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List of abbreviations

BDP: Biodiversity Damage Potential
BF: Bioaccumulation Factor
CF: Characterization Factor
DALY: Disability Adjusted Life Years lost
EF: Effect Factor
EQ: Ecosystem Quality
ET: Evapotranspiration
FAO : Food and Agriculture Organization
FF : Fate Factor
GIS: Geographical Information System
GW: Ground water
ICE: Interspecies Correlation Estimation
ILCD: International Reference Life Cycle Data System
IS: Impact Score
ISO: the International Organization for Standardization
LCA: Life Cycle Assessment
LCI: Life Cycle Inventory
LCIA: Life Cycle Impact Assessment
LEF: Linear Effect Factor
LU: Land Use
MCI: Marginal Cost Increase
MEF: Marginal Effect Factor
N: Nitrogen
NPP: Net Primary Productivity
NPPD: Net Primary Productivity Depletion
P: Phosphorus
PAF : Potentially Affected Species
PDF : Potentially Disappeared Species
PNOF : Potentially not occurring fraction of plant species
PNV: Potential Natural Vegetation
R: Resources
RSD: Relative Square Desviation
SC: Surplus Cost
SEF: Solar Energy Factor
SETAC: Society of Environmental Toxicology and Chemistry
SD: Soil Depth
SF: Soil sensitivity factor
SOC: Soil Organic Carbon
SSD: Species Sensitivity Distributions
SW: Surface water
UNEP : United Nation Environmental Program
USLE: Universal Soil Loss Equation
WP: Workpackage
XF: Exposure factor

4.8 NEW LIFE CYCLE IMPACT ASSESSMENT METHODS APPLIED TO TOMATO CASE STUDY

Introduction

The present deliverable concerns to the case study of fresh tomato production in a *parral* greenhouse on the coast of Almeria, Spain. This case study is one of the six case study areas of EU policy interest selected to show how the methodological improvements developed along LC-IMPACT research project work out in practice. LC-IMPACT was designed to address key factors in life cycle assessment methodology and the main goal of the project is to develop and further improve the life cycle impact assessment methods, characterization factors and normalization factors in a coherent and scientifically sound way.

Tomato (*Lycopersicon esculentum*) is the second most important worldwide vegetable crop after potato. The current tomato world production is about 130 million tonnes of fresh fruit produced on 4.6 million hectares, being the Mediterranean basin one of the most important regions of tomato production in the world. The Mediterranean area produces 19 % of the total world production (FAOSTAT 2007). *Parral* greenhouses are the most common greenhouse structures in Southern Spain, the region with the most extensive production of protected crops in Europe.

The main goal of this deliverable was to evaluate in detail the environmental assessment improvements provided as well as applicability and acceptance of the new LCIA methods developed over the project applied to our case study. A first evaluation of the new developed characterization models and stakeholders acceptance, in accordance with ILCD criteria, was performed in the correspondent tasks of LC-IMPACT project (reviews and stakeholder consultancy).

The methodology used for the analysis was the same as for the other case studies and it was based on the methodology described in the ILCD guide. According to the ILCD handbook (ILCD 2010), this study can be considered a C2 situation: an accounting description of the production system as it is, excluding interactions with other systems and without decision support (ILCD 2010).

The most common functional unit used in agriculture is yield; however to apply the new metods we have used the reference flow, 1 ha occupied during one year, which is the length period corresponding to greenhouse tomato crop in the area studied. In annexe we have included results expressed per kg of tomato, using therefore average yield as Functional unit.

The tomato fresh production was analysed to differentiate the foreground and the background systems with the purpose of identifying which processes can be managed by direct control (Figure 4.8.1). The foreground system for the tomato production system was depicted in several stages to facilitate the assessment and the interpretation of the results: greenhouse structure, auxiliary equipment, management, fertilizers, pesticides and waste management. A detailed description of the defined stages is described in annexe section 4.8.5.3.

The data used for the inventory phase were from long cycle tomato cultivation in the period between 2006 and 2010. Primary data of the foreground system were the specific data for the agricultural operations, such as water consumption, fertilizers and pesticides doses and yield, and were representative of the studied area located on the coast of Almeria (Southeast of Spain). These data were from a long cycle cultivation period and tomato crop plants were at a density of 1.23 plants·m^{-2} with two stems per plant. Criteria of best available technology were assessed. The greenhouse structure was modelled as a generic data set representing the typical structure of a *parral* greenhouse. Greenhouse average data were extrapolated from

several greenhouse sizes and extrapolation was based on verified measurements of *parral* greenhouses. Secondary data were average or generic for the background system and were obtained from the Ecoinvent database (Frischknecht, R. et al. 2007). Representativeness of data was looked from a technological, geographical and time-related perspective.

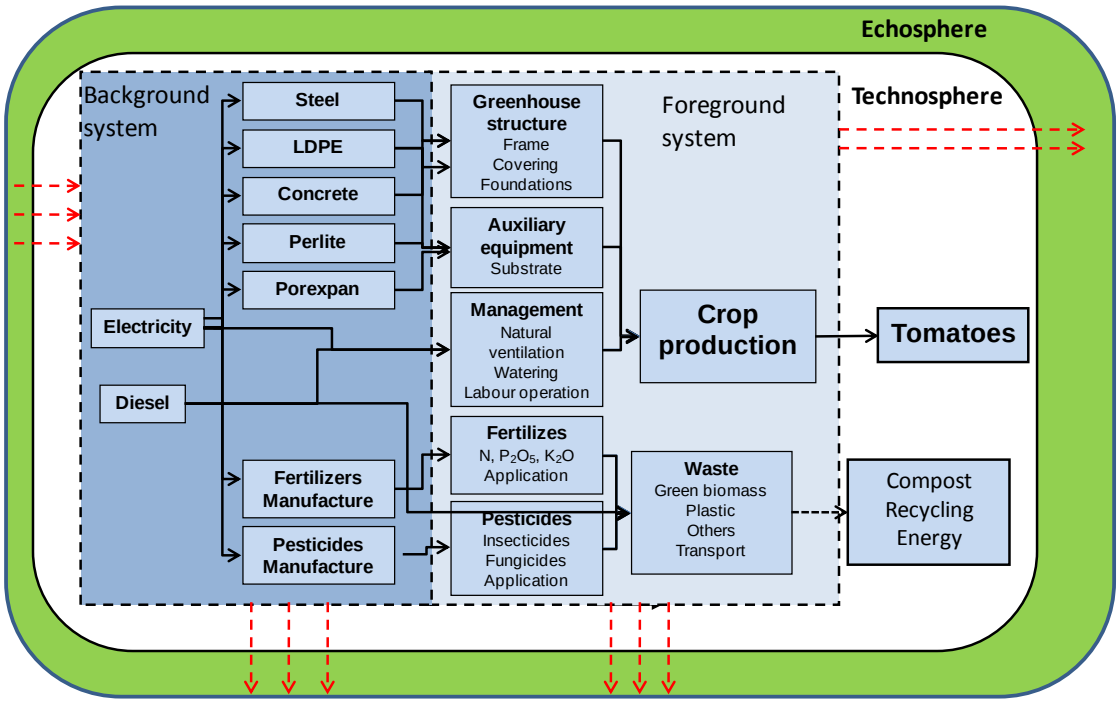

Figure 4.8.1 Flow diagram of fresh tomato production differentiating foreground system and background system

To conduct the study, we firstly performed a classical life cycle impact assessment (LCIA) following ReCiPe methodology (Goedkoop, M. et al. 2009) complemented with USEtox method (Rosenbaum, R. K. et al. 2008). The results indicated the main burdens in tomato production in a *parral* greenhouse. Nevertheless, a detailed analysis of the different contributions showed that topics such as land use and water consumption were assessed as flow indicators without environmental consequences. On the other side, toxicity categories did not take into account impacts of emissions, because of direct pesticide application, on human health. Tables 4.8.1, 4.8.2 and 4.8.3 show the main results in accordance with ReCiPe midpoint, USEtox and ReCiPe endpoint methods respectively, and will be used for the comparison of results with the new methods. A detailed description of the classical LCA for the case study in accordance with of the ILCD guidelines is enclosed as an annex in section 4.8.5 of this deliverable.

A second assessment was conducted with the new characterization methods developed in workpackages 1, 2 and 3. New characterization factors at different spatial resolution for land use, water use, toxicity categories, as well as improvement of non toxic impact categories were tested.

We have organized this deliverable in chapters for each one of the new LCIA methods. Each one of the new methods report includes a first section with a brief introduction of the new approach and a short description of the characterization factors (CFs), (a full description

was done by the respective authors in the corresponding deliverables). A second section shows the results when the new CFs were applied to our case study. A third section follows with the comments of improvements of the environmental assessment reached in our case study, where special attention was regarding spatial resolution and uncertainty, and finally we focus on the specific applicability for our case study, as in agricultural systems as extension. In this sense, we took into account the criteria of ILCD framework and requirements for LCIA methods (ILCD, 2010b, p 9-10) more related to direct applicability. In addition, we added comments related to the acceptance and direct reproducibility of criteria, with the aim to highlight the main conclusions reached from the application of newly LC-IMPACT characterization factors. This information could be useful to CFs developers and future users.

We have included details of the LCA for the case study as an annexe of the deliverable.

Table 4.8.1. Total midpoint impact categories for tomato production in a *parral* greenhouse by reference flow (1 hectare).

Impact category	Unit	Total
Climate change	Kg, CO_2 eq	3.5E+04
Ozone depletion	Kg, CFC-11 eq	3.8E-03
Terrestrial acidification	Kg, SO_2 eq	1.8E+02
Freshwater eutrophication	Kg, P eq	1.1E+00
Marine eutrophication	Kg, N eq	6.7E+00
Human toxicity	Kg, 1,4-DB eq	4.5E+03
Photochemical oxidant formation	Kg, NMVOC	9.4E+01
Particulate matter formation	Kg, PM10 eq	4.8E+01
Terrestrial ecotoxicity	Kg, 1,4-DB eq	5.5E+00
Freshwater ecotoxicity	Kg, 1,4-DB eq	1.9E+01
Marine ecotoxicity	Kg, 1,4-DB eq	5.1E+01
Ionising radiation	Kg, U235 eq	1.4E+03
Agricultural land occupation	m^2y	1.1E+04
Urban land occupation	m^2y	4.5E+02
Natural land transformation	m^2	7.6E+00
Water depletion	m^3	4.3E+03
Metal depletion	Kg, Fe eq	1.5E+03
Fossil depletion	Kg, oil eq	1.1E+04

Table 4.8.2. Results USEStox Recommended v.01 for tomato production in a *parral* greenhouse by reference flow (1 hectare).

Category	Unit	Total
Human toxicity, cancer	CTUh,cases	2.7E-06
Human toxicity, non-cancer	CTUh, cases	7.6E-06
Ecotoxicity	CTUe, PAF·m^3·d	1.6E+04

Table 4.8.3. Results for endpoint impact categories for tomato production in a *parral* greenhouse by reference flow (1 hectare).

Impact category	Unit	Total
Ecosystem quality	Species·yr	5.3E-04
Human health	DALY	6.5E-02
Resources	$	1.9E+03

4.8.1. Resource use impacts

4.8.1.1. Land resource use impacts and biodiversity

Introduction

Land use is currently covered in terms of biodiversity assessment. Biodiversity is a complex and multifaceted concept, involving several hierarchical levels (i.e. genes, species, ecosystems), biological attributes (i.e., composition, structure, function) and a multitude of temporal and spatial dynamics (see Deliverable 1.2). Biodiversity assessments therefore have to simplify this complexity into a few facets, which are quantifiable with current knowledge and data. The approach developed in LC-IMPACT proposes a global assessment including multiple taxonomic groups.

Due to the high importance of the foreground land use in our case study, and the ucertainty of the different flows in tha background process, we have only focused on the evaluation of the new impact method in foreground system.

New approach

The new approach introduced land use characterization factors from a species extinction model, which allows quantifying biodiversity impacts in LCIA due to land use for different world ecoregions based on empirical data. Three types of land use impacts can be distinguished in LCA. First, land is transformed (transformation impact) to prepare for the actual land use (occupation impact). Occupation and transformation impacts are thus considered fully reversible given large enough time horizons. However, permanent impacts can occur if the regeneration potential of an ecosystem is irreversibly compromised. (de Baan et al, submitted)

Four global land use types were classified based on the UNEP/SETAC LULCIA proposal: agriculture, pastures, urban and managed forest

Characterization factors

Regional CFs for occupation, transformation and permanent impacts were calculated per land use type for all WWF Ecoregions for different taxa: mammals, birds, amphibians and reptiles, and occupation and transformation CFs for plants. Median values were used as default CFs, upper and lower 95% confidence intervals as measure for uncertainty.

CFs were developed using the species-area relationship (SAR) model to assess the number of species that might be driven to extinction due to land use. Authors calculated the total number of non-endemic species lost per ecoregion and taxonomic group due to all land use within each region. This total regional damage was then allocated to the different land use types according to the area share they occupy and their habitat quality (de Baan et al., submitted).

Occupation and transformation impact scores can be easily aggregated, as they both express **regional** species loss·y·m^{-2}. Permanent impacts represent **global** species loss· y·m^{-2} and should thus better be kept separately.

Table 4.8.1.1.1 Characterization factors expressed as potentially lost non-endemic species per square meter to assess the effects of land use on Biodiversity Depletion Potential (BDP) per world average and ecoregion PA1219, Iberian forests & shrublands for agricultural land use.

Land use	CF. potentially lost non-endemic species·m^{-2}	lower 95%	upper 95%
World Average			
OCCUPATION Agriculture aggregated	**2.61E-10**	***-2.08E-10***	***1.17E-09***
TRANSFORMATION Agriculture aggregated	**1.69E-08**	***-2.27E-08***	***2.53E-07***
Ecoregion PA1219. Iberian forests & shrublands			
OCCUPATION Agriculture			
Mammals	4.74E-09	*-1.47E-09*	*1.63E-08*
Birds	2.36E-08	*-7.32E-09*	*8.12E-08*
Plants	4.86E-08	*-1.51E-08*	*1.67E-07*
Amphibians	8.51E-10	*-2.64E-10*	*2.93E-09*
Reptiles	2.92E-09	*-9.05E-10*	*1.00E-08*
Aggregated	**7.06E-09**	***-1.46E-09***	***2.52E-08***
TRANSFORMATION Agriculture			
Mammals	2.52E-07	*-7.07E-08*	*3.60E-06*
Birds	1.45E-06	*-4.14E-07*	*2.54E-05*
Plants	1.79E-06	*-6.72E-07*	*2.21E-05*
Amphibians	5.97E-08	*-1.80E-08*	*8.48E-07*
Reptiles	2.05E-07	*-6.18E-08*	*2.91E-06*
Aggregated	**6.42E-07**	***-1.97E-07***	***5.22E-06***

Inventory Flow

There are several flows related to land occupation for the different processes involved in the greenhouse tomato production (see inventory flows in excel sheet). From all of them, we took into account data from foreground field occupation due to the high importance to be included to test the new CFs.

Ecoregion corresponding to the foreground in our case study was PA1219 Southeastern Iberian forests & shrublands.

Land use type in accordance with UNEP/SETAC LULCIA would be defined as "5.1.5 Agriculture, arable, greenhouse, for foreground data". No existence of CF for specific agricultural land use type made us to go to the upper level land use type Agriculture.

In accordance with the new proposal, the inventory flows needed for the assessment of occupation are occupied area in m^2 and time of occupation in years per functional unit. For calculating transformation and permanent impacts the inventory flow required is transformed land area in m^2 per functional unit. One hectare divided by 15 years which is the assumed value of life-span for greenhouse is taken into account as the reference flow and one year as the temporal reference, which is the time required for the production of a tomato crop.

Results with the new CF

Specific aggregated ecoregion impact shows one order of magnitude higher than world average impact. Table 4.8.1.1.2 shows the results for impact score IS corresponding to world scale resolution and specific ecoregion CFs in our case study. As LCI flow is a fixed value, results are directly values from corresponding CFs. Transformation impacts resulted one order of magnitude higher than occupation impacts. Birds and plants, the species richest groups, showed the highest potential absolute species loss for both occupation and transformation impacts.

Table 4.8.1.1.2 Impact score expressed as potentially lost non-endemic species on biodiversity depletion potential due to land use per reference flow.

Land use	IS	lower 95%	upper 95%
World Average			
OCCUPATION Agriculture aggregated	**2.61E-06**	*-2.08E-06*	*1.17E-05*
TRANSFORMATION Agriculture aggregated	**1.12E-05**	***-1.51E-05***	***1.69E-04***
Ecoregion PA1219. Iberian forests & shrublands			
OCCUPATION Agriculture			
Mammals	4.74E-05	*-1.47E-05*	*1.63E-04*
Birds	2.36E-04	*-7.32E-05*	*8.12E-04*
Plants	4.86E-04	*-1.51E-04*	*1.67E-03*
Amphibians	8.51E-06	*-2.64E-06*	*2.93E-05*
Reptiles	2.92E-05	*-9.05E-06*	*1.00E-04*
Aggregated	**7.06E-05**	***-1.46E-05***	***2.52E-04***
TRANSFORMATION Agriculture			
Mammals	1.68E-04	*-4.71E-05*	*2.40E-03*
Birds	9.65E-04	*-2.76E-04*	*1.70E-02*
Plants	1.20E-03	*-4.48E-04*	*1.47E-02*
Amphibians	3.98E-05	*-1.20E-05*	*5.65E-04*
Reptiles	1.36E-04	*-4.12E-05*	*1.94E-03*
Aggregated	**4.28E-04**	***-1.32E-04***	***3.48E-03***

Improvements reached for the case study

For our case study in particular and for agricultural assessment in general, this new impact characterization method represents the first attempt to include impacts on biodiversity due to land use at this spatial resolution (ecoregion).

Comparing the new land occupation characterization method with the ReCiPe methodology, where land occupation was expressed as flow inventory of total area and time occupation, $m^2 \cdot y$, this new method allows to compare the activity under study with other major activities (i.e. urban, managed forest and pastures) and compared among different ecoregions, although the associated uncertainty does not allow to reach definitive conclusions.

Spatial resolution

The specific occupation and transformation CF for ecoregion PA1912 Southeastern Iberian forests & shrublands allowed us to calculate the site specific impact of the tomato

production on biodiversity. Comparison with world averages showed highest impacts, but again the associated uncertainty does not allow reaching definitive conclusions.

Uncertainty

As authors have commented uncertainty of the CFs was considerable. The intrinsic variability of biodiversity makes results uncertain. In particular for agricultural land use the regeneration times showed an important contribution (de Baan, 2013). The inclusion of lower and upper 95% confidence interval with the CFs gave a real idea of this uncertainty in the resulted impacts.

Applicability

The new indicator can be easily understood and interpretable and the characterization factors are straightforward to apply for general LCA practitioners. The flows required for the inventory can be easily provided for the foreground processes; However most of the flows in the background process could be characterized by a high degree of uncertainty, so carefully attention should be given when they acquire high importance.

Permanent characterization factors are not available for our case study, due to the highest value of permanent impacts; the use of CFs from neighbouring ecoregions could hamper the interpretation of results.

CFs availability for different taxonomic groups allows a more detailed analysis on biodiversity impacts and in specific comparisons among other impact categories.

Although world default value could be applied, the unknown exact location as well as the complexity of different occupation flows in background processes made difficult to conduct a full life cycle assessment without a high rate of uncertainty,

Although it is understandable the need to simplify land use types because of the complexity of this topic, the use of generic land use type (agriculture) instead of more specific ones (e.g. greenhouse agriculture of our case study), can hamper specific conclusions for different agricultural practices.

Even though the use of units of potentially lost non-endemic species have meant an advance in relation to old PDF, it is still difficult to compare with other impact categories, so an agreement on endpoint units for ecosystems quality would be required.

References

D1.6 Recommended assessment framework, method and characterisation and normalisation factors for land resource use impacts (phase 3). www.lc-impact.eu

de Baan, Laura Rob Alkemade, and Thomas Koellner (2013). Land use impacts on biodiversity in LCA: a global approach. Int J LCA. Online first

de Baan, Laura Christopher L. Mutel, Michael Curran, Stefanie Hellweg, and Thomas Koellner. Land use in LCA: Global characterization factors based on regional and global potential species Extinctions. EST (submitted)

4.8.1.2. Soil Erosion

Introduction

Soil erosion impact category refers to the Integration of ecosystem services in LCA by applying a globally applicable and spatially resolved method to include land occupation impacts on the erosion regulation.

For our case study, only the foreground agricultural stage was evaluated. However, we may consider results to be representative of the total soil losses during the complete life cycles of crops, as agriculture is by far the land use activity with higher soil erosion rates (Nuñez et al 2013). Soil erosion does never occur inside greenhouse, as the crop grows in a climate-protected environment; however we have considered the paths around greenhouses as part of land occupation which may be eroded. Similarly, rainfall over the greenhouse roof is always canalised to rainwater tanks or to the sewage system in *parral* greenhouses in southern Spain, which means that this rainfall does not lead either to water erosion. However, outdoor greenhouse, paths between greenhouses concentrate rainfall from the most elevated land. Water circulates following the maximum slope line and rainfall erosivity (USLE R-factor) increases (ΔR) compared to a scenario without greenhouse. The increment of soil erosion due to the greenhouse was assessed following the new LC-IMPACT approach.

New approach

Indicators of the new impact category were defined on the endpoint level and were modelled up to the entities described by the areas of protection (AoP), i.e. Natural resources and Natural environment (ecosystems quality).

Damage to resources (ΔR) is expressed as surplus energy needed to make the resource available at some point in the future. This is a suitable unit to evaluate soil depletion, which indicates the anticipated energy removal from nature to provide a unit of soil eroded during land occupation. Instead of using energy units (MJ-equivalents), the new approach uses emergy units (MJ-solar equivalents). Unlike the energy metric, emergy accounts for quality differences of the energy used to generate a product or service by converting raw units (e.g., kg soil, m^3 water) to a common basis, i.e., units of solar energy.

The effect of soil erosion on ecosystem quality (ΔEQ) is expressed using a growth-based value: NPPD (potential net primary production depletion). For an occupation of 1 m^2 and 1 year, NPPD ranges from 0 to 1 (percentage expressed as a decimal).

Characterization factors

The endpoint indicator for damage to resources combines the inventory flow (i.e., soil loss mass) with the local available soil reserves (SD_i, soil depth in the specific location i,), normalized with a reference soil depth (SD_{ref}, 3 m) and with the solar energy factor of soil (SEF_{soil}, 23.9 $MJ_{se}\ g^{-1}$) as the characterization factor. So the CF for damage to resources was 17.8 $MJ_{se}\ g^{-1}$.

The endpoint indicator for damage to ecosystem quality combines the inventory flow $a \cdot SOC_{loss}+b$ (mass of SOC losses transformed into $\%NPP_0$ losses) with NPP_0 values spatially resolved ($NPP_{0,i}$) at 5 arc-minutes (approximately 10×10 km^2) and then normalized with an NPP_0 value corresponding to that of the ecosystem with the highest biotic productivity worldwide ($NPP_{0,ref}$ = 1496 g C $m^{-2}y^{-1}$). Values were aggregated at different geographical scales as shown in table 4.8.1.2.1.

Table 4.8.1.2.1 Characterization factors to assess the effects of soil erosion on ecosystem quality for different spatial references.

Spatial reference	CF (-)	RSD	min	max
World	0.31	64.5	0	1
Europe	0.35	20.0	0	0.52
Spain	0.36	19.4	0.02	0.52
Local (36º50'-37º50' N and 1º50'-3º00' W)	0.24	-	-	-

Inventory Flow

In the LCI, information on SOC loss mass (USLE*%SOC), soil unit according to FAO and the universal soil loss equation erosion model (USLE, (was used to register soil losses in the LCI due to land occupation. USLE takes into account the effect of a particular land-use type on water erosion.

The indirect area corresponding to average dimensions of *parral* greenhouse from our case study (see 4.8.5 Annex, table 4.8.5.1) were calculated as a 190 m^2 (Path dimensions: 95m length * 1m width * 2 paths), which we considered as part of our functional unit, 1 ha.

As a temporal reference we used one year, which is the time required for the production of a tomato crop.

The georeferenced location of land use (longitude/latitude) should also be included if available. Failing that, a broader resolution (e.g., region, country) could be used, although this selection reduces the quality of LCI data (high variability of spatial conditions) and LCIA (uncertainty of grid-cell CFs and variability of country-aggregated CFs). Table 4.8.1.2.2 shows the data used to calculate inventory data in the case study of tomato production.

Table 4.8.1.2.2 Information needed in LCI.

Input	Data	Units
Location of the activity	36º48'N, 2º43'W	-
Type of land use	Agriculture, field margins and hedgerows	-
FAO soil unit[a]	Calcaric cambisol	-
Time of occupation	1	y
Area of occupation	190	m^2
Soil erosion by water	548.7[b]	g
SOC loss mass	3.3	g
a*SOC+b[c]	0.0133	-

[a] Data from the Harmonised World Soil Database.
[b] Estimated with USLE (Soil loss=R*K*LS*C*P).
[c] For cambisol a=1.32 and b=2.66

Results with the new CF

Table 4.8.1.2.3 shows the IS (impact score) results corresponding to different geographical scales resolution CFs for our case study. Specific impact shows that the use of country or continent CF, underestimates Impact.

Table 4.8.1.2.3 Results at endpoint damage at different geographical scales.

LCI	Units LCI	IS local	IS country	IS continent	IS world	Units IS
104.3	$kgha^{-1}y^{-1}$	$1.85 \cdot 10^{6}$	1.71E+06 *(1.47-1.95)·10^6*	1.51E+06 *(1.22-1.80)·10^6*	1.63E+06 *(1.20-2.05)·10^6*	MJ_{se}
0.013	$NPPD \cdot ha^{-1}$	$6.13 \cdot 10^{2}$	4.18E+02 *(3.87-5.73)·10^2*	4.67E+02 *(3.73-5.60)·10^2*	4.13E+02 *(1.47-6.80)·10^2*	NPPD

Improvements reached for the case study

For our case study in particular, and agricultural assessment in general, this new impact characterization method is particularly interesting because for the first time we can include impact of erosion on land use, one of the serious problems that cause and affects agriculture

Spatial resolution

The different CFs for the different geographical scales allowed us to compare the different results, showing a same scale of magnitude.

Uncertainty

CFs are given with RSD so IS can be calculated as an impact range, showing that the local calculations result is clearly higher than the more global ones. This would show that the global impact needs to be considered as a first approach.

Applicability

Although the indicator can be easily understood and interpretable and the characterization factors are straightforward to apply for general LCA practitioners, it requires an extra effort to prepare the inventory as considerable information is needed for its preparation.

Characterization factors are available at country, continent and world scale and can be easily applied. However, the high variability of local conditions makes results a little bit uncertain. In this sense, the inclusion of relative standard deviation in the results should be mandatory.

Impact scores are given as endpoint damages, which is an interesting approach from a dissemination point of view, because the different impacts can be aggregated in a few damages instead of extensive list of midpoint impacts. Nevertheless, the homogenization among the different methods would be appreciated to compare different impact categories. In this sense, the proposal of MJ_{se} seems an interesting one. For ecosystem quality, the use of the species·year approach would be more convenient.

The developed model can allow third parties to freely generate additional and consistent factors and to further develop models, e.g. incorporating further geographical/emission situation, temporal and spatial differentiation. For further improvements, provision of information on GIS database can help to reduce uncertainty.

References

D1.6 Recommended assessment framework, method and characterisation and normalisation factors for land resource use impacts (phase 3). www.lc-impact.eu

Núñez, Montserrat, Assumpció Antón, Pere Muñoz, Joan Rieradevall. 2013. Inclusion of soil erosion impacts in life cycle assessment on a global scale: application to energy crops in Spain. Int J Life Cycle Assess. DOI 10.1007/s11367-012-0525-5 .

4.8.1.3. Land use occupation and Functional diversity.

Not applicable because characterization factors are only developed for some countries of America.

References

D1.6 Recommended assessment framework, method and characterisation and normalisation factors for land resource use impacts (phase 3). www.lc-impact.eu

4.8.1.4. Wood extraction on a global scale.

Not applicable because wood extraction is a minor flow on the background process.

References

D1.6 Recommended assessment framework, method and characterisation and normalisation factors for land resource use impacts (phase 3). www.lc-impact.eu

4.8.1.5. Erosion due to agricultural land occupation on a global scale

Not applicable because crops covered are not related to our case study

References

D1.6 Recommended assessment framework, method and characterisation and normalisation factors for land resource use impacts (phase 3). www.lc-impact.euConsumptive water uses impact in inland wetlands

4.8.1.6. Consumptive water uses impact in inland wetlands

Introduction

Wetlands are complex ecosystems, which are providing multiple services such as water purification, buffering of water flows, resources for human uses (e.g., food, plants, water, building materials and medicines), as well as habitats for a wide range of biodiversity, of which a considerable part is dependent or linked to wetlands. More than 70% of the global freshwater withdrawals are used for agriculture (Verones et al. submitted).

A new method for assessing water consumption on wetland ecosystems was developed within this project by developing specific fate, effect and characterization factors. Characterization factors were derived for impacts of water consumption of surface and groundwater sources separately for wetlands of international importance in a site-specific manner, taking into account the threat level and rarity of different taxa and the habitat type wetland.

New approach

The aim of this method is the quantification of the potential impacts on wetland biodiversity due to water consumption across the globe. For this purpose fate factors (FF), accounting for on changes in water balances and areas of inland wetlands, and effect factors (EF), assessing the potential species loss due to wetland area loss, are developed. Amphibians, reptiles, water-dependent mammals, non-residential birds, and waterbirds were chosen as some of the representative taxa of wetland biodiversity. Wetlands provide food, water and shelter to resident as well as migratory birds. Therefore, a loss of wetlands would also be a severe drawback for migratory birds along their routes.

The wetlands were classified according to their main water source (surface water (SW) or groundwater (GW). Wetlands which are only fed by precipitation are classified as SW-fed wetlands (Verones et al. submitted).

Characterization factors

Characterization factors are calculated as a product of the fate factor and the effect factor. The unit for the CF is species-eq·y·m^{-3} water consumed and is thus showing the loss of species due to water consumption. There is a distinction in the approach for surface water-fed and groundwater-fed wetlands, but the FF is reflecting in both cases the relative area change due to marginal water consumption. Authors developed effect factors (EF) that quantify the contribution to potential global extinction of species due to a loss in wetland area that is caused by water consumption, by adapting the well-known species-area relationship that has been used in LCA before (Koellner 2003; Koellner et al. 2008; Schmidt 2008). EFs were calculated for each taxa as a function of species richness per taxon, vulnerability of species and risk of habitat loss. The unit of the effect factor is species-eq·m^{-2}, thus species-equivalents lost per square meter of wetland area lost. Characterization factors to assess the effects of groundwater consumption on inland wetlands are included in table 4.8.1.6.1.

Table 4.8.1.6.1 Characterization factors to assess the effects of groundwater consumption on inland wetland.

	CF Endpoint (PDF·m^3·y·m^{-3})		**CF Endpoint (species-eq·y·m^{-3})**	
Watershed area: South Spain	AVG	*SD*	AVG	*SD*
Waterbirds	2.50E-07	*9.90E-09*	3.08E-07	*5.96E-08*
Non-residential birds	2.50E-07	*9.90E-09*	2.53E-07	*9.62E-09*
Reptiles	2.26E-07	*8.94E-09*	3.25E-09	*1.43E-10*
Mammals	2.20E-07	*8.70E-09*	6.07E-10	*2.19E-11*
Amphibians	1.36E-07	*5.38E-09*	1.40E-07	*5.15E-09*
Specific site: Adra				
Waterbirds	2.49E-07		3.04E-07	
Non-residential birds	2.49E-07		2.51E-07	
Reptiles	2.19E-07		6.04E-10	
Mammals	2.25E-07		3.22E-09	
Amphibians	1.35E-07		1.39E-07	

Inventory Flow

The inventory flow needed for this impact category is water consumption. Although LCI flows account for the different sources of water abstracted in the full life cycle, we took

only the foreground system into account. Thus, irrigation water was used. Turbine use is an important flow in the background system, but its assessment was out of the scope of this deliverable. The water source used to irrigate was mainly groundwater, 86%, the remainder is water directly from precipitation. The total amount of groundwater consumed for irrigating the greenhouse tomato crop was estimated as 4,080 $m^3 \cdot ha^{-1}$, within a range from 2,650 to 5500 $m^3 \cdot ha^{-1}$ (see 4.8.5 Annex, section 4.8.5.3. management).

Results with the new CF

Results can be expressed as endpoint damage at two different units (PDF·m^3·y and species-eq·y) two different spatial scales, watershed and local for water birds, non-residents birds, water-dependent mammals, reptiles and amphibians. The results show that local impacts are slightly lower than results at watershed level, but included in the range of variability reported for watershed scale. Impacts due to water consumption show that waterbirds are the most affected species at endpoint level, while waterbirds and non-residential birds show similar impact score if PDF is used. While CFs are equal for both taxa if PDFs are used, due to the same area loss and the same species-area relationship, the different species richness and vulnerability change the results if species-equivalents are used at endpoint level (Verones et al. 2013). Thus, the latter takes differences in ecosystems species richness and vulnerability explicitly into account, attributing higher impacts to regions with rare or threatened species. The inclusion of these damages to the previous classical assessment shows that ecosystems damage increases due to the impact of groundwater consumption on wetland species. Assuming that all taxa have the same weight and relevance, the aggregated damage to ecosystems results in 2.85E-03 species-eq.·yr, which means an increase of more than 5 times in relation to previous assessments (table 4.8.3). Other weighting systems (e.g. according to species richness per taxa or ecological function) may be developed in future. For the time being the assumption holds that each taxa has the same importance.

Table 4.8.1.6.2 Results at endpoint wetland ecosystems damage for groundwater consumption.

Wetland target	IS (PDF·m^3·y·FU^{-1})		IS (species-eq·y·FU^{-1})	
Watershed area: South Spain				
Waterbirds	**1.02E-03**	*±4.04E-05*	**1.26E-03**	*±2.43E-04*
Non-residential birds	**1.02E-03**	*±4.04E-05*	1.03E-03	*±3.93E-05*
Reptiles	8.97E-04	*±3.55E-05*	2.48E-06	*±8.94E-08*
Mammals	9.22E-04	*±3.65E-05*	1.33E-05	*±5.84E-07*
Amphibians	5.55E-04	*±2.20E-05*	5.72E-04	*±2.10E-05*
Specific site: Adra				
Waterbirds	**1.02E-03**		**1.24E-03**	
Non-residential birds	**1.02E-03**		1.03E-03	
Reptiles	8.93E-04		2.47E-06	
Mammals	9.18E-04		1.31E-05	
Amphibians	5.52E-04		5.69E-04	

Improvements reached for the case study

Water depletion was assessed as a flow indicator at ReCiPe Midpoint level without conversion to Endpoint damage, so for our case study in particular, and agricultural assessment in general, this new impact is particularly important because it is the first time that impacts from water consumption can be included for assessing different animal species. The use of endpoint damage homogenised units to ReCiPe methods allowed us a clear comparison with the previous classical assessment, and therefore a clear quantification of what the new impact represents.

Spatial resolution

CFs have been developed for sub-watershed scales, defining for each wetland its individual catchment. In addition watershed averages have been calculated for Southern Spain. The comparison between both showed that local CFs made slightly lowest impacts but within the range of variability provided by the CFs.

Uncertainty

Uncertainty is included in the SD of CFs.

Applicability

The new characterization factors are straightforward to apply for general LCA practitioners, albeit with CF updated to local conditions. Global maps with CFs for surface and groundwater consumption are provided, and can be used as a screening methodology for wetlands of international importance.

Specific CFs for the tomato case study were developed and applied directly to the foreground water consumption inventory flow.

Endpoint CFs allows comparison of ecosystems damage produced by water consumption impacts with other impact categories.

References

D1.7 Recommended assessment framework, method and characterisation and normalisation factors for water resource use impacts (phase 3). www.lc-impact.eu

Verones, F.; Pfister, S.; Hellweg, S. Quantifying area changes of internationally important wetlands due to water consumption in LCA. Environ. Sci. Technol. (submitted)

4.8.1.7. Biodiversity impacts from salinity increase in a coastal wetland

Introduction

Coastal wetlands are among the most productive, valuable, and yet most threatened ecosystems in the world. They provide a critical interface between terrestrial and marine environments, where fresh water and salt water are often mixed. Coastal wetlands in arid and semi-arid zones experience periods of increasing salinity as a consequence of high evaporative conditions, variability of inflows, impacts of human pressure and their proximity to the sea.

The location chosen to develop this new characterization method was situated close to the location of the tomato case study. Therefore, in order to develop a methodology for salinity impacts, authors selected the coastal Spanish wetland “Albufera de Adra” as the case study. This location was in coincidence with the location of the present case study. Albufera de

Adra is located in a semi-arid region in Almería (South-East of Spain), where agricultural activities require substantial irrigation and areas with native vegetation and fauna are restricted to some small patches and wetlands. Albufera de Adra contains two lagoons, Nueva Lagoon and Honda. Nueva lagoon is situated closer to the sea than Honda, and Nueva lagoon is predominantly fed by groundwater.

New approach

This work derived the first CF for salinity impacts in a coastal wetland defined as the change in the Potentially Affected Fraction (PAF) of species due to a change in salinity and extraction of groundwater for crop irrigation. The CF for salinity impacts was based on a new effect factor and a locally specific new fate factor developed in Workpackge 1 (Amores et al, 2013)). CFs were developed in terms of potentially affected fraction of species (PAF) in the wetland taking into account the seasonal amount of water consumed by crops through irrigation.

The impact score can also be expressed as endpoint damage by conversion into species·yr including the recommended freshwater species density (7.89E-10 species·m^{-3}) and the conversion dPDF/dPAF = 1

Characterization factors

Characterization Factors (CF) in m^3·PAF·month·m^{-3}, were calculated as the product of a Fate Factor (FF in g·m^3·month·l^{-1}·m^3) and an Effect Factor (EF in PAF·l·g^{-1}). The CF for the salinity impact on this coastal wetland is defined as the change in the Potentially Affected Fraction (PAF) of species due to a change in salinity, which is caused by the change of groundwater for irrigation in the vicinity of the Nueva lagoon. This can be translated into the effect per m^3 of water consumed.

The FF is based on a salt balance and a water balance, and splitted each up into wet (X) and dry (Y) months.

The EF calculation was based on Species Sensitivity Distributions (SSD) from data collected describing the effect of salinity to several endpoints (e.g. survival, growth inhibition) on 17 species (plants, fishes, algae) native to the "Albufera de Adra" wetland.

Table 4.8.1.7.1 Characterization factor to assess the effects of salinity increase on coastal wetland.

Coastal wetland	CF (m^3·month·m^{-3})	Standard error
Nueva lagoon	3.16E-01	±1.84E-01

Inventory Flow

The inventory flow needed for this impact category is water consumption. Again we took into account the foreground system, which was irrigation water. The water source used to irrigate the crop was mainly groundwater, 86%. The total amount of groundwater consumed in irrigation of the greenhouse tomato crop was estimated as 4,080 m^3·ha^{-1} (see 4.8.5 Annex section 4.8.5.3 management).

Results with the new CF

Table 4.8.1.7.2 shows the IS results corresponding to endpoint ecosystems damage applying developed local CF. For our case study the score at endpoint level was 1.02E-06, ranging from 0.43E-06 to 1.61E-06 species·y·ha^{-1}, that means an increase between 0.08% to

0.30% related to the endpoint ecosystems quality damage calculated in the previous classical life cycle assessment (LCA) following ReCiPe methodology, 5.3E-04 species·y·ha^{-1} (table 4.8.3) and the same order of magnitude of terrestrial acidification ReCiPe midpoint impact, which was calculated as 1.06E-06 species·y·ha^{-1}.

Table 4.8.1.7.2 Results at midpoint biodiversity and endpoint ecosystems damage for salinity impact due to water consumption.

LCI	Units LCI	IS Midpoint PAF·m^3·y·FU^{-1}	IS Endpoint Species·y·FU^{-1}
4,080	m^3·ha^{-1}	1.29E+03 *(5.39E+02-2.04E+03)*	1.02E-06 *(4.25E-07-1.61E-06)*

Improvements reached for the case study

For our case study in particular, and agricultural assessment in general, this new impact category is particularly interesting because for the first time we can include salinity impact on biodiversity due to groundwater extraction. Similarly as in the previous method for the impact assessment of water consumption on wetland ecosystems, the use of same units to ReCiPe methods at endpoint damage level allow practitioners a clear comparison with the previous classical assessment, and therefore a clear quantification of what the new impact represents.

Spatial resolution

The CF for salinity impacts were developed specifically for the present case study. Therefore, although we can conclude that the spatial resolution fitted correctly with this case study, it is not yet a fully developed method to be applied for different location or spatial scales.

Uncertainty

Different scenarios and model uncertainties, as well as substance data and parameter uncertainty, were taken into account. Therefore, the impact score can be given within a range, which makes it a more valuable result.

Applicability

The characterization factor is straightforward to apply for analogous LCA studies similar to the Nueva lagoon case study. The CF needs to be updated to local conditions. Case-specific CFs can be produced by the practitioner but information related to hydrological conditions is needed. Once a CF is developed, it can be easily applied to LCI water flows.

The effect factor is transferable to any other coastal wetland region in the Mediterranean basin only if species composition is similar and the characteristics of the wetland are analogues. The fate factor is only locally valid, but the model can be adapted with the relevant hydrological flows of another wetland.

References

D1.7 Recommended assessment framework, method and characterisation and normalisation factors for water resource use impacts (phase 3). www.lc-impact.eu

Amores, Maria José; Francesca Verones; Catherine Raptis; Ronnie Juraske; Stephan Pfister; Franziska Stoessel; Assumpció Antón; Francesc Castells, Stefanie Hellweg. Biodiversity impacts from salinity increase in a coastal wetland Environ. Sci. Technol. (submitted)

4.8.1.8. Green water

Introduction

In LCA, water consumption of potential natural vegetation (PNV) is used to estimate the quantitative effect on water availability due to change in direct water uptake under human land occupation compared to the reference state, that is, PNV. The difference in these green water flows represents lack of recharge of groundwater and surface water runoff and the environmental effects should be assessed by characterization factors (CFs) in the LCIA step.

The proposed method aims at creating a regionalized LCA framework for soil-water evapotranspiration (ET). Rainwater harvested and reused is included in the definition and can be assessed as well. So far, only guidance to derive the LCI flow (called net soil-water consumption, $NET_{soil\text{-}water}$) is ready. Derivation of globally applicable CFs is outside the scope of the LC-IMPACT project.

New approach

Water consumption of the local PNV was estimated combining results from applying two assessment methodologies: 1) one empirical equation, based on potential evapotranspiration (ET_0) and precipitation (P) data 2) one empirical model, using remote-sensing data sets. The empirical model was used to calibrate the empirical equation.

Following the empirical equation, annual water consumption of the natural vegetation that would potentially grow in a given catchment ($ET_{PNV,i}$, in mm/y) can be calculated from the ratio of P to ET_0 in the catchment *i*

$$ET_{PNV,i} = \left(\frac{\left(\frac{Pi}{ET_{0,i}}\right)^k}{1+\left(\frac{Pi}{ET_{0,i}}\right)^k} \right)^{\frac{1}{k}} \times ET_{0,i}$$

Authors reported the value of the regionalized parameter k and annual contemporary water consumption of PNV adapted to local bio-geographic conditions on global dry lands. Results are reported at three different spatial aggregation levels: local aridity index at the grid-cell, ecoregions and biomes.

Characterization factor

CF for green water assessment has not been developed yet.

Inventory Flow

The model developed focuses on deriving the LCI flow, i.e., the net soil-water consumption, $NET_{soil\text{-}water}$. Table 4.8.1.8.1 summarizes the calculations performed in our case study at the three geographical scale resolutions.

Spatial variability and uncertainty in the results of our case study was estimated at the three geographical scales of assessment by taking into account the standard deviation of the k variable.

Table 4.8.1.8.1 Data to calculate $NET_{soil\text{-}water}$. Results are for the three geographical scales.

Data		Grid cell Aridity index=0.242	Ecoregion ID81221.Southwest Iberian Mediterranean sclerophyllous and mixed forests	Biome 12. Mediterranean forests, woodlands and scrub
P	$m^3 \cdot yr^{-1} \cdot ha^{-1}$	3,200 ± 1.442		
ET_0	$m^3 \cdot yr^{-1} \cdot ha^{-1}$	13,200 ± 437.9		
$ET_{soil\text{-}water}$ ≅ harvested rain	$m^3 \cdot yr^{-1} \cdot ha^{-1}$	667		
k		1.60±0.68[1]	1.03±0,0	1. 50±0.45
$ET_{PNV\ AVG}$	$m^3 \cdot yr^{-1} \cdot ha^{-1}$	3008.8	2,612.5	2,968.3
$NET_{soil\text{-}water\ AVG}$	**$m^3 \cdot yr^{-1} \cdot ha^{-1}$**	**-2,341.8**	**-1,945.5**	**-2,301.3**
$ET_{PNV\ MIN}$		2,612.5		2,635.9
$NET_{soil\text{-}water\ MIN}$		*-1,945.5*		*-1,968.9*
$ET_{PNV\ MAX}$		3,146.1		3,101.2
$NET_{soil\text{-}water\ MAX}$		*-2,479.1*		*-2,434.2*

[1] 1.03<k > 2.40 (see deliverable 1.2)

Results with the new CF

The lack of development of CFs for green water consumption does not allow us to comment this section further than in terms of inventory. However, this first attempt to have a proper inventory flow is a very promising approach for the second step in building CF (which is not an objective of this project).

Improvements reached for the case study

The inclusion of green water consumption is a very relevant aspect to take into account in agricultural case studies. Although there is not enough agreement in the scientific community on this topic yet, we gave the treatment of green water to the quantity of rainwater reused. In greenhouse production, rainwater is collected by greenhouse gutters and stored in irrigation ponds, being therefore subtracted from hypothetical natural vegetation. Therefore, the approach presented allows including green water consumption as a function of location in the inventory stage of an LCA study.

Spatial resolution

To implement this approach in LCA, authors recommend using k_{opt} and ET_{PNV} at the most detailed local aridity index level of detail. However, they provide also values for ecoregion or, in the worst case, the biome level, which can be applied in case the exact location of the activity under study is unknown and the only spatial information available is at coarser scales. For large countries or countries with very varied climate regions, both the average and the standard deviation values should be reported.

Uncertainty

k values are given with standard deviation, which allows assessment of uncertainty values of water consumption of PNV and therefore $NET_{soil\text{-}water}$ results.

In fact, uncertainty of the results is quite high, showing that the use of range values agree for the three geographical scales. Therefore, it should be advisable or even mandatory to always use uncertainty values when $NET_{soil\text{-}water}$ is calculated.

Applicability

LCI figures are available for practitioners at three regionalisation levels. This can facilitate the application in LCA studies with different detail of the geographic information of the water use inventory flows.

In addition, the manner in which the model is developed makes it possible to third parties to freely generate additional $NET_{soil\text{-}water}$ values, incorporating local data and specific geographical situation.

Development of the new method has also allowed the awareness of the importance of the datasets used as background systems, which are usually lacking of information to be included in the assessment, which highlights the need of improvement of datasets.

Further development of CFs will allow the complete LCA assessment of this resource.

References

D1.7 Recommended assessment framework, method and characterisation and normalisation factors for water resource use impacts (phase 3). www.lc-impact.eu

Núñez, Montserrat; Stephan Pfister; Philippe Roux; Assumpció Antón. Estimating water consumption of potential natural vegetation on global dry lands: setting up a LCA framework for green water flows. Environ. Sci. Technol. (submitted)

4.8.1.9. Fossil resource depletion

Introduction

Fossil resources are mostly used in a destructive or dissipative way: the largest part (coal, natural gas and more than 80% of crude oil) is combusted for energy production, either directly or via a conversion/purification step. The remaining part is used for its chemical properties in plastics and other synthetic materials, which eventually dissipates in the environment or is finally combusted as waste. The problem of fossil resource depletion is that the future availability of fossil resources decreases as regeneration (natural growth) is extremely slow and recovery (recycling) is not possible after combustion or dissipation.

New approach

Authors developed an improved method to assess fossil resource depletion based on surplus cost (SC), which is the global future cost increase due to marginal fossil resource use in the life cycle of products (Deliverable, 1.9). The marginal cost increase (MCI) is the long term average increase in cost after producing a certain amount of resource, based on the concept that first the least costly resources are extracted. The MCI is calculated (in US$ per kg^2 or US$ /$[m^3]^2$) using cost and resource availability data per production technique in case of crude oil and natural gas. For coal, cost and resource availability data per country were used. The SC is calculated as an indicator for fossil resource depletion and it follows three different societal perspectives used to differentiate the subjective choices regarding discounting and future production scenarios.

Characterization factor

The surplus cost is the sum of the cost in all years in the future, and the cost in year t is the MCI multiplied by the annual production (P_t) and a discount factor ($D_t = 1/[1+d]^t$; d is the discount rate): $SC = \Sigma(MCI * P_t * D_t)$.

CFs are given assuming D_t for different societal perspectives based on Cultural Theory. For each perspective, authors choose different discount rates: 15% for the individualist; 3% for the hierarchist; and 0% for the egalitarian selecting different future fossil resource production scenarios.

Inventory Flow

The LCI parameters are the mass or volume of crude oil, natural gas or coal extracted from the natural environment.

Results from new CF

The main processes involved in fossil depletion were energy consumption in the production of fertilizers, plastics and substrate (perlite). Since there was no need for a heating system in the greenhouse, greenhouse crop management had few direct energy inputs, mainly electricity to run watering pumps. Therefore, direct flows involved in fossil depletion came from background datasets, electricity and several production processes.

As far as we had not enough detailed information of background flows involved in our case study, we choose the new CFs for default values. Likewise, in coherence with our previous classical assessment, we performed a hierarchical approach for CFs.

Table 4.8.1.9.1 Results at endpoint resources damage for fossil resources per FU.

Flow	LCI unit·ha^{-1}	New IS endpoint Hierarchist		ReCiPe IS endpoint Hierarchist	
		US$_{2008}$	%	$	%
Natural gas, medium energy (HHV 35-40 MJ·m^{-3})	13.91 m^3	7.09E-01	0.1	3.90E+01	35.5
Coal, coking (HHV >24 MJ·kg^{-1})	1,710.0 kg	1.45E+00	0.2	7.40E+00	6.7
Crude oil, light (>31.1 degree API)	5,912.9 kg	6.50E+02	99.7	5.70E+01	51.8
TOTAL		**6.53E+02**		**1.10E+02**	

The results of the old method differed from the results of the new one and increased by six times, although it has to be taken into account that we are not comparing exactly the same monetary units. The main reason for this difference can be explained by the different contribution of the flows involved, as for the new approach crude oil was by far the main contributor (Table 4.8.1.9.1).

Improvements reached for the case study

Although results from the new approach seem coherent, we have not enough knowledge to detail reached improvements.

Spatial resolution

The new approach did not implement regional differentiation, because this would be one step further in the environmental mechanism, assessing the geopolitical effects that influence the short term supply risk. Authors considered this geopolitical effect outside the scope of LCA.

Uncertainty

The uncertainty of results from different simulation models on a future production scenario is under development. Up to now, the main uncertainty comes from the selection of flows. As far as we guess, practitioners will use default values. CFs default values could be given with uncertainty values.

Applicability

Default CFs are available and can be easily applied. Most of the cases, selection of specific CFs will depend on the selected datasets. Therefore, further work in software tools and databases should necessary.

Interpretation of the results can be difficult if the LCA practitioner is not an expert in resource depletion and economics.

Economics is a complex topic and therefore, units to represent results needs clear guidance. A future uncertainty analysis of the scenarios under development would help to understand the results.

References

D1.9 Recommended assessment framework, method and characterisation and normalisation factors for abiotic resource use impacts (phase 3). www.lc-impact.eu

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4.8.2. Ecotoxicity and human toxicity

4.8.2.1. Spatial differentiation for ecotoxicity and human toxicity

Introduction

Traditionally, life cycle impact assessment (LCIA) methods have mostly relied on generic, non-spatial and steady state multimedia environmental models. Contrary to the so-called global impact categories, such as global warming and ozone depletion, the need to have spatially-differentiated models for regional impact categories has arisen under the evidence that differences in fate and exposure mechanisms and differences in sensitivity and background levels for effect can vary significantly depending on different geographical contexts.

New approach

Main goal of this new approach was to take into account the influence of spatial variability for chemicals causing ecotoxicity and human toxicity, with special focus on analyzing the relevance of spatial variability in the impact of chemicals and supporting the development of compartment and chemical specific archetypes to be adopted in USEtox method.

Characterization factor

New CFs to be used in USEtox were calculated for different continental and subcontinental regions and the different emission compartments.

In our case study, we applied CFs for Europe continental region, rural air and freshwater, and agriculture soil comportments for human and ecosystems toxicity.

Inventory Flow

The inventory flows required were Kg of emission into the air, freshwater and agricultural soil of organic chemicals (note that for pesticides emissions there is yet a lot of discussion about their modelling in the inventory stage).

Results with the new CF

This new model showed that the most important contributors among organic chemicals were those related to air emissions. Regarding human toxicity, the most important flow contributors were carbon disulfide (84.6 %), fenbutetin (6.86 %) and chlorotalonil (5.36%). The first one, carbon disulfide, was not directly emitted by foreground processes, but the other two were emissions from pesticides applied to the crop (see inventory flows excel sheet and table 4.8.2.1.1). For aquatic ecosystems toxicity, chlorotalonil air emissions were the highest contribution (99.5%) to this impact category (Table 4.8.2.1.2).

It is important to clarify that the previous assessment was done only with the recommended USEtox CFs. If the inclusion of interim CFs had been taken into account, results would have changed because interim CFs give more importance to metal contributions. As far as the new approach only includes organic chemicals, it was considered better the comparison with the recommended version leaving metals out of the scope of this assessment (I encourage the inclusion of metals as further research).

Table 4.8.2.1.1 Results for the most important contributors to the Impact Score for Human toxicity assessment in Europe.

Emission compartment	CAS	Substance	LCI, Kg emitted	IS (cases)
Air	75-15-0	Carbon disulfide	1.47E-01	5.83E-06
Air	1897-45-6	Chlorothalonil	1.88E-01	3.69E-07
Air	13356-08-6	Fenbutatin oxide	2.05E-02	4.73E-07
Total Human Toxicity cases in air compartment				**6.90E-06**
TOTAL Human Toxicity cases				**7.16E-06**

Table 4.8.2.1.2 Results for the most important contributors to the Impact Score for Ecosystems toxicity assessment in Europe.

Emission compartment	CAS	Substance	LCI, kg emitted	IS (m^3·day)
Air	1897-45-6	Chlorothalonil	1.88E-01	1.38E+04
Total Ecosystems Toxicity in air compartment				**1.39E+04**
TOTAL Ecosystems Toxicity				**1.56E+04**

Improvements reached in the case study

Regarding human toxicity, results from new spatial CFs showed that impacts were reduced to 69.8% comparing with the previous assessment (table 4.8.2). Major differences were found in the comparison of the old method with the new one, on one side, because there was a global reduction of the values of CFs. For instance in the case of carbon sulfide, the contribution was reduced from 6.88E-06 units to 5.83E-06 units from the old version to the new one; however the contribution of carbon disulfide in the old version was 67% and in the new 81.5% (although we have added the pesticides). On the other side, we could conduct the assessment for more pesticide emissions with the new method, as the old method did not include characterization factors for a number of pesticide emissions. Nevertheless, results showed that most of the new emissions included for pesticides made low contributions, with the exception for fenbutatin oxide that made high impacts

For ecosystems toxicity impact category, results applying the new CFs showed a reduction of 4.5% comparing with to the previous classical assessment. This can be mainly explained because of the inclusion of new CFs for pesticides. However, both in the old version and in the new one, chlorotalonil was the most important contributor, with an important reduction of the impact score of this substance.

Spatial resolution

CFs are provided by continental and subcontinental scale in Europe. Therefore, it is assumed that more precise information regarding spatial differentiation has been assessed trough different models at different scales from continental to country, watershed, and grid

scale. The comparison with previous global versions is difficult because of the inclusion of more flows, especially pesticides, which have an important contribution.

Uncertainty

CFs are not provided with uncertainty values, so it is not possible to perform uncertainty assessment.

Applicability

Characterization factors are available and can be easily applied. For our case study, and agricultural systems in general, some pesticides showed to be important contributors to toxicity. In this sense, it would be advisable a review of the list of pesticides to be sure that the most popular pesticides and with high CFs are included.

USEtox method is a software tool available to practitioners, so case-specific CFs can be produced by any practitioner. However, a high expertise in chemistry is needed to develop new CFs.

Similarly, the correct interpretation of the results is quite complex. For example, can a practitioner understand clearly why fenbutatin oxide has higher impact than chlorotalonil for human toxicity and not for ecosystems?

Obviously, the high quantity of contributing flows to toxicity impact categories makes the assessment especially important to be confident with results.

Moreover, it is important to remark that for the case of pesticides, a better agreement in inventory calculations as well as the inclusion of some organic "natural" products should be performed to obtain more accurate assessments.

References

D2.3 Recommended assessment framework, method and characterisation factors for ecotoxicity and human toxicity (phase 3). www.lc-impact.eu

4.8.2.2. Human exposure to pesticides

Introduction

Impacts to human health because of pesticide application are poorly represented in existing LCIA approaches, since only effects from diffuse emissions are included, thereby disregarding ingestion exposure from residues in field crops after direct pesticide application. While in the case of diffuse emissions to environmental media, such as air and soil, the emission target is an environmental compartment, in the case of direct application, it is in the cultivated crop compartment where pesticides are finally consumed (Fantke et al 2011).

New approach

A new dynamic plant uptake model is hence presented to characterize impacts to health because of pesticides applied to food crops. The model is based on a flexible set of interconnected compartments and assesses various crop types with distinct properties and processes. Crop-specific human toxicity characterization factors are provided for use in life cycle impact assessment (LCIA) along with analyzing their variance between crop types, pesticides and application times (Fantke et al 2011 and Fantke et al 2012).

Crop leaf growth, initial spray drift and food processing are identified to be the main crop-related aspects driving the evolution of pesticide masses in the modelled system along

with pesticide properties, mainly octanol-water partition coefficient and degradation half-life in plants.

Detailed exchange processes between environmental media and vegetation have been introduced in multimedia models, traditionally considering steady-state conditions. However, for pesticide residues and their related impacts, steady-state is usually not obtained during the short time period from substance application to ultimate crop harvest, which is why the evolution of residues needs to be assessed dynamically. In addition, pesticide uptake and translocation mechanisms vary considerably between crop species and may indicate significant differences in related health impacts. Consequently, different crop-specific characteristics need to be taken into account as provided for single crop species.

Characterization factor

For impacts to human health, authors followed the general LCIA cause-effect chain by linking applied pesticide masses to health impacts via environmental fate, exposure and effects. When taking DALY (Disability Adjusted Life Years) as measure for overall population impacts, the human-toxicological population impact scores. Authors describe the characterization factor by multiplying the human effect factor for pesticide *i*, EF_i [$DALY \cdot kg_{intake}^{-1}$], by the total population intake fraction of the pesticide via ingestion of the crop *x*, $iF_{i,x}(t)$ [$kg_{intake} \cdot kg_{applied}^{-1}$]:

$$CF_{i,x}(t) = EF_i \times iF_{i,x}(t)$$

Characterization factors for a set of 121 pesticides applied to the six selected food crops, one of them tomato, have been provided.

Inventory Flow

We took into account the total mass of applied active ingredient $kg_{applied} \cdot ha^{-1}$.

Results with the new CF

Table 4.8.2.2.1 shows the results for the IS calculated for the example of pesticides application. The total impact to human toxicity impact category due to the use of pesticides via ingestion was 9.57-04 DALYs per ha, coming almost 25% from the use of insecticides and the rest from the use of fungicides. It is worthy to mention that copper chloride oxide, hydrate, one of the most popular fungicides, was again not taken into account because metals are out of the scope of this new method.

Table 4.8.2.2.1 LCI information, CFs and impact score for human toxicity impact category due to pesticide application. Example for the case study.

Date of application	Active Ingredient	Amount applied, kg·ha^{-1}	Type of pesticide	CF cases·kg^{-1}	IS cases·FU^{-1}
18	Copper Oxychloride	3.00	Fungicide		
36	Clofentezin	0.23	Insecticide	8.85E-04	2.04E-04
36	Fenbutatin Oxide	0.41	Insecticide	1.40E-06	5.76E-07
54	Spinosad	0.14	Insecticide	6.78E-05	9.50E-06
69	Azoxystrobin	0.30	Fungicide	5.26E-04	1.58E-04
96	Chlorothalonil	1.88	Fungicide	1.72E-04	3.23E-04
98	Spinosad	0.18	Insecticide	6.78E-05	1.22E-05
119	Copper Oxychloride	3.00	Fungicide	-	-
131	Chlorothalonil	1.88	Fungicide	1.72E-04	3.23E-04
142	Mancozeb	0.30	Fungicide	4.18E-04	1.25E-04
193	Copper Oxychloride	3.00	Fungicide	-	-
196	Mancozeb	0.30	Fungicide	4.18E-04	1.25E-04
220	Copper Oxychloride	3.00	Fungicide	-	-
237	Copper Oxychloride	3.00	Fungicide	-	-
Total	**Insecticides**	**0.96**			**2.26E-04**
Total	**Fungicides**	**19.66**			**7.31E-04**
TOTAL					**9.57E-04**

Improvements reached in the case study

For our case study in particular, and agricultural sector in general, this new impact category allowed us to assess human toxicity due to pesticides via ingestion from pesticides applied to treated crops. The inclusion of this new human toxicity impact changes dramatically the previous version of USEtox calculation. The previous assessment gave 1.03E-05 cases·FU^{-1} impact score, while the new calculation (9.57E-04 cases·FU^{-1} + 1.03E-05 cases·FU^{-1}) made an impact to human toxicity nearly two orders of magnitude higher.

Spatial resolution

This model is not spatially differentiated, but input parameters can be modified to cover various crops, cultivation conditions and food processing steps

Uncertainty

An extensive uncertainty assessment for CFs was performed in the development of the Crop dynamic model, CF. Uncertainties in the Intake fractions for case studies application came mainly because of the time period between harvest and time of application. CFs in the model were developed taking into account different dates of application along the crop period.

Applicability

Inputs from LCI are very clear and easy to provide by the practitioner. The results allow understandable identification of the significance of the impact.

CFs can be applied directly for the six crops included, wheat, rice, tomato, apple, potato, lettuce. Whether used as archetypes, they can cover a wide range of cereals, horticultural products, fruits, roots, tubers and leafy crops for most of the organic pesticides used all over the world.

In addition, a *Dynamic crop* model excel sheet is provided. Therefore, practitioners can adjust easily specific requirements related to the time of pesticide application and the characteristics of the crop, as well as new active ingredients. However, the use of the excel sheet is limited by the need to use Matlab to run the program, a software tool not commonly available out of the expertise community.

References

D2.3 Recommended assessment framework, method and characterisation factors for ecotoxicity and human toxicity (phase 3). www.lc-impact.eu

Fantke P., Juraske R., Antón A., Friedrich R., Jolliet O. 2011. Dynamic Multicrop Model to Characterize Impacts of Pesticides in Food. Environmental Science and Technology, 45 (20): 8842-8849

Fantke P., Wieland P., Juraske R., Shaddick G., Sevigné E., Friedrich R., Jolliet O., 2012. Parameterization models for pesticide exposure via crop consumption. Environ Sci Technol, 46 (23): 12864-12872

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4.8.2.3. Higher (warm-blooded) predator ecotoxicity

Introduction

The CF for warm-blooded predators in freshwater food chains was defined as the change in ecotoxic effects of a chemical on warm-blooded predators, resulting from a change in the emission of this chemical.

New approach

This refers to ecotoxicological impacts of organic chemicals on warm-blooded predators at the end of freshwater food chains, for the chemicals included in USEtox method. To this end, authors calculated fate and exposure factors for water and air compartments. Subsequently, they calculated bioaccumulation factors for warm-blooded predators, based on exposure via water, food, and air. Internal effect factors were calculated based on LD50-values for mammals and birds.

For the development of this method, authors enhanced the effect database with interspecies correlation estimation (ICE) toxicity models. This deliverable gives characterization

factors for the impact of organic chemicals on warm-blooded predators at the end of freshwater food chains for a list of 1,479 non-ionic chemicals for which aquatic ecotoxicity characterization factors are calculated with USEtox.

Characterization factor

The CF for warm-blooded predators in freshwater food chains was defined as the change in ecotoxic effects of a chemical x on warm-blooded predators, resulting from a change in the emission of chemical x. The new CF consists of a multiplication of the Fate Factor, Exposure Factor, Bioaccumulation Factor, and Effect Factor of a chemical, being $CF_{x,i}$ the ecotoxicological characterization factor of a chemical x emitted into an environmental compartment of emission (i) ($yr \cdot kg^{-1}$).

$$CF_{x,i} = \sum_{j} (FF_{x,i,j} \cdot XF_{x,j} \cdot BF_{x,j}) \cdot EF_{x}$$

Where the fate factor ($FF_{x,i,j}$) describes the fraction of the chemical x transferred from the emission compartment i to a compartment of reception j, and its subsequent residence time in compartment j ($yr \cdot m^{-3}$); the dimensionless exposure factor ($XF_{x,j}$) is the fraction of the chemical x in the receiving compartment j that is bioavailable for uptake by organisms; the bioaccumulation factor ($BF_{x,j}$) for substance x represents the predators' uptake potential of the bioavailable concentration in fresh water, food and air ($m^3 \cdot kg_{wwt}^{-1}$); and EF_x is the effect factor of chemical x describing the effects of chemical x on warm-blooded predators per unit of internal concentration ($kg_{wwt} \cdot kg^{-1}$).

Inventory Flows

We took into account kg of emissions from organic chemicals, to air, freshwater and agricultural soil compartments.

Results from new CF

The main contributor to higher predator impact category was the emission of the pesticide fenbutatin oxide, which contributed with almost 100% of the total impact. However, it is important to clarify that from the pesticides applied to the tomato crop production only three new CFs were available, and the CF for emissions to air by fenbutatin oxide was clearly the highest one.

Table 4.3.2.3.1 lists other major flows contributing to this impact category and coming from the different emission compartments. While emissions to air because of fenbutatin oxide were clearly related to a known foreground process, the pesticide application, other emissions were found to come from background processes, such as benzene water emissions. Since the results showed that these background emissions were not major contributors to the production system, we did not take them into consideration. It is important to wear in mind that the use of generic datasets (i.e. insecticides) can give misleading information. For instance, in our case study, the results showed two pesticides, carbofuran and cypermethrin as soil emissions. These two pesticides had not been applied to the crop and the emissions came from the generic dataset for pesticide production.

Improvements reached for the case study

This is a new impact category, which had not been taken into account previously. We consider it very important for our case study due to the importance of emissions to air because of pesticide application.

Due to the different indicator units used for the ecotoxicity impact to the new higher predators impact category, and ecotoxicity to Ecosystems in USEtox method, we made a rough estimation by converting PAF·m^3·day to y by dividing USEtox CFs by the volume of the freshwater compartment 6.76E+11 m^3, and subsequently multiplying them by 365 days.

Results of damage to ecosystems using the classical global assessment of USEtox method were compared with those obtained after improving USEtox method and an increase of 0.023% of toxicity impacts were found, which is not highly relevant

Although this does not appear as a high impact, it is important to be aware that there are not yet CFs for all the flows involved, especially for pesticides in agricultural systems. Since pesticide use can produce an important impact, authors think it is very important to calculate CFs for specific pesticides.

Table 4.8.2.3.1 Quantity and impact score of the main substances contributing to higher predators toxicity impact category.

Emission compartment	CAS	Substance	kg	IS (PAF·m^3·y·FU^{-1})
Air	13356-08-6	Fenbutatin oxide	4.10E-01	4.07E-08
Water	71-43-2	Benzene	1.51E-01	2.14E-17
Water	95-50-1	Benzene, 1.2-dichloro-	6.73E-03	4.53E-17
Water	108-90-7	Benzene, chloro-	9.22E-02	6.78E-18
Water	98-82-8	Cumene	4.16E-02	1.26E-17
Water	108-88-3	Toluene	3.23E-02	1.09E-17
Water	1330-20-7	Xylene	2.18E-02	6.89E-18
Soil	1563-66-2	Carbofuran	5.32E-04	4.36E-18
Soil	52315-07-8	Cypermethrin	7.52E-05	2.60E-18
TOTAL				**4.07E-08**

Spatial resolution

There are generic CFs without spatial differentiation. Therefore, it is recommended to take spatial differentiation into account in further approaches.

Uncertainty

Uncertainty analysis was not performed.

Applicability

The characterization factors are straightforward to apply by general LCA practitioners. However, relevant pesticides CFs were missed for agricultural application.

The indicator does not seem easy to understand, so it is difficult to judge or comprehend the results of the assessment.

References

D2.3 Recommended assessment framework, method and characterisation factors for ecotoxicity and human toxicity (phase 3). www.lc-impact.eu

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4.8.2.4. Terrestrial ecotoxicity of metal emissions.

Not applicable because there are not CFs for our location. Case study : 36º50'-37º50' N and 1º50'-3º00' W.

References

D2.3 Recommended assessment framework, method and characterisation factors for ecotoxicity and human toxicity (phase 3). www.lc-impact.eu

4.8.3. Non-toxic pollutant impacts

4.8.3.1. Freshwater eutrophication

Introduction

Nowadays endpoint CFs are available for European freshwaters yet they are site-generic and do not address potential differences across regions exposed to nutrient increases. This step is crucial to understand the extent of potential effects of phosphorus (P) discharges into freshwater biodiversity and to identifying which world's regions may trigger the highest impacts via eutrophication (D3.7).

New approach

The goal of this new model was to develop spatial-explicit quantitative relationships between the emission of P and relative species richness losses in inland freshwaters on the global scale (D 3.7).

Characterization factor

Authors derived endpoint CFs, (day·kg^{-1}·m^3) for four different biotic endpoints: autotrophs in lakes, autotrophs in rivers, heterotrophs in lakes and heterotrophs in rivers. CFs were based on the fate of P transport to downstream freshwaters (fate factors) and using three different types of effect factors, i.e. linear effect factors (LEF_a and LEF_b), marginal effect factor (MEF), and average effect factor (AEF).

Inventory Flows

None of the methods include nitrogen as a relevant pollutant in freshwaters, just P emissions.

For our case study perlite substrate retains all the phosphorous from fertilizers application (Antón 2004), therefore no foreground phosphorus emissions needs to be taken into account. Just to test the model we can use P emissions from background processes, which was a quantity of 0,077 kg coming mainly from the production of fertilizers, which we assume are produced in Spain and therefore we used country CFs

Results from new CF

Obviously, the impact results are directly proportional to CF values. IS results at country scale were lower than continent scale and this could be explained by the fact that Southern countries usually are less sensitive to P pollution.

Comparing to other impact categories with similar units, the results for freshwater eutrophication showed two orders of magnitude lower impact than marine eutrophication, and one order of magnitude lower than toxicity categories or previous assessment with USEtox models.

Improvements reached for the case study

While from a scientific and environmental point of view, improvements of this impact category are highly relevant, for our case study, in particular, improvements are less relevant because there was not an important P emission. Nevertheless, the inclusion of CF per countries and different taxonomic groups means a significant contribution to assess freshwater eutrophication.

Table 4.8.3.1.1 Total and partial impact score results for different spatial references for freshwater eutrophication.

Target species	$CF_{Spain\ Europe}$, $m^3 \cdot d \cdot kg^{-1}$	CF_{Europe} $m^3 \cdot d \cdot kg^{-1}$	IS_{Spain} $m^3 \cdot d \cdot FU^{-1}$	IS_{Europe} $m^3 \cdot d \cdot FU^{-1}$
Lake, Autotrophs	3.08E+04	1.43E+05	2,38E+03	1,10E+04
Lake, Heterotrophs	1.38E+04	4.78E+05	1,06E+03	3,69E+04
Stream, Autotrophs	8.69E+03	2.24E+04	6,71E+02	1,73E+03
Stream, Heterotrophs	7.07E+03	1.82E+04	5,45E+02	1,41E+03
TOTAL			**4,66E+03**	**5,10E+04**

Spatial resolution

Grid, country and continental CFs are provided. The resultant impacts can be very varied depending on the geographical unit chosen. The results show the importance of including spatial resolution for a better estimation of impacts, although they can be difficult to interpret for a practitioner without expertise knowledge in fate and effect issues. Again, although countries can be a convenient and understandable geographical unit, the size and variability of some of them can justify the development different regional spatial units.

Uncertainty

The inclusion of an environmental target level ($Cmax$) in the effect factor as it is done in the LEF_b, MEF and AEF factors allows the appraisal of the actual impacts compared to the best known scenario, where PNOF equals to zero.

Applicability

CFs are available for European countries and can be easily applied. However, considerable information is needed to produce new CFs. As far as it has been explained previously, the importance of including geographical units updated to relevant local conditions seems quite complex. Moreover, the different effect approaches can create confusion to choose the most appropriate one. Therefore, this is an indicator that requires a detailed guidance to be applied correctly.

References

D3.7 Recommended assessment framework, method and characterisation and normalisation factors for ecosystem impacts of eutrophying emissions (phase 3). www.lc-impact.eu

4.8.3.2. Marine eutrophication

Introduction

Marine eutrophication involves natural processes leading to an excessive growth of algal biomass in response to nutrient enrichment of marine systems. Once the plant nutrients, mainly nitrogen (N), are available for assimilation and growth, the excessive produced biomass can decrease the water quality (along with the degradation of organic matter from other sources) and bring undesirable effects to biological communities. Nutrient enrichment of coastal ecosystems, originated from freshwater runoff after the large-scale introduction of inorganic fertilizers and detergents worldwide, has been identified as the main cause for marine eutrophication. Until now, no endpoint method has been developed for marine eutrophication.

New approach

The method for marine eutrophication characterizes impacts at the endpoint level. The new approach covers endpoint damage for marine water eutrophication and can be applied worldwide. The Fate model uses emission data and N loss rate coefficients regarding the fate of N groundwater and surface freshwater, and a deposition model for atmospheric emissions (Deliverable 3.7).

Characterization factor

The estimation of potential impacts for marine eutrophication is calculated by applying Characterization Factors (CF) composed of Fate (FF), Exposure (XF), and Effect (EF) Factors.

The FF . estimates the N export to marine waters and the N losses in the marine compartment, thus expressing the changes in N amounts in this compartment. The FF depends on the N fate in soil, the atmospheric fate, fate in freshwater systems, and on the losses once in the marine compartment (denitrification, advection and sedimentation).

The XF expresses the conversion from nitrogen in the photic zone to organic matter (phytoplankton biomass) and to dissolved oxygen consumption in bottom waters.

The EF represents the change in the potentially affected fraction of species in the receiving marine ecosystem due to the change in dissolved oxygen.

The marine eutrophication model can be seen as a combination of an environmental mechanism governing the fate of nitrogen and another environmental mechanism governing the oxygen depletion that gives an impact on biota.

CFs have been developed for countries-to-receiving ecosystems, countries, regions/continents and world geographical levels.

Table 4.8.3.2.1 Characterization factors for different spatial scales for marine eutrophication.

Flows	$CF_{LME\text{-}Mediterranean}$ PAF m^3 d kg^{-1}	CF_{Spain} PAF m^3 d kg^{-1}	CF_{Europe} PAF m^3 d kg^{-1}	CF_{World} PAF m^3 d kg^{-1}
N_{air}	2.96E+03	3.68E+03	1.50E+04	7.05E+03
$N_{freshwater}$	1.11E+04	1.38E+04	3.96E+04	3.34E+04
$N_{groundwater}$	3.94E+03	4.89E+03	1.63E+04	1.49E+04
$N_{marinewater}$	2.35E+04	2.92E+04	n.a.	n.a.

n.a. – CFs not available as no country emissions of sewage water directly to coastal marine waters are available

Inventory Flows

The results from the LCI modelling typically include emissions to "air", "surface freshwater" and "groundwater" as environmental receiving compartments. An extra flow could be added to specifically cover effluent emissions directly to marine coastal waters ("marine water"). Again we have very different perspectives depending if we are considering foreground emissions, for which we know an exact location, or background emissions, for which we assume a country scale and compare it with the European scale. Therefore we have differentiated between foreground emissions due to the use of fertilizers and the remaining emissions corresponding to background processes. Total nitrogen compounds emitted to the different environmental compartments, air or water, need to be reported in the inventory as total amount of N. Direct releases to marine coastal waters are not common inventory emission flows using Ecoinvent database. All N releases from background process to water are, in the present model, referring to receiving surface freshwater. Emissions from treated sewage water or leaching of agricultural fields directly to coastal marine waters are not individually modelled, as usually they are collected and emitted to receiving freshwater before reaching marine water.

Major emissions of NO_3 come from leaching and arrive to groundwater. In order to include nitrate contribution to eutrophication, it is necessary to know which part of the groundwater will reach marine water. The scenario under study was on the Mediterranean coast and therefore we can agree that most of the groundwater reaches the sea. We estimated a potential risk of 5% of N surplus as nitrate emissions reaching the sea (see annex, section 4.8.4.3, fertilizers).

Results from new CF

Table 4.8.3.2.2 shows different results from applying different spatial resolution scales. For foreground emissions we have applied the Mediterranean CF, while we have tried different scale CFs for background emissions. Results show that the use of European CFs increase impacts 2.4 times.

In the previous assessment following ReCiPe methods, impacts to marine eutrophication were calculated as midpoint, kg N eq. Due to the different approaches (midpoint versus endpoint) and units, the comparison of results is not feasible.

On the other hand, if we compare the contribution to marine eutrophication impact category and the contribution to ecosystems toxicity impact category of the previous USEtox method (1.64E+04 PAF·m^3·d table 4.3.2), it appears that the inclusion of damage due to marine eutrophication represents an increase of almost 20% for ecosystems toxicity.

Table 4.8.3.2.2 Nitrogen emissions inventory flows for background and foreground systems and corresponding impact score results for different spatial references for marine eutrophication.

Flows	$LCI_{foreground}$ Kg N· FU^{-1}	$LCI_{background}$ Kg N·FU^{-1}	$IS_{Mediterranean}$ PAF m^3 d·FU^{-1}	IS_{Spain} PAF m^3 d·FU^{-1}	IS_{Europe} PAF m^3 d·FU^{-1}	IS_{World} PAF m^3 d·FU^{-1}
N_{air}	24.92	37.80	7.39E+04	1.39E+05	5.67E+05	2.67E+05
$N_{freshwater}$	--	1.34	0.00E+00	1.85E+04	5.31E+04	4.49E+04
$N_{groundwater}$	9.15	--	3.61E+04	0.00E+00	0.00E+00	0.00E+00
$N_{seawater}$	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
TOTAL			**1.10E+05**	**1.92E+05**	**6.20E+05**	**3.11E+05**

Improvements reached for the case study

This is a new method, so the main improvement related to our case study was the inclusion of marine eutrophication assessment as endpoint damage. Nevertheless, several points remain unclear to practitioners because main improvements are related to the scientific development of the new CFs, fate exposure and effect factors.

Spatial resolution

The existence of different spatial CFs can allow specify impact damage especially for foreground systems. Results will be more or less accurate depending on the knowledge of location for the background processes. In this sense, Impact stage has improved clearly, being the final result highly dependent on the inventory information availability.

Uncertainty

Uncertainty parameters for CFs have not been provided. However, uncertainty can be performed at geographical scale. In addition, uncertainty due to the inventory modelling needs to be added to the final result for this category.

Applicability

The new methodology offers one indicator result that is easy to understand and the different spatial scales of CFs are not difficult to apply. Thus, the use of the new method can be very easily applied by LCA practitioners. However, the interpretation of the damage result is quite complicated for non experts. In addition, it is important to be aware that the modelling of N compounds in the inventory, especially in agriculture, is a complex topic that adds uncertainty to the results.

References

D3.7 Recommended assessment framework, method and characterisation and normalisation factors for ecosystem impacts of eutrophying emissions (phase 3). www.lc-impact.eu

4.8.3.3. Terrestrial acidification

Introduction

Spatially-explicit global scale methodology for terrestrial acidification in Life Cycle Impact Assessment (LCIA) is currently unavailable. The objective of this new method was to derive characterization factors (CFs) that mathematically quantify the relation between an acidifying emission and its impact to the soil and biodiversity at country level.

New approach

The authors of the method developed two midpoint approaches: Type 1, based on soil sensitivity factor, and Type 2, based on excess of critical loads; and one endpoint approach based on the potentially not occurring fraction of species (PNOF).

In the midpoint level method, country (and continent) CFs for type 1 were provided. The method described in the corresponding deliverable (Deliverable 3.3) also includes atmospheric transport of pollutants across continents, which was not available up to now.

In the endpoint level method, similarly to the midpoint method, authors provide country and continent CFs.

Characterization factor

CFs for terrestrial acidification for midpoint Type 1 are obtained by the sum of the product between atmospheric fate factor (FF) and soil sensitivity factor (SF) for the different countries and continents. The atmospheric fate factor describes the link between the change in pollutant emission of an acidifying pollutant and the change in acid deposition in the receiving environment. The soil sensitivity factor evaluates the change in soil solution H^+ concentration due to a change in atmospheric deposits of a pollutant on soil.

The endpoint Type 3 CFs for changes in PNOF (%) following a pollutant emission are obtained by multiplying the FF, the SF, and the Ecological effect factor (EF), where EF_j is the vegetation effect factor representing the change in the PNOF following a change in soil pH.

Table 4.8.3.3.1 A selection of midpoint and endpoint CFs to calculate damages to terrestrial acidification in Spain and Europe, from the main contributing air emission flows.

Flows	CF $_{midpoint\ ,\ Spain}$ mol $H^+/L \cdot m^2 \cdot kg^{-1}$	CF $_{endpoint,\ Spain}$ $m^2 \cdot kg^{-1}$	CF $_{midpoint,\ Europe}$ mol $H^+/L \cdot m^2 \cdot kg^{-1}$	CF $_{endpoint,\ Europe}$ $m^2 \cdot kg^{-1}$
SO_2	2.50E-03	1.52E+01	3.61E-04	1.47E+01
NO_x	1.05E-03	5.59E+00	9.21E-03	2.76E+00
NH_3	5.72E-03	3.34E+01	4.51E-04	1.13E+01

Inventory Flows

SO_2, NO_x and NH_3 emissions into the air were registered from the inventory. The main contributors in the production system releasing these emissions were the manufacture and use of fertilizers for SO_2, NO_x and NH_3 and the different manufacturing processes for SO_2 and NO_x.

Results with the new CF

In our case study, we compared CFs in Spain and Europe. Regarding the midpoint category, it was found that the use of country CFs reduces the impact to 89% in relation to the European value. On the other side, the endpoint damage increases one and a half times the country value in relation to the European value. The results showed the difference in the amount of contribution of different pollutants. Units in the previous classical assessment, SO_2 eq, are different from the ones in the new method, making comparison of results difficult. Nevertheless, an attempt to compare the different flow contributions was made and showed in table 4.8.3.3.2. In the previous ReCiPe Midpoint assessment it was calculated a 52.3%, 19.6% and 28.1% contribution for SO_2, NO_x and NH_3 respectively, which also differs from the new ones. However it is difficult from a case study perspective catch up clearly these different contributions.

Table 4.3.3.3.2 Impact score for midpoint impact and endpoint damage for terrestrial acidification, applying new CFs at country (Spain) and continental (Europe) resolution.

Flows	$IS_{midpoint,\ Spain}$ mol H^+/L $m^2 \cdot FU^{-1}$		$IS_{endpoint,\ Spain}$ $m^2 \cdot FU^{-1}$		$IS_{midpoint,\ Europe}$ mol H^+/L $m^2 \cdot FU^{-1}$		$IS_{endpoint,\ Europe}$ $m^2 \cdot FU^{-1}$	
SO_2	2,11E-01	49,9%	1,28E+03	51,5%	3,03E-01	71,9%	1,24E+03	50,0%
NO_x	6,38E-02	15,1%	3,39E+02	13,7%	5,60E-02	13,3%	1,68E+02	6,8%
NH_3	1,48E-01	35,0%	8,63E+02	34,8%	1,16E-01	27,5%	2,91E+02	11,7%
TOTAL	**4,22E-01**		**2,48E+03**		**4,76E-01**		**1,70E+03**	

Improvements reached for the case study

Main improvements are related to specific CFs at country level. It is also important to point out that the inclusion of atmospheric transport across continents means an important contribution to the calculation of acidification impact.

Spatial resolution

Spatial variability was especially taken into account in this new method working at country level.

Uncertainty

Uncertainty values for CFs were not provided. However, an uncertainty assessment could be done comparing the different results to spatial scale

Applicability

As far as we know, the most relevant substances are included in the new method. Therefore, the most important acidifying chemicals are covered.

CFs are available at country and continental level and can be easily applied as far as practitioners know emission places. On the other hand, the interpretation of the impact and damage results is more difficult.

The use of country as a geo-spatial unit can hamper some results for larger and non-uniform countries. At this sense, update to local conditions of case-specific CFs cannot easily be performed by LCA practitioners because it requires high expertise in the developed models.

References

D3.8 Recommended assessment framework, method and characterisation and normalisation factors for ecosystem impacts of acidifying emissions (phase 3). www.lc-impact.eu

4.8.3.4. .Human health impacts of fine particulate matter formation

Introduction

The present work aims to fill the gap of consistent global modelling by developing an approach to derive globally applicable and spatially explicit characterization factors for particulate matter, because the extent of the impact per unit of emission can vary by an order of magnitude or even more between different sources

New approach

A global, spatially explicit assessment of the so called classical, priority, transboundary air pollutants (primary particulate matter, SO_2, NO_x and NH_3) has been conducted with regard to primary and secondary particulate matter and their impacts to human health.

Intake factors and characterisation factors have been derived. Characterization factors have been derived on endpoint level, i.e. the number of YOLLs and DALYs per unit of pollutant emission.

Characterization factor

A characterization factor (CF) of a pollutant p is a factor per unit of emission which quantifies the impact e.g., to human health, that is caused by the emission of a certain amount of the corresponding pollutant p. The size of the overall impact per unit of emission of a pollutant depends on the corresponding exposure of receptors to corresponding pollutants (in case of impacts to human health the receptors are the people) and the effects that these pollutants are causing. The burden per unit of emission is expressed as an intake factor (iF) [mg/kg] or [g/Mg] which depends on the concentration of the corresponding pollutant i, the number of people exposed to this concentration and their breathing rate. Since people take in the pollutants by inhalation, the iF reflects the accumulated intake of a pollutant i, i.e. the sum over the whole population. In case of primary particulate matter, pollutant p and pollutant i are the same substance. In case of secondary particulate matter, namely secondary inorganic aerosols, p represents the emission of SO_2, NO_x or NH_3 and i is the mass of secondary inorganic aerosols (SIA).

The mass of intake is assumed to be the product of pollutant i concentration in air [µg/m³], the average human breathing rate [m³/a]and the number of people exposed Different chemical transport models (CTM) models and approaches have been applied in order to cover different regional scales from local to global assessment. The entire world is included as receptor region.

Inventory

The main particulate matter flows are captured in background processes such as fertilizers production and structure and auxiliar equipment, so it is diffcult to know the exact

location of the processess, we assume that it could be Spain, therefore we apply the TM5 CFs for Spain

Table 4.8.3.4.1 Inventory flows, and CFs to calculate midpoint and endpoint damages to human health due to particulate matter at country scale (Spain).

Flows	LCI kg $_{pollutant\ emis}$FU^{-1}	$CF_{Midpoint}$ ppm	$CF_{Midpoint}$ DALY·kg^{-1}	$IS_{midpoint}$ mg· FU^{-1}	$IS_{enddpoint}$ DALY· FU^{-1}
PM < 2.5 m	4.99	2.37E+00	3.82E-04	1.18E+01	1.90E-03
SO_2	84.13	9.00E-01	1.45E-04	7.57E+01	1.22E-02
NO_x	60.78	3.40E-01	5.47E-05	2.07E+01	3.33E-03
NH_3	25.80	6.90E-01	1.11E-04	1.78E+01	2.87E-03
TOTAL				**1.26E+02**	**2.03E-02**

Results with the new CF

Table 4.8.3.4.1 shows values of inventory flow and CFs at midpoint level and country scale (Spain) and Midpoint impact. Endpoint as human health damage are 1.6 times higher than in the previous ReCiPe assessment. Results show that SO_2 emissions are the most important contributors (60.1%).

Improvements reached for the case study

Main improvements are related to spatially explicit CFs for particulate matter at country level. There is also the chance to apply CFs with a different degree of spatial resolution. However the unknowledge of background processes makes difficult the applicability of most suitable regional CFs. In addition the different units used mg PM? Related to classical assessment with ReCiPe (kg PM10 eq) make difficult to compare results. Nevertheless the comparison of contributions of different pollutants has changed a lot. In the previous classical assessment with ReCiPe SO_2 contributed 35.1%, while contribution of NOx was 27.9%, while in the new method contributions are 60.1 and 16.4% respectively This can be explained by the fact that the new method allows a better approach to specific country characteristics, because specific atmospheric chemistry and population density distribution for each country have been taken into account, which old methods did it on a European average basis hence, we have reduced implicit uncertainty due to the variability between countries.

Spatial resolution

TM5 CFs are provided by countries, which can be further aggregated to continents

Uncertainty

Uncertainty values for CFs were not provided. However, an uncertainty assessment could be done comparing the different results to spatial scale or attending the different archetypes.

Applicability

As far as we know, the most relevant substances are included. CFs are available at country and continental level and can be easily applied.

References

D3.9 Recommended assessment framework, method and characterisation and normalisation factors for human health impacts of fine particulate matter formation (phase 3). www.lc-impact.eu

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4.8.3.5. Ozone - human health impacts

Not applicable in our case study

References

D3.10 Recommended assessment framework, method and characterisation and normalisation factors for human health and ecosystem impacts of photochemical ozone formation (phase 3). www.lc-impact.eu

4.8.3.6. Noise

Not applicable in our case study

References

D3.11 Recommended assessment framework, method and characterisation and normalisation factors for noise impacts (phase 3). www.lc-impact.eu

4.8.4. Conclusions

As an overall conclusion it can be said that for agricultural production systems the newly developed impact categories contribute to fill the most important gaps related to land use, water consumption, pesticides toxicity and non-toxic emissions mainly those linked to fertilizers use. The possibility of including biodiversity damage due to land use and influence of water consumption in wetlands mean an important scientific advance to a more actual environmental assessment for agriculture. Likewise, the developed dynamic crop model, to assess human toxicity due to pesticides residues in food, leads to a better praxis of pesticides application, which also brings benefits to ecosystems biodiversity.

It is particularly important to point out the effort made to provide site-specific characterization factors. Although some criticism can be done to the use of administrative units, such as countries as a reference, for further studies it will be convenient to take into account similar ecohabitats as the reference units. It is worth mentioning that from the developed methodologies it will be a straightforward task of adaptability relying on geographic information systems to adapt the method to a given ecohabitat unit. This can be achieved as far as more detailed information becomes available.

Thanks to the further inclusion of CFs in softwares, the use of new methods will be very easily applied by LCA practitioners, especially if there is integration between LCA and GIS softwares. However, the interpretation of the damage results could be complicated for non experts. The use of endpoint damage homogenized units to ReCiPe methods allowed us a clear comparison with the previous classical assessment, and therefore a clear quantification of what the new impact represents. Although conversion of impacts in damage units increases uncertainty of results, from the general public point of view it would be convenient to use homogeneous units, which would make possible easy comparison between impacts.

The inclusion of uncertainty for characterization factors, as well as for inventory flows needs to be a compulsory subject in order to provide more accurate and precise environmental assessment.

In addition the application of new methods allow us to deepen in the inventory data, and pin down where background flows acquire a highlighted importance not properly taken into account when average data from generic data bases are used (e.g. for toxicity calculations). Special attention must be paid to the high quantity of contributing flows to toxicity impact categories, which makes the assessment especially important to be confident with results.

In this sense the application of newly developed characterization factors will enable a better approach to data quality processes.

So we can conclude that for our case study in particular, and for agricultural assessment in general, these new impact characterization methods represent a clear improvement; they allow a most detailed environmental assessment considering site–specific characteristics, one of the main drawbacks in agricultural processes until now.

4.8.5. Annex. Fresh tomato production case study LCA

4.8.5.1. Introduction

The environmental assessment of this case study is a full LCA and was conducted by IRTA (Institute of Agriculture and Food Research and Technology) as part of the work of workpackage 4 (WP4) of LC-IMPACT research project.

Land use, water consumption, technosphere inputs, emission outputs and tomato yield differ significantly among different years and producers due to differences in climate, soil and substrate characteristics. In this case study, these differences were accounted for, by considering a range of variability. This variability was based on the experience of local practices on relevant inputs, and on tomato yields.

Life cycle assessment (LCA) was the methodology used for the assessment following the ISO standards for LCA (ISO-14040 2006; ISO-14044 2006) and in accordance with ILCD guidelines (ILCD 2010).

4.8.5.2. Goal and scope definition

Introduction and overview

The overall goal of this case study is to perform a full LCA study on fresh tomato production to evaluate the methods, characterization factors and normalization factors on midpoint and endpoint level, as developed in LC-IMPACT (WP1, WP2 and WP3). The specific goals of this case study are:

- To collect environmental data for fresh tomatoes production.
- To apply and evaluate the newly developed operational life cycle impact assessment methodology with characterization factors and normalization factors in the technology case studies, comparing the results with old/conventional life cycle impact assessment methods. As conventional method we chose ReCiPe (Goedkoop, M. et al. 2009) because this method represents an improvement of CML midpoint indicators (Guinée, J. B. et al. 2002) and an advance of the endpoint Ecoindicator (Goedkoop, M. and Spriensma, R. 2000) method. In addition, we took into account USEtox (Rosenbaum, R. K. et al. 2008) consensus model for toxicity categories following recommendations of ILCD (ILCD 2011).
- To draw conclusions and recommendations for policy making for the case investigated.
- To provide feedback to WP1, WP2 and WP3 and contribute to the refinement of the methods developed.

Aspects of the goal definition

The intended application of the LCA results was to show how the methodological improvements of the new life cycle impact assessment methods work in practice, comparing the results with old life cycle impact assessment methods (ILCD 2010, p 30). This study is to analyse methodological issues and does not have the goal to provide information in support of any decision on fresh tomato production (ILCD 2010, p 31). The environmental inventory data resulting from this case study will be made available to the European Platform for LCA Data

Network according to the data format and quality requirements of the ILCD Handbook. The results of the assessment constitute the present deliverable.

The intended target audience is the European commission firstly, followed by the scientific community and finally general public because datasets will be part of ELCD database. Therefore, the target audience was internal and external. Results of the study will be used in other workpackages in LC-IMPACT project in order to test their characterization factors (CFs). The external intended target audience is the European commission firstly, followed by the scientific community and finally general public because datasets will be part of ELCD database

This study does not include a comparative assertion and therefore does not entail additional mandatory requirements under ISO 14040 (ILCD 2010, p 34).

This study is part of LC-IMPACT research project *Improved Life Cycle Impact Assessment methods (LCIA) for better sustainability assessment of technologies*, Seventh Framework Programme ENV.2009.3.3.2.1, commissioned and founded by the European Commission and with the accordance of ILCD (ILCD 2010, p 35).

We used an attributional LCA. According to the ILCD handbook (ILCD, 2010), this study could be considered a C2 situation: an accounting description of the production system as it is, excluding interactions with other systems and without decision support (ILCD 2010, p 37).

Scope definition

In this section, the object of the LCA of fresh tomato production is defined in line with the goal definition (ILCD 2010, p 51).

In order to ensure the quality of the results, all assumptions, data and methodological aspects were consistent for the different parts of the analysed system.

The guidelines in the ILCD handbook were followed to achieve a good reproducibility for this LCA study on fresh tomato production, in an objective and transparent way.

The functional unit is used to name and quantify the qualitative and quantitative aspects of the function of the production system. A system may have a number of possible functions and the one selected for the study depends on the goal and scope of the LCA. In this study, a single horticultural product was delivered, and, as in most agricultural LCA, mass FU was selected: 1 kg of classic loose tomatoes. This choice gave a reference to quantify all input and output flows.

Agricultural processes differ from industrial ones, mainly in their variability being the main reason the site-dependence and influence of external conditions. Therefore, in order to take into account that similar inputs can give different outputs, we have worked with a range of mass functional units. Yields taken into account were from 8 to 22 $kg \cdot m^{-2}$ tomatoes.

In order to facilitate the interpretation of results and the comparison between the old and the new LCIA methods, we have chosen the reference flow for the calculation of environmental impacts. The reference flow is the flow to which all input and output flows and it is in direct relation to the functional unit. In this study the reference flow was 1 ha, which includes greenhouse construction and paths around it.

In this case study, attributional life cycle inventory modelling principles and method approaches were applied. Therefore, the production system was analysed as it is (ILCD 2010, p 71).

No processes providing more than one function were identified in the production system. Therefore, there were no multifunctional processes to be analysed.

The system boundaries define which parts of the life cycle and which processes belong to the analysed system (ILCD 2010, p 93). They hence separate the analysed system from the rest of the technosphere. At the same time, the system boundaries also define the boundary between the analysed system and the ecosphere. The system boundary defined was from raw

materials extraction to the farm gate, including material waste disposal. Material disposal was included but not recycling processes, following the cut-off allocation procedure of Ekvall and Tillman (Ekvall, T. and Tillman, A. 1997). Neither packaging nor commercialisation processes were within the scope of the study, as the aim of this case study focused on means of tomato production. Additionally, transport of materials to and from the greenhouse were neither included in the assessment as production in a *parral* greenhouse is a type of local production system where all materials can be afforded from the near environs of the greenhouse. Therefore, the following life cycle stages and unit processes were taken into account:

- inputs and outputs in the manufacture of greenhouse structure, auxiliary equipment, climate control system, fertilizers and pesticides
- transport of materials
- production and use of fuels and electricity
- crop production and greenhouse management (consumption of water, fertilizers, pesticides and energy)
- recovery of used products or recycling
- disposal processes of waste and products

The tomato fresh production was analysed to differentiate the foreground and the background systems with the purpose of identifying which processes can be managed by direct control (Figure 4.8.1). The foreground system for the tomato production system was depicted in several stages to facilitate the assessment and the interpretation of the results: greenhouse structure, auxiliary equipment, management, fertilizers, pesticides and waste management.

Cut-off-criteria was applied to include the most relevant processes and flows in the production system. Following the cut-off criteria of the *International Reference Life Cycle Data System Handbook* (ILCD 2010), processes with environmental impact percentages below 5% were omitted when they were not considered relevant for an agricultural production system. This cut-off criterion was previously used in the LCA of tomato production in the EUPHOROS project (Torrellas, M. et al. 2013; Torrellas, M. et al. 2012b).

Basis for the impact assessment

Midpoint impact categories and endpoint damage defined by the method ReCiPe (Goedkoop, M. et al. 2009) were selected as a previous assessment. Additionally toxicity assessment trough impact categories defined by USEtox method (Rosenbaum, R. K. et al. 2008) was performed.

The SimaPro program version 7.3 was used for the environmental assessment, performing the compulsory classification and characterization phases defined by the ISO 14040 (ISO-14040 2006). Normalization was done in accordance with hierarchy perspective.

Representativeness and appropriateness of LCI data

The tomato production under study required a detailed data collection process and included the compilation of representative primary and secondary data of the system processes. As this is an attributional LCA, primary data were specific inventory data on the processes of the foreground system and secondary data were average or generic for the background system (ILCD 2010, p137). Representativeness of data was looked from a technological, geographical and time-related perspective (ILCD 2010, p122).

The data used for the inventory phase were from long cycle tomato cultivation in the period between 2006 and 2010. Primary data were the specific data for the agricultural operations, such as water consumption, fertilizers and pesticides doses and yield, and were representative of the studied area located on the coast of Almeria (Southeast of Spain). These data were from a long cycle cultivation period and tomato crop plants were at a density of 1.23 plants·m^{-2} with two stems per plant. Criteria of best available technology were assessed. The greenhouse structure was modelled as a generic data set representing the typical structure of a *parral* greenhouse. Greenhouse average data were extrapolated from several greenhouse sizes and extrapolation was based on verified measurements of *parral* greenhouses. Secondary data for the following processes were obtained from the Ecoinvent database (Frischknecht, R. et al. 2007): manufacture of greenhouse components, substrate, fertilizers and pesticides; electricity production mix; and materials transports, and disposal. The most similar processes to the ones in the production system were selected to model the tomato production in a *parral* greenhouse production system.

Types, quality and sources of required data and information

Data quality needs to be stated in accordance with ISO 14044 (2006) quality criteria. We followed the guidelines of the ILCD data quality indicators , which allowed us to classify the achieved data quality of the LCI datasets according to technological representativeness (TeR), geographical representativeness, (GR), time-related representativeness (TiR), completeness (C), methodological appropriateness (M) and precision (P) (ILCD 2010, p323).

With the application of the methodology proposed by the ILCD (ILCD, 2010, p 205) and complemented with criteria of a pedigree matrix (Weidema, B. and Wesnaes, M. 1996), it was found that the data quality of most of the components was basic, mainly due to sample variability.

4.8.5.3. Inventory analysis

The inventory phase involves the collection and quantification of the required data and relevant information for the analysed system. In this case study, the inventory was done in line with the goal and scope definition on tomato production in a *parral* greenhouse described previously. The performance of the inventory analysis was an iterative process. As data were collected and more knowledge was learned about the production system, new data requirements and limitations were identified. All relevant data to perform the environmental assessment was collected and authors think that extra information could add some more details but would not change significantly the sense of assessment of this case study.

All the materials processes were considered in the inventory. Manufacture of equipment and greenhouse elements included materials and processes such as drawing of pipes, coatings and plastic extrusion. Electricity consumption for greenhouse operations was included, and emissions released were calculated on the basis of the electricity production mix in Spain. Transport processes to or from the greenhouse included vehicle and road manufacture, maintenance and diesel consumption (Torrellas, M. et al. 2012a; Torrellas, M. et al. 2012c).

In this attributional modelling, the foreground system for the tomato production system was structured in six stages to facilitate the compilation of data and the comprehension of results: greenhouse structure, auxiliary equipment, management, fertilizers, pesticides and waste management. A detailed description of the defined stages is described in the next section.

LCI data collection

Data collection in this inventory was only required for the foreground system, provided all data in the background system could be sourced from referenced background databases (ILCD, 2010, p 190). A recompilation of data from previous studies performed by IRTA allowed us to build datasets covering the range of the different stages involved in the greenhouse tomato crop. These datasets provided data on the crop, yield, substrate, waste management and the agricultural operations such as the consumption of water, electricity, fertilizers and pesticides. Primary data relating to greenhouse dimensions were average data from specific *parral* greenhouses to represent the *parral* greenhouse.

The individual data for the inventory were quantitatively expressed as flows per reference flow, 1 ha (ILCD, 2010, p 200).

Direct land use was inventoried in the assessment. For CO_2 released by land use and land transformation, no emissions were included in the assessment because the transformation of the crop area where the greenhouse was built occurred 20 years prior the assessment (ILCD, 2010, p p235).

Description of the stages in the production system

The tomato production system in this case study was an agricultural system under a *parral* greenhouse. Crops can be cultivated directly in the soil or in substrate. Soilless crops are only a 20% of total crops in this area. Nevertheless, a soilless crop was selected in order to include the assessment of different resources, which in this case was perlite, a type a substrate. Therefore, the crop under study was a protected soilless crop, and the emissions from pesticide and fertilizer application were included in the assessment. The methods used to model the amount of these emissions are described below in *Fertilizers* and *Pesticides* sections.

Tomato production in a p*arral* greenhouse in Almeria, Spain

In the Mediterranean basin, the area devoted to protected horticultural crops went from nil in the 1950s to 120,000ha in 1985 and nowadays there are about 170000 ha of greenhouses and high tunnels. Spain has the greatest covered area in Europe, and the largest concentrations of protected crops are in the southeast with 30,000 ha in Almeria (Torrellas, M. et al. 2012a; Torrellas, M. et al. 2012c). Tomato is a major crop in Almeria with 6,262 ha. Currently, the major protected area on the coast of Almeria is covered by *parral* greenhouse, which is a local plastic greenhouse with a simple frame structure. In this area, 60% of tomato crops are produced in *parral* greenhouse, being a 20% of protected crops soilless crops grown in perlite substrate.

Protected greenhouses on the coast of Almeria cover an area within the following geographic data: Latitude between 36º50’ and 37º50’ N and Longitude 1º50’ and 3º00’ W (Figure 4.8.5.1).

The growing period was considered 12 months, planting from August to September and harvesting from November to July. A one and a half month of resting period, with no crop and empty greenhouse, was included in the total crop period.

As mentioned above, the production system was structured in six stages to facilitate the assessment and interpretation of results: greenhouse structure, auxiliary equipment, management, fertilizers, pesticides and waste management. A detailed description of the defined stages is described as follows:

Figure 4.8.5.1. White area of greenhouses in Almeria (Spain), in the Mediterranean basin.

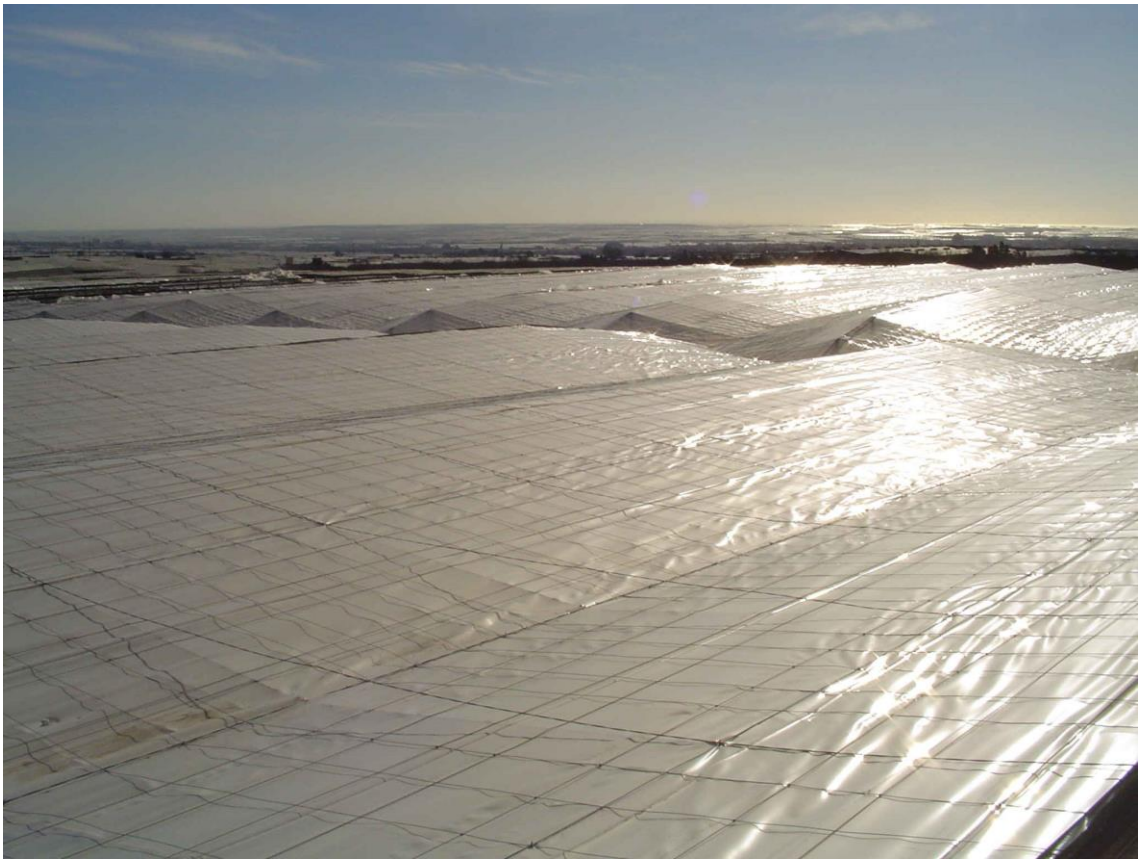

Figure 4.8.5.2 A typical *parral* greenhouse showing the main a traditional square steel-wire frame and plastic cover.

Greenhouse structure

A *parral* greenhouse is a simple steel or wooden frame structure with a plastic cover (figure 4.3.5.3). The main parts of the *parral* greenhouse structure include a vertical structure consisting mainly of a number of steel posts that can be located around the perimeter or inside the greenhouse with foundations consisting of concrete footings supporting the steel frame.

The roof is based on a traditional square steel-wire frame: a flexible horizontal structure made of single or corded wires that carry the force of wind uplift to the ground or provide support for the plastic mesh cover. The covering material is usually a multilayer of ethylene-vinyl acetate (EVA) and low-density polyethylene (LDPE) film. Natural ventilation is provided through roof vents in each span and two side wall vents. All the vents are covered with insect-proof screens.

The selection of average greenhouse dimensions and therefore material amount to be included in the inventory were done on the basis of a previous study (Antón , A. et al. submitted). A detailed list of the characteristics of the *parral* greenhouse for this case study is in Table 4.8.5.1.

Table 4.8.5.1 The main dimensions of *parral* structure greenhouse (Antón , A. et al. submitted).

Type	Average	Minimum	Maximum
Area (m^2)	7,710	432	22,500
Number of spans	8	3	15
Span width (m)	8.3	6	10
Greenhouse length (m)	95.1	24	150
Gutter height (m)	2.8	1.5	3.5
Ridge height (m)	3.9	2.5	4.5

We used equations developed by Antón et al. (submitted) to calculate the amount of the main greenhouse materials as a function of greenhouse size. The equations were developed by using the dimensions of 35 different real greenhouses, calculating the amount of materials needed for each size and establishing statistical regressions between greenhouse size variables (e.g. area covered, number of spans, perimeter and volume) and the amount of materials. The equations with the best fit to calculate the amount of steel in the structure, the plastic cover and the foundations were obtained when greenhouse area was used (ILCD, 2010, p 201). The best fit for other steel parts, such as the wire mesh and the gutters, was found by using the ratio of greenhouse volume to the number of spans. The zinc coating on the steel parts was calculated in terms of the total amount of steel. The structural part with the worst fit was the steel wire mesh. Plastic film cover showed a good fit to covered area while the plastic gutter fitted to volume and number of spans

Auxiliary equipment

This stage included all the auxiliary equipment needed to grow tomatoes: pipes and pumps of the irrigation system; benches and the substrate (Figure 4.8.5.3). The irrigation system was an open-loop drip system, without recirculation of drainage water. The watering system started with extraction of water from a well and then providing water to water tanks and fertilizer tanks. Pumps and injectors supplied water and fertilizers to a main pipe and this

to the secondary pipes, which finally provided water to the crop. There were as many secondary pipes as plant rows. Each tomato plant was watered by a dripper system. The plant rows run from side to side of the greenhouse and a central main path allowed labour operations. The management of the watering system is taken into account in the management stage.

The plastic components in the auxiliary equipment were the beds, pipes, drippers, micro tubes, stakes, the fertilizer tanks and the substrate layers. Steel elements were the injectors and the pumps. The substrate used was perlite in polyethylene bags of 30 L volume. Each bag contained three plants with 2 stems per plant, at a density of 1.23 plants·m^{-2} and at 8 kg weight per plant. Following the criteria of 5% cut-off and from the previous work (Torrellas, M. et al. 2012a) material included refers to secondary pipes, soil and benches cover plastic and substrate. Amount of material was represented by an average of 35 samples from different greenhouse sizes. Life span form all materials is 3 years.

Figure 4.8.5.3. Rows of perlite substrate bags, on polystyrene benches.

Management

The management stage included the operations performed during the crop period, i.e. land and water use, as a natural resource flows, as well as electricity and fuel consumptions during labour operations.

According to ILCD handbook, direct land use and land transformation should be inventoried along the needs of the applied LCIA method (if included in the impact assessment). In this case study, no emissions from land use transformation were included in the assessment because the transformation of the crop area where the greenhouse was built occurred 20 years prior the assessment (ILCD, 2010, p 235).

The water source used to irrigate was mainly groundwater. The total amount of water consumed was 4,748 m^3·ha^{-1} including a 25% watering surplus to avoid build-up of salts.

Nevertheless, it was estimated that water consumption could vary in a range from 265 $L \cdot m^{-2}$ to 550 $L \cdot m^{-2}$ depending on weather conditions and leaching fractions.

In addition and for this case study, the use of rainwater was taken into account. It was estimated that greenhouses in Almeria, except flat *parral* structures, collected rainwater by greenhouse gutters and then rainwater was stored in irrigation ponds. Therefore, the amount of rainwater estimated to be collected by greenhouses was calculated as a weighting average taking into account: the total greenhouse area in Almeria province after subtracting the flat *parral* greenhouse area (12,103 ha), the total area of Almeria province (46,676 ha), an average precipitation of 320 $L \cdot m^{-2}$ (Mojonera (2001-2011) and Adra (2003-2011) weather stations) and a 0.8 roof coefficient of rain collection (Farreny, R. 2011). These data meant that a 21% of total rainwater was collected. Assuming all greenhouses in the area were collecting water and there were enough irrigation ponds to store the water, an average value of 66.7 $L \cdot m^{-2}$ rainwater was estimated to be collected, which is in accordance with data suggested by Pérez Parra et al. (2002). Although there is not yet enough agreement in the scientific community on this topic, we assumed that the quantity of rainwater used was green water, and minimum and maximum values were estimated with data of minimum rain, 2005, and maximum rain, 2010 (MOJONERA (2001-2011) and ADRA (2003-2011) weather stations).

Electricity consumption included electricity to operate the irrigation system for drip irrigation, that can range between 0.10 $kWh \cdot m^{-3}$ for superficial water and 0.50 $kWh \cdot m^{-3}$ for groundwater (Corominas, J. 2010) and, with natural ventilation, the electricity to operate the vents (0.56 kWh vent motor, one per each span, 10 minutes a day and 120 days per crop (Antón, A. 2004). The electricity was provided by the public grid and dataset on electricity production mix in Spain was updated to year 2010 from Ecoinvent database.

Currently 40% of farms use a tractor, doing the operations of ground maintenance, pesticide treatments, and transport of produce to the centre of commercialization. Due to the fact that we analyzed a soilless crop, the use of a tractor for labours operations was reduced to apply plant protection products and to transport materials near around. In order to calculate the consumption of gasoil, more importance needs to be given to the size and power of the tractor. There is great variability of tractors in market and depending on their power the consumption of gasoil can range between 2.5 $L \cdot h^{-1}$ and 25 $L \cdot h^{-1}$. In this inventory, the tractor was 70 kW average power and consumed 10 $L \cdot h^{-1}$ gasoil, which is a low value adjusted to the type of operations done in the greenhouse, and a range of working hours between 150 to 400 h.

Pesticides

The assessment of impacts from toxic emissions is crucial to the relevance of LCA for many products. There are large differences between existing characterization models and a lack of consensus concerning the characterization methods used (Finnveden, G. et al. 2009). Pesticide is one of the specific substance groups for which LC-IMPACT targets the research to develop a new life cycle impact assessment method.

Pesticides stage included the production of all the pesticides applied to the crop, according to Green (1987) and Audsley et al. (2009).

The management of crop protection agents is a very important topic in horticultural production systems in order to reduce the consumption of chemicals with no risk of loss of yields. Specific treatments are necessary to fight against the large number of pests and diseases that can damage a tomato crop. There is considerable variability in active ingredient formulations and evaluations can be simplified by distinguishing between fungicides and insecticides. In this case study, environmental impacts because of pesticide production was calculated distinguishing between fungicides and insecticides, except for Chlorothalonil and

Mancozeb that were included as active ingredients. Regarding emissions produced during application we took into account air emissions due to drift fraction going out greenhouse, 5%, (Antón, 2004) this is also a controversial issue, which scientific community has not reach yet an agreement in the model to be used. Table 4.3.4.2 includes inventory data for pesticide environmental assessment.

It is difficult to give an average and standard deviation because pesticide application is strongly depended on climate conditions, pests and farm practices. For this case study, we selected one example as possible application (Fundación_Cajamar 2008) and it was used as trial to test the new models (table 4.3.5.2). We understand that the assessment of variability of this topic is a complex issue out of the scope of the project. Nevertheless, it is worth to mention that as this is a real example, the use of fungicides is more common than insecticides use, due to the fact that the use of insecticides is decreasing thanks to the biologic control.

Table 4.8.5.2 Pesticides processes included in the inventory.

Date	Active ingredient	Amount applied, kg·ha^{-1}	Type of pesticide
18	Copper Oxychloride	3.00	fungicide
36	Clofentezin	0.23	Insecticide
36	Fenbutatin Oxide	0.41	Insecticide
54	Spinosad	0.14	Insecticide
69	Azoxystrobin	0.30	fungicide
96	Chlorothalonil	1.88	fungicide
98	Spinosad	0.18	Insecticide
119	Copper Oxychloride	3.00	fungicide
131	Chlorothalonil	1.88	fungicide
142	Mancozeb	0.30	fungicide
193	Copper Oxychloride	3.00	fungicide
196	Mancozeb	0.30	fungicide
220	Copper Oxychloride	3.00	fungicide
237	Copper Oxychloride	3.00	fungicide
Total	**Insecticides**	**0.96**	
Total	**Fungicides**	**19.66**	

Fertilizers

Due to the important environmental contribution of fertilizers use and because and it is highly dependent on the selection of fertilizers, in our reference case scenario, we used different fertilizer products and doses in order to catch their variability in the inventory. Therefore, as inputs we included the average of the amount of applied fertilizers (see table 4.8.5.3).

Regarding outputs, there are different approaches and parameters to calculate emissions. Emissions from agriculture are highly variable depending on climate, soil type, farming practice and many other inter-related factors. The emissions included were NH_3-N to air from chemical fertilizer; NO_3-N, $PO_4$and K to water; N_2-N, N_2O-N, NO_x-N to air; and N, P, K balance in soil. As a general rule and following the methodology proposed by Audsley (1997), a mineral balance between provided nutrients (N and P) and uptake by the plant, retention in soil or substrate and air emissions for N needs to be calculated to ensure the total input equals the total output.

Nutrient uptake differs strongly among crops and is affected by growth stage, climatic conditions and ion composition of nutrient solution. Nitrogen uptake by the vegetation was based on measurements in Antón study for a tomato crop in a perlite substrate (Antón, A. 2004), which were 49.3 $g \cdot m^{-2}$.

Ammonia emitted to air: Ammonium ($NH4^+$) contained in fertilizers can easily be converted into ammonia (NH_3) and released to the air. Table 4.8.5.3 gives average values for the main chemical used fertilizers.

Table 4.8.5.3 Average and RSD of five of the most common recommended fertilizers.

Fertilizer	**Unit**	1	2	3	4	5	AVG	RSD
Calcium nitrate	$kg \cdot ha^{-1}$	2,616.6	1,308	1,918.4	1,391.3	2,345.7	1,916.0	30.0
Nitric acid (56%)	$L \cdot ha^{-1}$	685.4	683.4	590.2	661.4	1795.9	883.3	57.9
Monoamonium Phosphate	$kg \cdot ha^{-1}$	273.0	-	-	-	-	54.6	223.6
Ammonium Nitrate	$kg \cdot ha^{-1}$	-	-	189.94	189.9	189.9	114.0	91.3
Potassium nitrate	$kg \cdot ha^{-1}$	1,787	1787	2,891.8	3,247.9	916.4	2,126.0	44.2
Potassium sulphate	$kg \cdot ha^{-1}$	1,356.6	1,357	403.6	-	2,003.8	1,024.2	78.9
Magnesium sulphate	$kg \cdot ha^{-1}$	227.9	228	-	-	-	91.2	136.9
Phosphoric acid (72%)	$L \cdot ha^{-1}$	419.7	403.6	613.3	613.3	613.3	532.7	20.8
Total -N	**$kg \cdot ha^{-1}$**	**734.9**	**499.2**	**792.3**	**763.6**	**714.9**	**701.0**	**16.6**
Total -P_2O_5	**$kg \cdot ha^{-1}$**	**417.9**	**209.9**	**318.9**	**318.9**	**318.9**	**316.9**	**23.7**
Total -K_2O	**$kg \cdot ha^{-1}$**	**1,500.3**	**1,500.5**	**1,532.0**	**1,494.04**	**1,423.5**	**1,490.1**	**2.7**

Calculation of N_2O emissions were based on the model described by Nemecek in Ecoinvent Report 15 (Nemecek, T. and Kägi, T. 2007), which in turn is an adaptation of the IPCC method for calculating N_2O emissions (IPCC 1996). In this model, direct and indirect emissions of N_2O are included. In our case study with a soilless culture there were not indirect emissions produced by soil micro-organisms and following these authors we considered a conservative direct emission factor of 1.25% N lost as N_2O. NO_x-N emissions to air were estimated as 10% of N_2O-N emissions 15 (Nemecek, T. and Kägi, T. 2007), (Audsley, E. 1997).

Several factors can affect the risk of nutrients leaching in greenhouse crops, such as the crop itself, the watering management (and therefore its fraction leaching), the type of substrate and the collection or not of leaching. In accordance to Antón (Antón, A. 2004), perlite substrate retains all the phosphorous, therefore no phosphorus emissions were taken into account. In the case of N and as a first approach, we used the difference in the N balance between inputs and outputs as potential leaching. ReCiPe methodology takes into account NO_3 leaching as a potential contributor to marine eutrophication ecosystems, not surface water. To

include nitrate contribution to eutrophication it is necessary to know which part of the ground water will reach marine water. The scenario under study was on the Mediterranean coast and therefore we can agree that most of the ground water reaches the sea. We estimated a potential risk of 5% of N surplus as nitrate emissions reaching the sea (Van Drecht, G. et al. 2003).

Emissions in the production of fertilizers were also included in the fertilizer stage.

Waste management

All materials taking part in the production system have a period of life after which can follow different waste treatments, such as reuse, recycling, incineration, composting and delivery to landfill.

Waste management included transport of waste materials to landfill, emissions at landfill, and transport of green biomass to the compost plant.

Several wastes material treatments were taken into account on the basis of agricultural practices in the area as indicated in Table 4.8.5.4. Green biomass was treated at the compost plant, considering a 60% loss of fresh weight at the time of transport. Only emissions due to transports to the landfill and composting plant, and emissions due to landfill disposal were included in the study.

Table 4.8.5.4 Disposal treatments estimated for waste materials in tomato production in Spain (IRTA 2008).

Materials		Recycling	Landfill	Incinerator	Compost plant
15 years life materials	Metals	100%			
	Concrete	50%	50%		
Plastics	Altogether	90%	10%		
Substrate	Substrate	50%	50%		
	Plastic bags	50%	50%		
Dry green biomass	40% fresh weight				100%

For the management of waste from cultivation, we used the “cut-off” method defined by Ekvall and Tillman (Ekvall, T. and Tillman, A. 1997). In accordance to this method, each product should only be assigned the environmental impacts directly caused by the use of that product.

In the case of waste disposal, such treatment is fully attributable to the system being studied; while for recycled or reused waste, it is considered its burdens should be attributed to the system that will use it as a material source. Therefore, the process of recycling shall be included in the new material created in substitution of raw material in another system. We also made the assumption that the recycling company was going to the greenhouse to collect the materials. This was the reason why only transport and emissions for materials transported to landfill were counted. In the case of green biomass, transport to the composting plant was included as part of the system because as far as we know it is usually done in this way.

Waste management was studied grouping all materials in the greenhouse according to the following criteria: their span life (structural materials), type of material (plastic and green biomass) and function (substrate). Thus, the following groups were defined:

- 15 years life materials: Steel, concrete, in the structure.

- Plastics: PE, and polystyrene. Plastic films such as the greenhouse cover and substrate bags were estimated to have a life span of three years.
- Substrate: Perlite useful life was 3 years.
- Green biomass: Once the crop was over, it was estimated that plants were cut and let dry partially in the greenhouse. From previous experience it was assumed that 40% of the fresh weight of plants is transported to the composting plant.

To transport waste materials we took into account a lorry 3.5-7.5t, EURO5/RER U. and a distance of 5 km to landfill and 10 km to compost plant. This situation needs to be considered as an example because several scenarios could be possible

Generic data refers to data that are not based on direct measurements or calculation for the respective process(es) in the system. Generic data were used only if data for a specific process was unavailable, not environmentally significant, or refer to a process in the background system. In case generic data were used, their sources were referenced and taken into account in the assessment of quality. Examples of generic data can include:

- Data from literature and scientific papers.
- Industry-average life cycle data from life cycle inventory databases, industry association reports, government statistics, etc.

Secondary data were from Ecoinvent database v2.2. In some cases, they were adapted to have more update information (e.g electricity mix 2010).

Variability in Agriculture is very high. In order to choose representative scenarios, we can choose between a selection of experimental and representative field, a complete survey or modelling processes. From previous projects, we had data from experimental fields that were representative of selected processes. We introduced variability for the different inputs and calculated uncertainty, following the criteria of lognormal distribution. For those inputs with a very wide range, we worked with a worst and best case (e.g electricity irrigation pump).

The following criteria were taken into account in the modelling of the system:

Structure: development of equations to model the quantity of materials, and assessment for the most common dimensions.

Auxiliary equipment: use of the most representative data including some variability in the volume of substrate.

Management: average between the worst and the best option.

Fertilizers: average and assessment of different application practices.

Pesticides: assessment of one example as representative in tomato crop production.

Waste: Example of the most common practice. We included variability regarding transport means.

Greenhouse tomato production in hydroponics is a single crop, with neather co-products nor rotations to be taken into account. In some cases, green waste can be reused as a compost or biomass to be burnt. Similarly plastic waste can be recycled or converted in energy. In order to avoid multifunctionality process we have taken out the scope these processes. Instead we have calculated different % of landfill management.

4.8.5.4. Impact assessment

Life Cycle Impact Assessment (LCIA) is the phase in an LCA where the inputs and outputs of elementary flows that were collected and reported in the inventory are translated into impact indicator results, related to human health, natural environment and resource depletion. The results of LCIA should be seen as environmentally relevant impact potential

indicators, rather than predictions of actual environmental effects (ILCD, 2010). In this case study, LCIA results were calculated using the classical method ReCiPe, and midpoint and endpoint impact categories, and normalization were included. Toxicity was also evaluated with midpoint USEtox method.

Midpoint impact assessment

Since there was no need for a heating system in the greenhouse, greenhouse crop management had few direct energy inputs. The main burdens in the product system were fertilizers, management, auxiliary equipment and the structure. The absolute and relative contributions of the production system and the stages to the impact categories are shown in table 4.8.5.5 and figure 4.8.5.4 respectively.

Fertilizers made the main contributions to eleven of the seventeen midpoint impact categories selected for the LCIA, being between 76.3% and 31.9% depending on the impact category. Major contributions were to urban land occupation (76.3%), marine eutrophication (66.9%), terrestrial acidification (64.7%) and metal depletion (49.8%) impact categories.

Management stage totally dominated the impact to water depletion (94.8%) and agricultural land occupation (93.3%).

Auxiliary equipment made the highest contribution to ozone depletion (50.2%), natural land transformation (49.6%), fossil depletion (40%) and terrestrial ecotoxicity (35.6%). It made the second highest burdens to eight impact categories, with contributions between 34.3% and 2.7%.

The structure was the major burden to human toxicity (77.3%) and ionising radiation (32.6%), and was the second burden to freshwater eutrophication (37.7%), metal depletion (34.5%), terrestrial ecotoxicity (34.0%), marine ecotoxicity (31.1%) and fossil depletion (26.4%).

Pesticides and waste management stages made low contributions to the impact categories. Pesticide contributions were lower than 7.7% and waste management lower than 2.3%. Waste management made negative contributions to natural land transformation.

USEtox toxicity assessment

The results for the toxicity assessment with USEtox method are included in figure 4.8.5.5 and table 4.8.5.6. The structure was the main contributor to human toxicity non-cancer impact category, as in the evaluation with ReCiPe method for human toxicity, and the auxiliary equipment was the main contributor to human toxicity cancer impact category. On the other hand, pesticides were the main contributor to ecotoxicity impact category with USEtox method.

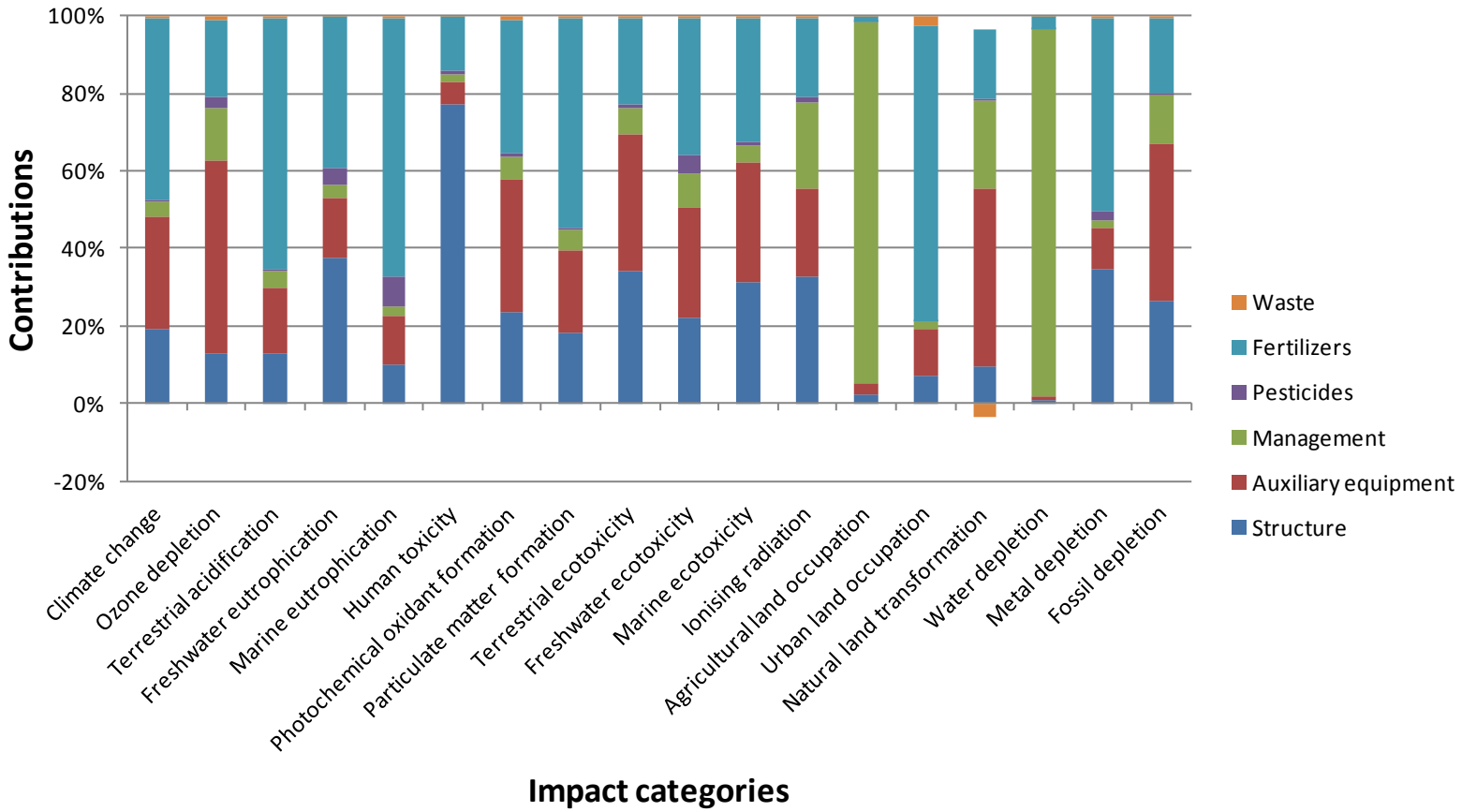

Figure 4.8.5.4 Stage relative contributions to ReCiPe midpoint impact categories for tomato production in a *parral* greenhouse.

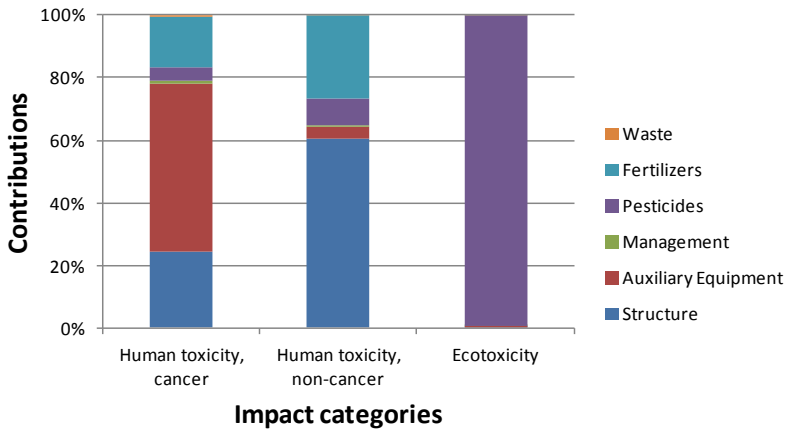

Figure 4.8.5.5 Stage relative contributions to USEtox impact categories for tomato production in a *parral* greenhouse.

ReCipe endpoint assessment

The environmental performance of the tomato production in a *parral* greenhouse was evaluated for the ReCiPe endpoint impact categories: damage to ecosystem diversity, damage to human health and damage to resource availability Life cycle impact assessment results are presented by absolute and relative contributions of the production system and the stages in table 4.8.5.7 and figure 4.8.5.6 respectively.

Fertilizers were the main burden to damage to human health (46.8%) and damage to ecosystem diversity (46.1%). Auxiliary equipment was the main burden to damage to resource availability (39.0%).

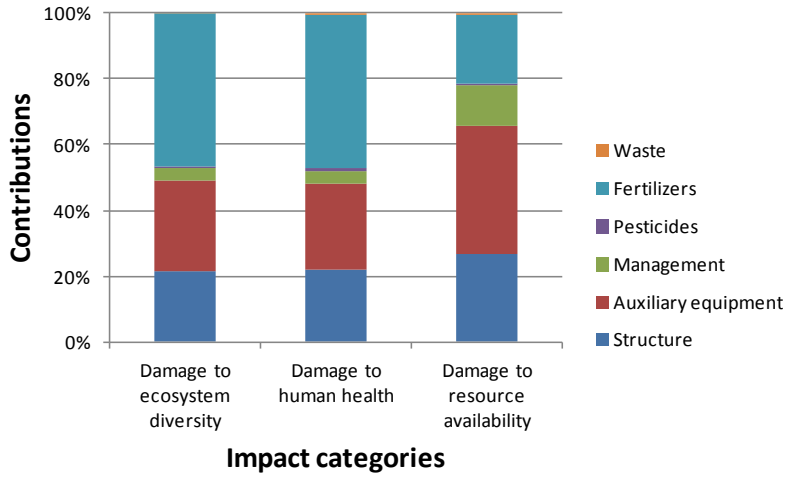

Figure 4.8.5.6 Stage relative contributions to ReCiPe endpoint impact categories for tomato production in a *parral* greenhouse.

Table 4.8.5.5 Stage contributions to midpoint impact categories for tomato production in a *parral* greenhouse by functional unit (1tonne of tomatoes).

Impact category	Unit	Total	Structure	Auxiliary equipment	Management	Pesticides	Fertilizers	Waste
Climate change	kg CO2 eq	**2.3E+02**	4.5E+01	6.8E+01	8.7E+00	1.3E+00	**1.1E+02**	1.1E+00
Ozone depletion	kg CFC-11 eq	**2.5E-05**	3.2E-06	**1.3E-05**	3.4E-06	7.5E-07	5.1E-06	2.3E-07
Terrestrial acidification	kg SO2 eq	**1.2E+00**	1.6E-01	2.0E-01	5.6E-02	6.5E-03	**7.8E-01**	4.8E-03
Freshwater eutrophication	kg P eq	**7.0E-03**	2.6E-03	1.1E-03	2.2E-04	3.3E-04	**2.7E-03**	1.9E-05
Marine eutrophication	kg N eq	**4.4E-02**	4.4E-03	5.6E-03	1.0E-03	3.4E-03	**3.0E-02**	2.5E-04
Human toxicity	kg 1,4-DB eq	**3.0E+01**	**2.3E+01**	1.7E+00	5.7E-01	2.8E-01	4.2E+00	5.6E-02
Photochemical oxidant formation	kg NMVOC	**6.2E-01**	1.5E-01	2.1E-01	3.7E-02	3.4E-03	**2.1E-01**	7.9E-03
Particulate matter formation	kg PM10 eq	**3.2E-01**	5.9E-02	6.7E-02	1.7E-02	1.9E-03	**1.7E-01**	2.3E-03
Terrestrial ecotoxicity	kg 1,4-DB eq	**3.7E-02**	1.3E-02	**1.3E-02**	2.5E-03	3.0E-04	8.2E-03	2.2E-04
Freshwater ecotoxicity	kg 1,4-DB eq	**1.2E-01**	2.7E-02	3.6E-02	1.0E-02	6.4E-03	**4.3E-02**	6.8E-04
Marine ecotoxicity	kg 1,4-DB eq	**3.4E-01**	1.1E-01	1.1E-01	1.5E-02	3.5E-03	**1.1E-01**	1.6E-03
Ionising radiation	kg U235 eq	**9.1E+00**	**3.0E+00**	2.1E+00	2.0E+00	1.3E-01	1.8E+00	5.4E-02
Agricultural land occupation	m2a	**7.2E+01**	1.7E+00	1.9E+00	**6.7E+01**	2.2E-02	1.1E+00	1.7E-02
Urban land occupation	m2a	**3.0E+00**	2.1E-01	3.6E-01	5.8E-02	6.2E-03	**2.3E+00**	6.9E-02
Natural land transformation	m2	**5.1E-02**	5.1E-03	**2.5E-02**	1.2E-02	2.3E-04	9.7E-03	-1.8E-03
Water depletion	m3	**2.9E+01**	3.0E-01	1.5E-01	**2.7E+01**	7.7E-03	1.0E+00	1.2E-02
Metal depletion	kg Fe eq	**1.0E+01**	3.5E+00	1.1E+00	1.9E-01	2.5E-01	**5.0E+00**	5.4E-02
Fossil depletion	kg oil eq	**7.3E+01**	1.9E+01	**3.0E+01**	9.2E+00	4.5E-01	1.4E+01	4.9E-01

Table 4.3.5.6 Stage contributions to USEtox (Recommended v.01) impact categories for tomato production in a *parral* greenhouse by functional unit (1tonne of tomatoes).

Category	Unit	Total	Structure	Auxiliary equipment	Management	Pesticides	Fertilizers	Waste
Human toxicity, cancer	CTUh	**1.8E-08**	4.3E-09	**9.6E-09**	2.1E-10	7.0E-10	2.9E-09	8.6E-11
Human toxicity. non-cancer	CTUh	**5.0E-08**	**3.1E-08**	1.8E-09	2.5E-10	4.5E-09	1.3E-08	7.0E-11
Ecotoxicity	CTUe	**1.1E+02**	3.0E-01	3.0E-01	3.1E-02	**1.1E+02**	8.6E-02	2.5E-03

Table 4.3.5.7 Stage contributions to endpoint impact categories for tomato production in a *parral* greenhouse by functional unit (1 tonne of tomatoes)

Impact category	Unit	Total	Structure	Auxiliary equipment	Management	Pesticides	Fertilizers	Waste
Ecosystem quality	Species.yr	**3.5E-06**	4.8E-07	6.1E-07	**1.4E-06**	1.1E-08	1.0E-06	7.2E-09
Human health	DALY	**4.3E-04**	9.4E-05	1.1E-04	1.7E-05	2.5E-06	**2.0E-04**	2.2E-06
Resources	$	**1.3E+01**	3.4E+00	**5.0E+00**	1.5E+00	9.3E-02	2.7E+00	8.5E-02

4.8.5.5. Interpretation

The LCA for tomato production in this case study was conducted in order to be used for the application and evaluation of the new characterization factors developed in LC-IMPACT. The interest was to analyse the methodological improvements of LC-IMPACT method, and to compare the results from the full LCA conducted with conventional LCIA methods with those calculated with LC-IMPACT method. Conventional methods were ReCiPe (Goedkoop et al., 209) and USEtox (Rosenbaum et al., 2008). At this section we conclude with the corresponding interpretation related to the classical assessment, it is expected to the end the project to compare with the results from the application of new methods.

The results with ReCiPe at midpoint level showed the contributions of the stages in the production system for eighteen impact categories. Major contributors were the auxiliary equipment, the structure, fertilizers and management.

The auxiliary equipment was a major contributor because of the inclusion of substrate production in this stage. The substrate perlite totally dominated the impact to all impact categories, because of the high energy consumption in its production. The reduction of the amount of substrate could be a cleaner alternative as it has been recently evaluated in EUPHOROS project (Montero et al., 2011, Torrellas et al., 2012a). These authors found that when the volume of substrate was reduced by 25%, the auxiliary equipment contributions to abiotic depletion, global warming and cumulative energy demand decreased by 10 to 12%. Recycled of substrate is also a recommended option.

The structure made high contributions due principally to the high amount of steel in the frame and plastics in the cover and the gutter. The *parral* structure is a simple structure which a much lower amount of steel and plastic than in a high-technology greenhouse as a multi-tunnel greenhouse. Nevertheless, the tomato production in the Mediterranean basin, with favourable climate conditions, needs little amount of energy and inputs besides fertilizers and water. In this type of unheated passive greenhouse, the structure becomes a major burden.

Fertilizer application is an important issue in tomato production to focus on, in order to reduce their contribution to impact categories. Fertilizer impacts are mainly because their emissions in the production processes. As water consumption was high, fertilizer consumption was also high. Therefore, an efficient balance of both fertilizers and water should be recommended. Emissions because of application were especially significant to terrestrial acidification and marine eutrophication impact categories. The implementation of a closed-loop irrigation system could reduce completely these types of emissions as ammonia emissions will not contribute to terrestrial acidification and nitrate emissions will not reach the marine ecosystems.

The energy consumption was the main reason for the high contributions of the management stage. The consumption of diesel by the tractor and electricity by the irrigation system were the two most demanding energy processes, as the energy consumption for ventilation was not significant. In this sense, the use of renewable energies could contribute to the improvement of energy consumption in tomato production.

The analysis at endpoint level with ReCiPe method was conducted to analyse the environmental performance of the tomato production at three areas of protection: ecosystems, human health and resources. In this analysis, fertilizers made the highest contribution to human health; management made the highest contribution to ecosystems; and the auxiliary equipment to resources. The processes contributing to these impacts were as mentioned previously the production of fertilizers, the energy consumption and the production of perlite, respectively. The analysis at endpoint level can mean higher uncertainty

in the results. On the other hand, the inclusion of three impact categories instead of eighteen, as at midpoint level, can make interpretation more comprehensible, especially for a non-expertise audience.

The tomato production system was also analysed with USEtox method, with general consensus for the calculation of impacts to toxicity impact categories. The inclusion of this analysis complemented the analysis at midpoint level with ReCiPe. In USEtox, environmental impacts for human toxicity are distinguished between cancer and non-cancer. The structure was the main contributor to human toxicity non-cancer impact category, as it was for human toxicity with ReCiPe. On the other hand, the auxiliary equipment made the highest contribution to human toxicity cancer impact category. In the case of ecotoxicity, pesticides stage dominated the impact. The different characterization factors in one method and the other made the different results. Toxicity evaluation is a complex issue and different characterization methods can give different results. ReCiPe and USEtox method does not include characterization factors for most of the emissions of pesticide active ingredients into the air or via ingestion of food consumption. The toxicity assessment in the newly LC-IMPACT method is an improvement of USEtox method and includes characterization factors for many of the substances that had none characterization factor in the USEtox method. Surely, LC-IMPACT will improve the toxicity assessment of pesticides, a very important topic in agricultural production.

Regarding data quality assessment, it is needed to be said that the criteria established by ILCD guidelines are a little bit ambiguous for TeR, GR, TiR, C and M. On the other side weight of Precision factor is very high due to the intrinsic variability of agricultural system, which produces a low score for most of the datasets involved. A further revision of these criteria could be convenient in order to avoid major subjectivity.

In this first assessment of tomato production with classical methods, land use and water use were assessed as flow indicators. These are two other relevant topics in agricultural production for which it would be desirable to conduct a more detailed environmental assessment. For these topics, the contribution of LC-IMPACT will no doubt be an advance. This is the main focus of LC-IMPACT project, to deliver new characterization factors to improve the present ones.

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4.8.7. Supplementary information

4.8.7.1 Inventory flows: LCI case study tomato task 4.3. xls

Table 4.8.7.1.1 Inventory flows of tomato production in *parral* greenhouse

Substance	Compartment	Unit	Total
1-Butanol	Air	µg	1,2E+01
1-Pentanol	Air	mg	5,7E+02
1-Pentene	Air	mg	4,3E+02
1-Propanol	Air	g	4,3E+00
1,4-Butanediol	Air	µg	2,5E+02
2-Aminopropanol	Air	ng	3,3E+02
2-Butene, 2-methyl-	Air	µg	9,6E+01
2-Methyl-1-propanol	Air	g	1,0E+00
2-Nitrobenzoic acid	Air	ng	3,6E+02
2-Propanol	Air	g	3,1E+00
Acenaphthene	Air	µg	1,6E+01
Acetaldehyde	Air	g	9,0E+00
Acetic acid	Air	g	5,3E+01
Acetone	Air	g	9,9E+00
Acetonitrile	Air	mg	4,5E+02
Acrolein	Air	mg	5,0E+00
Acrylic acid	Air	mg	8,1E+00
Actinides, radioactive, unspecified	Air	Bq	5,9E+00
Aerosols, radioactive, unspecified	Air	Bq	3,1E+01
Aldehydes, unspecified	Air	mg	3,1E+02
Aluminium	Air	g	8,8E+02
Ammonia	Air	kg	2,6E+01
Ammonium carbonate	Air	mg	6,8E+00
Aniline	Air	µg	3,6E+02
Anthranilic acid	Air	ng	2,6E+02
Antimony	Air	mg	3,5E+02
Antimony-124	Air	µBq	2,5E+02
Antimony-125	Air	mBq	2,6E+00
Argon-41	Air	Bq	1,2E+04
Arsenic	Air	g	4,1E+00
Arsine	Air	ng	9,4E+01
Azoxystrobin	Air	g	1,5E+01
Barium	Air	mg	9,9E+02
Barium-140	Air	mBq	1,7E+02
Benzal chloride	Air	ng	1,9E+01
Benzaldehyde	Air	mg	1,8E+00
Benzene	Air	g	1,3E+02
Benzene, 1-methyl-2-nitro-	Air	ng	3,1E+02
Benzene, 1,2-dichloro-	Air	mg	9,5E+02
Benzene, ethyl-	Air	g	6,1E+00
Benzene, hexachloro-	Air	mg	4,2E+01
Benzene, pentachloro-	Air	µg	2,9E+02
Benzo(a)pyrene	Air	mg	1,3E+02
Beryllium	Air	mg	9,5E+00
Boron	Air	g	3,6E+01
Boron trifluoride	Air	ng	1,3E+00
Bromine	Air	g	4,6E+00
Butadiene	Air	mg	3,7E+02
Butane	Air	g	3,0E+02
Butene	Air	g	6,3E+00

Substance	Compartment	Unit	Total
Butyrolactone	Air	µg	5,0E+01
Cadmium	Air	g	1,6E+00
Calcium	Air	g	1,7E+01
Carbon-14	Air	Bq	1,3E+05
Carbon dioxide, biogenic	Air	kg	4,0E+02
Carbon dioxide, fossil	Air	kg	2,2E+04
Carbon dioxide, land transformation	Air	kg	7,2E+00
Carbon disulfide	Air	g	1,5E+02
Carbon monoxide, biogenic	Air	kg	1,1E+00
Carbon monoxide, fossil	Air	kg	3,3E+01
Cerium-141	Air	mBq	4,1E+01
Cesium-134	Air	mBq	1,9E+00
Cesium-137	Air	mBq	3,4E+01
Chloramine	Air	g	2,0E+00
Chlorine	Air	g	1,1E+02
Chloroacetic acid	Air	µg	8,6E+02
Chloroform	Air	mg	1,2E+01
Chlorosilane, trimethyl-	Air	mg	1,7E+00
Chlorosulfonic acid	Air	µg	2,1E+00
Chlorothalonil	Air	g	1,9E+02
Chromium	Air	g	2,5E+01
Chromium-51	Air	mBq	2,6E+00
Chromium VI	Air	mg	5,4E+02
Clofentezine	Air	g	1,1E+01
Cobalt	Air	g	1,4E+00
Cobalt-58	Air	mBq	3,6E+00
Cobalt-60	Air	mBq	3,2E+01
Copper	Air	g	5,3E+01
Copper chloride oxide, hydrate	Air	g	7,5E+02
Cumene	Air	g	1,7E+01
Cyanide	Air	g	3,5E+00
Cyanoacetic acid	Air	µg	1,8E+00
Diethylamine	Air	µg	1,6E+02
Dimethyl malonate	Air	µg	2,2E+00
Dinitrogen monoxide	Air	kg	3,6E+01
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	Air	µg	1,9E+01
Dipropylamine	Air	µg	1,0E+02
Ethane	Air	g	5,3E+02
Ethane, 1,1-difluoro-, HFC-152a	Air	mg	6,9E+01
Ethane, 1,1,1-trichloro-, HCFC-140	Air	µg	5,7E+01
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	g	1,5E+00
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	µg	3,8E+02
Ethane, 1,2-dichloro-	Air	g	1,1E+01
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	mg	5,5E+01
Ethane, hexafluoro-, HFC-116	Air	mg	2,4E+02
Ethanol	Air	g	9,0E+00
Ethene	Air	g	4,9E+01
Ethene, chloro-	Air	g	2,5E+00
Ethene, tetrachloro-	Air	µg	1,8E+02
Ethyl acetate	Air	g	1,5E+01
Ethyl cellulose	Air	mg	2,9E+01
Ethylamine	Air	mg	5,0E+02
Ethylene diamine	Air	mg	7,8E+02
Ethylene oxide	Air	mg	3,1E+02
Ethyne	Air	g	2,6E+00
Fenbutatin oxide	Air	g	2,1E+01
Fluorine	Air	mg	4,3E+02
Fluosilicic acid	Air	mg	2,4E+02
Formaldehyde	Air	g	8,4E+01
Formamide	Air	g	1,0E+00
Formic acid	Air	g	3,4E+00
Furan	Air	mg	8,6E+02
Heat, waste	Air	GJ	3,6E+02
Helium	Air	g	1,3E+01
Heptane	Air	g	4,8E+01
Hexane	Air	g	1,4E+02
Hydrocarbons, aliphatic, alkanes, cyclic	Air	g	1,7E+00
Hydrocarbons, aliphatic, alkanes, unspecified	Air	g	2,4E+02
Hydrocarbons, aliphatic, unsaturated	Air	g	1,3E+01
Hydrocarbons, aromatic	Air	g	3,1E+02
Hydrocarbons, chlorinated	Air	g	5,3E+01
Hydrogen	Air	g	3,4E+02
Hydrogen-3, Tritium	Air	kBq	7,2E+02
Hydrogen chloride	Air	g	7,3E+02
Hydrogen fluoride	Air	g	1,5E+02
Hydrogen peroxide	Air	mg	2,2E+01
Hydrogen sulfide	Air	g	8,1E+01
Iodine	Air	g	2,3E+00

Substance	Compartment	Unit	Total
Iodine-129	Air	Bq	1,3E+02
Iodine-131	Air	Bq	4,6E+03
Iodine-133	Air	mBq	3,9E+02
Iodine-135	Air	mBq	4,1E+02
Iron	Air	g	2,1E+01
Isocyanic acid	Air	mg	8,4E+01
Isoprene	Air	mg	4,0E+01
Isopropylamine	Air	µg	2,4E+00
Krypton-85	Air	Bq	3,7E+04
Krypton-85m	Air	Bq	3,0E+03
Krypton-87	Air	Bq	9,8E+02
Krypton-88	Air	Bq	1,1E+03
Krypton-89	Air	Bq	3,3E+02
Lactic acid	Air	µg	7,9E+01
Lanthanum-140	Air	mBq	1,4E+01
Lead	Air	g	2,9E+01
Lead-210	Air	Bq	2,7E+03
m-Xylene	Air	g	4,6E+00
Magnesium	Air	g	1,2E+01
Mancozeb	Air	g	3,0E+01
Manganese	Air	g	1,8E+00
Manganese-54	Air	mBq	1,3E+00
Mercury	Air	g	5,5E+00
Methane, biogenic	Air	g	8,4E+02
Methane, bromo-, Halon 1001	Air	ng	4,4E+00
Methane, bromochlorodifluoro-, Halon 1211	Air	mg	1,2E+02
Methane, bromotrifluoro-, Halon 1301	Air	mg	1,4E+02
Methane, chlorodifluoro-, HCFC-22	Air	mg	7,3E+02
Methane, dichloro-, HCC-30	Air	g	1,7E+00
Methane, dichlorodifluoro-, CFC-12	Air	mg	8,0E+02
Methane, dichlorofluoro-, HCFC-21	Air	µg	4,4E+00
Methane, fossil	Air	kg	7,5E+01
Methane, monochloro-, R-40	Air	g	7,7E+00
Methane, tetrachloro-, CFC-10	Air	mg	1,3E+02
Methane, tetrafluoro-, CFC-14	Air	g	1,9E+00
Methane, trichlorofluoro-, CFC-11	Air	µg	7,2E+00
Methane, trifluoro-, HFC-23	Air	mg	1,4E+00
Methanesulfonic acid	Air	µg	1,8E+00
Methanol	Air	g	1,1E+02
Methyl acetate	Air	ng	8,2E+01
Methyl acrylate	Air	mg	9,2E+00
Methyl amine	Air	mg	2,6E+01
Methyl borate	Air	mg	2,1E+02
Methyl ethyl ketone	Air	g	1,5E+01
Methyl formate	Air	mg	2,8E+02
Methyl lactate	Air	µg	8,7E+01
Molybdenum	Air	mg	4,1E+02
Monoethanolamine	Air	mg	9,6E+02
Nickel	Air	g	2,3E+01
Niobium-95	Air	µBq	1,6E+02
Nitrate	Air	g	3,6E+01
Nitrobenzene	Air	µg	4,8E+02
Nitrogen oxides	Air	kg	6,1E+01
NMVOC, non-methane volatile organic compounds, unspecified origin	Air	kg	2,0E+01
Noble gases, radioactive, unspecified	Air	kBq	1,2E+06
Ozone	Air	g	3,6E+01
PAH, polycyclic aromatic hydrocarbons	Air	g	2,6E+00
Particulates, < 2.5 um	Air	kg	5,0E+00
Particulates, > 10 um	Air	kg	9,2E+00
Particulates, > 2.5 um, and < 10um	Air	kg	4,5E+00
Pentane	Air	kg	3,9E+00
Phenol	Air	g	1,1E+01
Phenol, 2,4-dichloro-	Air	µg	4,4E+01
Phenol, pentachloro-	Air	mg	3,4E+01
Phosphine	Air	µg	7,0E+00
Phosphorus	Air	mg	9,9E+02
Platinum	Air	µg	1,9E+00
Plutonium-238	Air	µBq	1,7E+01
Plutonium-alpha	Air	µBq	3,9E+01
Polonium-210	Air	Bq	3,5E+03
Polychlorinated biphenyls	Air	mg	5,0E+01
Potassium	Air	g	4,7E+01
Potassium-40	Air	Bq	2,1E+02
Propanal	Air	g	2,8E+00
Propane	Air	g	3,6E+02
Propene	Air	g	2,8E+01
Propionic acid	Air	g	1,3E+00
Propylamine	Air	mg	3,3E+02

Substance	Compartment	Unit	Total
Propylene oxide	Air	mg	8,8E+02
Protactinium-234	Air	Bq	1,8E+01
Radioactive species, other beta emitters	Air	Bq	1,1E+03
Radium-226	Air	Bq	4,5E+03
Radium-228	Air	Bq	2,4E+02
Radon-220	Air	Bq	6,1E+03
Radon-222	Air	kBq	5,6E+04
Ruthenium-103	Air	µBq	3,5E+01
Scandium	Air	mg	4,4E+00
Selenium	Air	mg	8,5E+02
Silicon	Air	g	3,0E+02
Silicon tetrafluoride	Air	g	1,8E+00
Silver	Air	mg	1,1E+01
Silver-110	Air	µBq	3,4E+02
Sodium	Air	g	2,2E+01
Sodium chlorate	Air	mg	3,5E+01
Sodium dichromate	Air	mg	1,5E+01
Sodium formate	Air	mg	5,0E+00
Sodium hydroxide	Air	mg	8,1E+01
Spinosad	Air	g	1,6E+01
Strontium	Air	g	1,2E+00
Styrene	Air	g	1,1E+01
Sulfate	Air	kg	9,9E+00
Sulfur dioxide	Air	kg	8,4E+01
Sulfur hexafluoride	Air	mg	4,9E+02
Sulfur trioxide	Air	mg	3,8E+00
Sulfuric acid	Air	mg	1,7E+01
t-Butyl methyl ether	Air	mg	1,2E+01
t-Butylamine	Air	µg	3,8E+00
Terpenes	Air	mg	3,8E+02
Thallium	Air	mg	2,1E+01
Thorium	Air	mg	5,7E+00
Thorium-228	Air	Bq	5,3E+01
Thorium-230	Air	Bq	3,5E+03
Thorium-232	Air	Bq	1,1E+02
Thorium-234	Air	Bq	1,8E+01
Tin	Air	mg	5,0E+02
Titanium	Air	g	1,2E+00
Toluene	Air	g	5,5E+01
Toluene, 2-chloro-	Air	µg	1,4E+02
Trimethylamine	Air	ng	1,5E+02
Tungsten	Air	µg	5,2E+01
Uranium	Air	mg	7,3E+00
Uranium-234	Air	Bq	3,6E+03
Uranium-235	Air	Bq	9,9E+00
Uranium-238	Air	Bq	3,8E+03
Uranium alpha	Air	Bq	9,5E+02
Vanadium	Air	g	5,0E+01
Water	Air	kg	1,3E+00
Xenon-131m	Air	Bq	4,7E+03
Xenon-133	Air	kBq	1,6E+02
Xenon-133m	Air	Bq	4,9E+02
Xenon-135	Air	kBq	6,3E+01
Xenon-135m	Air	Bq	3,8E+04
Xenon-137	Air	Bq	9,0E+02
Xenon-138	Air	Bq	7,4E+03
Xylene	Air	g	4,7E+01
Zinc	Air	g	3,5E+02
Zinc-65	Air	mBq	6,7E+00
Zirconium	Air	mg	5,8E+00
Zirconium-95	Air	mBq	6,5E+00
Aluminium	Raw	kg	9,4E+00
Anhydrite	Raw	g	1,5E+01
Baryte	Raw	kg	1,8E+01
Basalt	Raw	kg	3,1E+00
Borax	Raw	mg	1,8E+02
Bromine	Raw	kg	6,0E+00
Cadmium	Raw	g	2,0E+00
Calcite	Raw	kg	2,0E+03
Carbon dioxide, in air	Raw	kg	6,0E+02
Carbon, in organic matter, in soil	Raw	g	6,7E+02
Chromium	Raw	kg	7,1E+00
Chrysotile	Raw	g	2,3E+00
Cinnabar	Raw	mg	2,1E+02
Clay	Raw	kg	8,4E+02
Clay, bentonite	Raw	kg	4,6E+00
Coal, brown	Raw	kg	1,3E+03
Coal, hard	Raw	kg	1,7E+03

Substance	Compartment	Unit	Total
Cobalt	Raw	mg	1,1E+02
Colemanite	Raw	g	2,1E+02
Copper, 0.99% in ulphide, Cu 0.36% and Mo 8.2E-3% in crude ore, in ground	Raw	g	6,1E+02
Copper, 1.18% in ulphide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	Raw	kg	3,1E+00
Copper, 1.42% in ulphide, Cu 0.81% and Mo 8.2E-3% in crude ore, in ground	Raw	g	8,2E+02
Copper, 2.19% in ulphide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	Raw	kg	4,1E+00
Diatomite	Raw	µg	6,8E+02
Dolomite	Raw	kg	1,1E+00
Energy, gross calorific value, in biomass	Raw	MJ	7,3E+03
Energy, gross calorific value, in biomass, primary forest	Raw	MJ	4,7E+01
Energy, kinetic (in wind), converted	Raw	MJ	2,4E+03
Energy, potential (in hydropower reservoir), converted	Raw	MJ	1,0E+04
Energy, solar, converted	Raw	MJ	2,9E+02
Feldspar	Raw	mg	3,5E+00
Fluorine, 4.5% in apatite, 1% in crude ore, in ground	Raw	kg	5,9E+01
Fluorine, 4.5% in apatite, 3% in crude ore, in ground	Raw	kg	3,0E+01
Fluorspar	Raw	kg	3,2E+00
Gallium	Raw	µg	5,3E+02
Gas, mine, off-gas, process, coal mining/m3	Raw	m3	1,4E+01
Gas, natural/m3	Raw	m3	4,6E+03
Gold	Raw	mg	6,3E+01
Gold, Au 1.1E-4%, Ag 4.2E-3%, in ore, in ground	Raw	mg	2,9E+01
Gold, Au 1.3E-4%, Ag 4.6E-5%, in ore, in ground	Raw	mg	5,3E+01
Gold, Au 2.1E-4%, Ag 2.1E-4%, in ore, in ground	Raw	mg	9,6E+01
Gold, Au 4.3E-4%, in ore, in ground	Raw	mg	2,4E+01
Gold, Au 4.9E-5%, in ore, in ground	Raw	mg	5,7E+01
Gold, Au 6.7E-4%, in ore, in ground	Raw	mg	8,8E+01
Gold, Au 7.1E-4%, in ore, in ground	Raw	mg	1,0E+02
Gold, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground	Raw	mg	6,0E+00
Granite	Raw	µg	4,7E+01
Gravel	Raw	kg	1,3E+04
Gypsum	Raw	g	1,5E+00
Indium	Raw	mg	5,9E+01
Iodine	Raw	g	5,2E+02
Iron	Raw	kg	2,5E+02
Kaolinite	Raw	kg	1,2E+00
Kieserite	Raw	kg	1,0E+02
Lead	Raw	g	9,0E+02
Lithium	Raw	g	3,0E+01
Magnesite	Raw	kg	6,2E+01
Magnesium	Raw	g	1,1E+00
Manganese	Raw	kg	1,2E+00
Metamorphous rock, graphite containing	Raw	kg	3,0E+00
Molybdenum	Raw	g	1,9E+01
Molybdenum, 0.010% in ulphide, Mo 8.2E-3% and Cu 1.83% in crude ore, in ground	Raw	g	7,6E+01
Molybdenum, 0.014% in ulphide, Mo 8.2E-3% and Cu 0.81% in crude ore, in ground	Raw	g	1,1E+01
Molybdenum, 0.022% in ulphide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground	Raw	g	9,7E+00
Molybdenum, 0.025% in ulphide, Mo 8.2E-3% and Cu 0.39% in crude ore, in ground	Raw	g	3,9E+01
Nickel, 1.13% in ulphide, Ni 0.76% and Cu 0.76% in crude ore, in ground	Raw	g	3,1E+02
Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	Raw	kg	1,6E+01
Occupation, arable	Raw	m2a	1,0E+04
Occupation, arable, non-irrigated	Raw	m2a	2,6E+00
Occupation, construction site	Raw	m2a	2,5E+02
Occupation, dump site	Raw	m2a	2,9E+01
Occupation, dump site, benthos	Raw	m2a	1,6E+00
Occupation, forest, intensive	Raw	m2a	1,3E+02
Occupation, forest, intensive, normal	Raw	m2a	5,8E+02
Occupation, forest, intensive, short-cycle	Raw	m2a	1,2E+01
Occupation, industrial area	Raw	m2a	1,5E+01
Occupation, industrial area, benthos	Raw	cm2a	1,5E+02
Occupation, industrial area, built up	Raw	m2a	2,4E+01
Occupation, industrial area, vegetation	Raw	m2a	3,2E+01
Occupation, mineral extraction site	Raw	m2a	3,4E+01
Occupation, permanent crop, fruit, intensive	Raw	m2a	9,0E+00
Occupation, shrub land, sclerophyllous	Raw	m2a	4,4E+00
Occupation, traffic area, rail embankment	Raw	m2a	5,5E+00
Occupation, traffic area, rail network	Raw	m2a	6,5E+00
Occupation, traffic area, road embankment	Raw	m2a	9,0E+00
Occupation, traffic area, road network	Raw	m2a	3,7E+01
Occupation, urban, discontinuously built	Raw	cm2a	1,9E+02
Occupation, water bodies, artificial	Raw	m2a	1,8E+01
Occupation, water courses, artificial	Raw	m2a	9,5E+00
Oil, crude	Raw	kg	5,9E+03
Olivine	Raw	g	6,0E+00
Pd, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	Raw	mg	9,7E+00
Pd, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	Raw	mg	2,3E+01
Peat	Raw	kg	5,9E+00
Perlite	Raw	ton	6,7E+00

Substance	Compartment	Unit	Total
Phosphorus	Raw	kg	1,2E+02
Phosphorus, 18% in apatite, 4% in crude ore, in ground	Raw	kg	2,4E+02
Potassium chloride	Raw	kg	2,8E+03
Pt, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	Raw	µg	1,9E+02
Pt, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	Raw	µg	6,8E+02
Rh, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore, in ground	Raw	µg	1,0E+02
Rh, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore, in ground	Raw	µg	3,2E+02
Rhenium	Raw	µg	1,6E+02
Sand	Raw	g	5,2E+02
Shale	Raw	g	4,3E+01
Silver, 0.007% in ulphide, Ag 0.004%, Pb, Zn, Cd, In, in ground	Raw	mg	6,9E+02
Silver, 3.2ppm in ulphide, Ag 1.2ppm, Cu and Te, in crude ore, in ground	Raw	mg	4,9E+02
Silver, Ag 2.1E-4%, Au 2.1E-4%, in ore, in ground	Raw	mg	4,6E+01
Silver, Ag 4.2E-3%, Au 1.1E-4%, in ore, in ground	Raw	mg	1,0E+02
Silver, Ag 4.6E-5%, Au 1.3E-4%, in ore, in ground	Raw	mg	1,0E+02
Silver, Ag 9.7E-4%, Au 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore, in ground	Raw	mg	6,7E+01
Sodium chloride	Raw	kg	2,4E+02
Sodium nitrate	Raw	mg	1,7E+01
Sodium sulphate	Raw	g	7,9E+02
Stibnite	Raw	µg	7,0E+01
Sulfur	Raw	g	6,8E+02
Talc	Raw	g	1,3E+02
Tantalum	Raw	mg	5,4E+02
Tellurium	Raw	mg	7,4E+01
Tin	Raw	g	5,8E+01
TiO2, 54% in ilmenite, 2.6% in crude ore, in ground	Raw	kg	2,2E+00
TiO2, 95% in rutile, 0.40% in crude ore, in ground	Raw	mg	7,9E+02
Transformation, from arable	Raw	cm2	6,5E+01
Transformation, from arable, non-irrigated	Raw	dm2	4,7E+02
Transformation, from arable, non-irrigated, fallow	Raw	cm2	1,1E+01
Transformation, from dump site, inert material landfill	Raw	dm2	3,9E+01
Transformation, from dump site, residual material landfill	Raw	dm2	4,8E+01
Transformation, from dump site, sanitary landfill	Raw	mm2	8,5E+02
Transformation, from dump site, slag compartment	Raw	mm2	3,3E+02
Transformation, from forest	Raw	dm2	4,9E+02
Transformation, from forest, extensive	Raw	dm2	5,7E+02
Transformation, from forest, intensive, clear-cutting	Raw	dm2	4,2E+01
Transformation, from industrial area	Raw	cm2	2,0E+02
Transformation, from industrial area, benthos	Raw	mm2	7,6E+01
Transformation, from industrial area, built up	Raw	cm2	8,4E+02
Transformation, from industrial area, vegetation	Raw	dm2	1,4E+01
Transformation, from mineral extraction site	Raw	dm2	1,2E+02
Transformation, from pasture and meadow	Raw	dm2	2,4E+02
Transformation, from pasture and meadow, intensive	Raw	cm2	3,8E+01
Transformation, from sea and ocean	Raw	dm2	1,6E+02
Transformation, from shrub land, sclerophyllous	Raw	dm2	9,1E+01
Transformation, from tropical rain forest	Raw	dm2	4,2E+01
Transformation, from unknown	Raw	dm2	5,3E+02
Transformation, to arable	Raw	dm2	1,9E+01
Transformation, to arable, non-irrigated	Raw	dm2	4,7E+02
Transformation, to arable, non-irrigated, fallow	Raw	cm2	4,3E+01
Transformation, to dump site	Raw	cm2	8,8E+02
Transformation, to dump site, benthos	Raw	dm2	1,6E+02
Transformation, to dump site, inert material landfill	Raw	dm2	3,9E+01
Transformation, to dump site, residual material landfill	Raw	dm2	4,8E+01
Transformation, to dump site, sanitary landfill	Raw	mm2	8,5E+02
Transformation, to dump site, slag compartment	Raw	mm2	3,3E+02
Transformation, to forest	Raw	dm2	1,1E+02
Transformation, to forest, intensive	Raw	dm2	8,5E+01
Transformation, to forest, intensive, clear-cutting	Raw	dm2	4,2E+01
Transformation, to forest, intensive, normal	Raw	dm2	4,7E+02
Transformation, to forest, intensive, short-cycle	Raw	dm2	4,2E+01
Transformation, to heterogeneous, agricultural	Raw	dm2	2,2E+01
Transformation, to industrial area	Raw	dm2	1,3E+01
Transformation, to industrial area, benthos	Raw	cm2	3,5E+01
Transformation, to industrial area, built up	Raw	dm2	6,3E+01
Transformation, to industrial area, vegetation	Raw	dm2	4,8E+01
Transformation, to mineral extraction site	Raw	dm2	5,9E+02
Transformation, to pasture and meadow	Raw	dm2	9,1E+01
Transformation, to permanent crop, fruit, intensive	Raw	dm2	1,3E+01
Transformation, to sea and ocean	Raw	mm2	7,6E+01
Transformation, to shrub land, sclerophyllous	Raw	dm2	8,7E+01
Transformation, to traffic area, rail embankment	Raw	cm2	1,3E+02
Transformation, to traffic area, rail network	Raw	cm2	1,6E+02
Transformation, to traffic area, road embankment	Raw	cm2	6,3E+02
Transformation, to traffic area, road network	Raw	dm2	6,3E+01
Transformation, to unknown	Raw	dm2	2,3E+01
Transformation, to urban, discontinuously built	Raw	mm2	3,8E+02

Substance	Compartment	Unit	Total
Transformation, to water bodies, artificial	Raw	dm2	**2,0E+01**
Transformation, to water courses, artificial	Raw	dm2	**1,0E+01**
Ulexite	Raw	g	**4,6E+00**
Uranium	Raw	g	**1,0E+02**
Vermiculite	Raw	mg	**5,5E+02**
Volume occupied, final repository for low-active radioactive waste	Raw	cm3	**1,5E+02**
Volume occupied, final repository for radioactive waste	Raw	cm3	**3,7E+01**
Volume occupied, reservoir	Raw	m3y	**1,6E+02**
Volume occupied, underground deposit	Raw	cm3	**2,1E+02**
Water, cooling, unspecified natural origin/m3	Raw	m3	**5,8E+02**
Water, lake	Raw	l	**5,6E+02**
Water, river	Raw	m3	**5,2E+01**
Water, salt, ocean	Raw	m3	**7,7E+00**
Water, salt, sole	Raw	m3	**2,7E+03**
Water, turbine use, unspecified natural origin	Raw	m3	**6,1E+04**
Water, unspecified natural origin/m3	Raw	m3	**1,6E+02**
Water, well, in ground	Raw	m3	**4,1E+03**
Wood, hard, standing	Raw	l	**1,4E+02**
Wood, primary forest, standing	Raw	l	**4,3E+00**
Wood, soft, standing	Raw	l	**4,5E+02**
Wood, unspecified, standing/m3	Raw	cm3	**3,8E+01**
Zinc	Raw	kg	**1,2E+02**
Zirconium	Raw	mg	**6,9E+02**
2,4-D	Soil	mg	**1,5E+02**
Aclonifen	Soil	mg	**2,4E+00**
Aldrin	Soil	µg	**2,1E+02**
Aluminium	Soil	g	**1,1E+02**
Antimony	Soil	µg	**3,1E+01**
Arsenic	Soil	mg	**4,4E+01**
Atrazine	Soil	µg	**5,5E+01**
Barium	Soil	g	**5,2E+01**
Benomyl	Soil	µg	**9,7E+02**
Bentazone	Soil	mg	**1,2E+00**
Boron	Soil	g	**1,4E+00**
Cadmium	Soil	mg	**7,5E+00**
Calcium	Soil	g	**4,8E+02**
Carbetamide	Soil	mg	**1,0E+00**
Carbofuran	Soil	mg	**5,3E+02**
Carbon	Soil	g	**3,3E+02**
Chloride	Soil	kg	**1,7E+00**
Chlorothalonil	Soil	mg	**5,8E+02**
Chromium	Soil	mg	**5,8E+02**
Chromium VI	Soil	g	**2,0E+00**
Cobalt	Soil	mg	**4,5E+00**
Copper	Soil	g	**1,4E+00**
Cypermethrin	Soil	mg	**7,5E+01**
Fenpiclonil	Soil	mg	**2,3E+01**
Fluoride	Soil	g	**6,5E+00**
Glyphosate	Soil	g	**1,5E+00**
Heat, waste	Soil	MJ	**2,0E+02**
Iron	Soil	g	**9,3E+02**
Lead	Soil	mg	**6,7E+01**
Linuron	Soil	mg	**1,9E+01**
Magnesium	Soil	g	**9,1E+01**
Mancozeb	Soil	mg	**7,6E+02**
Manganese	Soil	g	**8,7E+00**
Mercury	Soil	µg	**2,6E+02**
Metaldehyde	Soil	µg	**3,4E+02**
Metolachlor	Soil	mg	**1,4E+02**
Metribuzin	Soil	mg	**2,7E+01**
Molybdenum	Soil	mg	**1,1E+00**
Napropamide	Soil	µg	**6,1E+02**
Nickel	Soil	mg	**5,2E+01**
Oils, biogenic	Soil	g	**1,2E+01**
Oils, unspecified	Soil	kg	**1,6E+01**
Orbencarb	Soil	mg	**1,4E+02**
Phosphorus	Soil	g	**7,4E+00**
Pirimicarb	Soil	µg	**1,2E+02**
Potassium	Soil	g	**4,9E+01**
Silicon	Soil	g	**3,1E+01**
Sodium	Soil	g	**2,2E+02**
Strontium	Soil	g	**1,0E+00**
Sulfur	Soil	g	**6,5E+01**
Sulfuric acid	Soil	µg	**1,0E+01**
Tebutam	Soil	mg	**1,4E+00**
Teflubenzuron	Soil	mg	**1,8E+00**
Thiram	Soil	mg	**1,7E+00**
Tin	Soil	mg	**1,2E+00**

Substance	Compartment	Unit	Total
Titanium	Soil	mg	3,2E+02
Vanadium	Soil	mg	9,0E+00
Zinc	Soil	g	4,6E+00
1-Butanol	Water	mg	8,3E+01
1-Pentanol	Water	g	1,4E+00
1-Pentene	Water	g	1,0E+00
1-Propanol	Water	g	1,9E+00
1,4-Butanediol	Water	µg	1,0E+02
2-Aminopropanol	Water	ng	8,2E+02
2-Methyl-1-propanol	Water	g	2,5E+00
2-Methyl-2-butene	Water	µg	2,3E+02
2-Propanol	Water	µg	1,3E+01
4-Methyl-2-pentanone	Water	µg	1,1E+02
Acenaphthene	Water	mg	1,3E+00
Acenaphthylene	Water	µg	8,3E+01
Acetaldehyde	Water	g	1,3E+01
Acetic acid	Water	g	4,7E+01
Acetone	Water	g	1,1E+00
Acetonitrile	Water	µg	1,5E+00
Acetyl chloride	Water	g	1,1E+00
Acidity, unspecified	Water	g	1,7E+01
Acrylate, ion	Water	mg	1,9E+01
Actinides, radioactive, unspecified	Water	Bq	2,0E+02
Aluminium	Water	g	8,0E+01
Ammonium, ion	Water	g	6,9E+02
Aniline	Water	µg	8,5E+02
Antimony	Water	g	1,6E+01
Antimony-122	Water	mBq	9,9E+01
Antimony-124	Water	Bq	3,7E+01
Antimony-125	Water	Bq	3,9E+01
AOX, Adsorbable Organic Halogen as Cl	Water	g	4,3E+00
Arsenic, ion	Water	g	4,2E+01
Barite	Water	kg	1,0E+00
Barium	Water	g	1,9E+02
Barium-140	Water	mBq	4,4E+02
Benzene	Water	g	1,5E+02
Benzene, 1,2-dichloro-	Water	g	6,7E+00
Benzene, chloro-	Water	g	9,2E+01
Benzene, ethyl-	Water	g	5,1E+00
Beryllium	Water	mg	2,4E+01
BOD5, Biological Oxygen Demand	Water	kg	4,3E+01
Borate	Water	g	1,0E+02
Boron	Water	g	7,6E+01
Bromate	Water	g	1,2E+01
Bromide	Water	kg	5,2E+00
Bromine	Water	g	2,0E+02
Butene	Water	g	3,7E+00
Butyl acetate	Water	mg	1,1E+02
Butyrolactone	Water	µg	1,2E+02
Cadmium, ion	Water	g	8,2E+00
Calcium, ion	Water	kg	3,1E+02
Carbon disulfide	Water	g	4,7E+00
Carbonate	Water	g	1,5E+02
Carboxylic acids, unspecified	Water	g	9,1E+02
Cerium-141	Water	mBq	1,7E+02
Cerium-144	Water	mBq	5,3E+01
Cesium	Water	mg	2,1E+02
Cesium-134	Water	Bq	3,5E+01
Cesium-136	Water	mBq	3,1E+01
Cesium-137	Water	Bq	2,3E+04
Chloramine	Water	g	1,8E+01
Chlorate	Water	g	9,4E+01
Chloride	Water	kg	1,3E+03
Chlorinated solvents, unspecified	Water	g	1,7E+00
Chlorine	Water	mg	3,5E+02
Chloroacetic acid	Water	mg	3,4E+01
Chloroacetyl chloride	Water	µg	1,1E+00
Chloroform	Water	mg	1,1E+00
Chlorosulfonic acid	Water	µg	5,4E+00
Chromium-51	Water	Bq	5,4E+01
Chromium VI	Water	g	1,6E+02
Chromium, ion	Water	g	5,2E+00
Cobalt	Water	g	2,4E+00
Cobalt-57	Water	mBq	9,8E+02
Cobalt-58	Water	Bq	3,5E+02
Cobalt-60	Water	Bq	2,8E+02
COD, Chemical Oxygen Demand	Water	kg	4,6E+01
Copper, ion	Water	g	1,1E+01

Substance	Compartment	Unit	Total
Cumene	Water	g	4,2E+01
Cyanide	Water	g	1,7E+01
Dichromate	Water	mg	5,2E+01
Diethylamine	Water	µg	3,8E+02
Dimethylamine	Water	mg	1,2E+02
Dipropylamine	Water	µg	2,4E+02
DOC, Dissolved Organic Carbon	Water	kg	1,3E+01
Ethane, 1,2-dichloro-	Water	g	1,4E+01
Ethanol	Water	g	6,8E+00
Ethene	Water	g	5,3E+00
Ethene, chloro-	Water	mg	2,7E+01
Ethyl acetate	Water	mg	3,1E+02
Ethylamine	Water	g	1,2E+00
Ethylene diamine	Water	g	1,9E+00
Ethylene oxide	Water	mg	6,0E+02
Fluoride	Water	kg	3,3E+00
Fluosilicic acid	Water	mg	4,4E+02
Formaldehyde	Water	g	8,7E+00
Formamide	Water	g	2,5E+00
Formate	Water	mg	1,2E+00
Formic acid	Water	mg	7,3E+02
Glutaraldehyde	Water	mg	1,3E+02
Heat, waste	Water	MJ	9,2E+03
Hydrocarbons, aliphatic, alkanes, unspecified	Water	g	2,8E+01
Hydrocarbons, aliphatic, unsaturated	Water	g	2,6E+00
Hydrocarbons, aromatic	Water	g	1,1E+02
Hydrocarbons, unspecified	Water	g	1,1E+02
Hydrogen-3, Tritium	Water	kBq	5,4E+04
Hydrogen peroxide	Water	mg	2,8E+02
Hydrogen sulfide	Water	mg	3,2E+02
Hydroxide	Water	g	3,4E+00
Hypochlorite	Water	g	2,5E+00
Iodide	Water	g	4,5E+02
Iodine-131	Water	Bq	7,1E+00
Iodine-133	Water	mBq	2,7E+02
Iron-59	Water	mBq	7,5E+01
Iron, ion	Water	kg	3,3E+00
Isopropylamine	Water	µg	5,7E+00
Lactic acid	Water	µg	1,9E+02
Lanthanum-140	Water	mBq	4,6E+02
Lead	Water	g	1,0E+01
Lead-210	Water	Bq	7,7E+05
Lithium, ion	Water	g	7,7E+01
m-Xylene	Water	g	1,0E+01
Magnesium	Water	kg	2,0E+01
Manganese	Water	g	6,6E+01
Manganese-54	Water	Bq	2,2E+01
Mercury	Water	mg	3,4E+02
Methane, dichloro-, HCC-30	Water	g	5,0E+00
Methanol	Water	g	1,5E+01
Methyl acetate	Water	ng	2,0E+02
Methyl acrylate	Water	mg	1,8E+02
Methyl amine	Water	mg	6,3E+01
Methyl formate	Water	mg	1,1E+02
Molybdenum	Water	g	5,4E+00
Molybdenum-99	Water	mBq	1,6E+02
Nickel, ion	Water	g	2,0E+01
Niobium-95	Water	Bq	4,5E+00
Nitrate	Water	kg	3,2E+00
Nitrite	Water	g	1,1E+00
Nitrobenzene	Water	mg	1,9E+00
Nitrogen	Water	g	5,9E+02
Nitrogen, organic bound	Water	g	7,8E+01
o-Xylene	Water	µg	5,9E+02
Oils, unspecified	Water	kg	1,3E+01
PAH, polycyclic aromatic hydrocarbons	Water	g	1,3E+00
Phenol	Water	g	3,7E+01
Phosphate	Water	kg	1,6E+01
Phosphorus	Water	g	7,7E+01
Polonium-210	Water	Bq	1,2E+06
Potassium-40	Water	Bq	9,3E+04
Potassium, ion	Water	kg	1,7E+01
Propanal	Water	g	2,0E+00
Propene	Water	g	2,9E+01
Propionic acid	Water	µg	1,1E+02
Propylamine	Water	mg	7,9E+02
Propylene oxide	Water	g	2,1E+00
Protactinium-234	Water	Bq	3,2E+02

Substance	Compartment	Unit	Total
Radioactive species, alpha emitters	Water	Bq	**2,1E+03**
Radioactive species, Nuclides, unspecified	Water	Bq	**1,2E+05**
Radium-224	Water	Bq	**1,1E+04**
Radium-226	Water	kBq	**1,1E+03**
Radium-228	Water	Bq	**2,1E+04**
Rubidium	Water	g	**2,1E+00**
Ruthenium-103	Water	mBq	**3,4E+01**
Scandium	Water	mg	**3,4E+02**
Selenium	Water	mg	**8,8E+02**
Silicon	Water	g	**4,3E+02**
Silver-110	Water	Bq	**2,5E+02**
Silver, ion	Water	mg	**2,6E+02**
Sodium-24	Water	Bq	**1,2E+00**
Sodium formate	Water	mg	**1,2E+01**
Sodium, ion	Water	kg	**9,6E+02**
Solids, inorganic	Water	kg	**5,1E+00**
Solved solids	Water	kg	**4,3E+00**
Strontium	Water	g	**4,1E+02**
Strontium-89	Water	Bq	**5,8E+00**
Strontium-90	Water	Bq	**1,3E+05**
Sulfate	Water	kg	**7,4E+02**
Sulfide	Water	g	**7,2E+01**
Sulfite	Water	g	**6,7E+00**
Sulfur	Water	kg	**1,9E+01**
Suspended solids, unspecified	Water	kg	**7,6E+00**
t-Butyl methyl ether	Water	mg	**4,8E+02**
t-Butylamine	Water	µg	**9,2E+00**
Technetium-99m	Water	Bq	**3,7E+00**
Tellurium-123m	Water	Bq	**4,3E+00**
Tellurium-132	Water	mBq	**9,3E+00**
Thallium	Water	mg	**1,6E+01**
Thorium-228	Water	Bq	**5,2E+04**
Thorium-230	Water	Bq	**4,4E+04**
Thorium-232	Water	Bq	**5,7E+01**
Thorium-234	Water	Bq	**3,2E+02**
Tin, ion	Water	mg	**5,5E+01**
Titanium, ion	Water	mg	**9,1E+02**
TOC, Total Organic Carbon	Water	kg	**1,3E+01**
Toluene	Water	g	**3,2E+01**
Toluene, 2-chloro-	Water	µg	**2,9E+02**
Tributyltin compounds	Water	mg	**3,5E+02**
Triethylene glycol	Water	g	**1,3E+00**
Trimethylamine	Water	ng	**3,6E+02**
Tungsten	Water	mg	**7,5E+02**
Uranium-234	Water	Bq	**3,9E+02**
Uranium-235	Water	Bq	**6,4E+02**
Uranium-238	Water	Bq	**4,0E+05**
Uranium alpha	Water	Bq	**1,9E+04**
Urea	Water	g	**2,4E+00**
Vanadium, ion	Water	g	**1,3E+00**
VOC, volatile organic compounds, unspecified origin	Water	g	**7,6E+01**
Xylene	Water	g	**2,2E+01**
Zinc-65	Water	Bq	**1,6E+01**
Zinc, ion	Water	g	**1,4E+02**
Zirconium-95	Water	mBq	**1,9E+02**

4.8.7.2 Data quality criteria

Table 4.8.7.2.1 Data quality for the different processes involved following guidelines of ILCD 2010

Type	Name		DQR
–Reference flow	hectarea		
	Structure		
–From technosphere	Steel recycled /RER	BASIC	2,6
–From technosphere	Polyethylene, LDPE, granulate, at plant/RER	BASIC	2,5
–From technosphere	Concrete, normal, at plant/CH	DATA ESTIMATE	3,3
–From technosphere	Polypropylene, granulate, at plant/RER	BASIC	2,7
–From technosphere	Steel recycled/RER	HIGH Q	1,5
–From technosphere	Wire drawing, steel/RER	HIGH Q	1,5
–From technosphere	Polyethylene, HDPE, granulate, at plant/RER	DATA ESTIMATE	3,2
–From technosphere	Injection moulding/RER	BASIC	2,7
–From technosphere	Drawing of pipes, steel/RER	BASIC	2,6
–From technosphere	Zinc coating, pieces/RER	BASIC	2,1
–From technosphere	Extrusion, plastic film/RER	HIGH Q	1,5
–From technosphere	Extrusion, plastic film/RER	DATA ESTIMATE	3,2
–From technosphere	Zinc coating, pieces/RER	BASIC	2,1
	Auxiliary equipment		
–From technosphere	Polyethylene, LDPE, granulate, at plant/RER	HIGH Q	1,5
–From technosphere	Extrusion, plastic film/RER	HIGH Q	1,5
–From technosphere	Polyethylene, LDPE, granulate, at plant/RER	BASIC	2,1
–From technosphere	Extrusion, plastic film/RER	BASIC	2,1
–From technosphere	Polyethylene, LDPE, granulate, at plant/RER	HIGH Q	1,6
–From technosphere	Extrusion, plastic film/RER	HIGH Q	1,6
–From technosphere	Polystyrene, expandable, at plant/RER	BASIC	2,1
–From technosphere	Foaming, expanding/RER	BASIC	2,1
–From technosphere	Expanded perlite, at plant/CH	HIGH Q	1,6
–From technosphere	Polyethylene, PE, granulate, at plant/RER	HIGH Q	1,6
–From technosphere	Drawing of pipes, PE/RER	HIGH Q	1,6
	Management		
–From environment	Green water	DATA ESTIMATE	3,1
–From environment	Water, well in ground	DATA ESTIMATE	3,1
–From technosphere	Watering, Electricity /ES	DATA ESTIMATE	3,1
–From technosphere	Vents, Electricity /ES	BASIC	3,0
–From technosphere	Diesel, at regional storge/RER	DATA ESTIMATE	3,1
	Pesticides		
–From technosphere	Chlorothalonil /RER	BASIC	2,5
–From technosphere	Mancozeb /RER	BASIC	2,5
–From technosphere	Fungicides /RER	BASIC	3,0
–From technosphere	Insecticides /RER	BASIC	3,0
–To environment	air emissions	DATA ESTIMATE	3,1

	Fertilizers		
–From technosphere	Calcium nitrate	BASIC	3,0
–From technosphere	Nitric acid (56%)	BASIC	3,0
–From technosphere	Monoamonium Phosphate	BASIC	3,0
–From technosphere	Ammonium Nitrate	BASIC	3,0
–From technosphere	Potassium nitrate	BASIC	3,0
–From technosphere	Potassium sulphate	BASIC	3,0
–From technosphere	Magnesium sulphate	BASIC	3,0
–From technosphere	Phosphoric acid (72%)	BASIC	3,0
–To environment	Dinitrogen oxide, N_2O	BASIC	2,9
–To environment	Nitrogen oxides, Nox	BASIC	2,9
–To environment	Ammonia, NH_3	BASIC	2,9
–To environment	Nitrate	BASIC	3,0
	Waste management		
–From technosphere	Transport, lorry 3.5-16t, fleet average/RER	BASIC	1,7
–To technosphere	Disposal, inert waste, 5% water, to inert material	BASIC	2,8

4.8.7.3 Normalization

Table 4.8.7.3.1 Normalizated scores for classical assessment with ReCiPe methods for 1ton of tomato

IMPACT	UNITS IMPACT SCORE	IMPACT SCORE	NORMALISATION FACTORS	UNITS NF	NORMALISATION SCORE
Impact category	**Unit**	**IS·ton^{-1} tom**	**NF WORLD 2000**		**person·y**
Climate change Human Health	DALY	3,27E-04			
Ozone depletion	DALY	5,47E-08			
Human toxicity	DALY	2,22E-05			
Photochemical oxidant formation	DALY	2,46E-08			
Particulate matter formation	DALY	8,41E-05			
Ionising radiation	DALY	1,52E-07			
Human health	**DALY**	**4,34E-04**	**1,35E-02**	**DALY/p·y**	**3,21E-02**
Climate change Ecosystems	species.yr	1,85E-06			
Terrestrial acidification	species.yr	7,09E-09			
Freshwater eutrophication	species.yr	3,20E-10			
Terrestrial ecotoxicity	species.yr	5,58E-09			
Freshwater ecotoxicity	species.yr	1,12E-10			
Marine ecotoxicity	species.yr	6,06E-11			
Agricultural land occupation	species.yr	1,37E-06			
Urban land occupation	species.yr	6,33E-08			
Natural land transformation	species.yr	2,49E-07			
Ecosystems quality	**species.y**	**3,55E-06**	**9,17E-04**	**species.y/p·y**	**3,88E-03**
Metal depletion	$	7,44E-01			
Fossil depletion	$	1,21E+01			
Resources	**$**	**1,29E+01**	**2,45E+02**	**$/p·y**	**5,26E-02**

Table 4.8.7.3.2 Normalizated scores for LC-Impact newly developed methods

IMPACT	UNITS IMPACT SCORE	IMPACT SCORE	NORMALISATION FACTORS	UNITS NF	NORMALISATION SCORE
		IS·ton^{-1} tom			person·y
Land use & Biodiversty Occupation Agr.	potentially lost non-endemic species	4,71E-07			
Land use & Biodiversty Transformation Agr.	potentially lost non-endemic species	2,85E-06			
Erosion Natural Resources	$Mj_{se}·m^2·y$	1,23E+04	9,75E+17	Mjse·m$^{2·}$/y	**7,7E-05**
Erosion Ecosystem Quality	NPPD·m^2·y	4,09E+00	3,59E+12	NPPD·m^2·y/y	**6,9E-03**
Wetland target Specific site: Adra	PDF·m3·y	2,94E-05	1,46E-06	PDF·m3·y/person	**2,0E+01**
Wetland target Specific site: Adra	species-eq·y	1,90E-05	4,57E-06	species-eq/person	**4,2E+00**
Total Human Toxicity cases	cases	4,77E-08	1,49E+05	cases/y	**2,0E-03**
Total ecosystems toxicity	PAF·m3·day	1,04E+02	3,05E+12	PAF m^3·d/y	**2,1E-01**
Human Toxicity pesticides intake	cases	6,38E-06	1,49E+05	cases/y	**2,6E-01**
Marine eutrophication Mediterranean	PAF m^3 d	7,33E+02	2,32E+11	PAF m^3·d/person.y	**3,2E-09**
Freshwater eutrophication	m^3 d	3,11E+01	7,06E+12	m^3	**2,7E-02**
Acidification, midpoint Spain	mol H+/L m^2	2,94E-03	*		**2,9E-01**
Acidification, endpoint Spain	in m^2	1,65E+01	*		**3,6E-01**
Particular matter formation	DALY	2,70E-04	6,51E+07	DALY	**2,5E-02**
metal resource	$US\$_{2010}$/kg	1,61E-09	7,83E+00	$US\$_{2010}$/person.y	**2,1E-10**
fossil resource	$US\$_{2010}$/kg	4,35E+00	9,59E+01	$US\$_{2010}$/person.y	**4,5E-02**

**Normalization factors calculated by substances*