-01	NA
Polycyclic aromatic hydrocarbons (PAHs)	NA	NA	NA	NA	1.9E+01	NA	NA	6.4E+01	8.3E+01
Tetrachloroethylene (PER)	NA	NA	NA	NA	NA	NA	NA	NA	NA
Trichlorobenzenes (TCBs) (all isomers)	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vinyl chloride	NA	NA	NA	NA	1.2E+01	NA	NA	NA	NA
Zinc and compounds (as Zn)	NA	NA	1.2E+03	1.9E+03	2.1E+05	2.5E+03	NA	7.5E+02	2.4E+04

[a] Color-coding indicates the number of reported year in 2007-2010, i.e. 1 (salmon fill), 2 (green fill), 3 (blue fill) and 4 (purple fill).

[b] Geometric standard deviations were also calculated for 4-point data sets (10 values for France and one value each for DE and SK). Ranges between 1.3 and 1.8 were obtained for all points but FR-PCB (5.3), FR-PAH (2.6) and DE-Zn (3.6) (notation: 'country_code-substance').

Method F – Pesticides

Method F addresses the emissions of pesticides. Because of commercial interests between the chemical producing companies, sale, use or emission data at the level of single substances or active ingredients (AI), which are necessary for risk assessments or life cycle assessment, are typically not available. Data are often limited to target class totals (e.g. total mass of fungicides or insecticides) and sometimes chemical classes (e.g. mass of triazoles or organophosphorus). Extrapolations are therefore needed. A generic and comprehensive framework was therefore developed. It allows estimating fractions of applied pesticides reaching environmental media/crops (viz. air, soil, surface water and plant) as input to quantify pesticide emissions/crop residues for any region/country from different levels of publicly available data. The outcome of the framework should support both risk assessment (RA) and life cycle assessments in the quantification of impacts on human health (e.g. ingestion following plant uptake or groundwater contamination, inhalation following spreading to the air) and ecosystems (ecotoxicity for terrestrial and aquatic organisms, etc.).

Although not all the components of the framework are fully operational, it has been applied to determine the emissions of active ingredients for EU-27 countries for the years 1990-2010 based on an EC study (EC, 2007). The developed framework is part of a scientific article in preparation (Fantke et al. 2014).

Framework

The framework is designed to assist the quantification of pesticide fractions starting from different levels of publicly available data. Figure F-1 provides an overview of the framework. The ideal set of data is illustrated by the white boxes, which define the different input data required. The grey boxes are extrapolation steps that should be followed in the absence of data. Detailed guidance is provided for each of them in the following sub-sections.

It should be noted that the emission inventories for EU-27 countries as documented in the following section will be refined for the years 2000-2010 at a later stage, i.e. when the entire framework is established, including default values and recommendations based on the detailed application data from the UK (FERA 2013) and California (CPDR 2013). Current gaps in recommended default values for some key extrapolation steps (e.g. step (d)) prevent the full application of the framework to the EU-27 countries.

Our defined starting point is a given crop (wheat, etc.) or crop type (cereals, etc.). We, hence, start our extrapolation scheme by looking at crop production area and then move to pesticides applied to that crop (type). In case a list of substances or application data are not crop (type)-specific, they need to be allocated (Figure F-1, indicated with ***). For a given list of pesticides, we recommend to check for each substance in a considered location/country whether it is authorized for use on the given crop according to national regulatory databases (e.g. BVL, 2013; FOAG, 2013). For given application data, we recommend to start from target class/chemical class combinations and find all pesticides belonging to these classes by looking into public databases (Kegley et al., 2011; Wood, 2013), before checking the authorization status of these pesticides for a given crop as described above. After pesticides have been allocated to crops/crop types, further extrapolation steps might be required as described in the following. In our recommendations for RA we assume worst-case scenarios, whereas for LCA we assume best estimates based on average values. Given the purpose of the present project, best estimates are adopted.

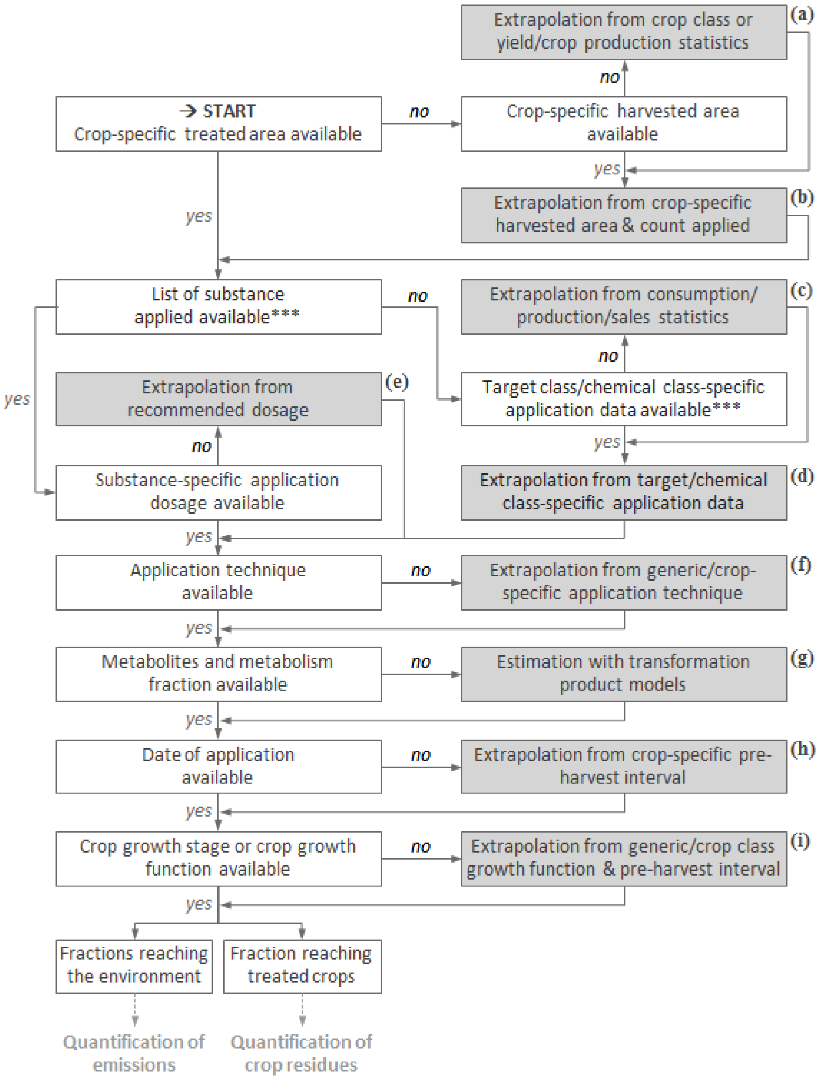

Figure F-1. Schematic workflow for quantifying fractions reaching environmental media and crops from applied pesticide masses as input for calculating emission inventories and crop residues based on different levels of data availability with 9 possible data extrapolation steps (a – i). ***Crop allocation required.

(a) Extrapolation of crop-specific harvested area from crop class or yield/crop production statistics

Crop-specific harvested areas are essential to quantitatively assess agro-economic aspects and are usually available at country level for several crops and crop classes (FAOstat, 2013b; Eurostat, 2013d; EC, 2007). For spatial levels like municipal or county level, harvested areas are often reported by national authorities (e.g. NASS, 2013; ISTAT, 2013). If harvested areas are missing for specific crops, they can be derived from crop yield and production statistics, which are usually reported along with harvested area. We recommend for RA and LCA to use data on harvested areas (or crop yield and production) whenever available for specific crops, and to otherwise obtain harvested areas from similar crops in combination with crop class summaries reported by e.g. FAOstat (2013b). More specifically, we recommend for RA to add harvested areas of all reported crops per region and allocate the remaining area to the crop of interest. For LCA, we instead recommend identifying if production information of the considered crop is available for other regions/countries, where the average share on crop class can then be applied, or otherwise applying average areas remaining after adding reported crops in adjacent regions. In all cases, the total harvested area per crop class should not be exceeded.

(b) Extrapolation of crop-specific treated area from crop-specific harvested area & count applied

Areas actually treated with pesticides are required for assessing pesticide emissions and residues. However, crop-specific treated areas are rarely reported, since they are also pesticide-specific and furthermore depend on pest pressure distribution (US-EPA, 2000; Kellogg et al., 2002). Exceptions are: the pesticide usage surveys in United Kingdom for 1990 onwards (FERA, 2013); California's pesticide use reporting program for 1989 onwards

(CDPR, 2013); and the USDA National Agricultural Statistics Service for 1990 onwards (NASS, 2013), where treated areas are given for various pesticide-crop combinations. In all other cases treated areas may be obtained from harvested areas as reported in e.g. FAOstat (2013b), Eurostat (2013d), EC (2007), from which organic farming areas must be subtracted per crop as they vary significantly between countries/regions. Organic farming areas are given in e.g. FAOstat (2013c), Eurostat (2013e). Remaining harvested areas can finally be combined with pesticide-specific application counts stated in national regulatory databases (e.g. BVL, 2013; FOAG, 2013), EFSA assessment reports (EFSA, 2013), or pesticide products information (e.g. Bayer, 2013; Syngenta, 2013). We recommend for RA to assume that total harvested areas minus organic farming areas are treated and multiplied with pesticide-specific application counts. For LCA, we instead recommend dividing pesticide-specific total mass applied reported by e.g. FERA (2013), CDPR (2013) by typical application counts for each crop to arrive at average treated areas. In any case, treated areas may exceed harvested areas (because of multiplication factors defined by the application counts).

(c) Extrapolation of application data from production/sales statistics

Pesticide emission inventories and crop residues crucially rely on actual pesticide amounts applied per crop. In most cases, however, such information is not readily available (Fantke et al., 2012a). Instead, data on pesticide consumption, production, or sales along with data on import and export are often reported by international bodies (e.g. FAOstat, 2013d) or regional/national authorities (e.g. OECD, 2008; US-EPA, 2011; Eurostat, 2013f; MST, 2013). For RA and LCA we recommend using these data as proxy for actual application amounts assuming that

$$application = \underbrace{production + import - export}_{consumption\ or\ (net)\ sales} - storage. \qquad (1)$$

When import/export data are missing, we recommend to assume for RA that 100% of pesticide sales are consumed within each country and for LCA that net sales per country on average equal 70% to 85% (FAOstat, 2013c; Kellogg et al., 2002), which varies greatly between countries. Data on storage as e.g. derived from annual carry-over stocks are rarely available or cannot be allocated to the year and country of production (FAO, 2001). Hence, we recommend including storage data, wherever available and to assume that consumption equals actual application, where storage data are missing.

(d) Extrapolation of formulation/active ingredient-specific application data from target class/chemical class application data

Since toxicity differs between pesticides (Sanborn et al., 2004), it is crucial to use pesticide-specific application data. However, data for individual pesticides are usually not available, but confidential and reported to authorities for internal use only. Exceptions are data reported for the five most extensively used pesticides per crop and country for European Union member states between 1992 and 2003 (EC, 2007), data from pesticide usage surveys in United Kingdom for 1990 onwards (FERA, 2013), data from the agricultural chemical use program (NASS, 2013), and data from California's pesticide use reporting program for 1989 onwards (CDPR, 2013). In other cases, we rely on data reported at the level of target class, such as fungicides (World Resources Institute, 2010; US-EPA, 2011; Zhang et al., 2011), chemical class, such as triazoles (Eurostat, 2013f; FAOstat, 2013e), or sometimes for combined target/chemical class, such as triazole fungicides (EC, 2007). However, chemical classes contribute to different target classes and vice versa with e.g. organophosphorus fungicides (fosetyl), herbicides (anilofos), or insecticides (dichlorvos), where application amount between target classes within chemical class or between chemical classes within target class can vary considerably (see Section S-2, supplementary information, in Fantke et al. 2013a). For RA and LCA, we recommend to first disaggregating target class or chemical class data (see Table S1, supplementary information, in Fantke et al. 2013a) to get combined target/chemical class data and then further towards data for individual pesticides, for which mean application dosages in Table S1 (supplementary information, in Fantke et al. 2014) can be applied. Finally, application dosages can be combined with treated crop areas to determine applied masses per pesticide and crop. A similar extrapolation scheme is available from the European Environment Agency (EEA, 2009), which we do not recommend to apply, mainly because most listed pesticides are presently withdrawn from the global market.

(e) Extrapolation of crop-specific dosage {or mass} applied from recommended dosage {and crop-specific treated area}

The dosage (mass per area) at which a particular pesticide is applied to a specific crop is the most important piece of information to quantify pesticide emissions and residues. When the applied pesticides are known, but applied mass or dosage per crop are not quantified, we recommend for RA and LCA to combine crop-specific treated areas with recommended dosages to determine the total pesticide mass applied per crop. Recommended dosages for numerous pesticides are found in Tomlin (2012), national regulatory databases (e.g. BVL, 2013; FOAG, 2013), EFSA assessment reports (EFSA, 2013), FAO residue reports (FAO, 2013), or pesticide products information (e.g. Bayer, 2013; Syngenta, 2013). In case dosages refer to product formulations, they must be combined with mass fractions of pesticides on the formulations, usually available in the same sources.

(f) Extrapolation of application technique from generic/crop-specific application technique

Along with crop characteristics and environmental conditions, application technique affects pesticide environmental distribution after application (Meijs, 2008), since techniques including aerial spray, foliar application, soil surface application, water add-on, etc. all show different potentials for drift, runoff or leaching, partly due to different formulations (Ganzelmeier et al., 1995; Caldwell, 2006; US-EPA, 2009). If application techniques are not available for specific substance-crop combinations, they may be derived on the basis of the same crop-target class combination, since pesticides are often applied in combination against one or more crop-specific pests (Matthews, 2000). Hence, for pesticides falling into the same crop-target class category, we recommend in RA and LCA to apply the same application technique. In addition, we recommend looking into the formulation type, such as wettable powder or granule, as given in Tomlin (2012) or pesticide products information (e.g. Bayer, 2013; Syngenta, 2013). Formulation types are listed in GCPF (2008) and are usually applied via specific techniques, e.g. wettable powders are typically applied as foliar sprays, while granules are directly applied to soil surfaces as explained in Matthews (2000). Finally, target class and application date helps identifying the technique, where we recommend for RA and LCA to assign soil application to soil insecticides, nematicides, and all pre-emergence pesticides, and to assign foliar spray to plant growth regulators and defoliants in line with Kellogg et al. (2002).

(g) Estimation of metabolites and metabolism fraction with transformation product models

Structurally related transformation products (metabolites) are often more persistent, mobile, bioaccumulative, or toxic than the applied pesticide itself (Fenner et al., 2000; Mekenyan et al., 2005). Biotransformation processes may be significant in air, water, soil, plants, and animals/humans, of which only air is relevant for our extrapolation framework. Transformation in air is generally restricted, since pesticides are bound in formulations upon application, but might still be relevant for some pesticides, mainly via hydroxyl radical reactions (Atkinson et al., 1999). To include metabolites in RA or LCA, transformation media, metabolism fractions, and metabolites properties are required. Metabolism fractions and media are for some metabolites given in FOOTPRINT (2013). To predict metabolism fractions and associated metabolites where data are missing, Ng et al. (2011) used the Pathway Prediction System (UM, 2013b) and the Biocatalysis/Biodegradation Database (UM, 2013a), both further described in Ellis et al. (2008) and Gao et al. (2010). However, the Pathway Prediction System only considers aerobic biodegradation and, hence, disregards transformation in air. Properties of metabolites are largely unknown (Ng et al., 2011), but are for some substances available in FOOTPRINT (2013). Considering the inconclusive relevance of metabolism in air and the existing data situation, we recommend to only include metabolism in air into RA and LCA, if FOOTPRINT (2013) or other sources already provide sufficient data, and otherwise state that metabolites are not considered.

(h) Extrapolation of date of application from crop-specific pre-harvest interval

Pesticide application dates are key inputs for assessing pesticide dynamics with respect to crop residues, freshwater ecotoxicity, etc. Examples are plant models, in which the period after pesticide application drives residues in harvest (Fantke et al., 2012b, 2013). Since application dates as reported by e.g. CDPR (2013) are usually not available in national/multinational usage statistics aggregating over full years, they may be extrapolated from the pesticide-crop combination-specific minimum pre-harvest interval (PHI) as time between last tolerable pesticide application and crop harvest (US-EPA, 2000). PHIs are stated in national regulatory databases (e.g. BVL, 2013; FOAG, 2013), EFSA assessment reports (EFSA, 2013), and FAO residue reports (FAO, 2013). PHIs are based on safety-oriented, often generic maximum residue levels and, hence, have conservative character. In RA, we therefore recommend to define application dates by subtracting PHIs from harvest dates. In LCA, we recommend for fungicides, insecticides, and defoliants usually applied shortly before harvest to also derive application dates from PHIs. For herbicides usually applied at pre-emergence or during early crop stages to not damage the cultivated crop (Juraske et al., 2009; Fantke et al., 2011) and for plant growth regulators, we instead recommend to derive application dates from typical application times as reported in pesticide products information (e.g. Bayer, 2013; Syngenta, 2013).

(i) Extrapolation of crop growth stage or crop growth function from generic/crop class growth function & pre-harvest interval

Along with application dates, information on crop growth stage is essential to determine fractions of applied pesticides that are finally intercepted by crops upon application, thereby also affecting fractions reaching the soil surface. Crop growth stages can be described by growth functions or pre-defined stages based on crop phenology. Growth functions typically focus on plant mass or leaf area and are available in several publications, of which e.g. Fantke et al. (2011) summarizes leaf area development functions for six crop archetypes. If growth functions describe plant mass, Rein et al. (2011) explain how mass, transpiration and leaf area are related to convert from mass to leaf area for crops following logistic growth. Phenological crop growth stages are defined in Lancashire et al. (1991) and Meier et al. (2009) and applied at aggregated level to various crops in Kruijne et al. (2011). We recommend for RA and LCA to use data on crop growth stages, if available and growth functions, if stages are not defined. Crop class-specific data or functions can be used, if crop-specific information is missing, based on crop phenology similarities. Finally, generic growth functions might be applied, if no data are available at all, and combined with PHI (sources described above) to determine typical crop growth stages.

Application to EU-27 countries

The framework was applied although not all extrapolation steps could be fully realised as default values that should accompany some of the extrapolation steps and be defined based on UK and Californian application data have not been integrated yet.

Step (a-b) – Harvested areas

The pesticide use data that are used in further steps to estimates quantities of applied pesticides are related to harvested areas (EC 2007). Therefore harvested areas were considered over treated area.

Harvested areas were extracted from Eurostat (2013d). Two different data sets, annual data [apro_cpp_crop] and data by NUTS 2 regions [agr_r_crops] (aggregated over countries), were used as some of the data in one are not reported in the other, and vice versa. Area data were collected for 9 crop types: cereals, maize, oilseeds, potatoes, sugar beets, vegetables, fruit trees, citrus fruits and vineyards (crop types corresponding to available pesticide use data). Data on cereals include rice. To be consistent with pesticide use data, areas for maize are the sum of areas for green maize and grain maize (note that green maize data are not reported for most EU countries in FAOstat).

Although being nearly complete, the area data sets still contained some gaps for some year-country combinations. To fill in the gaps, the averages of harvested areas for the reported years were calculated and used as proxies.

Step (c-e) – Pesticide use data

The report from the EU Commission on “the use of plant protection products in the European Union” over a 10-year time frame, i.e. 1992 – 2003 (EC 2007), is currently the best available source for pesticide statistics. The Commision’s work on pesticides has led to a regulation on pesticides statistics (EC, 2009) that should lead to publication of sales data by 2013 (not yet available at the level of active ingredients or chemical-target classes) and use data on the period 2010-2015 by 2016.

In this study, the EC (2007) report was used. It also supported scientific publications in the past, e.g. Fantke et al. (2012). It contains detailed information on pesticide usage disaggregated in EU countries (EU-27 minus Bulgaria and Romania) and major types of crops (cereals, maize, oilseed, potatoes, sugar beet, citrus, wine grapes, fruit trees, and vegetables; other types of crops are reported in a section “Others”, which, for the reported countries, appears to have a limited pesticide consumption). Across the different sections of the report, the following data can be extracted:

1. The top-5 amounts of active ingredients used for each country and for each type of crop (year 2003). Gaps however exist wherever the data were flagged confidential.
2. The top-5 chemical class with their associated total dosage (e.g. in kg-AI/ha) for each country and for each type of crop (year 2003)
3. The top 5 chemical class with their associated total dosage for each type of crop and for each of the 3 major classes of pesticides, namely fungicides, insecticides, herbicides (year assumed to be 2003)

The data from (2) and (3) are very similar and most dosages reported in (2) can be found in (3), which support the assumptions that the data from (3) are for the year 2003. However, in data set (2), information on other pesticide classes, e.g. plant growth regulators, are also reported. Therefore, the 2 data sets can be considered as partially complementary.

Several gaps occur in the data set (1) because of confidentiality issues related to specific active ingredients, e.g. glyphosate. These active ingredients are flagged "confidential" in the report and despite being in the top 5 used active ingredients, no quantification is actually provided. To fill in these gaps, the dosage of the chemical class to which the unreported active ingredient belongs was combined with the harvested area of the considered type of crop to reach a quantification of the AI application. The assumption behind such gap-filling procedure is that the AI is representative for its chemical class, i.e. it is the major AI used within its chemical class for the considered type of crop in the considered country. When 2 AIs belonging to the same chemical class were reported in the top-5 AIs, either one of the two was not confidential, which enabled to subtract its amount to the total computed from the dosage of the chemical class (most of the cases) or the 2 AIs were allocated equal amount unless information on the ranking was known (e.g. if quantities applied for nr. 3 and nr. 5 are known, the unknown quantity of nr. 4 needs to fall within the range defined by available figures for nr. 3 and nr.5 active ingredients in a top-5 list). The results of this gap-filling procedure were individually checked by evaluating whether or not the top-5 ranking was respected. In nearly all occurrences, this was the case. Specific minor assumptions have been performed where needed.
After this gap-filling procedure, two outcomes can be defined:

- the applied quantity of 5 active ingredients in 2003 for each country/crop system (25 countries times 7-9 crop types per country, depending on agriculture uses)
- the total dosages of chemical-target classes for each country-crop combination for 2003 (about 10-20 chemical-target classes for each crop-country system)

The combination of total dosages with harvested areas for the year 2003 and the further aggregation of the results for each crop type typically amounted to a mass of pesticides close to the totals separately reported in EC (2007), thus demonstrating an acceptable completeness of the data with respect to chemical-target classes.

For extrapolation, the framework recommends the use of application dosage for combined target-chemical classes (see extrapolation step (d) in framework). Mean values from the framework have not been determined yet. The EC (2007) report only total dosages, which equal the sum of all used active ingredients within a chemical-target class divided by the total harvested area. This total dosage is different from the actual average dosage of the chemical-target class, which is defined as the average of the mass of each active ingredient used on a specific treated/harvested area. While the latter can aid extrapolating to active ingredients within each chemical-target class (because of low variability – see extrapolation step (d)), the former cannot be used for such purposes as it would yield important biases. To extrapolate to other years, the country-specific distribution of active ingredients as of 2003 was therefore determined and assumed to remain valid for all other years. Several uncertainties are associated with this assumption, e.g. the ban, abandon and/or replacement of certain active ingredients along the 90s and the 2000s (e.g. see illustrative Figure F-2) and the biases introduced by the no-use of actual dosages for some active ingredients.

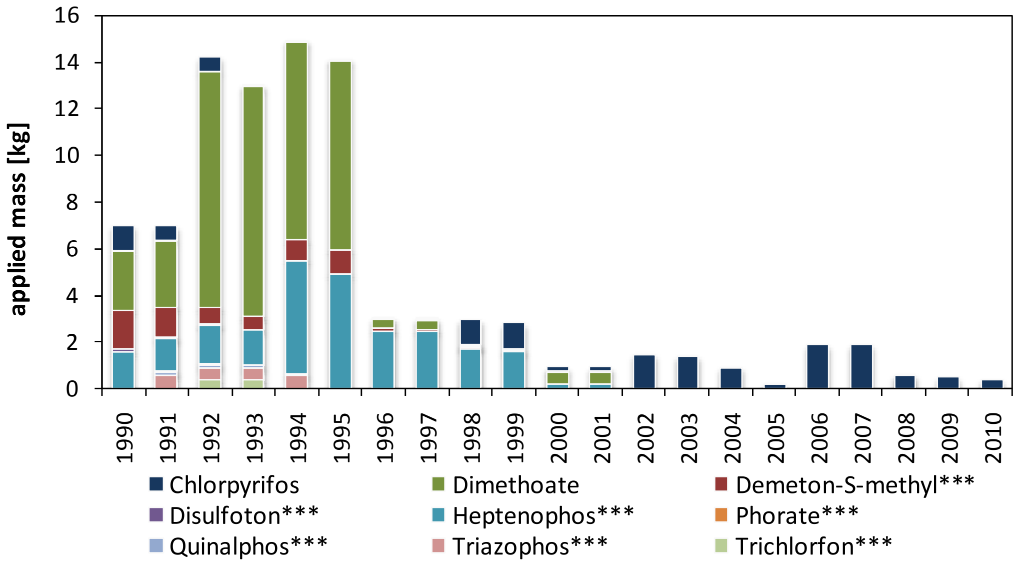

Figure F-2. Organophosphate insecticides applied to beet crops in UK in 1990-2010. Substance marked with "***" are not authorised anymore (in 2013) for use in Europe on beet crops. Source: http://ec.europa.eu/sanco_pesticides/public/

For each crop type and country, the distributions of active ingredients for 2003 were determined by (i) calculating the total mass from the product of total dosages of chemical-target classes with harvested areas for 2003; (ii) subtracting the mass of single active ingredients reported in the top-5 to the total mass obtained, wherever relevant; (iii) assign the remaining mass equally to all active ingredients listed within the chemical-target classes (for consistency, list taken from the EC report). The resulting distributions thus amounted to 100% within each crop/country/chemical-target class system.

The total country-specific mass of chemical-target classes were determined for all years within the period 1990-2010 by combining the collected harvested areas with the total dosages for the year 2003. The distributions of active ingredients were then applied to each total mass of chemical-target classes to obtain the individual masses of active ingredients for each country/year/crop/chemical-target classes system.

Steps (f-i) – Application technique, metabolites, application date and crop growth stage

In line with the developed framework, a foliar spray application was assumed for all crops and no metabolism was assumed to take place. Average application time were based on Fantke et al. (2011), who report typical average times between pesticide application and crop harvest for herbicides and aggregated over fungicides and insecticides for six archetype crops, i.e. wheat, paddy rice, tomato, apple, lettuce, potato. With consideration of these data, the application of the dynamic multicrop model (dynamiCROP model; Fantke et al. 2011) can yield average fractions of pesticides applied to crops reaching plant surface, air, soil surface and surface water. For generic application of all pesticides but herbicides, fractions of 64% to plant surface, 15% to air, 20% to soil surface, and 1% to surface water are considered. These fractions do not apply to herbicides, which are applied at early crop development stage (unlike insecticides and fungicides typically applied at later development stages), and hence result in larger fractions reaching to the soil surface. Fractions of 10% to plant surface, 15% to air, 74% to soil surface and 1% to surface water are thus considered for generic application of herbicides,. These two sets of fractions were applied to all crop types but fruit trees and citrus fruits, for which the first distribution is also assumed valid for herbicides (since trees are perennial crops).

The application of these distributions to the data resulting from the previous step led to the mass of active ingredients reaching each primary environmental media/crop for each country/year/crop/chemical-target classes system. These were then aggregated over crops and chemical-target classes to obtain the emission inventory of active ingredients for each year and country.

Fate modelling from technosphere to biosphere

In life cycle assessment, several schools exist as whether or not to consider the agricultural soil as part of the technosphere with regard to pesticide application.

The main rationale for the proponents to this thesis is that the spreading is intentional and serves the purpose of increasing crop production. Only the fraction of pesticides reaching the biosphere should thus be included in an emission inventory prior to impact assessment. Once applied, pesticides are either taken up by the plants or end up in different compartments (e.g. air via wind drift, surface water via run-off, etc). Emission models such as the PestLCI model can thus be used for this purpose. It was designed to predict the different fractions of applied pesticides that would be released to air, surface water and groundwater (Birkved and Hauschild 2007; Dijkman et al. 2012), and thus models the fate of pesticides from the technosphere to the biosphere. Opponents to such consideration argue that terrestrial organisms in the field should also be covered in the impact assessment, and therefore rejects the need of emission models.

It is clear that no consensus currently exist on (i) where to fix the boundaries between the inventory and the impact assessment and (ii) what emissions to include in the inventory (e.g. Workshop on 'pesticides in LCA'; 11/05/2013, SETAC Glasgow, UK). Stakeholders may therefore not support an inventory that already embeds the outcome of an emission model as it may lead to important biases (e.g. see Laurent et al. 2011). In addition, possibilities are rather limited to apply an emission model to the current study. Although refined in its version 2.0, the PestLCI model still has a field-oriented focus, i.e. at micro-level, and is not yet operational with regard to a use at macro-scale as required in the current study. Therefore, these two gaps, i.e. lack of commonly accepted approach and lack of robust, operational emission models, led to only consider the primary distribution in the final inventory (as determined in the previous section).

Method I – Total N and total P to water and soil

Data sources

Nutrients are emitted to water by point sources and diffuse sources. Examples of point sources are urban waste water and industrial waste water. Diffuse emissions to water occurs from runoff and leaching from fertilizers and manure applied to agricultural soil. Nutrient input into soil also consists of direct and indirect emissions. Where direct emissions are for example from fertilizer application, and indirect emissions from atmospheric deposition.

No complete data source is found that can provide nutrient emission data for both the water and soil compartment.

The EEA database "Waterbase – Emissions to water" is a database that contains emissions from both point and diffuse sources, however, data availability is poor (EEA, 2013b). Only 11 countries report any data on nutrient emissions from agriculture, urban waste water, and industrial waste water.

The European Pollutant Release and Transfer Register (E-PRTR) provides emissions by point sources (EEA, 2013a). The E-PRTR only reports data for the years 2007-2010, but all EU27 countries are available. However, not all emissions are present, since there is a reporting threshold.

Estimation technique

For the reasons of data availability, the emissions of nutrients to water and soil are estimated. The estimation method is divided into nutrient emissions from agriculture, and nutrient emissions from wastewater. The estimation technique makes use of various databases, which are reported in the text.

Estimation of N and P from agriculture (to soil and subsequently water)

Nutrients that end up in the water from the agricultural sector are first emitted to the soil. IPCC (2006) makes a distinction between direct and indirect emissions. Direct emissions come from synthetic fertilizers, animal manure applied to soils, N-fixing crops, and crop residue. Indirect emissions are soil (re-)emissions resulting from nitrogen that has leached from the soil or from atmospheric deposition. The direct and indirect emissions are lowered with losses to water and air (volatilization) and output. Output consists of removal of nutrients through harvest and grazing, as well as from removal of crop residues from the field. The nitrogen balance is summarized in the equation below:

$$Nutrient\ balance\ soil = N_{input} - loss\text{-}_{water} - loss_{air} - N_{output}$$

$$Loss_{water} = frac_{LEACH} * (direct\ emission\ synthetic\ fertilizer \\ + direct\ emission\ animal\ manure\ applied\ to\ soils)$$

$$Loss_{air} = frac_{GASF} * direct\ emission\ synthetic\ fertilizer + frac_{GASM} \\ * direct\ emission\ animal\ manure\ applied\ to\ soils$$

Where

$Frac_{LEACH}$ = fraction of N input to soils that is lost through leaching and run-off
$Frac_{GASF}$ = fraction of synthetic fertilizer N applied to soils that volatilizes as NH_3 and NO_x
$Frac_{GASM}$ = fraction of livestock N excretion that volatilizes as NH_3 and NO_x
N_{INPUT} = direct emissions + indirect emissions

All data is provided by the national inventories delivered to the UNFCCC (2013). No data on N output is available. N output is calculated by using the ratios (by country, by year) between Input and Output provided by Eurostat and to multiply them to the Input provided by UNFCCC to get the estimated N in output. For some of the years this information is not available. In these cases it is investigated if there is a trend over time for the input/output present and if regression over time can be used (F test). When no such trend is available, the average input/output ratio is used to fill in the missing ratios.

Phosphorous

UNFCCC (2013) does not provide data on phosphorus emissions, hence Eurostat (2013g) data are used. The Eurostat data has some missing data; the P input values are extrapolated from N input UNFCCC data, the missing P output values are extrapolated from N output data from Eurostat. The underlying assumption is that there is correlation between total phosphorous and total nitrogen, both for inputs and outputs. The soil balance for phosphorous is calculated as follows:

$$P\ balance\ soil = P_{input} - loss_{water} - P_{output}$$

Where

P_{input} is extracted from Eurostat (2013), missing values are extrapolated using the N input (direct + indirect emissions) from UNFCCC (2013)

P_{output} is extracted from Eurostat (2013g), missing values are extrapolated using the already gapfilled N output values from Eurostat. N output from Eurostat is gap-filled using method L, trends of similar flows; missing values are extrapolated using cereal production data from FAOstat (2013b).

$Loss_{water}$ = P_{input}*10%

The value of 10% loss of P to water is a global average reported by Bouwman et al. (2009).

Estimation of N and P from wastewater (flow flagged as Method I.2)

Van Drecht et al. (2009) published a method to estimate N and P emissions from sewage for the years 1970, 1990, 2000, 2030, and 2050. Not only household wastewater, but also industrial emissions are included in this method. No distinction is made between these two sources. The N and P emissions from wastewater are estimated for the years 1990-2010 and all 27 countries. For this estimation method data is extracted from various sources as summarized in Table I-2.

Table I-2. Parameters needed to estimate N and P from wastewater

parameter	Source
protein intake	FAO stat (2013f)
removal efficiency N	Van Drecht et al 2009
removal efficiency P	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)

The emission of nitrogen to surface water depends on the emissions by humans as well as the characteristics of the wastewater treatment (e.g. typology and people connected).

The N emission to surface water (kg person^{-1} year^{-1}) is calculated by:

$$E_{SW}^{N} = E_{hum}^{N} D(1 - R^{N})$$

Where

E^{N}_{SW} is the N emission to surface water (kg person^{-1}year^{-1})

E^{N}_{hum} is the human N emission (kg person^{-1}year^{-1})

D is the fraction of the total population that is connected to sewerage systems (estimation method at the end of this chapter)

R^{N} is the overall removal of N through wastewater treatment, which varies by type of treatment

When there are different kinds of wastewater treatment plants present in a country, the total E^{N}_{SW} is the sum of the E^{N}_{SW} from each of the wastewater treatment plant typologies (e.g. D0: no treatment; D1: primary treatment; D2, secondary treatment; D3, tertiary treatment).

According to Van Drecht et al. (2009), the human N emissions depend on the protein consumption as follows:

$$E_{hum}^{N} \approx 0.365 * I_{hum}^{N}$$

Where

I^{N}_{hum} is the protein N intake in g person^{-1} d^{-1}

This relation is assumed to be consistent for the purposes of this estimation. The protein intake is extracted from FAOstat. FAOstat provides dietary protein supply for the EU27 (FAOstat 2013f). The N content in protein is assumed to be 16%, accordingly to Van Drecht et al. (2009).

The FAOstat database provides protein intake in 3 year (e.g. 1990-1992, 1991-1993, 2007-2009). In which the average over 1990-1992 is assumed to represent 1991. For the year 1990, the average over 1990-1992 is used. The 2007-2009 average is used for the years 2008, 2009, and 2010. Other missing years are investigated The average is used unless a clear upward/downward trend is visible (Lithuania). In that case linear regression over time is performed..

The human P emissions (E^{P}_{hum}) can be calculated from E^{N}_{hum} by multiplying with a factor 1/6 according to Van Drecht et al. (2009).

The final step in calculating the P emission that is discharged to the surface water is as follows:

$$E_{SW}^{P} = (E_{hum}^{P} + E_{Ldet}^{P} + \frac{E_{Ddet}^{P}}{D})D(1 - R^{P})$$

Where;

E^{P}_{SW} is the P emission to surface water (kg person^{-1}a^{-1})

E^{p}_{hum} is the human P emission (kg person^{-1}a^{-1})

E^{P}_{Ldet} is the P emission from laundry detergents (kg person^{-1}a^{-1})

$E^{P}_{Ldet} = E_{Ldet} * f^{P}_{Ldet} * (1 - f^{Pfree}_{Ldet})$

E_{Ldet} via RPA (2006), 9 countries missing, average taken for missing values. Value used for all years

f^{P}_{Ldet} is 0.25 kg/kg (Drecht et al. 2009)

f^{Pfree}_{Ldet} via RPA (2006), Bulgaria and Romania missing, average from other countries used. Value used for all years

E^{P}_{Ddet} is the P emission from dishwater detergents (kg person^{-1}a^{-1}) for the population connected to the sewerage systems

$E^{P}_{Ddet} = E_{Ddet} * f^{P}_{Ddet} * (1 - f^{Pfree}_{Ddet})$

E_{Ddet} via RPA (2006), 9 countries missing, average from other countries used for missing values. Value used for all years

f^{P}_{Ddet} is 0.117 kg/kg (Drecht et al. 2009)

f^{Pfree}_{Ddet} use f^{Pfree}_{Ldet}

D is the fraction of the population connected to a wastewater treatment plant

R^{P} is the overall removal of P through wastewater treatment

Again, when there are different kinds of wastewater treatment plants present in a country, the total E^{P}_{SW} is the sum of the E^{P}_{SW} from each of the wastewater treatment plant typologies (e.g. no treatment, primary treatment, secondary treatment, tertiary treatment).

Fraction of people connected to wastewater treatment

The fraction of people connected to sewerage without treatment, with primary treatment, with secondary treatment, and with tertiary treatment are required for the method of Van Drecht et al (2009). Eurostat (2013h) and OECD (2013a) provided data, but the coverage is incomplete. Linear extrapolation over time is used when possible for the missing years for each country, keeping in mind that fractions cannot be less than 0 or more than 1. For Slovakia there is only data on sewerage connection without treatment available. There are no countries that have similar trends for all 3 treatment types. For Slovakia the average of the in Eurostat reported values are used (year specific). Linear extrapolation over time is used for the other missing values when possible, deviations are discussed below and flagged.

Austria: The estimated values using linear regression over time do not fall between the reported values. The estimated values are too high for D2, too low for D3. For this reason nonlinear regression is used. For D2 exponential regression resulted in the best fit. For D3 polynomial regression resulted in the best fit.

Belgium: Missing values in D1 are assumed 0, since the values for 1996-2009 are all 0

Bulgaria: For D1 linear regression over time is used, which resulted for 1990 in a negative value, 1990 was assumed 0.

For D3 linear regression over time is used to estimate 2010. For 1990-1992 a value of 0 is assumed

Cyprus: Missing values for D0 and D1 are assumed to be 0. For D3 linear regression over time is used, which resulted for 1990-1991 in negative values, 1990-1991 is assumed 0.

Czech Republic: Missing values for D1 are assumed to be 0. The sum of D0, D1, D2, and D3 exceeds 100% for the 90's. This is probably caused by the (outlier) value of 1999 in D2. The outlier is removed and linear regression over time is used to estimate the missing values for D2.

Denmark: Missing values for D0 are assumed to be 0. For D2 linear regression over time results in negative values for 3 years. As a solution, the trend of 1999 and later (e.g. do not take into account years before 1999 in the linear regression) is followed. For D3 linear regression results in estimated values for 2003-2009 that are higher than the reported value for 2010. As a solution, the trend of 1999 and later (e.g. do not take into account years before 1999 in the linear regression) is followed.

Estonia: Missing value for D0 is assumed to be 0. For D1 linear regression over time results in a negative value for 2010. The value of 2009 (reported values are constant for 1998-2009) is used for 2010.

Finland: For D0-D2, missing years are assumed to be 0.

France: For D0 a constant value of 2% is assumed for the missing years, since 2% is reported for 1995, 1998, 2001, 2004. For D1-D3 only the years 2001 and 2004 are reported. A linear relationship over time is assumed for the years 2002-2010 for D2 and for all years of D3. Extrapolation over time for the years before 2002 in D2 results in values that are too high. These values are replaced by the highest value for each year reported for the other countries in D2 (e.g. define a yearly threshold and reduce the values for France to these thresholds).

Germany: For D1 linear regression over time is used, which resulted for 2006, 2008, and 2008 in negative values; hence 0 is assumed for these years. For D2 and D3 there are inconsistent estimations when linear regression over time is used to estimate missing years; e.g. D3 1990 is higher than reported value 1991, while expected to be lower. D2 1990 is lower than reported value 1991, while expected to be higher. Estimated values for D3 2008 and 2009 are higher than reported values for 2007 and 2010. For the estimates in D2 and D3 a polynomial regression over time is used, since this provides a more appropriate fit.

Greece: For D0 linear regression over time used to estimate missing values, for 2008 0 is assumed, since 2007 and 2009 both reported 0. For D3 linear regression over time results in negative values for 1990 and 1991. A value of 0 is assumed for these two years.

Hungary: For all flows (D0-D3) the year 1991 is missing, and filled in by using the average of 1990 and 1992.

Italy: For D0 no values are reported, a percentage of 0 is assumed. For D1 linear regression over time results in negative values for 2006-2010, 0 is assumed since 2005 was also 0 and declining trend can be observed. For D2 linear regression over time is used, this results in a negative value for 2010, 0 is assumed. The sum of D0-3 exceeds 100% for 2008-2010. For these years in D3 the values are replaced by the highest value for each year reported for the other countries in D3 (e.g. define a yearly threshold and reduce the values for Italy D3 to these thresholds).

Latvia: For the missing years in D0, "0" is assumed since for 2006 and 2007 "0" is reported. No other years are reported. For D1 a constant value of 2% is assumed, the years 2002-2007 report 2% and there are no other years available.

Lithuania: For D0 linear regression over time is used, which results in a negative value for 2010, 0 is assumed, since 2005-2009 also report 0. The sum of D0-D3 exceeds 100% for 1990-1992. This was solved by using not all years in the extrapolation of D1, but only 2005-2009. Including 2002 and 2003 in the extrapolation leads to an overestimation for the early 90's.

Luxembourg: 0 is assumed for the missing years in D0.

Malta: Use the closest year available to fill in the missing years (red):

year	D0	D1	D2	D3
1990	87	0	0	13
1991	87	0	0	13
1992	87	0	0	13
1993	87	0	0	13
1994	87	0	0	13
1995	87	0	0	13
1996	87	0	0	13
1997	87	0	0	13
1998	87	0	0	13
1999	87	0	0	13
2000	64	0	36	0
2001	64	0	36	0
2002	64	0	36	0
2003	64	0	36	0
2004	64	0	36	0
2005	64	0	36	0

2006	64	0	36	0
2007	65	0	35	0
2008	58	0	35	7
2009	52	0	35	13
2010	52	0	35	13

Netherlands: For D2 and D3 the year 2009 is not reported, the average of 2008 and 2010 is used.
Poland: Linear regression over time is used to estimate missing values in D3. However, the regression results in negative values for the extrapolated years 1990-1994. A value of 0 was assumed for 1990-1994.
Portugal: For D1 no consistent trend in values is observed, the closest available year is used to fill in the gaps. Linear regression over time is used for D3, this resulted in negative values for 1991 and 1992, a value of 0 is assumed for these years.
Romania: For D1 no consistent trend in values is reported. The average value is used for the missing years. For D3 the years 2004 and 2005 report 0, for the other (missing) years, 0 is assumed.
Slovakia: Only values for D0 are reported. The EU average (of reported values) is used for D1-D3.
Slovenia: For D2 linear regression over time is used, which resulted in negative values for 1990-1996, 0 is assumed. For D3 linear regression over time is used, which resulted in negative values for 1990-1996, 0 is assumed.
Spain: Using linear regression over time, the sum of D0, D1, D2, and D3 exceeds 100% for 2009, probably caused by overestimation of D2 2009. For D2 a polynomial (order 2) regression is a better fit for the data and solves to exceedance of 100% issue.
Sweden: For D0 and D1, missing years are assumed to be 0, since surrounding years also report 0.

Methods J – Water consumption

The category Resource depletion - water consumption consists ideally of subcategories of abstractions and discharges. The data availability varies for each subcategory, and so do the estimation methods. The issues with data availability, as well as the estimation technique are treated separately for each category to provide the most complete overview. Although a bottom-up estimation of cooling water was developed so to calculate net water abstraction, such result leaded to very high of cooling water discharge, are hardly comparable to gross water withdrawals. For this reason only gross withdrawals are reported in this inventory.

Method J1- Total gross freshwater abstraction

Data sources

Freshwater abstraction can occur from surface water and groundwater. Eurostat (2013i), OECD (2013b), and FAO-Aquastat (2013) provide total freshwater abstraction values, as well as separate data for surface water and groundwater abstraction. Because of data completeness, gross freshwater abstraction is accounted for in this inventory, with no distinction between groundwater and surface water. Combining the above mentioned datasets still leaves large data gaps for these 3 flows, an overview is shown in Table J-1 for gross freshwater abstraction.

Estimation technique

Estimations have been developed on the basis of Eurostat (2013i) disaggregated total withdrawals per sector (i.e. covering: households, public water supply; agriculture, forestry, fishing; for irrigation purposes; by mining and quarrying; by manufacturing industry; production of electricity, for cooling purposes; other industries). The only exception is water used by hydroelectric facilities to generate electricity which is not included on purpose to the total withdrawals. Missing data is estimated by calculating country specific (when available) or EU27 average withdrawal coefficients for the following aggregated sectors: households, agriculture, energy, industries. Such factors are based on what reported by Eurostat (2013i) and are complemented with detailed regional statistics gathered by

Vandecasteele et al. (2013). The proxy variables used to multiply such coefficients are: agricultural surface, resident population, energy production, gross value added from industry, for the respective sectors.

For comparison, another method is developed using data from the water footprint network (Mekonnen and Hoekstra (2011a; 2011b). The water footprint network provides data on the coefficients of water demand by agricultural production typology, as well as domestic and industrial water consumption. Such coefficients have been multiplied by proxies such as cropland by crop type (FAOstat, 2013b), inhabitants (Eurostat, 2013b) and industry gross value added (GVA) (UNSD, 2013) so to calculate total withdrawals. This method does not allow for separation between surface water and ground water, and gross/net/returned water. By comparing these results to the totals calculated above it results that withdrawals based on water footprint coefficients are a factor 9 lower than those reported by Eurostat and other statistics for EU27 totals.

Issues/limitations

The differences resulting from the two estimation methods are representative of the high uncertainty characterizing these figures. Further refinements of the method should take into account the distinction between groundwater and surface water, as well as net abstraction in contrast to gross abstraction as modelled in this inventory. This might be very relevant for cooling water for energy production.

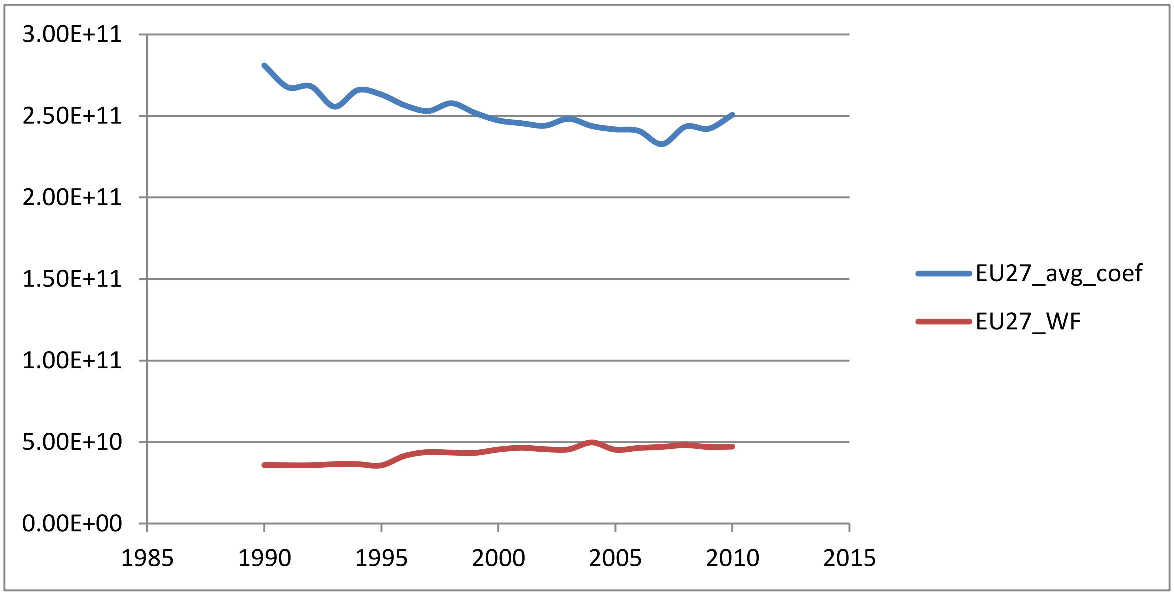

Figure J-1. Water withdrawals in EU27 (m^3) comparing figures from Vandecasteele et al 2013 based on Eurostat and from water footprint network

Table J-1. Data availability in Eurostat (2013i), OECD (2013b), and FAO-Aquastat (2013) databases on freshwater abstraction

	Eurostat		OECD		Aquastat	
	Abstraction fresh. surface water	Abstraction fresh. groundwater	Abstraction fresh. surface water	Abstraction fresh. groundwater	Abstraction fresh. groundwater	Abstraction fresh. groundwater
Country	**Years available**	**Years available**	**Years available**	**Years available**	**Years available**	**Years available**
Austria	1990-1999	1990-1999	1990-1995	1990, 1995	1990, 1997, 1999	1990, 1997, 1999
Belgium	1994-2007	1994-2007	1995-2009	1995-2010	1997, 2000, 2007	1997, 2000, 2007
Bulgaria	1990-2009	1990-2009	not present	not present	2000, 2007, 2009	2000, 2007, 2009
Cyprus	1998-2009	1998-2009	not present	not present	2007, 2009	2007, 2009
Czech Republic	1990, 1995-2009	1990, 1995-2009	1990, 1992-2010	1990, 1992-2010	1997, 2000, 2009	1997, 2000, 2009
Denmark	1996-2009	1990, 1991, 1995-2009	1990, 1991, 1995-2009	1990, 1991, 1995-2009	2007, 2009	2007, 2009
Estonia	1990-2009	1990-2009	1990, 1995, 2000-2010	1990, 1995, 2000-2010	2005	2005
Ireland	1994, 2005, 2007	1994, 2005, 2007	-	-	-	-
Finland	1990-1995, 1999	1990-1995, 1999-2005	1990-1995, 1999, 2001, 2006	1990-1995, 1999-2006	1990, 1995, 1999	1990, 1995, 1999
France	1991-1994, 2000-2007	1991-1994, 2000-2007	1990-1994, 1997-2010	1990-1994, 1997-2010	1990, 1997, 2000, 2007	1990, 1997, 2000, 2007
Germany	1991, 1995, 1998, 2001, 2004, 2007	1991, 1995, 1998, 2001, 2004, 2007	1991, 1995, 1998, 2001, 2004	1991, 1995, 1998, 2001, 2004, 2007	2007	2007
Greece	1990-1993, 1995-1996, 2000-2007	1990-1993, 1995-1996, 2000-2007	1990, 1995, 1997, 2000-2007	1990, 1995, 1997, 1998, 2000-2007	2000, 2007	2000, 2007
Hungary	2007-2008	1992-2009	1990, 1992-2008	1990, 1992-2008	-	-
Italy	-	-	-	-	-	-
Latvia	1991-2007	1991-2007	not present	not present	2000	2000
Lithuania	1990, 1993-2009	1990, 1993-2009	not present	not present	1995	1995
Luxembourg	1995, 1999, 2009	1995, 1999, 2009	1995, 1999, 2009, 2010	1995, 1999, 2009, 2010	1990, 1995, 1999	1990, 1995, 1999
Malta		1995-2009	not present	not present	-	-
Netherlands	1990, 1991, 1996, 2001, 2003-2008	1990, 1991, 1996, 2001, 2003-2008	1991, 1996, 2001, 2003-2010	1991, 1996, 2001, 2003-2010	1990, 2005, 2008	1990, 2005, 2008
Poland	1990-2009	1990-2009	1990-2010	1990-2010	1990	1990
Portugal	1990, 1998	1990, 1998	1998, 2007	1998, 2007	1998	1998
Romania	1990-2009	1990-2009	not present	not present	2009	2009
Slovakia	1990-2003, 2005-2009	1990-2009	1990-2010	1990-2010	1997, 2000, 2007	1997, 2000, 2007
Slovenia	2002-2009	1991-1994, 1996-1999, 2002-2009	2002-2010	2002-2010	2009	2009
Spain	1991, 1993, 1997-2008	1991, 1993, 1997-2008	1991, 1993, 1995, 1997-2010	1991, 1993, 1995, 1997-2010	1990, 1997, 2000, 2007, 2008	1990, 1997, 2000, 2007, 2008
Sweden	1990-2007	1990-2007	1990-2007, 2010	1990-2007, 2010	1997, 2000, 2007	1997, 2000, 2007
United Kingdom	-	-	-	-	1990, 1995, 2006	1990, 1995, 2006

Method J2 - Desalinated water production

The definition of desalinated water in Eurostat (2013i) is the “total volume of water obtained from desalination processes”.

Data sources

Eurostat (2013i) has limited data on desalinated water abstraction. Eurostat data are complemented with data from FAO-Aquastat (2013). FAO-Aquastat provides some values that are probably incorrect (e.g. desalinated water production in land-locked Austria and Hungary). For this reason, Aquastat values are not included when provided for land-locked countries.

Estimation technique

When no data is reported, it is not clear whether a country produces no desalinated water or just does not report data. When for a country no data is reported for all years in all three databases, production is assumed to be not occurring. The general estimation rules and assumptions used are as follows;

1. When a country does not report data and is surrounded by land; assume 0
2. When a country reports 0 for several years, assume 0 for missing years
3. When a country reports values for some years; investigate linear extrapolation over time and/or ad hoc solution if extrapolation of the whole time period is not appropriate
    a. Cyprus: 2009 value is used for 2010 to avoid underestimation
    b. Malta: 2009 value is used for 2010 to avoid underestimation
    c. Denmark, Ireland, Finland, France, Greece, Italy, Poland, Portugal, and UK report the same value over time, with large gaps of missing years in between. Values for these missing years are assumed the stay constant

No data was found for Germany, Romania, and Slovenia. Romania and Slovenia are almost completely landlocked and 0 is reported in the inventory. For Germany no other data sources were found and 0 is reported in the inventory. This assumption is made because the coastline of Germany is limited and the neighbouring country (NL) also reports 0 while having a coast line.

FAO-Aquastat (2013) reports desalinated water production in Austria, without access to the sea. FAO-Aquastat reports one value from their questionnaire in 1990 and reports the same value for 1997 and 2000 as “estimated”. 0 was assumed for all years including 1990, 1997, and 2000. For Hungary, Eurostat reports 0 for 5 years, FAO-Aquastat reports very small abstraction values for 3 years. All missing years from the Eurostat database are set to 0, and the FAO-Aquastat values are not used.

Methods K – Time interpolation

Estimation techniques

For several types of data, gaps can be estimated by linear interpolation through the available data per flow and per member state. The accuracy of such an interpolation is measured by the p value of an F-test; when the p-value is lower than 0.05, the regression is considered significant. This method is applied to domestic biomass production flows (Method K1), energy production flows (Method K2), and metal (ore) and mineral production (Method K3).

Method K1 - Domestic biomass production

Data sources

Table K.1 shows the data sources that were used for linear interpolation over time per flow for domestic biomass production. The data sources that were used are described in Table K.2. Besides missing years and Member States in the data sources as indicated in Table K.2, there are many gaps scattered through the years and Member States. All data gaps were filled by linear interpolation over time despite the fact this was not always significant.

For crop residues, wood and fish, the Eurostat - Material flow accounts (Eurostat, 2013k) table - Domestic Extraction Used - was used as the flow names correspond to that table. Domestic extraction used is the input from the natural environment to be used in the economy. It is the annual amount of raw material (except for water and air) extracted from the natural environment. The flows are expressed in 1000 tonnes. For fodder crops and grazed biomass, the Eurostat - Crops products (Eurostat, 2013d) table was used. For land use organic agriculture, the Eurostat - organic, fully converted (Eurostat, 2013e) table was used. For the yields, the harvested production figures were divided by the area. Harvested production means production including on-holding losses and wastage, quantities consumed directly on the farm and marketed quantities, indicated in units of basic product weight.

Issues/comments

Dividing the harvested production by the harvested area resulted in some doubtful yield figures. Therefore, if the conventional crop yield is lower, the organic crop yield is assumed the same as the conventional yield. Values that are still larger than 100 tonnes/ha, were replaced by a not available sign, because there are no crops from the list in Europe that can potentially reach such high yields.

Table K.1. Data source used per flow for domestic biomass production

Flow	Data source
A.1.2.1 Crop residues (used)	Eurostat - Material flow
Fodder - Total	Eurostat - Crops
Fodder from arable land	Eurostat - Crops
Annual green fodder	Eurostat - Crops
Other annual green fodder	Eurostat - Crops
Green maize	Eurostat - Crops
Cereals harvested green	Eurostat - Crops
Perennial green fodder	Eurostat - Crops
Clover and mixtures	Eurostat - Crops
Lucerne	Eurostat - Crops
Other legumes (sainfoin, sweet clover)	Eurostat - Crops
Temporary grasses and grazings	Eurostat - Crops
Temporary grasses	Eurostat - Crops
Temporary grazings	Eurostat - Crops
Permanent meadows	Eurostat - Crops
Permanent pasture	Eurostat - Crops
Total of permanent grassland (pastures and meadows)	Eurostat - Crops
Timber (Industrial roundwood)	Eurostat - Material flow
Wood	Eurostat - Material flow
Wood fuel and other extraction	Eurostat - Material flow
A.1.4.1 Fish catch	Eurostat - Material flow
A.1.4.2 All other aquatic animals and plants	Eurostat - Material flow
A.1.5 Hunting and gathering	Eurostat - Material flow
Domestic land use organic agriculture (by FAOstat subclasses or equivalent	Eurostat – Organic prod
Yields in kg per ha per year of above crops	Eurostat – Organic prod/ Eurostat – Organic/ Eurostat - Crops

Table K.2. Descriptions of the data sources used

Data source	Description from Eurostat website
Eurostat - Material flow (2013k) • [env_ac_mfa] • 1990-2011 • All EU27 Member States, except for Malta and Finland	Eurostat's economy-wide material flow accounts (EW-MFA) constitute a comprehensive data framework systematically recording the inputs of materials to European economies in a detailed breakdown by material categories such as fossil energy carriers, biomass, metal ores etc.
Eurostat – Crops (2013d) • [apro_cpp_crop] • 1955-2013	Crop statistics refer to the following types of annual data: • area, production harvested and yield for cereals and for other main field crops (mainly dried pulses, root crops, fodder and industrial crops);

Data source	Description from Eurostat website
• All EU27 Member States, except for Malta	• area, production harvested and yield for a large number of fruits and vegetables and • agricultural land use. Definitions used in this database: • Areas refer to the area under cultivation. Area under cultivation means the area that corresponds to the total sown area, but after the harvest it excludes ruined areas (e.g. due to natural disasters). If the same land parcel is used twice in the same year, the area of this parcel can be counted twice. It is expressed in 1000 ha. • Production means the harvested production. Harvested production means production including on-holding losses and wastage, quantities consumed directly on the farm and marketed quantities, indicated in units of basic product weight. It is expressed in 1000 tonnes. • Harvest year means the calendar year in which the harvest begins. • Yield means the harvested production per area under cultivation. It is expressed in kg per ha.
Eurostat – Organic prod (2013e) • [food_in_porg2] • 1999-2012 • All EU27 Member States, except for PT, LU, EL, DE, DK, CY, and BE	Certified organic crop production (in 1000 tonnes) and yields (kg per ha) from fully converted areas by crops products Breakdown by crops: • Arable land crops: Cereals, Protein crops, Root crops (potatoes, sugar beets, fodder roots), Industrial crops, Fresh vegetables, melons and strawberries, Forage plants, Other arable land crops, Permanent grassland (pastures and meadows) • Permanent crops: Fruit, Berries, Citrus fruit, Olives, Vineyards, Other permanent crops Defiitions used in this database: • Farming is considered to be organic if it complies with "Council Regulation (EC) No 834/2007 of 28 June 2007 (OJ No L 189/1991) on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91". • Organic area = Fully converted area (expressed in ha) • Only fully converted area can be considered to be organic. It fulfils all the conditions of production established in the above-mentioned regulation.
Eurostat – Organic (2013e) • [food_in_porg1] • 1999-2012 • All EU27 Member States, except for PT, LU, EL, DE, DK, CY, and BE	Certified organic crop area (in 1000 ha) by crops products Breakdown by crops: • Arable land crops: Cereals, Protein crops, Root crops (potatoes, sugar beets, fodder roots), Industrial crops, Fresh vegetables, melons and strawberries, Forage plants, Other arable land crops, Permanent grassland (pastures and meadows) • Permanent crops: Fruit, Berries, Citrus fruit, Olives, Vineyards, Other permanent crops Definitions used in this database: • Farming is considered to be organic if it complies with "Council Regulation (EC) No 834/2007 of 28 June 2007 (OJ No L 189/2007) on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91". • The area defined comprises all crop area. It might include secondary and other crops, so it might be not strictly comparable with the definition of Utilised Agricultural Area (only area of main crops) in the Farm Structural Survey. • Based on the level of conversion, data have to be reported on: - Fully converted area (= organic area). It fulfils all the conditions of production established in the above-mentioned regulation. Only this area can be considered to be organic. - Area in period of conversion. Area in process to be organic. It fulfils the conditions, but a period of time is required to eliminate prohibited products in the organic production methods. (It varies for type crop) - Total area : sum of the fully converted area and area in period of conversion

Method K2– Resource depletion - energy

Data sources

For primary energy production statistics, the Eurostat – Energy tables were used as shown in Table K.3. The tables contain data from 1990 to 2011 and for all Member States. Only some data are not available for Cyprus and Malta. The missing data are also not available from the national statistics agencies and not from other international databases, such as the United Nations Energy Statistics Database and the UNFCCC database. Hence, these values had been considered as not occurring.

Table K.3. Table names, products, indicators and units that were used from the Eurostat Energy database

Reference	Table name	Product	Indicator	Unit
Eurostat (2013l)	Supply, transformation, consumption - solid fuels - annual data (nrg_101a)	Hard coal, lignite/brown coal, peat	Primary* production	TJ
Eurostat (2013m)	Supply, transformation, consumption - oil - annual data (nrg_102a)	Crude oil	Primary production	TJ
Eurostat (2013n)	Supply, transformation, consumption - gas - annual data (nrg_103a)	Natural gas	Primary production	TJ
Eurostat (2013o)	Supply, transformation - nuclear energy - annual data (nrg_104a)	Nuclear heat	Primary production	TJ
Eurostat (2013p)	Supply, transformation, consumption - renewables and wastes (total, solar heat, biomass, geothermal, wastes) - annual data (nrg_1071a)	Solar thermal, geothermal energy,	Primary production	TJ
Eurostat (2013q)	Supply, transformation, consumption - renewables (hydro, wind, photovoltaic) - annual data (nrg_1072a)	Hydro power, wind power, solar photovoltaic	Primary production	TJ

*Primary production (or Indigenous Production): all production within national boundaries including off-shore production. Production should only include marketable production, excluding volumes returned to formation. Such production should include all crude oil, NGL, condensates and oil from shale and tar sands, etc. It should also include the receipts of additives/oxygenates by refineries and blending plants from outside the refinery sector (joint Eurostat/IEA/UNECE, 2013)

Method K3– Resource depletion - metal ores and minerals

Data sources

Table K.5 shows the data sources that were used per flow for estimating the data gaps in the metal (ore) production flows. The data sources are described in Table K.6. Figure K.1 gives an indication of what shares of the data were taken from the data sources, what share was estimated and assumed zero. Besides missing years and Member States in the data sources as indicated in Table K.7, there are some gaps scattered through the years and Member States. The data gaps of the British Geological Survey (BGS) (1995, 2000, 2002, 2012) sources were evaluated per flow and member state. When there were only 6 or less data-points larger than zero for a specific flow in a member state, the gaps were assumed zero. When the last known data-point was (almost) zero, the following data-points were assumed zero. The remaining data-gaps were filled by time interpolation. Most regressions were significant. Only in a few cases, all between 1990 and 1993, it was not significant. In those cases, averages of relevant periods after the data-gaps were used.

The data-gaps of the Raw Materials Group (RMG) (2013) data (1990-1997) were linearly interpolated over time.

For most metal resources, the British Geological Survey (BGS) provides the most complete data between 1990 and 2010 in all EU27 member states. Table K.6 shows the minerals, countries and completeness between 1990 and 2010 or the estimation type that was applied for filling the gaps. The countries that are not listed for a mineral are not reported by BGS, either because no production of that mineral takes place in those countries or no data was available for publication by BGS. However, it is not known which the case is. The BGS data are based on territorial country specific primary production, expressed in metric tonnes. The Eurostat PRODCOM (PRODCOM/Eurostat, 2013) database was chosen for the non-metal minerals. The production quantity indicator was used from the annual sold table in the PRODCOM database. The unit is always kg. The sold quantity deviates from the produced quantity because the latter includes what is retained by the producer for use in the production of another product. The produced quantity would therefore be more precise, but the issue is that the sold quantity table is much more complete. So, it is likely that this assessment underestimates the quantity of actually extracted minerals.

Issues/limitations

There is a large inconsistency between the metal content from BGS and ores from RMG per type of metal, as for some countries metal content is recorded and no ore and vice versa. Within the RMG data, a similar inconsistency occurs and metal content from RMG and BGS are not corresponding. This is because companies do not always report both the ore and metal content and the country total coverage is not always the same. The BGS source includes data for countries and years that are missing in the RMG source and vice versa, because the sources have a different coverage of the industry. In fact, it is not clear how RMG accounts and allocate extractions from enterprises that have legal entity in one country and extracts outside of it (both intra and extra EU). Hence, for the sake of territorial consistency, BGS statistics were preferred over RMG when both available for the same year, country and metal.

Data on Indium production are available in BGS not as primary extraction but as refinery production as this metal in Europe is produced as co-produced with Zinc and other metals (Polinares, 2012). Not being a primary extraction it has been excluded from the inventory, however the inclusion of this value (equal to 55 tons) might be very relevant in life cycle impact assessment as Indium has one of the highest characterization factors in the methodology recommended in the ILCD (EC-JRC, 2011) and PEF (EC, 2013).

Similarly, Strontium has high characterization factor and the value of its production is substantially differs from BGS and United States Geological Survey (USGS, 2012) sources, of a factor 2. For consistency with the rest of the dataset BGS data were used.

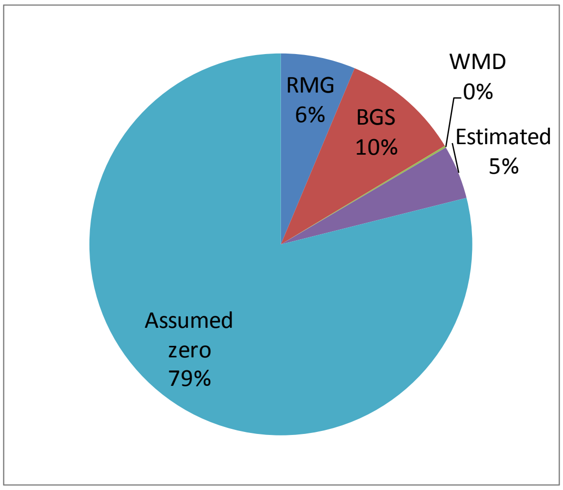

Figure K.1. Percentage of data for metal flows from the different sources, estimated or assumed zero

Table K.5. Metal flows and the data sources used

Flow	Source
Iron ores - gross ore	British Geological Survey
new sub-category: Iron ores - metal content	Raw Materials Group
Copper ores - gross ore	Raw Materials Group
Copper ores - metal content	British Geological Survey
Nickel ores - gross ore	Raw Materials Group
Nickel ores - metal content	British Geological Survey
Lead ores - gross ore	Raw Materials Group
Lead ores - metal content	British Geological Survey
Zinc ores - gross ore	Raw Materials Group

Flow	Source
Zinc ores - metal content	British Geological Survey
Tin ores - gross ore	No data
Tin ores - metal content	British Geological Survey
Gold ores - gross ore	Raw Materials Group
Gold ores - metal content	British Geological Survey
Silver ores - gross ore	Raw Materials Group
Silver ores - metal content	British Geological Survey
Platinum and platinum-group metal ores - gross ore	Raw Materials Group
Platinum and platinum-group metal ores - metal content	British Geological Survey
Platinum	British Geological Survey
Palladium	British Geological Survey
Bauxite and other aluminium ores - gross ore	British Geological Survey
Bauxite and other aluminium ores - metal content	British Geological Survey
Bauxite	British Geological Survey
Alumina	British Geological Survey
Aluminium metal	British Geological Survey
Uranium ores - gross ore	Raw Materials Group
Uranium ores - metal content	British Geological Survey
Thorium ores - gross ore	Not in EU27
Thorium ores - metal content	Not in EU27
Arsenic ores - gross ore	No data
Arsenic ores - metal content	British Geological Survey
Bismuth ores - gross ore	No data
Bismuth ores - metal content	British Geological Survey
Chromium ores - gross ore	British Geological Survey
Chromium ores - metal content	World Mining Data
Lithium ores - gross ore	No data
Lithium ores - metal content	World Mining Data
Magnesium ores - gross ore	No data
Magnesium ores - metal content	British Geological Survey
Manganese ores - gross ore	British Geological Survey
Manganese ores - metal content	Raw Materials Group
Mercury ores - gross ore	No data
Mercury ores - metal content	British Geological Survey
Molybdenum ores - gross ore	Not in EU27
Molybdenum ores - metal content	Not in EU27
Strontium ores - gross ore	No data
Strontium ores - metal content	British Geological Survey
Tungsten ores - gross ore	No data
Tungsten ores - metal content	British Geological Survey
Antimony	Not in EU27
Beryllium	Not in EU27
Cobalt	British Geological Survey
Gallium	World Mining Data
Germanium	Not in EU27
Indium	Not in EU27
Niobium	Not in EU27
Rare earths	Not in EU27
Tantalum	Not in EU27
Titanium	British Geological Survey
Rhenium	Not in EU27
Tellurium	Not in EU27
Vanadium	Not in EU27
Cadmium	British Geological Survey
Selenium	British Geological Survey

Table K.6. Description of the data sources used for metals

Data source	Years	Member States	Description
British Geological Survey (1995, 2000, 2002, 2013)	1990-2010	AT, BE, BG, CY, CZ, DE, EL, ES, FI, FR, HU, IE, IT, NL, PL, PT, RO, SE, SI, SK, UK	The British Geological Survey is a public sector organisation we are responsible for advising the UK government on all aspects of geoscience as well as providing impartial geological advice to industry, academia and the public.

Raw Materials Group (2013)	1998-2010	BG, EL, ES, FI, FR, IE, IT, PL, RO, SE, SK, UK	For 30 years, Intierra and Raw Materials Group have been the mining industry's preferred sources of data, analysis, consulting, reports and mineral information maps. They have provided resource sector intelligence for suppliers, financiers, governments, exploration and mining companies.
World Mining Data (2014)	1990-2010	Finland, Greece, Hungary, Portugal, Spain	The annual World Mining Data reports are publications of the BMWFJ (German Ministry of Science, Family and Youth) and the International Organising Committee for the World Mining Congresses

Table K.7: Minerals, countries and completeness of the BGS database or estimation type applied

Mineral name	Country code	Completeness/estimation type
Alumina	DE	Complete
Alumina	EL	Complete
Alumina	ES	Time interpolation
Alumina	FR	Complete
Alumina	HU	Complete
Alumina	IE	Complete
Alumina	IT	Complete
Alumina	RO	Complete
Alumina	SI	only 1 data point
Alumina	SK	only 6 data points >0 and 1 zero
Alumina	UK	Time interpolation
Aluminium metal	AT	only 1 data point
Aluminium metal	DE	Complete
Aluminium metal	EL	Complete
Aluminium metal	ES	Complete
Aluminium metal	FR	Complete
Aluminium metal	HU	last known almost zero
Aluminium metal	IT	Complete
Aluminium metal	NL	Complete
Aluminium metal	PL	last known zero
Aluminium metal	RO	Complete
Aluminium metal	SE	Complete
Aluminium metal	SI	Complete
Aluminium metal	SK	Complete
Aluminium metal	UK	Complete
Arsenic ores - metal content	BE	Complete
Arsenic ores - metal content	DE	Time interpolation
Arsenic ores - metal content	FR	Time interpolation
Arsenic ores - metal content	PT	Time interpolation
Bismuth ores - metal content	BG	Time interpolation
Bismuth ores - metal content	IT	only 1 data point
Bismuth ores - metal content	RO	Complete
Cadmium	BE	last known almost zero
Cadmium	BG	Complete
Cadmium	DE	last known zero
Cadmium	ES	average/last known almost zero
Cadmium	FI	last known almost zero
Cadmium	FR	Complete
Cadmium	IT	last known almost zero
Cadmium	NL	Complete
Cadmium	PL	Complete
Cadmium	RO	only 2 data points
Cadmium	UK	last known almost zero
Chromium ores - gross ore	EL	only 1 data point
Chromium ores - gross ore	FI	Time interpolation
Cobalt	FI	Time interpolation

Mineral name	**Country code**	**Completeness/estimation type**
Copper ores - metal content	BG	Complete
Copper ores - metal content	CY	between zeros
Copper ores - metal content	ES	Complete
Copper ores - metal content	FI	Complete
Copper ores - metal content	PL	Complete
Copper ores - metal content	PT	Complete
Copper ores - metal content	RO	Complete
Copper ores - metal content	SE	Complete
Gold ores - metal content	BG	Complete
Gold ores - metal content	CZ	only 2 data points
Gold ores - metal content	ES	last known almost zero
Gold ores - metal content	FI	Complete
Gold ores - metal content	FR	last known almost zero
Gold ores - metal content	HU	only 3 data points
Gold ores - metal content	IT	peak
Gold ores - metal content	PL	Time interpolation
Gold ores - metal content	PT	Complete
Gold ores - metal content	RO	Complete
Gold ores - metal content	SE	Complete
Gold ores - metal content	SK	Time interpolation
Gold ores - metal content	UK	only 4 data points
Iron ores - gross ore	AT	Complete
Iron ores - gross ore	BG	last known almost zero
Iron ores - gross ore	DE	Complete
Iron ores - gross ore	ES	last known almost zero
Iron ores - gross ore	FI	Complete
Iron ores - gross ore	FR	last known almost zero
Iron ores - gross ore	PT	Time interpolation; last two data broken trend downwards
Iron ores - gross ore	RO	Complete
Iron ores - gross ore	SE	Complete
Iron ores - gross ore	SK	trend break
Iron ores - gross ore	UK	Complete
Lead ores - metal content	AT	only 2 data points
Lead ores - metal content	BG	Complete
Lead ores - metal content	DE	only 1 data point
Lead ores - metal content	EL	Complete
Lead ores - metal content	ES	last known almost zero
Lead ores - metal content	FI	only 6 data points >0
Lead ores - metal content	IE	Complete
Lead ores - metal content	IT	Complete
Lead ores - metal content	PL	Complete
Lead ores - metal content	RO	Complete
Lead ores - metal content	SE	Complete
Lead ores - metal content	SI	only 2 data points
Lead ores - metal content	SK	only 2 data points
Lead ores - metal content	UK	Complete
Magnesium ores - metal content	FR	last known almost zero
Magnesium ores - metal content	IT	only 1 data point
Manganese ores - gross ore	AT	only 7 data points/not significant trend
Manganese ores - gross ore	BG	Complete
Manganese ores - gross ore	EL	only 6 data points/not significant trend
Manganese ores - gross ore	HU	Complete
Manganese ores - gross ore	IT	Time interpolation
Manganese ores - gross ore	RO	Complete

Mineral name	**Country code**	**Completeness/estimation type**
Mercury ores - metal content	ES	Complete
Mercury ores - metal content	FI	Complete
Mercury ores - metal content	SI	Complete
Nickel ores - metal content	EL	Complete
Nickel ores - metal content	ES	Complete
Nickel ores - metal content	FI	Complete
Palladium	PL	Complete
Platinum	PL	Complete
Selenium	BE	Complete
Selenium	DE	Complete
Selenium	FI	Complete
Selenium	PL	Complete
Selenium	SE	Complete
Silver ores - metal content	BG	Complete
Silver ores - metal content	DE	Complete
Silver ores - metal content	EL	no significant trend, but no alternative
Silver ores - metal content	ES	Time interpolation
Silver ores - metal content	FI	Time interpolation
Silver ores - metal content	FR	Time interpolation
Silver ores - metal content	IE	Time interpolation
Silver ores - metal content	IT	Time interpolation
Silver ores - metal content	PL	Time interpolation
Silver ores - metal content	PT	Time interpolation
Silver ores - metal content	RO	Time interpolation
Silver ores - metal content	SE	Time interpolation
Silver ores - metal content	SK	only 6 data points >0
Silver ores - metal content	UK	only 6 data points >0
Strontium ores - metal content	ES	Complete
Strontium ores - metal content	UK	only 4 data points
Tin ores - metal content	PT	Complete
Tin ores - metal content	UK	last known almost zero
Tungsten ores - metal content	AT	Complete
Tungsten ores - metal content	ES	only 3 data points
Tungsten ores - metal content	PT	Complete
Uranium ores - metal content	CZ	Complete
Uranium ores - metal content	DE	Complete
Uranium ores - metal content	ES	last known zero
Uranium ores - metal content	FR	last known almost zero
Uranium ores - metal content	HU	only 6 data points >0
Uranium ores - metal content	PT	last known almost zero
Uranium ores - metal content	RO	Complete
Zinc ores - metal content	AT	only 2 data points
Zinc ores - metal content	BG	Complete
Zinc ores - metal content	CZ	only 2 data points
Zinc ores - metal content	DE	only 1 data point
Zinc ores - metal content	EL	Complete
Zinc ores - metal content	ES	last known almost zero
Zinc ores - metal content	FI	Complete
Zinc ores - metal content	FR	Complete
Zinc ores - metal content	IE	Complete
Zinc ores - metal content	IT	only 6 data points >0
Zinc ores - metal content	PL	Complete
Zinc ores - metal content	PT	only 5 data points
Zinc ores - metal content	RO	Complete

Mineral name	Country code	Completeness/estimation type
Zinc ores - metal content	SE	Complete
Zinc ores - metal content	SI	only 3 data points
Zinc ores - metal content	SK	only 1 data point
Bauxite	EL	Complete
Bauxite	FR	Complete
Bauxite	HU	Complete

Methods M – ionising radiation

Method M1 – Upscaling of ionizing radiation from electricity production

A previous study (Wegener Sleeswijk et al. 2008) had estimated emissions of ionizing radiations from energy production at the level of EU25+3, by derivation of emission factors from the UK Environment Agency pollution inventory (EA, 2006) and installed power capacity from ANU (2006). Very likely such approach lead to an overestimation of total emissions (in particular of ^{137}Cs), as not all the EU countries producing energy have domestic plants dedicated to spent-fuel reprocessing as the UK have. In fact, as reported by the World Nuclear Association (WNA) (2013) on the basis of OECD/NEA (2007) and Kok (2007), commercial reprocessing facilities which have been active within the EU-27 territory are currently located in United Kingdom and France. Moreover, as reported by UNSCEAR (2008) also Germany had a research reprocessing plant in the period 1990-2004, nowadays dismissed. The rest of the EU-27 countries do not have such plants. In order to take into account such difference, in this work the emissions from electricity production and spent fuel reprocessing were accounted separately. In addition, figures on radionuclides emissions from non-energy sectors are added (Method N) along with estimates of end-of-life scenarios for gypsum boards in the construction sector (Method O).

Data sources

The following sources were used for upscaling of ionising radiation from electricity production:

- UNSCEAR 2008 Report: "Sources and effects of ionizing radiation" (UNSCEAR, 2008). Table A-5 Energy generated by nuclear power plants in the period 1998–2002 (GW a), Table A-7 Tritium released from nuclear power plants in airborne effluents (GBq), Table A-8 Iodine-131 released from nuclear power plants in airborne effluents (GBq), Table A-9 Carbon-14 released from nuclear power plants in airborne effluents (GBq), and Table A-11 Tritium released from nuclear power plants in liquid effluents (GBq). The tables contain data for the following EU countries: Belgium, Bulgaria, Czech Rep., Finland, France, Germany, Hungary, Lithuania, Netherlands, Romania, Slovakia, Slovenia, Spain, Sweden, and United Kingdom
- Ecoinvent 3.01 unit processes (Weidema et al., 2013), only on site emissions:
    - electricity, high voltage, production, nuclear, boiling water reactor (BWR), in CH, DE, ES, FI, SE
    - electricity, high voltage, production, nuclear, pressure water reactor (PWR), in BE, CZ, DE, ES, FI, FR, UK, HU, KR, NL, RO, SE, SI, SK, and BG
    - electricity, high voltage, production, hard coal, in AT, BE, BG, CZ, DE, DK, ES, FI, FR, UK, HR, HU, IE, IT, NL, NO, PT, RO, SE, SI, SK
- Eurostat - Supply, transformation, consumption - electricity - annual data (nrg_105a) (Eurostat, 2013r):
    - Gross electricity generation Main activity electricity only – Nuclear
    - Gross electricity generation Main activity electricity only – Anthracite
    - Gross electricity generation Main activity electricity only – Coking coal
    - Gross electricity generation Main activity electricity only – Other bituminous
    - Gross electricity generation Main activity electricity only - Sub-Bituminous Coal
    - Gross electricity generation Main activity electricity only - Lignite/Brown Coal

The Ecoinvent 3.01 description of the datasets is as follows:

- This dataset describes the electricity available on the high voltage level in this country. This is done by showing the transmission of 1kWh electricity at high voltage.
- This activity starts from 1kWh of electricity fed into the high voltage transmission network.
- This activity ends with the transport of 1 kWh of high voltage electricity in the transmission network over aerial lines and cables. This dataset includes: - electricity inputs produced in this country and from imports - the transmission network - direct emissions to air (ozone and N_2O) - electricity losses during transmission. This dataset doesn't include - electricity losses during transformation, as these are included in the dataset for transformation - Zinc emissions from steel masts. Steel masts used for aerial lines are coated in order to prevent corrosion. The commonly used process is hot-dip galvanising using zinc as anticorrosive. In general a duplex process is used applying a zinc and paint coating to further improve the corrosion protection. In addition, the selection of the colour can improve the embedding into the landscape (van Oeteren, 1988). With this additional protection the zinc emissions into soil can be neglected (van Oeteren, 1988). - leakage of insulation oil from cables and electro technical equipment (transformers, switchgear, circuit breakers) because this only happens in case of accidental release - data for electromagnetic fields - SF6 emissions during the transmission, as these are allocated to the market dataset for medium voltage. - SF6 emissions during production and deconstruction of the switchgear, as these are accounted for in the transmission network dataset.
- The annual production volumes of all electricity production datasets in Ecoinvent 3.01 are taken from IEA/OECD statistics and are valid for 2008. The datasets are not available for other years in which the production mixes may be significantly different. So, this results in unknown inaccuracies for our estimations.
- This dataset has been extrapolated to the year of the calculation (2013).

The Eurostat electricity production source (2013r) is complete for all years between 1990 and 2010 and for all Member States.

Estimation technique

Emissions from nuclear power production

The average Tritium, Carbon-14 and Iodine-131 emissions to air and Tritium emissions to water in MBq per kWh between 1998 and 2002 were calculated per country and for all EU27 member states from the UNSCEAR data by summing the annual emissions and the electricity production per power plant when both data are available and by dividing the emissions by the production. For the remaining years, the 5 year average (1998-2002) is used, because no increasing or decreasing trends over the years could be determined. The EU27 average values were used for the member states that are not in the UNSCEAR tables.

The average Tritium, Carbon-14 and Iodine-131 emissions to air and Tritium emissions to water in MBq per kWh per year and per country were multiplied by the total nuclear electricity production per year and per country from Eurostat.

The remaining ionizing radiation emissions (i.e. radionuclides other than tritium, Carbon-14 and Iodine-131) were based on the Ecoinvent 3.01 data unit processes: Electricity, high voltage//electricity production, nuclear, pressure water reactor (PWR) and Electricity, high voltage//electricity production, nuclear, boiling water reactor (BWR). The main assumption is that emissions per kWh estimated from process data are representative for all the countries but Germany and France, and for all years between 1990 and 2010. Only for Germany and France, the emissions from PWR in Ecoinvent 3.01 deviate from the ones of other countries. The emissions from BWR only deviates for Germany, so the emissions for the missing member states were assumed the same as for the countries other than Germany.

The fraction of electricity produced by pressure water reactors and the fraction produced by boiling water reactors were calculated based on the UNSCEAR data. For most member states, 100% from pressure water reactors and 0% from boiling water reactors was assumed, except for Finland (0% and 100% resp.), Germany (72% and 28% resp.), Spain (80% and 20% resp.), Sweden (29% and 71% resp.). The emissions from pressure water reactors and boiling water reactors were multiplied by their fractions and by the annual nuclear power production from Eurostat per member state.

Emissions from coal fired power production

Data on emissions from coal fired power production were taken from Ecoinvent 3.01 '*unit processes Electricity, high voltage//electricity production, hard coal*', which covered AT, BE, BG, CZ, DE, DK, ES, FI, FR, UK, HU, IE, IT, NL, PT, RO, SE, SI, SK. The emissions from coal powered plants of missing EU countries (CY, EE, EL, LT, LU, LV, MT,PL) in the Ecoinvent 3.01 database (MBq per kWh) were assumed as the average of the EU member states included in Ecoinvent 3.01,. The emission factors were then multiplied by the total annual electricity production from the different types of coal retrieved from Eurostat (2013l; 2013m) (Anthracite, Coking coal, Other bituminous, Sub-Bituminous Coal, Lignite/Brown Coal).

The emissions from nuclear power production and coal fired power production were aggregated.

Issues/limitations

Additional data on liquid discharges from nuclear installations had been made recently available by the of OSPAR Commission (2013a) however it has not yet been included in the inventory

Method M2 - Emissions of radionuclides to air and water from nuclear spent-fuel reprocessing

Data sources

In this inventory the amount of radionuclides emitted from fuel reprocessing is estimated on the basis of UNSCEAR data (2008) for 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 activity statistics from the International Panel on Fissile Materials (IPFM) (Schneider and Marignac, 2008; Forwood, 2008). The data on quantities of spent-fuel processed are lacking for the years 2008 to 2010. Prospective estimates instead of reported quantities have been used (IPFM, 2008b) for the plants located in the UK. For France, the last reported data on spent-fuel processed was taken as representative also 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% (JRC elaborations on Eurostat data 2013r).

Issues/limitations

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 Bq equivalents. The emissions of ^{137}Cs to air are not quantified in the inventory. The characterization factor for this radionuclide ranks 8th among the emissions to air in terms of impacts, as reported by Frischknecht et al. (2000). Wegener Sleeswijkand Huijbregts (2010) 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. Additional data on liquid discharges from nuclear installations had been made recently available by the of OSPAR Commission (2013a) however it is yet included in the current inventory.

Method N – Extrapolation of discharges of radionuclides from the non-nuclear sectors

Data sources

Ionizing radiation to water data are available from the OSPAR Commission (OSPAR, 2013b; 2013c). OSPAR members are Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom. Data for the following sectors were available: Manufacture of Am sources of GTLDs & Ionising Chamber Smoke Detectors, Medical Sector, Phosphate industry, Primary steel manufacture, Radiochemical production, Titanium dioxide pigment manufacturers, Universities & Research centres and Rare earth production, as presented in Table N.1.

Data gaps

Table N.1 shows the data available from the OSPAR database. The data are specified per substance, country, sector and year. There are only data available between 2005 and 2010. Due to the large data gaps, estimations were necessary.

Estimation techniques

The extrapolation of ionizing radiation emissions in non OSPAR countries was based on average emission factors calculated on the basis of the OSPAR dataset and multiplied for proxies (production statistics or sector's value added), assuming a significant linear correlation between the emissions and production or value added.

The significance of the regression is measured by the p value of an F-test; when the p-value is lower than 0.05, the regression is considered significant. The following sources are specified:

Oil gas extraction

Discharges from oil/gas extraction (including on-shore) in non OSPAR member states are estimated on the average discharges per MJ (lower heating value) of primary production of crude oil in the OSPAR region (Eurostat, 2013m). Table N.2 shows the data that were available for these regressions.

Other sectors

For the other sectors (Manufacture of Am sources of GTLDs & Ionising Chamber Smoke Detectors, Medical Sector, Phosphate industry, Primary steel manufacture, Radiochemical production, Rare earth production, Titanium dioxide pigment manufacturers, Universities & Research centres), estimations resulted to be not significant or even not possible due to insufficient data and reference statistics. The available data reported in the OSPAR for these sectors were included in the inventory database, but no data were estimated for the missing years and member states.

Table N.1. Available data from the OSPAR database in TBq

Substance	Country	Sector	2005	2006	2007	2008	2009	2010
H-3	CH	Manufacture of Am sources of GTLDs & Ionising Chamber Smoke Detectors	0.007	0.06	0.022	0.0193	0	0
H-3	UK	Manufacture of Am sources of GTLDs & Ionising Chamber Smoke Detectors	0.000303	0	0	0	0	0
I-131	BE	Medical Sector	6.91	11.5	4.89	4.75	5.63	10.1
I-131	CH	Medical Sector	0.05	0.0186	0.015	0.0143	0.0128	0.0105
I-131	DK	Medical Sector	0	1.24	1.492	0.00138	1.59	2.11
I-131	IE	Medical Sector	0.381	0.4193	0.4754	0.48	0.597	0.715
I-131	IS	Medical Sector	0	1.21	0	0	0	0
I-131	NL	Medical Sector	0	0.82	3.1	0	0	0
I-131	NO	Medical Sector	1.39	1.456	1.116	1.095	1.177	1.297
I-131	PT	Medical Sector	0	4.62E-10	0	0	0	0
I-131	SE	Medical Sector	0.5	0.52	0.49	0.53	0.5	0.7
I-131	UK	Medical Sector	10.51	10.86	10.45	10.58	10.56	11.05
Tc-99	BE	Medical Sector	2.53E-05	2.71E-05	2.58E-05	0	0	0
Tc-99	DK	Medical Sector	0	1.03E-07	1.06E-07	0	0	0
Tc-99	ES	Medical Sector	0	3.03E-10	2.99E-10	0	0	0
Tc-99	IE	Medical Sector	4.65E-08	4.6E-08	4.5E-08	0	0	0
Tc-99	IS	Medical Sector	0	1E-08	0	0	0	0
Tc-99	NL	Medical Sector	0	2.12E-07	4.7E-07	0	0	0
Tc-99	NO	Medical Sector	8E-08	9E-17	6E-08	0	0	0
Tc-99	PT	Medical Sector	0	1.34E-10	0	0	0	0
Tc-99	SE	Medical Sector	2.6E-08	2.71E-08	2.6E-08	0	0	0
Tc-99	UK	Medical Sector	6.1E-07	6.19E-16	5.6E-07	0	0	0
Cr-51	IS	Medical Sector	0	0.000296	0	0	0	0
Pb-210	NL	Phosphate industry	0	0.00022	0.00046	0.0021	0.0015	0.00053
Po-210	NL	Phosphate industry	0	0.00028	0.00024	0.0011	0.0011	0.00034
Pb-210	NL	Primary steel manufacture	0	0.0002	0.00019	0.00019	0.000172	0.000185
Po-210	NL	Primary steel manufacture	0	0.0002	0.00018	0.00016	0.000128	0.000175
H-3	CH	Radiochemical production	0	0	0	0	0	0.0277
H-3	SE	Radiochemical production	0	0	0	0	0	5.9
H-3	UK	Radiochemical production	40.4	24.8	28.1	14.4	20.7	1.15
C-14	SE	Radiochemical production	0	0	0	0	0	91.5
C-14	UK	Radiochemical production	0.894	0.951	0.663	0.8318	0.4544	0.016941
Cr-51	UK	Radiochemical production	0.00025	9.5E-14	3.96E-05	0.00002	4.72E-05	0
I-125	UK	Radiochemical production	0	1.87E-15	1.26E-06	7.4E-07	1.41E-06	0
Pb-210	UK	Radiochemical production	0.00001	0	0	0	0	0
Po-210	UK	Radiochemical production	0.0088	0	0	0	0	0
Ra-228	FR	Rare earth production	0.000415	0	0	6.76E-05	0	0
Th-228	FR	Rare earth production	8.53E-05	0	0	8.86E-05	0	0
Pb-210	ES	Titanium dioxide pigment manufacturers	0.0005	0.05	0.00003	0.00003	0.00003	0.00003
Pb-210	NL	Titanium dioxide pigment manufacturers	0	0.0018	0.00027	0.0021	0.0034	0.0036
Po-210	ES	Titanium dioxide pigment manufacturers	0	0	0.00003	0.00003	0.00003	0.00003
Po-210	NL	Titanium dioxide pigment manufacturers	0	0.0018	0.00027	0.0021	0.0034	0.0036
Ra-226	ES	Titanium dioxide pigment manufacturers	0.0003	0.03	0.000025	0.00002	0.00002	0.00002
Ra-226	NL	Titanium dioxide pigment manufacturers	0	0.0073	0.0045	0.0021	0.0034	0.0036
Ra-228	ES	Titanium dioxide pigment manufacturers	0.0003	0.03	0.00005	0.00005	0.00005	0.00005
Ra-228	NL	Titanium dioxide pigment manufacturers	0	0.0076	0.0024	0.0013	0.0027	0.0016
H-3	BE	Universities & Research centres	0.0485	0.0168	5.11	0.222	0.0179	0.0223
H-3	CH	Universities & Research centres	0.05	0.075	0.0264	0.0202	0.0117	0.0228
H-3	ES	Universities & Research centres	0.00135	0.00234	0.00216	0.00239	0.00193	0.00199
H-3	IE	Universities & Research centres	0.000965	0.001009	0.000852	0.003333	0.000436	0.000465
H-3	NO	Universities & Research centres	0	0	0	0.000675	0.001248	0.000802
H-3	UK	Universities & Research centres	0.833	0.8185	0.7503	0.59	0.28263	0.5424
C-14	BE	Universities & Research centres	0.0055	0.00106	0.00123	0.00371	0.000261	0.0131
C-14	CH	Universities & Research centres	0.0069	0.0077	0.0059	0.0056	0.0054	0.00374
C-14	ES	Universities & Research centres	0.00078	0.00105	0.00101	0.00112	0.00091	0.00094
C-14	IE	Universities & Research centres	0.00006	0.00101	0.000067	0.000406	0.001089	0.008841
C-14	NO	Universities & Research centres	0	0	0	7.38E-05	0.000431	3.05E-05
C-14	UK	Universities & Research centres	0.397	0.17112	0.17808	0.2076	0.176	0.1708
P-32	ES	Universities & Research centres	0.00413	0.00531	0.0051	0.00566	0.00458	0.00472
P-32	IE	Universities & Research centres	0.0004	0.000041	5.43E-05	0.000146	0.000444	2.4E-06
P-32	NO	Universities & Research centres	0	0	0	9.8E-06	0.000291	3E-07
P-32	UK	Universities & Research centres	0.077	0.05987	0.0687	0.0472	0.03862	0.03055
S-35	ES	Universities & Research centres	0.0315	0.03235	0.03106	0.03447	0.0279	0.02876
S-35	IE	Universities & Research centres	0.000093	0.00066	4.6E-06	0.000043	0.000009	0
S-35	NO	Universities & Research centres	0	0	0	4E-07	0.000057	0.000026
S-35	UK	Universities & Research centres	0.0872	0.0889	0.0718	0.0525	0.0462	0.0306
Cr-51	ES	Universities & Research centres	0.00089	0.0013	0.00125	0.00138	0.00111	0.00113
Cr-51	IE	Universities & Research centres	1E-07	0.000001	2E-08	0	0	4E-11
Cr-51	NO	Universities & Research centres	0	0	0	0.000002	6.42E-05	1.07E-05
Cr-51	UK	Universities & Research centres	0.01895	0.01631	0.01565	0.00969	0.00821	0.010113
I-125	BE	Universities & Research centres	27.8	30.5	10.5	18	1.48	3.09
I-125	ES	Universities & Research centres	0.00041	0.00077	0.00073	0.00079	0.00064	0.0007
I-125	IE	Universities & Research centres	0.000107	0.000141	0.000239	0.000195	0.000154	0.000105
I-125	NO	Universities & Research centres	0	0	0	2.08E-05	1.13E-05	3.9E-06
I-125	UK	Universities & Research centres	0.02597	0.0269	0.028767	0.02779	0.03021	0.0278

Table N.2. Discharges from oil/gas extraction (including on-shore) in non OSPAR member states and corresponding oil production from Eurostat and the relevant regression statistics

Country	Year	Pb-210 in MBq	Ra-226 in MBq	Ra-228 in MBq	Th-228 in MBq	H-3 in MBq	Oil production in TJ
IE	2005	0	0	0	:	:	0
NO	2005	:	390	:	:	2700	5331883
UK	2005	35	341	169	:	618	3308221
DK	2006	1	4	1	:	:	723823
IE	2006	0	0	0	:	:	0
NL	2006	10	100	150	:	:	57418
NO	2006	39	461	388	:	382	4914300
UK	2006	55	255	225	:	:	2983416
DK	2007	1	33	15	0	:	652267
NL	2007	10	100	130	:	:	88518
NO	2007	52	528	397	:	1674	4738639
UK	2007	27	238	200	:	:	3012519
DE	2008	0	0	0	:	:	128801
DK	2008	1	14	9	0	76	602852
IE	2008	0	0	0	:	:	0
NL	2008	8	130	140	:	:	73879
NO	2008	42	461	372	:	1234	4529685
UK	2008	51	216	153	:	:	2803530
DE	2009	0	0	0	:	:	117638
DK	2009	12	10	6	0	:	555183
IE	2009	0	0	0	:	:	0
NL	2009	29	150	140	:	:	55983
NO	2009	45	478	363	:	658	4266039
UK	2009	105	303	200	1	:	2694731
DE	2010	0	0	0	:	:	105666
DK	2010	17	66	21	0	:	522443
IE	2010	0	0	0	:	:	0
NL	2010	11	120	140	:	:	43456
NO	2010	36	486	385	:	50	3927388
UK	2010	38	367	134	1	:	2501207
Slope	**Bq/kJ**	**1.22E-05**	**9.89E-05**	**7.68E-05**	**2.70E-07**	**2.48E-04**	
p-value		**1.72E-09**	**4.05E-18**	**2.38E-14**	**4.92E-04**	**5.65E-03**	

Issues/limitations

For non-OSPAR countries the inventory is less complete as there are less data available. Hence, the emissions of radioactive substances arising from non-nuclear activities other than Oil and gas sector are not properly accounted for. For other sectors also data from OSPAR member countries for the period 1990-2010 are not reported nor estimated. Estimations of discharges from oil/gas extraction do not distinguish emission factors between on-shore and off-shore activities; hence the robustness of the estimation is limited in this respect. In addition, the inventory lacks in assessing 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.

Method O – Ionizing radiation emissions from gypsum plaster and ceramics end of life

Gypsum plaster

Data sources

The end of life scenarios for gypsum is used from the Ecoinvent 3.01 (Weidema et al., 2013) life cycle inventory data (market for waste gypsum, GLO), resulting in ionizing radiation emissions per kg of product. This scenario consists of 70% inert material landfill and 30% sanitary landfill. These activities are specific to the technology encountered in Switzerland in 2000. The datasets were extrapolated to the year of the calculation (2013). All immediate and future emissions from landfill of one tonne of gypsum are included.

The PRODCOM (PRODCOM/Eurostat, 2013) database was used for gypsum plaster production. The following item was selected from the database: 23522000 Plasters consisting of calcinated gypsum or calcium sulphate (including for use in building, for use in dressing woven fabrics or surfacing paper). The production quantity indicator was used from the annual sold table in the PRODCOM database. The unit is always kg. The sold quantity deviates from the produced quantity because the latter includes what is retained by the producer for use in the production of another product. The produced quantity would therefore be more precise, but the issue is that the sold quantity table is much more complete.

Data gaps

Table O.1 shows the data available from PRODCOM for Plasters consisting of calcinated gypsum or calcium sulphate. There are no data available before 1995.

Estimation technique

The emissions from the Ecoinvent 3.01 data were multiplied by the total production of the product. Data gaps in the PRODCOM data, shown as colon signs (:) in Table O.1, were estimated by extrapolation over time.

Ceramics

For ceramics, there is a product in the PRODCOM database: 23201100 Ceramic goods of siliceous fossil meals or earths including bricks, blocks, slabs, panels, tiles, hollow bricks, cylinder shells and pipes). However, there is no end of life scenario available in Ecoinvent 3.01 or any other LCI database. Hence the estimations were not performed.

Issues/limitations

The emission of radionuclides from gypsum boards used in construction is partially accounted for within the inventory, covering only the end-of-life (EoL) phase. The use phase is not assessed but it could be relevant to assess, for instance, emissions of radon isotopes. The technological and geographic representativeness of this process in Ecoinvent 3.01 is low for EU27. Emissions associated to use and EoL phase of tiles and ceramics are currently missing from the inventory but should be assessed as well.

Method Q – Crops

Data source

The production of crops (in tonnes) and the land used (in ha) is extracted from the FAOstat – crop production (2013b) database, so to account for domestic land use within the EU27. For some countries, the data related to early 90's are systematically missing and these values need to be estimated.

Estimation technique

The estimation technique differs for each country:

Belgium/Luxembourg*:* Until 1999, Belgium and Luxembourg reported data together. For 2000-2010 the data are reported separately for these two countries. The average ratio between the reported values in 2000-2010 is used to determine the allocation of the data for 1990-1999. There was no consistent (significant) trend over time found in the ratio's (F test). For this reason the average ratio was used.

Czech Republic/Slovakia: For the years 1990-1992, CZ and SK reported as one under Czechoslovakia. For 1993-2010 the data are reported separately for these two countries. The average ratio between the reported values in 1993-2010 is used to determine the allocation of the data for 1990-1992. There was no consistent (significant) trend over time found in the ratio's (F test). For this reason the average ratio was used.
Estonia, Latvia, Lithuania, Slovenia (1990 and 1991 missing): Linear regression over time is performed to estimate the years 1990 and 1991. If regressions resulted in negative estimates for Ha and tonnes production, a value of 0 was reported in the inventory.Issues/limitations

In case of other missing years NA is reported when value is not reported.

Method R – Land use & land use change

Data source

Data on land use and land use change for forest land, cropland, grassland, wetland, settlements, and other land are extracted from UNFCCC (2013). Of the 27972 values reported in this theme, over 19000 could be extracted directly from UNFCCC (in the final database around 7000 missing values were assumed 0 and 252 estimated on the basis of the approaches developed below, leaving around 1500 records blank). Missing values are investigated and subject to general estimation rules, as reported below. UNFCCC data availability is good with the exception of Cyprus and Malta.

Estimation technique

CY and MT
Corine land cover data is used to estimate the land use and land use change flows for Cyprus and Malta (EEA, 2012b). "Land use", "remaining land", and "total land converted to" are included for Forest land, Crop land, Grass land, and Settlements. For the other flows empty values (' ') are reported. Corine land cover provides data for 1990, 2000, and 2006. The remaining years are estimated via interpolation and extrapolation, using linear regression over time. The land use and land use change flows of Corine do not exactly match the land use categories of UNFCCC. The Table R-1 shows the land use categories from Corine that are used to represent the flows in the inventory:

Table R-1. Flows in inventory coupled to Corine land use categories

Flow From Inventory	**Land use category**
Cropland	Occupation, agriculture, mosaic
Cropland	Occupation, arable
Cropland	Occupation, arable, non-irrigated
Cropland	Occupation, heterogeneous, agricultural
Cropland	Occupation, permanent crop
Cropland	Occupation, permanent crop, fruit
Cropland	Occupation, permanent crop, irrigated
Cropland	Occupation, permanent crop, vine, intensive
Forest land	Occupation, forest, extensive
Forest land	Occupation, forest, intensive
Grassland	Occupation, grassland/pasture/meadow
Settlements	Occupation, urban, continuously built
Settlements	Occupation, urban, discontinuously built
Settlements	Occupation, urban, green areas
*Land converted to Cropland	Transformation, to agriculture
*Land converted to Cropland	Transformation, to arable
*Land converted to Cropland	Transformation, to arable, non-irrigated
*Land converted to Cropland	Transformation, to heterogeneous, agricultural
*Land converted to Cropland	Transformation, to permanent crop
*Land converted to Cropland	Transformation, to permanent crop, fruit
*Land converted to Cropland	Transformation, to permanent crops, irrigated
*Land converted to Cropland	Transformation, to permanent crop, vine
*Land converted to Forest land	Transformation, to forest, extensive
*Land converted to Forest land	Transformation, to forest, intensive

*Land converted to Grassland	Transformation, to grassland/pasture/meadow
*Land converted to Settlements	Transformation, to urban
*Land converted to Settlements	Transformation, to urban, continuously built
*Land converted to Settlements	Transformation, to urban, discontinuously built

General estimation technique and assumptions for EU27 (minus CY and MT)

The other 25 countries do provide more complete data. The general rules for dealing with missing years or completely missing flows are (cropland is used as example);

-When the flow "forest land changed to crop land" is missing, but "wetland to crop land" is reported: assume 0 for "forest land to crop land"

-When no flow to crop land is reported for a year(s), but other years are reported in this flow, report 0 for the missing years

-When no change from other land types to cropland is reported, case-specific assumptions had been made by investigating the National Inventory Report (UNFCCC, 2013). Cases in which the National Inventory Reports is investigated are summarized below.

Issues/comments

Settlements

Data on land use transformation to settlements are believed to be incorrectly reported within the UNFCCC for many of the EU countries. In fact, the total land use transformation to urban areas is unrealistically high if compared to other EU databases such as the Land cover and land use, landscape (LUCAS) (Eurostat 2013s; 2014). Thus estimates on the yearly transformation to urban areas (from any land use) were done on the basis of yearly changes in the extension of urban areas. The result led to a figure in line with to LUCAS reported statistics.

Forest land

Greece reports no values for land change to forest land for 1990-1993, additionally for 1994-2010 only crop land is converted to forest land. The national inventory report is investigated to determine if these gaps can be assumed 0 or if they are not measured or calculated. The NIR of Greece was investigated and for 1990-1993 there is no land converted to forest land. For 1994-2010 all land change to forest land comes from cropland. The missing values for Greece are set to 0 in the inventory.

Cropland

Spain reports no data on land converted to cropland. Data for cropland remaining cropland is complete. The NIR mentions subsidized reforestation from cropland and land use change from cropland to grassland and settlements. There is no mention of land change to cropland. Missing values for land change to cropland are assumed 0.

Grassland

-

Wetland

Italy, Latvia, Slovakia, Spain, and the United Kingdom report no values for land changed to wetland. Values for wetland remaining wetland are present (and are non-zero).

Italy reports a constant area of wetland for 1990-2010 in the NIR. Assume 0 for land changed to wetland.

Latvia reports a constant area of wetland for 1990-2010 in the NIR. Assume 0 for land changed to wetland.

Slovakia reports a constant area of wetland for 1990-2010 in the NIR. Assume 0 for land changed to wetland.

Spain does not mention land changed to wetland in the NIR. Assume 0 for land changed to wetland.

United Kingdom no land use change to wetland in the NIR. Report 0 for land changed to wetland

Overseas territories

The Danish and the French inventories include also overseas territories. Overall such inclusion does not have a strong effect at the level of impact assessment, as Greenland (DK) is classified as "Other" land and its characterisation factor is then 0 in the method recommended within the ILCD. In case of France, the inclusion of those territories has a small to negligible effect on the totals.

Method S – GHG emissions

Method S1 - GHG emissions - CO_2, CH_4, N_2O

Data source

The dataset is based on UNFCCC (2013). Other models and datasets such as EDGAR v4.2 (EC-JRC/PBL, 2011) and GAINS (IIASA, 2013) report data for GHGs, however because of completeness, consistency and robustness (as discussed in Method T1), UNFCCC data were used to build the inventory.
Table S-1 shows the flows that are included in the inventory. The values from LULUCF are calculated by lowering the UNFCCC values for GHG including LULUCF with the UNFCCC values for GHG excluding LULUCF.

Table S-1. GHG flows

Source	Emission	specification	
UNFCCC	CO2	Total excluding LULUCF	kg
UNFCCC	CH4	Total excluding LULUCF	kg
UNFCCC	N2O	Total excluding LULUCF	kg
UNFCCC	CO2	LULUCF	kg
UNFCCC	CH4	LULUCF	kg
UNFCCC	N2O	LULUCF	kg
UNFCCC	Direct N_2O emissions from N fertilization of Forest Land and Other	LULUCF	kg
UNFCCC	CO2 emissions from agricultural lime application	LULUCF	kg
	Biomass Burning:		
UNFCCC	CO2	LULUCF	kg
UNFCCC	CH4	LULUCF	kg
UNFCCC	N2O	LULUCF	kg

Estimation technique

Missing values occur mainly in the flows “Direct N_2O emissions from N fertilization of Forest Land and Other”, “CO2 emissions from agricultural lime application”, and “Biomass burning”. Several National inventory reports are investigated and “not occurring” and “negligible” are provided as explanation for the missing values (UNFCCC 2013). However, most of these values could be considered 0. For the remaining flows, the missing values are less frequent and summarized in table S.2.

Method S2 - GHG emissions - HFCs, PFCs and SF_6

Values for SF6 are provided by UNFCCC (2013) as CO_2 equivalents and not in mass. Therefore, the characterization factor available in the impact assessment methods recommended by EC-JRC (2011) and PEF (EC, 2013) was used to calculate back the mass of SF6 then included in the inventory. Data-gaps were filled by using time-interpolation assuming as representative the trend fitting the best the observed data (linear or exponential).
Data on hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are provided by UNFCCC as aggregates and expressed in kg of CO_2 equivalents. In order to estimate their equivalent aggregate mass, average characterization factors with time horizon 100 years were applied (GWP_{100} = 2.53E+03 for HFCs and 7.61E+03 for PFCs). For consistency with the data source, the average was calculated on the basis of characterization factors as reported by UNFCCC[8]. Missing HFCs flows (period 1990-1994

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[8] https://unfccc.int/ghg_data/items/3825.php

for several countries) were estimated by assuming an exponential trend, as observed in other EU countries. Missing data on PFCs were estimated by using as proxy the emission of SF6 which was found to be positively correlated to this flow.

Methods T – Emissions into air

Method T1 – emissions of NH_3, NO_x, SO_x, CO, PM_{10}, $PM_{2.5}$

The dataset is based on UNFCCC (2013), EEA (2013c) and EMEP (2013) data as discussed in the sections below. Other models and datasets such as EDGAR v4.2 (EC-JRC/PBL, 2011) and GAINS (IIASA, 2013) report data for NOx, SOx, CO, NH_3, PM10 and PM2.5 The choice of the dataset has been done on the basis of the following elements: coverage of the EU-27 member states, completeness of the time series, 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 according to UNFCCC guidelines (UNFCCC, 2006) and reviewed by an international scientific panel[9]. Data on GHGs as well as on CO and NOx and other sectoral data are submitted by the parties to the UNFCCC. As reported in the UNFCCC web-site[10] "*Each national communication of an Annex I Party is subject to an "in-depth" review conducted by an international team of experts and coordinated by the secretariat. National communications from non-Annex I Parties are not subject to such a review, but they are considered by the expert group set up by the Subsidiary Body on Implementation to deal with issues relating to these communications*".

The European Monitoring and Evaluation Programme (EMEP) is a scientifically based and policy driven programme under the Convention on Long-range Transboundary Air Pollution (CLRTAP) for international co-operation to solve transboundary air pollution problems. Under this framework the EMEP Centre on Emission Inventories and Projections (CEIP) maintains and further develops emission database and provides support to the Parties. Overall, it provides two emission datasets available for download: '*Officially reported emission data*' (EMEP/CEIP, 2013a), referred in this document as *EMEP_reported* and '*Emissions as used in EMEP models*' (EMEP/CEIP, 2013b) and referred in this document as *EMEP_modeled*. The latter is an aggregated and data-gap filled version of the former, which in turns consists of data reported by countries under the CLRTAP convention, following the EMEP/EEA inventory guidelines (EMEP/EEA, 2013). The *EMEP_modeled* dataset had been used when complete and available. The dataset covers from the 80s' to 2013 for NOx, SOx, NH3, CO, PM10, PM2.5, with some limitations, in particular for PM10 and PM2.5 for the time period 1990-2000, for many EU countries, for both datasets.

The European Topic Centre for Air Pollution and Climate Change Mitigation (ETC/ACM) of the European Environment Agency collects data on emissions of air pollutants from EEA countries which are then submitted to the LRTAP Convention. European data (EEA, 2013d) are presented in three different formats:

- National emissions to LRTAP Convention - NFR09 sector classification
- National emissions to LRTAP Convention - NFR02 sector classification
- Consolidated table for all countries in the NFR09 format (*EEA_consolidated)*

The latter dataset (referred in this document as *EEA_consolidated*) (EEA, 2013c) contains data-gap filled tables, covering the majority of the EU countries and pollutants under CLRTAP; however figures on emissions of PM10 and PM2.5 are missing for Greece and Luxembourg. In principle the EEA datasets should be completely consistent with what reported to EMEP by member countries (i.e. EMEP - *Officially reported emission data*), whereas differences can be found in comparison to the

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[9] http://unfccc.int/national_reports/annex_i_ghg_inventories/review_process/items/2762.php

[10] http://unfccc.int/national_reports/items/1408.php

dataset EMEP - *Emissions as used in EMEP models* as different assumptions are made by EMEP and EEA to data-gap filling.

EDGAR v4.2 (EC-JRC/PBL, 2011) is a bottom-up modelling exercise based on activity data and emission factors. It covers from 1990 up to 2008 (as a result of the fast-track expansion of EDGAR v4.1), the flows NO_x, SO_x, NH_3, CO, PM10, PM2.5. It has the advantage of being coherent among the different EU member states. However, there is no periodical review and update process.

Table T-1. Available datasets and relative coverage of pollutants

	Dataset				
Pollutant	***UNFCCC (2013)***	***EMEP_reported (EMEP/CEIP, 2013a)***	***EMEP_modeled(EMEP/CEIP, 2013b)***	***EEA_consolidated (EEA, 2013c)***	***EDGAR v4.2 (EC-JRC/PBL, 2011)***
CO	x (missing LU for 2006-2010; missing for Poland and Slovenia for 1990 and 1991))	x	x	x	x (from 1990 to 2008)
NO_X (as NO_2)	x (missing LU for 2006-2010; missing for Poland and Slovenia for 1990 and 1991)	x	x	x	x (from 1990 to 2008)
SOx (as SO_2)		x	x	x	x (from 1990 to 2008)
NH_3		x	x	x	x (from 1990 to 2008)
PM_{10}		x	x (from 1999 to 2010)	x (not GR and LU)	x (from 1990 to 2008)
$PM_{2.5}$		x	x (from 1999 to 2010)	x (not GR and LU)	x (from 1990 to 2008)

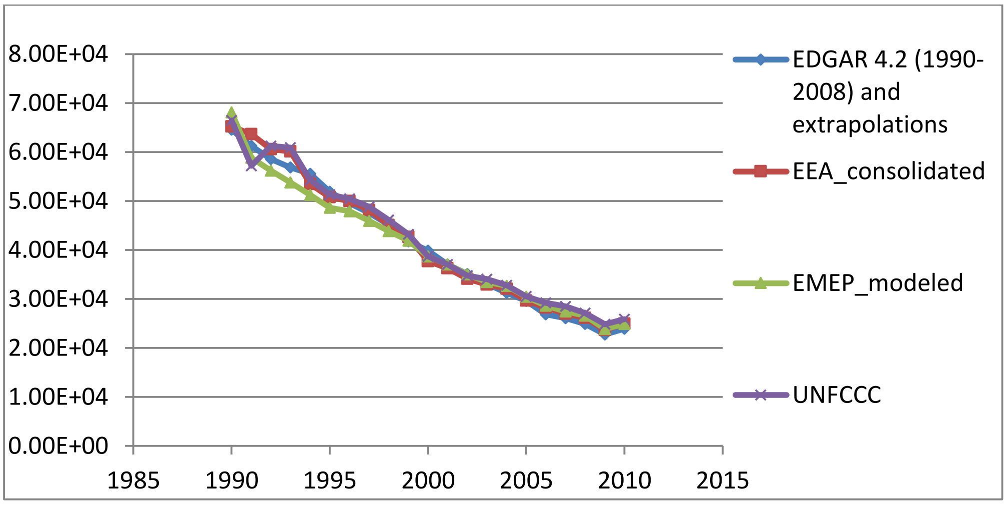

Figure T-1. CO emitted in EU 27 (in 10E6 Kg) from EDGAR 4.2, EEA_consolidated, EMEP_modeled and UNFCCC

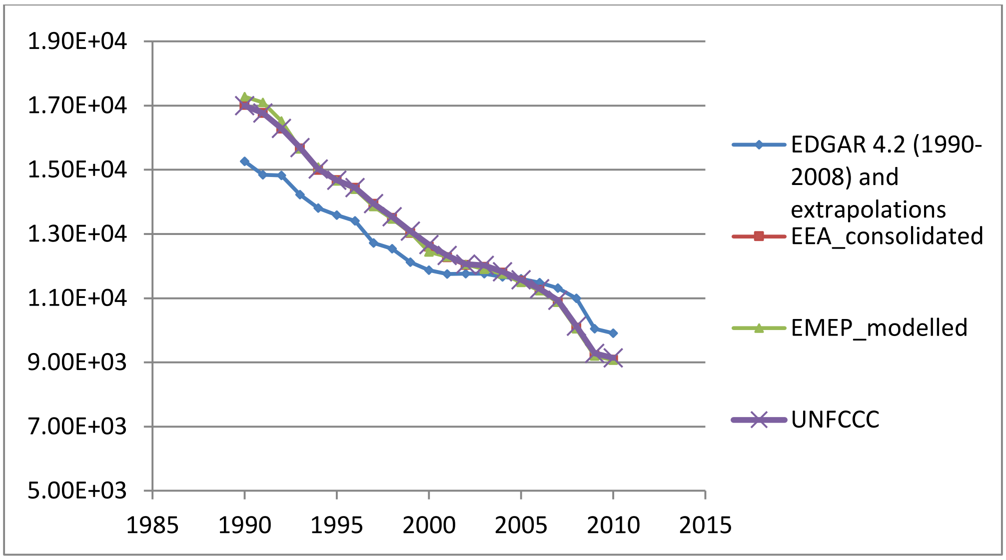

Figure T-2. NO_x and NO_2emitted in EU 27 (in 10E6 Kg) from EDGAR 4.2, EEA_consolidated, EMEP_modeled and UNFCCC

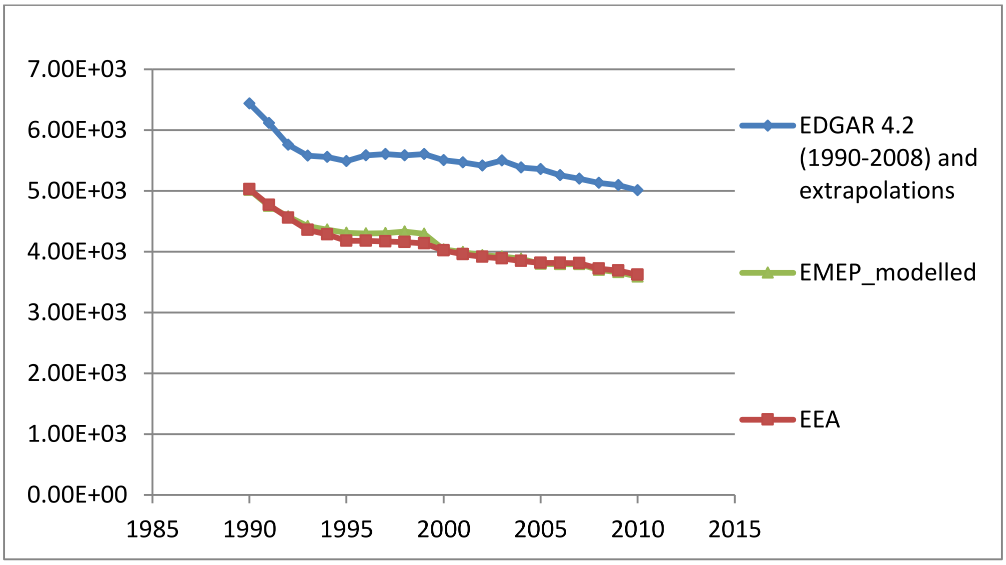

Figure T-3. NH_3 emitted in EU 27 (in 10E6 Kg) from EDGAR 4.2, EEA_consolidated and EMEP_modeled

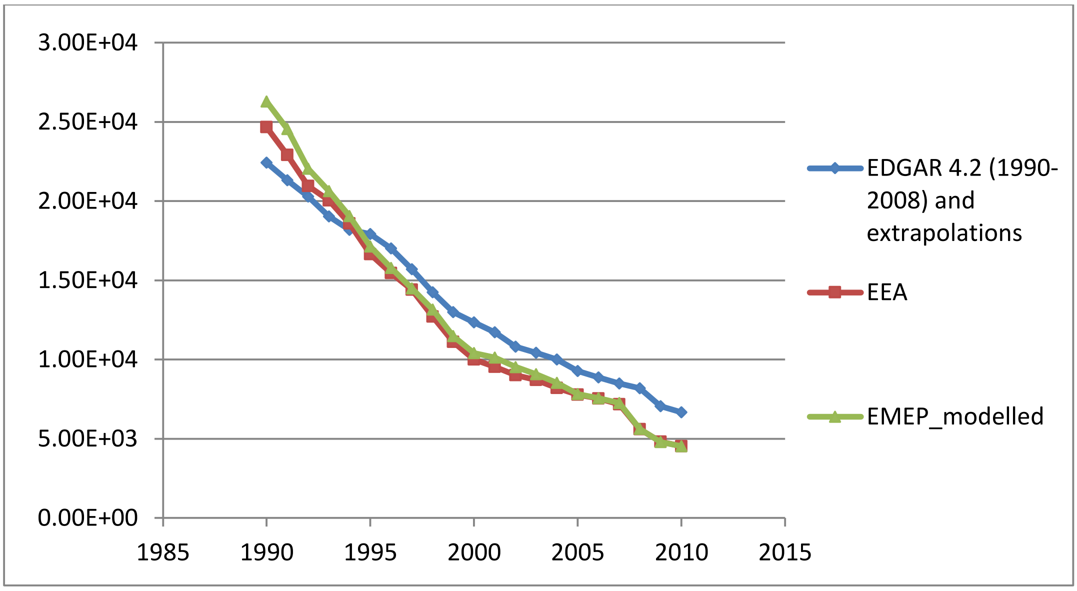

Figure T-4. SO_x and SO_2 emitted in EU 27 (in 10E6 Kg) from EDGAR 4.2, EEA_consolidated and EMEP_modeled

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 among data sources has been set as follows: *UNFCCC > EMEP_modeled = EEA_consolidated > EMEP_report > EDGARv4.2.*

Such hierarchy does not apply for PM10 and PM2.5, where:
EEA_consolidated > EMEP_modeled > EMEP_report > EDGARv4.2

This is because of the fact that *EMEP_modeled* does not provide values before 1999 whereas *EEA_consolidated* does. The latter dataset, however, does not provide figures for Greece (GR) and Luxembourg (LU), hence some estimation techniques had been applied (see section T3 below).
Overall, UNFCCC (2013) has been used as data source for NOx (reported as NO_2) and CO, with the addition of estimated values for LU (see method T2); the *EMEP_modeled* database (EMEP/CEIP, 2013b) had been used for SO_x (reported as SO_2) and NH_3, whereas the EEA_consolidated dataset had been used for $PM_{2.5}$ and PM_{10}, with the addition of estimations for Greece and Luxembourg (see method T3).

Limitation to the use of PM10, PM2.5 and PM0.1 for life cycle impact assessment (LCIA)
The current inventory contains estimations for PM_{10}, $PM_{2.5}$ and $PM_{0.1}$ emissions occurring within each of the EU-27 member countries. Attention must be paid when using such inventories in the context of LCIA because, as argued by Humbert[11], PM_{10} contains all particles which are smaller in diameter than 10 micron, including, thus, $PM_{2.5}$ which, in turn, contains $PM_{0.1}$. Treating the three of them as commonly done with emissions occurring independently one to each other would lead to double-counting in the LCIA phase.

Method T2 – estimation of missing emissions of NOx and CO

The UNFCCC dataset does not provide some of the figures for NOx and CO for Luxembourg, Poland and Slovenia for different years, as reported in table below. The missing data are estimated by averaging the values reported in *EMEP_modeled* (EMEP, 2013b) and *EEA_consolidated* (EEA, 2013c).

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[11] Sebastien Humbert, personal communication to Lorenzo Benini, October 2014

Table T-2. Missing values for the flows CO, NOX, and NMVOC.

Country	Flow	Year	Estimation method	Flag
Poland	CO excl LULUCF	1991	Use average EMEP_modeled EEA_consolidated	
Poland	CO incl LULUCF	1991	Assumed equal to excl LULUCF	
Luxembourg	NOX excl LULUCF	2006-2010	Use average between EMEP_modeled and EEA_consolidated	
Luxembourg	CO excl LULUCF	2006-2010	Use average between EMEP_modeled and EEA_consolidated	
Luxembourg	CO incl LULUCF	2006-2010	Assumed equal to excl LULUCF	
Luxembourg	NOX incl LULUCF	2006-2010	Assumed equal to excl LULUCF	
Slovenia	NOX incld LULUCF	1990	Assumed equal to excl LULUCF	
Slovenia	CO incl LULUCF	1990	Assumed equal to excl LULUCF	
Slovenia	NOX excl LULUCF	1990	Use average between EMEP_modeled and EEA_consolidated	
Slovenia	CO excl LULUCF	1990	Use average between EMEP_modeled and EEA_consolidated	

Method T3 – estimation of missing emissions of PM_{10}, $PM_{2.5}$

As pointed out in the section above, the *EEA_consolidated* dataset (EEA, 2013c) did not report the data for countries Greece and Luxembourg for both PM10 and PM2.5. In order to estimate PM10 emissions for time series 1990-2010 for GR and LU several alternative approaches based on proxy variables. Both the EDGAR v4.2 (EC-JRC/PBL, 2011) (covering from 1990 to 2008) and the *EMEP_modeled* (EMEP/CEIP, 2013b) datasets (covering from 2000 to 2010) had been used as proxies. Two sets of yearly ratios were calculated between *EEA_consolidated* / *EMEP_modeled* and between *EEA_consolidated* / *EDGARv4.2*, for the total values EU27 minus GR and LU. Such ratios are then respectively multiplied to the time series for GR and LU. These two estimations are then averaged together (for the period 2000 – 2010), leading to the figure reported in the inventory. The methodology builds on the assumption that average yearly ratios assessed for the totals (EU27 minus GR and LU) are representative also for GR and LU, this is not guaranteed.

PM2.5 had been calculated by multiplying PM10 emissions data calculated above by the share of PM2.5 over PM10. Such average ratios are calculated from the *EMEP_modeled* dataset, time series 2000-2010, countries GR and LU. The ratios are equal to 0.64 for GR and 0.74 for LU.

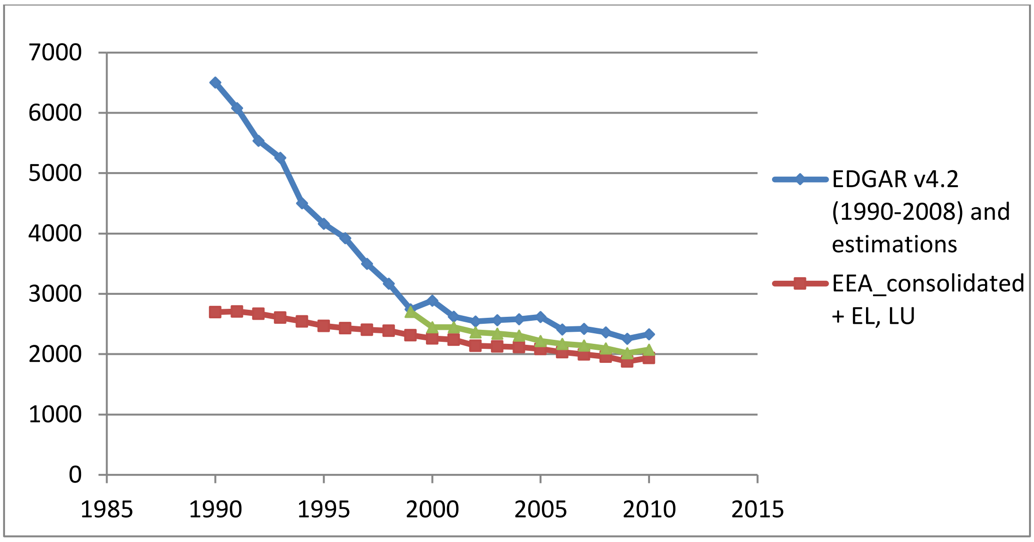

Figure T-5. PM10 emitted in EU 27 (in 10E6 Kg) from EDGAR 4.2 and EEA_consolidated

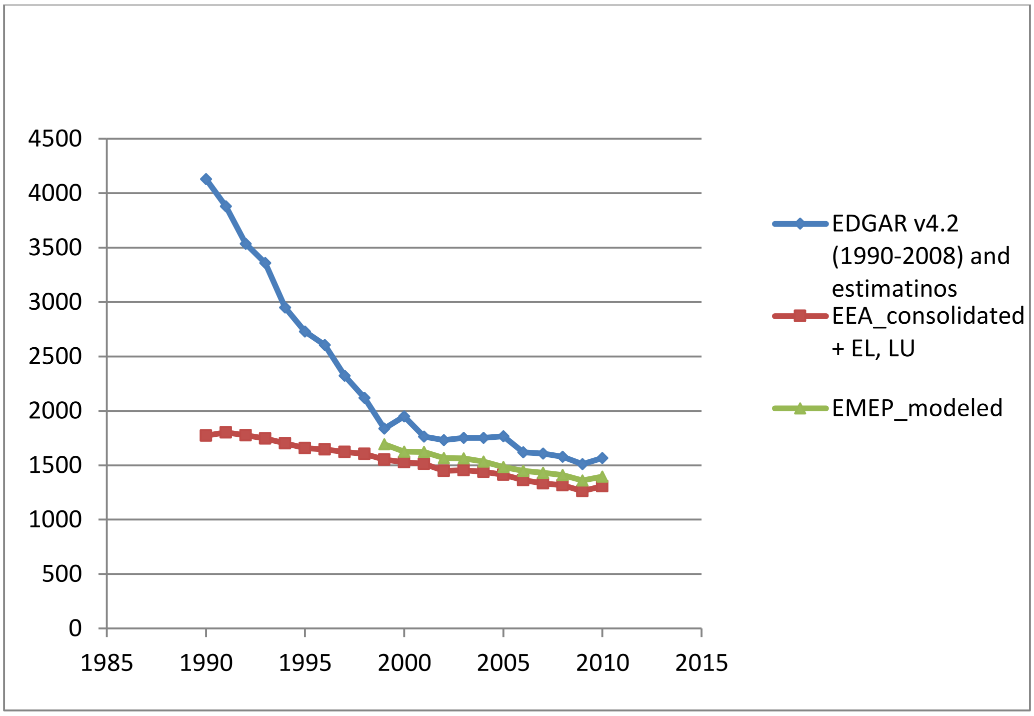

Figure T-6. PM $_{2.5}$ emitted in EU 27 (in 10E6 Kg) from EDGAR 4.2, EEA_consolidated and EMEP_modeled

Method T4 – PM$_{0.1}$ emissions

This method is not coherent with method T3. Being based on EDGARv4.2 instead of EEA and EMEP/CEIP datasets, this method is likely to overestimate values of PM$_{0.1}$, especially for the period 1990-2000, where the differences are most severe between the datasets used (see charts above). Future updates will address this issue. Such flow is not characterized within the ILCD recommended LCIA methods, hence it does not currently contribute to impacts.

Data availability for PM$_{10}$

Currently there is no database with PM$_{0.1}$ emissions available. However, there are several databases available that report PM$_{10}$ emissions. PM$_{10}$ emission data above a certain threshold are submitted by countries to the Convention on Long Range Transboundary Air pollution. These emissions can be extracted from, for example, the CEIP database (CEIP 2013). The PM$_{10}$ emissions are reported for all EU27 countries and per sector (NFR09 classification) and the database is up to date until 2010. There are, however, gaps in the data in the earlier years (see Table T-3).

Table T-3. Data availability for PM10 emissions reported under the LTRAP convention

Country	**temporal coverage**	**Country**	**temporal coverage**
AT	1990, 1995, 2000-2010	LV	2000-2010
BE	2000-2010	LT	1995, 2007-2010
BG	1990-2010	LU	-
CY	2000-2010	MT	2000-2010
CZ	2007-2010	NL	1990-2010
DK	2000-2010	PL	2006-2010
EE	2000-2010	PT	1990-2010
IE	1990-2010	RO	2005-2010
FI	2000-2010	SK	2000-2010
FR	1990-2010	SI	2000-2010
DE	1995-2010	ES	2000-2010
EL	-	SE	1990-2010
HU	2007-2010	UK	1990-2010
IT	1990-2010		

Another option is using the more complete database EDGAR V4.2 developed by EC-JRC/PBL (2011). EDGAR V4.2 also reports sector and country specific PM10 emission data up to the year 2008. Emission data in the EDGAR database are estimated using emission factors based on activity data, as reported below.

> http://edgar.jrc.ec.europa.eu/methodology.php
>
> *Emissions (EM) for a country C are calculated for each compound x on an annual basis (y) and sector wise (for i sectors, multiplying on the one hand the country-specific activity data (AD), quantifying the human activity for each of the i sectors, with the mix of j technologies (TECH) for each sector i, and with their abatement percentage by one of the k end-of-pipe (EOP) measures for each technology j, and on the other hand the country-specific emission factor (EF) for each sector i and technology j with relative reduction (RED) of the uncontrolled emission by installed abatement measure k, as summarized in the following formula:*
>
> $$EM_C(y,x)=\sum_{i,j,k}\left\lfloor AD_{C,i}(y)*TECH_{C,i,j}(y)*EOP_{C,i,j,k}(y)*EF_{C,i,j}(y,x)*\left(1-RED_{C,i,j,k}(y,x)\right)\right\rfloor$$

Upon examination of the emissions in the EDGAR 4.2 database it became apparent that the estimates are larger compared to the values in the EMEP/CEIP database (see Table H-2). For this reason it is not possible to combine these two datasets. Table H-2 shows the PM_{10} emissions (in kg) for 1990 as estimated by Edgar 4.2 and reported in the EMEP/CEIP database for 1990.

Table T-4. PM10 emissions (in kg) for 1990 as estimated by Edgar 4.2 and reported in the CEIP database.

1990	Edgar 4.2	CEIP
Austria	7.57E+06	3.98E+06
Belgium	1.14E+07	NE
Bulgaria	2.10E+07	3.09E+06
Cyprus	3.49E+05	NA
Czech Republic	5.78E+07	NA
Denmark	1.10E+07	NA
Estonia	1.01E+07	NA
Ireland	8.27E+06	1.73E+06
Finland	1.35E+07	1.99E+06
France	6.36E+07	5.34E+07
Germany	7.28E+07	NA
Greece	1.19E+07	NA
Hungary	1.21E+07	0.00E+00
Italy	4.31E+07	2.39E+07
Latvia	3.46E+06	1.73E+06
Lithuania	3.25E+06	4.57E+03
Luxembourg	1.49E+06	NA
Malta	4.30E+05	NA
Netherlands	1.24E+07	6.79E+06
Poland	9.94E+07	NA
Portugal	7.90E+06	6.38E+06
Romania	2.09E+07	NE
Slovakia	9.89E+06	NA
Slovenia	2.56E+06	NA
Spain	5.82E+07	NE
Sweden	8.80E+06	5.16E+06
United Kingdom	5.79E+07	2.72E+07
EU27	6.31E+08	NA

Estimation technique

The PM10 emissions can be used to estimate the PM0.1 emissions by using size fractionation profiles, which estimate the proportion of PM0.1 in PM10 emissions. The size fractionation profiles indicate the amount of PM10 by mass that is in the PM0.1 size range. The fractionation profiles from the study from AMEC Environment & Infrastructure (2011) prepared for the European Commission are used. AMEC Environment & Infrastructure (2011) reports that the fractionation profiles that are available from literature sources are in general derived from measurements or models. The UK emissions inventory team has provided the PM fractionation profiles used in the study, this was the most appropriate single source of data available. Motivation for this choice is provided in the supporting information of AMEC Environment & Infrastructure (2011). Fractionation profiles are defined for 8 categories; power generation, industrial combustion, residential and commercial, road transport, other transport and mobile machinery, industrial processes, agriculture, and other. The category *Industrial Processes* is divided into 27 sectors for which separate fractionation profiles are reported. Table H-3 show the fractionation profiles from the study. Table H-4 show how the profiles are allocated to all the NFR sector codes.

The first step in the PM0.1 estimation is to allocate the sectors specific emissions provided by Edgar 4.2 to the available fractionation profiles. Subsequently the PM10 emissions (1990-2008) are multiplied with the fractionation profiles. All estimates are flagged as Method H.

2009 & 2010

As stated in the beginning of this sections, the years 2009 and 2010 are missing from the Edgar 4.2 database. The PM0.1 estimates are as a consequence also missing. Linear regression over time is used to extrapolate the missing years from the calculated PM0.1 data. Using linear regression over the whole time period is not always appropriate, for example in cases that present with different trends over time. In those cases the time span that is the most representative of the occurring trend is used. Figure H-1 shows the PM10 emissions for 1990-2008 for Czech Republic. In this case linear regression over the whole time span leads to underestimation of the emissions; 2001-2008 is a more appropriate time span to use to estimate the values for 2009 and 2010. Information on the years used for the linear regression is included in the file PM0.1 RU 29-07-2013.xlsx. The estimations for 2009 and 2010 are based on time interpolation.

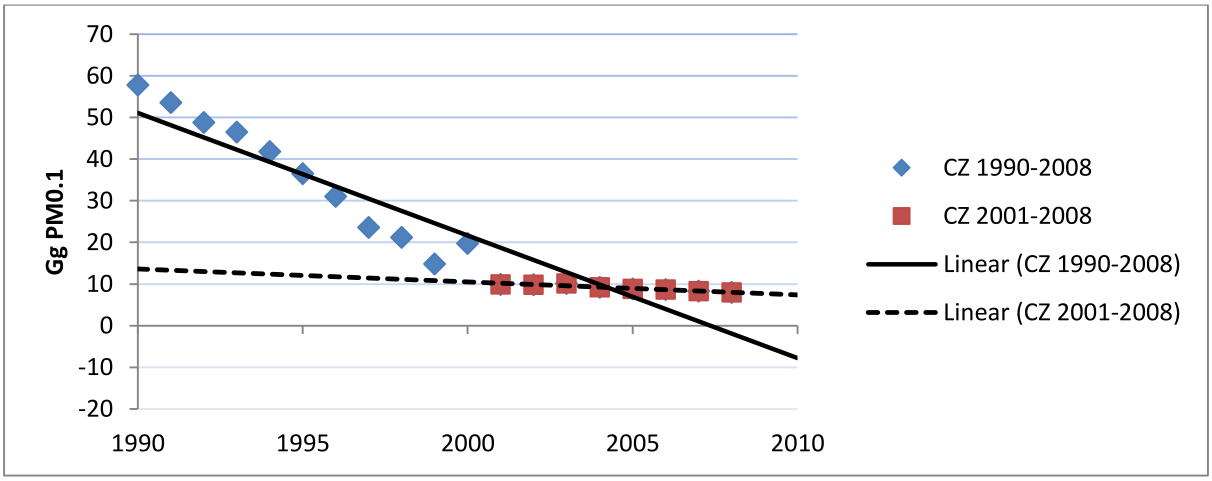

Figure T-7. $PM_{0.1}$ emissions (Gg) for 1990-2008 and 2001-2008 for Czech Republic

Limitations

Striking differences between PM10 data reported in EMEP/CEIP (2013b) and EEA (2013c) and EDGAR v4.2 are found as reported in the charts above, under section Method T3. Updated version of this method should be based on EEA (2013c) data.

Table T-5. Fractionation $PM_{0.1}/PM_{10}$ fractionation profiles for each sector as reported by AMEC Environment & Infrastructure 2011.

Aggregated sector	**NFR code**	**Fractionation profile ($PM_{0.1}/PM_{10}$)**
power generation		0.08
industrial combustion		0.17
residential and commercial		0.07
road transport		0.32
other transport and mobile machinery		0.26
agriculture		0.08
other		0.0001
industrial processes		0.04
	2A1	0
	2A2	0.1
	2A	0.07
	2A4	0.07
	2A5	0.07
	2A6	0.07
	2A7a	0
	2A7b	0
	2A7c	0
	2A7d	0.42
	2B	0.07
	2B2	0.07
	2B3	0.07
	2B4	0.07
	2B5a	0
	2B5b	0
	2C1	0.05
	2C2	0.07
	2C3	0.17
	2C	0.07
	2C5b	0.07
	2C5c	0.07
	2C5d	0.07
	2C5e	0.03
	2C5f	0.07
	2D1	0.05
	2D2	0.07

Table T-6. Allocation of fractionation profiles from AMEC Environment & Infrastructure (2011) to NFR sector codes used in EDGAR v4.2 (EC-JRC/PBL, 2011)

NFR code	**Description NFR category**	**Fractionation profile ($PM_{0.1}/PM_{10}$)**	**Sector description by AMEC 2011.**
1 A 1 a	Public electricity and heat production	0.08	power generation
1 A 1 b	Petroleum refining	0.08	power generation
1 A 1 c	Manufacture of solid fuels and other energy industries	0.08	power generation
1 A 2 a	Stationary combustion in manufacturing industries and construction: Iron and steel	0.17	industrial combustion
1 A 2 b	Stationary Combustion in manufacturing industries and construction: Non-ferrous metals	0.17	industrial combustion
1 A 2 c	Stationary combustion in manufacturing industries and construction: Chemicals	0.17	industrial combustion
1 A 2 d	Stationary combustion in manufacturing industries and construction: Pulp, Paper and Print	0.17	industrial combustion
1 A 2 e	Stationary combustion in manufacturing industries and construction: Food processing, beverages and tobacco	0.17	industrial combustion

NFR code	Description NFR category	Fractionation profile ($PM_{0.1}/PM_{10}$)	Sector description by AMEC 2011.
1 A 2 f i	Stationary combustion in manufacturing industries and construction: Other (Please specify in your IIR)	0.17	industrial combustion
1 A 2 f ii	Mobile Combustion in manufacturing industries and construction: (Please specify in your IIR)	0.17	industrial combustion
1 A 3 a ii (i)	Civil aviation (Domestic, LTO)	0.26	other transport and mobile machinery
1 A 3 a i (i)	International aviation (LTO)	0.26	other transport and mobile machinery
1 A 3 b i	Road transport: Passenger cars	0.32	road transport
1 A 3 b ii	Road transport: Light duty vehicles	0.32	road transport
1 A 3 b iii	Road transport: Heavy duty vehicles	0.32	road transport
1 A 3 b iv	Road transport: Mopeds & motorcycles	0.32	road transport
1 A 3 b v	Road transport: Gasoline evaporation	0.32	road transport
1 A 3 b vi	Road transport: Automobile tyre and brake wear	0.32	road transport
1 A 3 b vii	Road transport: Automobile road abrasion	0.32	road transport
1 A 3 c	Railways	0.26	other transport and mobile machinery
1 A 3 d i (ii)	International inland waterways	0.26	other transport and mobile machinery
1 A 3 d ii	National navigation (Shipping)	0.26	other transport and mobile machinery
1 A 3 e	Pipeline compressors	0.08	power generation
1 A 4 a i	Commercial / institutional: Stationary	0.07	residential and commercial
1 A 4 a ii	Commercial / institutional: Mobile	0.07	residential and commercial
1 A 4 b i	Residential: Stationary plants	0.07	residential and commercial
1 A 4 b ii	Residential: Household and gardening (mobile)	0.07	residential and commercial
1 A 4 c i	Agriculture/Forestry/Fishing: Stationary	0.07	residential and commercial
1 A 4 c ii	Agriculture/Forestry/Fishing: Off-road vehicles and other machinery	0.07	residential and commercial
1 A 4 c iii	Agriculture/Forestry/Fishing: National fishing	0.07	residential and commercial
1 A 5 a	Other stationary (including military)	0.07	residential and commercial
1 A 5 b	Other, Mobile (including military, land based and recreational boats	0.07	residential and commercial
1 B 1 a	Fugitive emission from solid fuels: Coal mining and handling	0.08	power generation
1 B 1 b	Fugitive emission from solid fuels: Solid fuel transformation	0.08	power generation
1 B 1 c	Other fugitive emissions from solid fuels	0.08	power generation
1 B 2 a i	Exploration, production, transport	0.08	power generation
1 B 2 a iv	Refining / storage	0.08	power generation
1 B 2 a v	Distribution of oil products	0.08	power generation
1 B 2 b	Natural gas	0.08	power generation
1 B 2 c	Venting and flaring	0.08	power generation
1 B 3	Other fugitive emissions from geothermal energy production , peat and other energy extraction not included in 1 B 2	0.08	power generation
2 A 1	Cement production	0	industrial processes
2 A 2	Lime production	0.1	industrial processes
2 A 3	Limestone and dolomite use		industrial processes
2 A 4	Soda ash production and use	0.07	industrial processes
2 A 5	Asphalt roofing	0.07	industrial processes
2 A 6	Road paving with asphalt	0.07	industrial processes
2 A 7 a	Quarrying and mining of minerals other than coal	0	industrial processes
2 A 7 b	Construction and demolition	0	industrial processes
2 A 7 c	Storage, handling and transport of mineral products	0	industrial processes
2 A 7 d	Other Mineral products	0.42	industrial processes
2 B 1	Ammonia production		industrial processes
2 B 2	Nitric acid production	0.07	industrial processes
2 B 3	Adipic acid production	0.07	industrial processes
2 B 4	Carbide production	0.07	industrial processes
2 B 5 a	Other chemical industry	0	industrial processes
2 B 5 b	Storage, handling and transport of chemical products	0	industrial processes
2 C 1	Iron and steel production	0.05	industrial processes
2 C 2	Ferroalloys production	0.07	industrial processes
2 C 3	Aluminum production	0.17	industrial processes

NFR code	**Description NFR category**	**Fractionation profile ($PM_{0.1}/PM_{10}$)**	**Sector description by AMEC 2011.**
2 C 5 a	Copper production	0.07	industrial processes
2 C 5 b	Lead production	0.07	industrial processes
2 C 5 c	Nickel production	0.07	industrial processes
2 C 5 d	Zinc production	0.07	industrial processes
2 C 5 e	Other metal production	0.03	industrial processes
2 C 5 f	Storage, handling and transport of metal products	0.07	industrial processes
2 D 1	Pulp and paper	0.05	industrial processes
2 D 2	Food and drink	0.07	industrial processes
2 D 3	Wood processing	0.07	industrial processes
2 E	Production of POPs	0.07	industrial processes
2 F	Consumption of POPs and heavy metals (e.g. electricial and scientific equipment)	0.07	industrial processes
2 G	Other production, consumption, storage, transportation or handling of bulk products	0.07	industrial processes
3 A 1	Decorative coating application	0.0001	*other*
3 A 2	Industrial coating application	0.0001	*other*
3 A 3	Other coating application	0.0001	*other*
3 B 1	Degreasing	0.0001	*other*
3 B 2	Dry cleaning	0.0001	*other*
3 C	Chemical products	0.0001	*other*
3 D 1	Printing	0.0001	*other*
3 D 2	Domestic solvent use including fungicides	0.0001	*other*
3 D 3	Other product use	0.0001	*other*
4 B 1 a	Cattle dairy	0.08	agriculture
4 B 1 b	Cattle non-dairy	0.08	agriculture
4 B 2	Buffalo	0.08	agriculture
4 B 3	Sheep	0.08	agriculture
4 B 4	Goats	0.08	agriculture
4 B 6	Horses	0.08	agriculture
4 B 7	Mules and asses	0.08	agriculture
4 B 8	Swine	0.08	agriculture
4 B 9 a	Laying hens	0.08	agriculture
4 B 9 b	Broilers	0.08	agriculture
4 B 9 c	Turkeys	0.08	agriculture
4 B 9 d	Other poultry	0.08	agriculture
4 B 13	Other	0.08	agriculture
4 D 1 a	Synthetic N-fertilizers	0.08	agriculture
4 D 2 a	Farm-level agricultural operations including storage, handling and transport of agricultural products	0.08	agriculture
4 D 2 b	Off-farm storage, handling and transport of bulk agricultural products	0.08	agriculture
4 D 2 c	N-excretion on pasture range and paddock unspecified	0.08	agriculture
4 F	Field burning of agricultural wastes	0.08	agriculture
4 G	Agriculture other(c)	0.08	agriculture
5 A	Forest fires	0.15	*Biomass burning (value extracted from appendix)*
5 C	Grassland fires	0.15	*Biomass burning (value extracted from appendix)*
6_A	Solid waste disposal on land	0.0001	*other*
6 B	Waste-water handling	0.0001	*other*
6 C a	Clinical waste incineration (d)	0.0001	*other*
6 C b	Industrial waste incineration (d)	0.0001	*other*
6 C c	Municipal waste incineration (d)	0.0001	*other*
6 C d	Cremation	0.0001	*other*
6 C e	Small scale waste burning	0.0001	*other*
6 D	Other waste(e)	0.0001	*other*
7_A	Other (included in national total for entire territory)	0.0001	*other*
1 A 3 a ii (ii)	Civil aviation (Domestic, Cruise)	0.26	other transport and mobile machinery
1 A 3 a i (ii)	International aviation (Cruise)	0.26	other transport and mobile machinery
1 A 3 d i (i)	International maritime navigation	0.26	other transport and mobile machinery

Conclusion and outlook

Inventory of emissions and resources use are related to very different source of pressure to the environment. The population of these inventories is very challenging as data are coming from different sources and, where data gaps occur, extrapolation strategies should be adopted.

This document provides the background methodology for building inventories of emissions to air, water and soil occurring in the territory of the EU (“domestic”) as well as resource extraction in EU to be used as input data for calculating normalisation factors (NFs) for Environmental Footprint (EC - European Commission, 2013) and life cycle based indicators for resource efficiency (EC-JRC, 2012a and b). The resulting inventory is more complete of any previous inventory used for calculating normalisation factors. However, some limitations are still affecting the inventory.

The inventory is primarily based on extensive data collection at EU level, from different sources. Despite the use of well-established sources, a number of odd figures and outliers have been identified (as reported, e.g. in Benini et al 2014a) and those may imply problem in impact estimation.

Moreover, for missing flows, extrapolation strategies have been adopted and gap filling activities undertaken for their calculation. The extrapolation methodology implies a number of shortcomings in the data robustness which should be carefully considered when using the data for normalisation.

For each method reported in the current report, uncertainties has been described and possible future improvements identified. This is of utmost importance in the context of policy support.

Indeed, the Environmental Footprint (EF) guides, i.e. the Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF) provide a method for modelling the environmental impacts of the flows of material/energy and the emissions and waste streams associated with a product or organisation throughout its life cycle. The proposed methodology for building LCA-compliant national inventories of emissions and resource extraction contributes to the EF implementation, especially during the three year pilot phase of developing Product Environmental Footprint Category Rules (PEFCRs) and Organisation Environmental Footprint Sector Rules (OEFSRs). With that the work also contributes to the related COM (2013) 196 final Building the Single Market for Green Products.

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Introduction/Conclusion and outlook

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Estimation strategy

Method A

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European Commission
EUR 26871 EN – Joint Research Centre – Institute for Environment and Sustainability

Title: **Methodology for building LCA-compliant national inventories of emissions and resource extraction**

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Luxembourg: Publications Office of the European Union

2014 – 93pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424 (online), ISSN 1018-5593 (print)

ISBN 978-92-79-43262-0 (PDF)
ISBN 978-92-79-43263-7 (print)

doi: 10.2788/18238

LB-NA-26871-EN-N

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doi: 10.2788/18238

ISBN 978-92-79-43262-0