Project no. **288974**

SENSE

'HarmoniSed Environmental Sustainability in the European food and drink chain'

Grant agreement for: Collaborative project

Theme [KBBE.2011.2.5-01]
[Environmental sustainability in the European food and drink chain]

Deliverable: D2.1

Life cycle assessment of orange juice

Due date of deliverable: 15.02.2013
Actual submission date: 11.06.2013

Start date of project: 01/02/2012 Duration: 36 months

Contact person responsible for this deliverable: Niels Jungbluth
e-mail: jungbluth@esu-services.ch

Organisation responsible for this deliverable:
ESU-services Ltd., www.esu-services.ch

Project co-funded by European Commission within the Seventh Framework Programme		
Dissemination level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

DOCUMENT INFO

Authors

Authors	Partner	E-mail
Geneviève Doublet	ESU	doublet@esu-services.ch
Niels Jungbluth	ESU	jungbluth@esu-services.ch
Matthias Stucki	ESU	jungbluth@esu-services.ch
Salome Schori	ESU	jungbluth@esu-services.ch

Document Control

Document version #	Date	Change
V1.9	21.12.2012	Life cycle inventory

Distribution List

Date	Issue	Group
21.12.2012	V1.9	Consortium
07.05.2013	V3.0	Consortium review

LIST OF TABLES

LIST OF FIGURES

GLOSSARY AND ACRONYMS

CIP	Clean-In-Place
eq	equivalent
FCOJ	Frozen Concentrated Orange Juice
GWP	Global Warming Potential
HDPE	High-Density Polyethylene
KEPI	Key Environmental Performance Indicator
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory Analysis
LDPE	Low-Density Polyethylene
LLDPE	Linear Low-Density Polyethylene
MSWI	Municipal Solid Waste Incinerator
NFC	Not-From-Concentrate
PET	Polyethylene Terephthalate
SENSE	Harmonised Environmental Sustainability in the European food and drink chain
SME	Small and Medium Enterprises

EXECUTIVE SUMMARY

This case study investigates a cradle-to-gate life cycle assessment of the production of Not-From-Concentrate (NFC) orange juice in Spain. The distribution and selling by retailers is not part of the assessment. The functional unit assessed is one litre of NFC orange juice in one litre PET bottle, one-way, at the bottling plant.

The goal of the LCA is to identify the most relevant sources of environmental impacts and prioritise the essential input data, i.e. the key environmental performance indicators (KEPIs). The KEPIs will be the inputs of a web-based SENSE-tool that will provide comprehensive environmental information on each SME involved in the supply chain e.g. a citrus producer, a juice processing plant, a bottling plant. The second aim of the study is the identification of some regionalisation potentials to be implemented in the SENSE-tool in order to account for some regional characteristics within the EU.

The assessment is valid for one producer in Spain. All data were provided by Zuvamesa, a NFC orange juice producer in the region of Valencia. All foreground data refer to 2011. The allocation between the orange juice and the by-products from the juice extraction at the juice processing plant is made using an economic approach based on the shares of product in the annual turnover.

The impact assessment is done using midpoint impact assessment methods defined in WP1 of the SENSE project (Aronsson et al. 2013). Indicators for climate change, eutrophication, acidification, human toxicity, ecotoxicity, land use, abiotic resource depletion and water depletion are included in the assessment.

The global warming potential (GWP) calculated for 1 l orange juice packed in a 1.0 l PET bottle is 0.67 kg CO_2-eq. This is quite low compared to literature data. The impact assessment of the NFC orange juice shows that the main life cycle step depends on the impact categories assessed. About 50% of the climate change and abiotic resource depletion are due to the bottling process. The impact categories land use, water depletion and freshwater ecotoxicity are dominated by the orange cultivation (more than 95 %). The orange cultivation contributes around 50 % to the acidification and freshwater eutrophication. The four main contributors to the orange cultivation are the electricity use for the irrigation, the N-fertiliser and P_2O_5-fertiliser use and the production and application of pesticides. The most relevant processes for the juice pressing are the electricity use and thermal energy use. The main contributor to the bottling process is the manufacture of the PET bottle.

The KEPIs are proposed as simple to measure indicators that can be used in the SENSE tool to calculate the environmental impacts for other case studies. The KEPIs identified for the NFC orange juice production are shown in Table 1.1. They are identified for each life cycle step: orange cultivation, orange juice processing and bottling and are associated to the impact drivers identified in the case study. The list of KEPIS is displayed horizontally below the list of life cycle step and the impact categories are listed vertically on the left. If one KEPI contributes substantially to an impact category, the cell is coloured in red. If there is no contribution, the cell is green. The cell sometimes includes the main pollutant concerning a specific impact category and influenced by a specific KEPI.

An important question of the SENSE project is the adjustment of the SENSE tool to regional characteristics. Since data are publicly available on country-specific electricity mix and there might be considerable differences in the environmental impacts, it is recommended to implement country-specific electricity mix in the SENSE tool. It is also recommended to regionalise water depletion, acidification and terrestrial eutrophication impact assessment methods since country-specific characterisation factors are already available. Considering the life cycle inventory (LCI) background data, the packaging production should account for country-specific recycling rates and recycling routes including disposal routes.

Table 1.1 Suggestion of KEPIs for the NFC orange juice production

Impact category	Orange cultivation								Orange juice processing					Bottling				Main pollutants
Unit	kg orange/ha	kg N/ha	kg P2O5/ha	kg/ha	l/ha	kWh/ha	ha	m3/ha	%	kg orange/l orange juice	kWh/l orange juice	MJ/ l orange juice	m3/ha	% (orange juice/ total juice)	kWh/l orange juice	MJ/ l orange juice	type/l orange juice	
Key Environmental Performance Indicator (KEPI)	Yield	N-fertiliser use	P2O5-fertiliser use	Pesticide and active substance content	Diesel use incl. machineries	Electricity use (irrigation)	Land use	Water use	Share of products in turnover	Yield	Electricity use	Thermal energy use	Wastewater treatment	Share of orange juice in total juice processed	Electricity use	Thermal energy use (natural gas, steam, cooling energy, compressed air)	Type of container (e.g. PET, glass, Tetrapack)	
All impact categories	x								x	x								
Climate change		N2O			CO2	CO2					CO2	CO2			CO2	CO2	CO2	CO2, CH4, N2O
Human toxicity			HM		HM												HM	Heavy metals (HM)
Acidification		NH3			NOx												SO2	SO2, NOx, NH3
Eutrophication, terrestrial		NOx			NOx													NO3, NH3
Eutrophication, freshwater			PO4				PO4						PO4				PO4	PO4
Eutrophication, marine		NO3			NOx													NO3 (Nitrate), NOx
Ecotoxicity, freshwater			HM	PPP	HM													Heavy metals (HM) Plant Protection Products (PPP)
Land use							x											Land use (m2a and type)
Abiotic resource depletion					x	x					x				x	x	x	Fossil resources (oil, gas, coal)
Water depletion								x					x					Water use

1 Outline of the LCA Studies

1.1 Overview

Task 2.1 of the SENSE project investigates current food production in a regional perspective. Three Life Cycle Assessment (LCA) case studies are performed according to the methodology developed in WP1 (Aronsson et al. 2013). The followings selected food chains are studied in three separate reports:

- dairy & beef production in Romania
- orange juice production in Spain
- fish aquaculture in Iceland

The goal of Task 2.1 is to propose a selection of key environmental performance indicators (KEPIs) and a suitable scope of essential input data based on LCA results, interpretation and sensitivity analysis. The required information for the LCA (e.g. water, energy, materials consumption) shall be prioritised according to the most important environmental impacts. Moreover, a set of allocation rules for the selected food chains is to be discussed and proposed.

Thus, a systematic overview of the life cycle of food and drink products and their environmental impacts associated is to be presented as an overall goal of the project, taking into account the diversity within this sector and in the different regions across the European market. This should provide the SENSE framework to overcome the variations in the environmental approaches of companies that produce similar products in different regions.

1.2 System boundaries

The first step considered in all three case studies is the cultivation of the crops or the breeding of the animals respectively. This is followed by the harvest and further processing, transportation and storage. The last stage considered in the three LCA studies is the last production stage including the transport packaging. The distribution and selling by retailers as well as the food preparation and consumption at the household or in restaurants are not part of the assessment.

1.3 Questions to be answered

The following questions shall be addressed by these case studies:

- What are the most relevant stages in the life cycle?
- What are the key environmental performance indicators (KEPIs) to be requested in the SENSE tool for each stage?
- Which system boundaries shall be applied in the SENSE tool?
- What are the recommendations regarding the allocation rules?
- How are the results affected by regional background data?
- How do regional emission models affect the results?
- How are the results affected by a regionalised impact assessment?

1.4 Inventory basic assumptions

The LCI methodology follows in many aspects the methodology applied to the ecoinvent background data (Frischknecht et al. 2007). The following main assumptions are considered:

- Standard ecoinvent distances are used for the transport of materials from their production site to the processing plant or the farm. This is 10 km by van, 70 km by lorry (25 t) and 30 km by freight train. Ecoinvent transport unit processes are used (Spielmann et al. 2007).
- Infrastructure is included with a life time of 50 years and a construction time of 2 years
- The name of pesticide and the amount active ingredient applied are used to model the environmental fate in the inventory. The environmental fate is assumed to be 100 % to soil. This statement follows the code of life cycle inventory practice (de Beaufort-Langeveld et al. 2003) which is also applied in the ecoinvent background data.
- Waste management is included
- Recycling processes are not included (cut-off approach)
- Country specific datasets for electricity and tap water are used. In the inventory, electricity always refers to low voltage electricity.

1.5 Impact Assessment Methods

The midpoint impact categories applied for the LCA case studies of three food chains were defined in a separate deliverable (Aronsson et al. 2013). Long-term emissions are excluded from the assessment. Since there are midpoints categories, no endpoints results are computed and not weighting is applied. Table 1.1 shows the selected impact categories used in this case study.

Table 1.1 Midpoint impact categories chosen for the SENSE project (Aronsson et al. 2013)

Impact category	**Methods**	**Indicator unit**
Climate change	Bern Model – IPCC (Solomon et al. 2007)	kg CO2-eq
Human toxicity	USEtox Model (Rosembaum et al, 2008)	CTUh (Comparative Toxic unit for humans)
Acidification	Accumulated Exceedance (Seppälä et al, 2006, Posch et al, 2008)	molc H+-eq
Eutrophication, terrestrial	Accumulated Exceedance (Seppälä et al, 2006, Posch et al, 2008)	molc N-eq
Eutrophication, freshwater	EUTREND Model (Goedkoop et al. 2009)	kg P-eq
Eutrophication, marine	EUTREND Model (Goedkoop et al. 2009)	kg N-eq
Ecotoxicity, freshwater	USEtox Model (Rosembaum et al, 2008)	CTUe (Comparative Toxic Unit for ecosystems)
Land use	Soil Organic Matter model (Milà I Canals et al, 2007b)	kg C deficit
Abiotic resource depletion	CML 2002 (Guinée et al, 2002)	kg antimony (Sb)-eq
Water depletion	Ecological scarcity model (Frischknecht et al. 2009)	European m^3 water-eq

1.6 Key Environmental Performance Indicators (KEPI)

The goal of the SENSE project is to develop an internet tool for SME's (small and medium enterprises) in the food sector so that they can assess their environmental performance. SME's will have to enter some data about their business that will be used to calculate the environmental impacts as accurate as possible in a simplified way. Through the three case studies elaborated in this project and with a literature review on existing LCA studies (Landquist et al. 2013), the key data the SME's have to provide are identified. These key data are named as key environmental performance indicators (KEPIs). They should be easy-to-measure indicators that can be provided by the operators of farms and food industries.

2 Life Cycle Assessment of NFC Orange Juice

2.1 Goal and Scope

2.1.1 Object of Investigation

The object of investigation of this case study is a cradle-to-gate life cycle assessment of the production of Not-From-Concentrate (NFC) orange juice produced in Spain.

2.1.2 Functional Unit

The functional unit is defined as "**one litre of NFC orange juice in 1.0 l PET bottle, one-way, at bottling plant**" produced in Spain.

2.1.3 System Boundaries

The life cycle inventory of orange juice production encompasses the whole supply chain. The first step is the cultivation of the oranges, which are then transported either directly to the juice processing plant or to the packing house. At the packing house, the oranges are washed and sorted to separate the oranges for the fresh consumption market from the ones whose size or visual appearance are not suitable for fresh market. The oranges sent to the fresh market are excluded from the inventory of the NFC orange juice. In the following case study, 60% of the oranges come from the packing house. At the juice processing facility, oranges are transformed into orange juice, orange pulp and other by-products such as animal feed, essential oils and D-Limonene. The further processing of these by-products is not considered in the inventory of the NFC orange juice. The orange juice and pulp are transported to the filling plant where they are blended and bottled in a PET bottle. A model of the production system is shown in Figure 2-1. Transport is labelled in green, infrastructure in blue and orange products in orange. The inventory data refers to the reference year 2011.

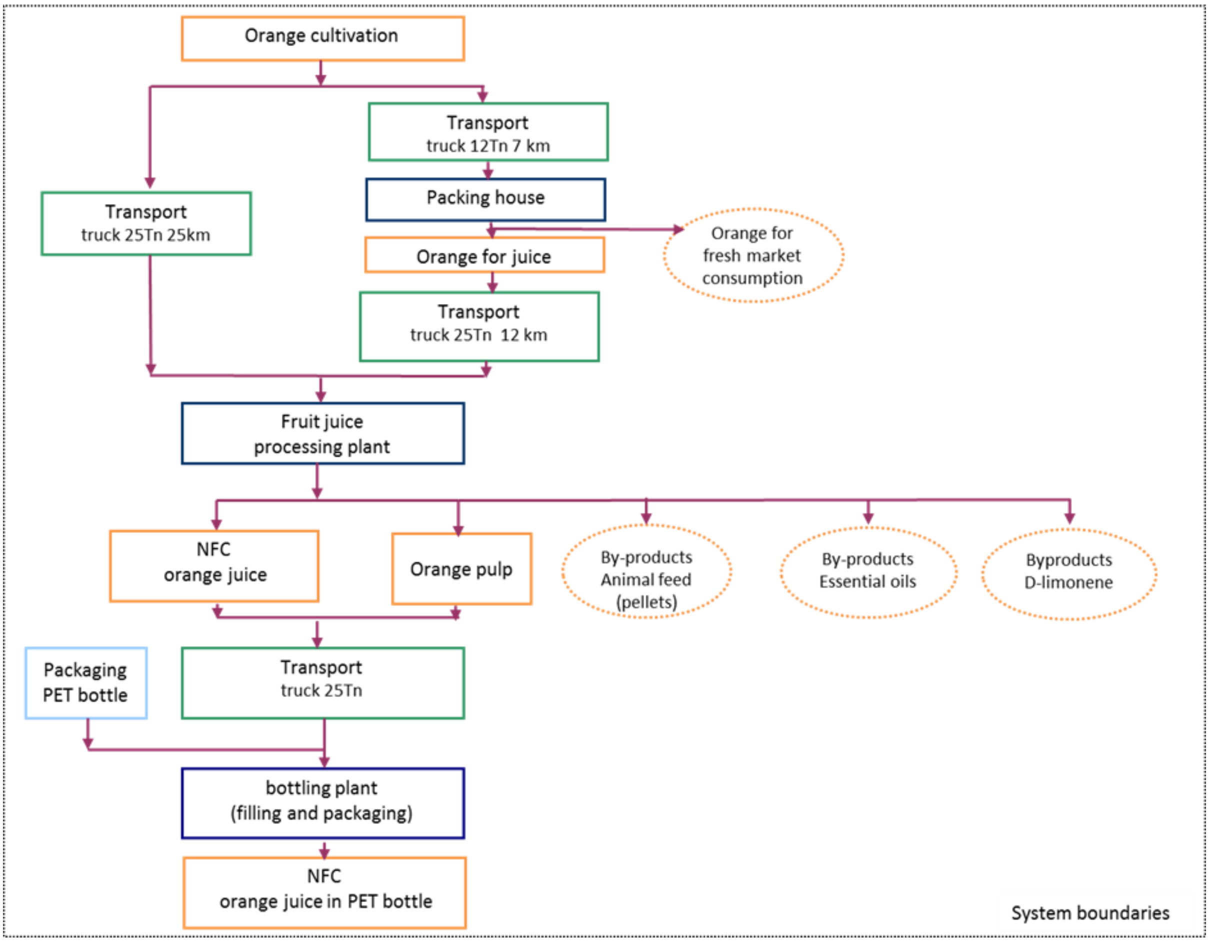

Figure 2-1 Product system of orange juice production in this study

2.1.4 Main Data Sources

Foreground inventory data are provided in a questionnaire by Zuvamesa S.A., which controls over 60% of the citrus production in Spain[1]. These data refer to the year 2011. Foreground data include

- Quantities of materials and energy used for the cultivation of oranges
- Quantities of materials and energy used in the orange juice processing
- Quantities of materials and energy used for the packaging of the orange juice
- Economic shares of turnover for single products

Missing foreground data on the packaging are completed using literature data (Doublet 2012) as well as data from the database of ESU-services (Jungbluth et al. 2013).

The primary source of background inventory data used in this study is the ecoinvent data v2.2 (ecoinvent Centre 2010), which contains inventory data of many basic materials, energy carriers, waste management and transport services. These data are complemented with updated, publicly available data (LC-inventories 2013).

---

[1] http://www.zuvamesa.com/

2.2 Life cycle inventory analysis

This is a summary of the life cycle inventory. The detailed and complete inventory is available in a confidential annex.

2.2.1 Orange cultivation

Life cycle inventory data refer to the integrated production of oranges of the variety “Navel Lane Late”. The integrated production means that the soil and environment diversities are essential components. Nutrients cycles are balanced and a holistic approach is applied by taking the farm as a unit of analysis[2]. The total area cultivated is 14.42 ha with 400 trees per hectare and a total annual production of 695 tons of oranges. Consequently, the annual yield is 48’200 kg/ha. The amounts of fertilisers, diesel, electricity and water use for the orange cultivation are given in Table 2.1. Fertigation is used at the farm, which means that fertilisers are injected in the drip irrigation system installed at the farm.

Table 2.1 Inputs for the oranges cultivation in 2011

Input	**Unit**	**Amount per ha**
Yield	kg/ha	48200
Land use	ha	1
K_2O Fertilizer	kg-K_2O/ha	69
Potassium nitrate	kg-K_2O/ha	69
N Fertilizer	kg-N/ha	56
Ammonium nitrate	kg-N/ha	30
Potassium nitrate	kg-N/ha	26
P_2O_5 Fertilizer	kg-P_2O_5/ha	40
Phosphoric acid	kg-P_2O_5/ha	40
Diesel use	kg/ha	66
Electricity for irrigation pumps	kWh/ha	3498
Water (groundwater)	m^3/ha	4390

The names of the pesticides applied with their respective content of active ingredients are given in Table 2.2. The content of active ingredient was given by the farm. The amount of active ingredient is used to model both production and emissions of pesticides. Standard distances are used for the transport to farm. Biological control of pests is also achieved by the use of special insects produced by Fontestad. However, insects are not included in the inventory since no ecoinvent dataset exists and none could be created.

---

[2] http://www.agroscope.admin.ch/proficrops/05416/05650/index.html?lang=fr

Table 2.2 Pesticide use and amount of active ingredient in kg per ha for the cultivation of oranges in 2011

Insecticide	**Amount kg/ha**	**Active ingredient**	**Content**	**Amount of active ingredient kg/ha**
Dursban	2.5	Chlorpyrifos	75% weight/weight	1.880
Borneo	0.3	Etoxazole	11% weight/weight	0.033
Citrolina	20	Paraffin oil	98% weight/weight	4.000
Fungicide	**Amount**	**Active ingredient**	**Content**	**Amount of active ingredient**, kg/ha
Aliette	5	Fosetyl-aluminium	80% weight/weight	0.300
Herbicide	**Amount**	**Active ingredient**	**Content**	**Amount of active ingredient**, kg/ha
Iron chelate	30	FeEDTA	13% Fe 87% EDTA	3.9 26.1

In Table 2.3, a comparison of the inventory data for the cultivation of oranges with some LCA studies is shown (Landquist et al. 2013). The yield from the case study is higher than the ones found in literature. According to citrus experts in the Valencia region, the average yield in this region is 60’000 kg/ha and the case study has a lower yield than usual[3]. It is difficult to compare the amounts of fertilisers applied since they are reported with different units. The range of pesticides use varies greatly among the literature so it is difficult to identify a trend. The amount given is not the content of active ingredient but the overall amount applied. The amount of diesel use is also much smaller than other literature values. One must pay attention on the electricity use, which is much higher than other literature values. The amount of water use is in the same range as the literature value for another drip irrigation in Spain (Sanjuan et al. 2005).

---

[3] Email with Roger Marqués, Zuvamesa on 09.11.2012

Table 2.3 Energy and material consumption from LCA studies about orange production (Landquist et al. 2013)

Region	**Literature**	**Method of production**	**Yield (kg/ha)**		**Fertilisers**	**Pesticides**	**Energy**	**Water**
			Average	**Range**	**kg/ha**	**Kg/ha**	**L/ha**	**m^3/ha**
US (Florida)	(Dwivedi et al. 2012)		30000	17000-34000	16-0-16 (1400kg/ha)	Copper, Zn, Mn, B (13.3kg/ha) Pesticides var. (6.2l/ha)	Diesel (1151L/ha) Gasoline (339L/ha)	-
Brazil (S.Paulo)	(Coltro et al. 2009)	Conventional: Various	30500	14209-54528	871kg/ha (10-2000kg/ha)	82,5kg/ha (2-400kg/ha)	Diesel (144,5 L/ha) Elec. (22,3GJ)	5300
Brazil (S.Paulo)	(Knudsen et al. 2011a)	Organic: Small scale	18000	12000-21000	Organic: 87kg N/ha	Copper (0,3kg/ha)	Diesel (185L/ha)	-
Brazil (S.Paulo)	(Knudsen et al. 2011a)	Organic: Large scale	23000	17000-29000	Organic:185kg N/ha	Copper (5,5kg/ha)	Diesel (272L/ha)	-
Italy (Sicily)	(Beccali et al. 2009)		25000	20000-30000	240kg/ha N, 100kg P2O5, 180 kg/ha K2O	Herbicides (1,2kg/ha) Pesticides (3,3kg/ha)	Diesel (301 L/ha)	3000-5000
Spain (Valencia)	(Sanjuan et al. 2005)	Integrated Prod: Drip irrigation	30000		Ammonium nitrate (782kg/ha), phosphoric acid (120kg/ha), KNO3(293kg/ha), manure (3600kg/ha)			5000
Spain (Valencia)	Questionnaire Zuvamesa (2011)	Integrated production with fertigation	48200		P-fertiliser (40 kg kg-P_2O_5/ha) N-fertiliser (56 kg-N/ha) K-fertiliser (69 kg-K_2O/ha)	Pesticides: (27.8 kg/ha) Herbicide (30 kg/ha)	Diesel : 78 L/ha Electricity 3500 kWh/ha	4390

2.2.2 Orange at packing house

In our case study, 40% of the oranges come directly from the orange grove. 60% come from the packing house where they are sorted in order to select the oranges for the fresh market consumption.

2.2.3 Orange juice processing

The fruit juice plant processes 104’500 tons oranges and 38’000 tons clementines per year. All citrus fruits come from Spain. The juice processing plant could subdivide its material and energy flows between the orange and clementine processing. Hence, all energy and material flows (including wastes) in the following inventory only refer to the production of NFC orange juice and no allocation is required between the clementine and the oranges. Nonetheless, the infrastructure is given on a whole-of-factory basis and is allocated to the oranges and clementine processed.

The oranges are pressed and the pulp is separated from the juice, which is pasteurised. Aseptic pulp and juice are stored chilled under aseptic conditions. The main inputs are listed in Table 2.4. They are given in yearly amounts and per litre of orange juice produced.

Table 2.4 inputs in 2011 for the processing of oranges

Input	Unit	Yearly amounts	Amount per l orange juice
Oranges	kg	104534000	2.29
Electricity	kWh	7656000	0.15
Natural gas	MJ	793474	0.68
Tap water	m3	234566	0.0051
Detergents (Soda 30-50%)	kg	395440	0.0089
Detergent nitric acid	kg	14830	0.0003

The plant's production volumes in 2011 and the orange products' shares in the annual turnover are given in Table 2.5. The plant produces NFC fruit juice as well as citrus pellets, raw citrus pellets, aseptic orange pulp, essential oils and D-limonene. The total amount of NFC orange juice is 40'630 tons or 38'770 litres using a density of 1.048 kg/l (Dwivedi et al. 2012). The orange juice given in litre is used in the inventory. Only 54 % of the mass of the oranges processed are directly converted into products. The rest is water contained in the fruit peels that is released when the peels are squeezed and also evaporated and condensed when the peels are further dried.

Table 2.5 Production volumes of the fruit juice processing plant in 2011 and products' shares in turnover

Orange products	Unit	Orange amounts	Shares in annual turnover %
NFC orange juice	tons/a	40630 (38770 litres)	85
Animal feed (citrus peels)	tons/a	9711	7
Animal feed (raw citrus peels)	tons/a	4405	0
Aseptic orange pulp	tons/a	1580	5
Essentials oils	tons/a	198	2
D-limonene	tons/a	66.5	1
Total products	tons/a	56589	100

The electricity use to extract 1 l of NFC orange juice is similar to the literature value but the amount of natural gas is much higher in the literature.

Table 2.6 Energy consumption to produce 1 l of NFC orange juice

		Electricity kWh	Natural gas m3	Diesel l	Gasoline l
US (Florida)	Dwivedi (2012)	0.11	2.18 MJ[1]	7.5E-4 (0.027 MJ)[2]	8.33E-5 (0.0026 MJ)[3]
Spain (Valencia)	Questionnaire Zuvamesa (2011)	0.15	0.68 MJ	na	na

[1] density of 0.8 kg/m3 and density of 45.4 MJ/kg using 1 $Nm^3=1.06\ m^3$

[2] density of 0.84 kg/l and a heating value of 42.8 MJ/kg

[3] density of 0.75 kg/l and heating value of 42.5 MJ/kg

2.2.4 Bottling process

The bottling plant processes 60’000 tons NFC orange juice (or 57’252 l) and 21’301 tons NFC clementine juice and 368 tons orange pulp per year. At the bottling plant, the orange juice is blended with the pulp before the bottling. For 1 l of NFC orange juice, there is 2 % orange pulp. The NFC juice is then pasteurized and transferred to an aseptic filler tank. The juice is filled in a 1.0 l PET bottle and capped under aseptic conditions. Then, the filled bottles are labelled. The inputs for the bottling process are shown in Table 2.7. The natural gas is used to produce steam. The electricity consumption does not include the production of compressed air and cooling energy. They are shown separately from the electricity use.

Table 2.7 Inputs per litre orange juice at the bottling plant

Inputs	Unit	Per litre orange juice bottled
NFC orange juice	l	0.98
Orange pulp	kg	0.02
Electricity use	kWh	0.026
Natural gas	MJ	0.14
Compressed air	m3	0.023
Cooling energy	kWh	0.038
Tap water	kg	0.17

PET bottles are delivered to the plant shaped as preforms. Preforms are heated and blown into bottles under aseptic conditions. All inputs referring to the bottling process were given in the questionnaire with the exception of the data related to the packaging, which were taken from Doublet (2012) (see Table 2.8). The PET bottle includes a HDPE cap and a label made of OPS sleeve. The LDPE and LLDPE foils refer to the secondary and tertiary packaging. There are 600 bottles per pallet. There is a cardboard intermediate layer between the bottles palletized.

Table 2.8 Annual inputs for the bottling of 1 l NFC orange juice in 2011.

Packaging	Unit	Amount per 1 l orange juice
PET Bottle	l	1
PET granulate	kg	0.043
Inner layer	kg	0.0023
HDPE cap	kg	0.0037
OPS sleeve	kg	0.0022
Total weight per bottle	kg	0.051
LDPE foil (secondary packaging)	kg	0.0028
LLDPE foil (tertiary packaging)	kg	0.0003
Intermediate cardboard layer (tertiary packaging)	kg	0.0024
Europallet	unit	0.00005

2.3 Life Cycle Impact Assessment

2.3.1 Orange cultivation

The relative contribution of the orange cultivation to each impact category is illustrated in Figure 2-2. The material and energy flows are grouped and assessed in different categories (see Table 2.9).

The Global Warming Potential (GWP) of 1 kg oranges at the orange grove is 0.07 kg CO_2-eq. The electricity use for irrigation is the main contributor (50 %) due to the CO_2 and N_2O emissions resulting from the combustion of coal and natural gas. The N_2O emissions resulting from the N-fertiliser application and the CO_2 emissions from the production of nitric acid used for the production of the fertilizer cause 25 % of the climate change impacts. The energy use and the chemicals used in the production of pesticides generate 10 % of the GWP.

The human toxicity cancer effects impact category is dominated by the P_2O_5-fertiliser (70 %) due to the emissions of chromium, zinc and copper after application on the field, which depend on their content in the fertiliser. The share of the diesel use (10 %) is explained by the zinc emissions from the tyre abrasion and the chromium emissions resulting from the machinery manufacture. Both are background data. The contribution of the electricity (8 %) is explained by the chromium emissions due to the use of hard coal for the electricity production in the background system.

The contribution of the electricity to the human toxicity non-cancer effects impact category is negligible (3%) and the share of the P_2O_5-fertiliser is reduced to 56 %. The main difference with the cancer effects is the chromium, which do not have any human toxicity non-cancer effects.

The N-fertiliser use is the main contributor to the acidification, terrestrial and marine eutrophication impact categories, with 50 %, 70 % and 85 % respectively. The main reason is the emissions into air of NO_x and NH_3 due to the use on fields. The NO_x, NH_3 and SO_2 emissions due to the electricity production are also important in these three impact categories.

The phosphorus run-off and leaching from land to the water are responsible for 55 % of the freshwater eutrophication impacts. The electricity production contributes 20% to the impacts. The production of pesticides and the production and use of P_2O_5-fertiliser use contribute each around 10 % to the results.

The freshwater ecotoxicity is dominated by the pesticides emissions, especially the Chlorpyrifos emissions due to the use of the insecticide Dursban.

The electricity use contributes 60 % to the abiotic resource depletion. The share of the production of pesticides is 20 %. The rest is shared between the N-fertiliser production and the diesel production.

The water depletion impact category is dominated by the water use for irrigation.

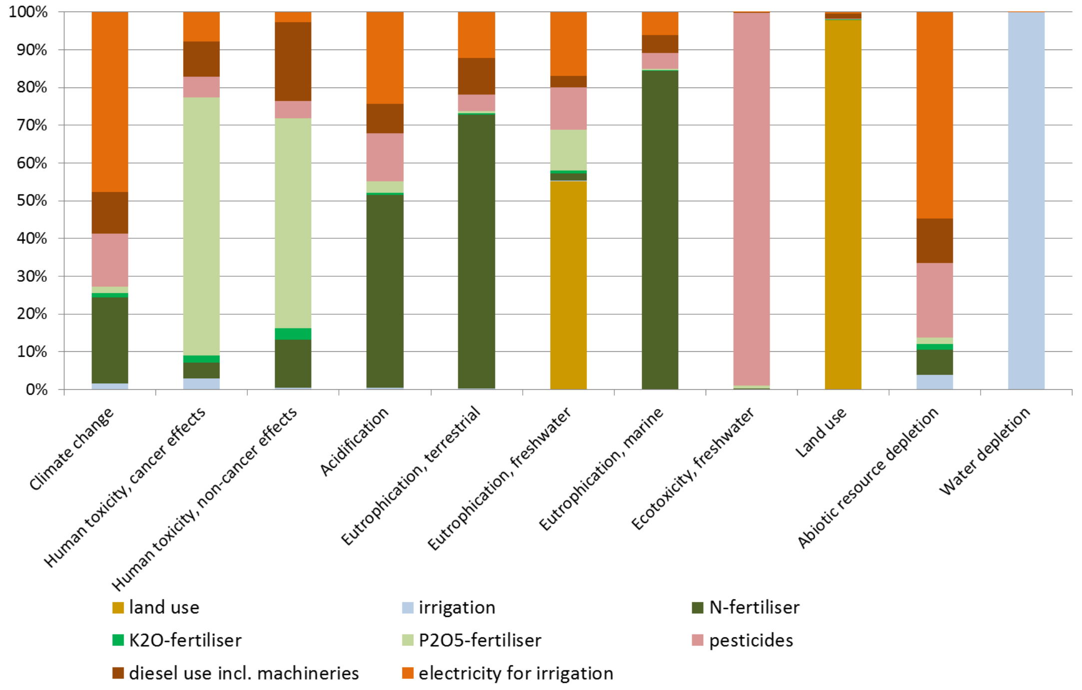

Figure 2-2 Analysis of the environmental impacts of orange at orange grove in Spain. The relative scale (100%) shows the contribution of different inputs and outputs.

Table 2.9 Legend explanation of Figure 2-2

Legend	**Included processes**
Land	Land occupied for the crop cultivation, grazing and fallow land as well as the emissions to water and air due to the part of leaching of phosphorus from the cultivated soil not directly dependent on fertilizer and manure use.
Irrigation	The water use for irrigation as well as infrastructure (pipes, pumps and soil preparation) are included
K2O-Fertiliser	Chemical production, transport and emissions to water (K) and soil (element content) due to the use
N-Fertiliser	Chemical production, transport and emissions to air (N_2O, NH_3, $NO_{x)}$, water (NO_3) and soil (element content) due to the use
P_2O_5-Fertiliser	Chemical production, transport and emissions to water (PO_4) and soil (element content) due to the use
Pesticides	Chemical production, transport and emissions to soil (element content) due to the use
Diesel use incl. machineries	Diesel consumption including emissions resulting from the diesel combustion and emissions to soil from the tyre abrasion. Manufacture of agricultural machineries (tractor, trailer, harvester, tillage…) and building shed for storage included
Electricity for irrigation	Electricity consumption for the irrigation pumps

2.3.2 Orange juice processing

The relative contribution of the orange juice processing to each impact category is shown in Figure 2-3. The grey bar represents the cultivation of orange. The focus is on the impacts from the orange juice processing. The main contributors to all impact categories are the electricity and thermal energy use. Indeed, the electricity causes 20 % of the climate change and abiotic resource depletion impacts and 25% of the acidification effects. The thermal energy use, i.e. natural gas, generates 15 % of the climate change and abiotic resource depletion impacts. Another important process is the wastewater treatment that makes almost 20 % of the freshwater eutrophication impacts. The contribution of other processes such as other material use, e.g. detergents and cooling material, waste treatment, infrastructure is negligible.

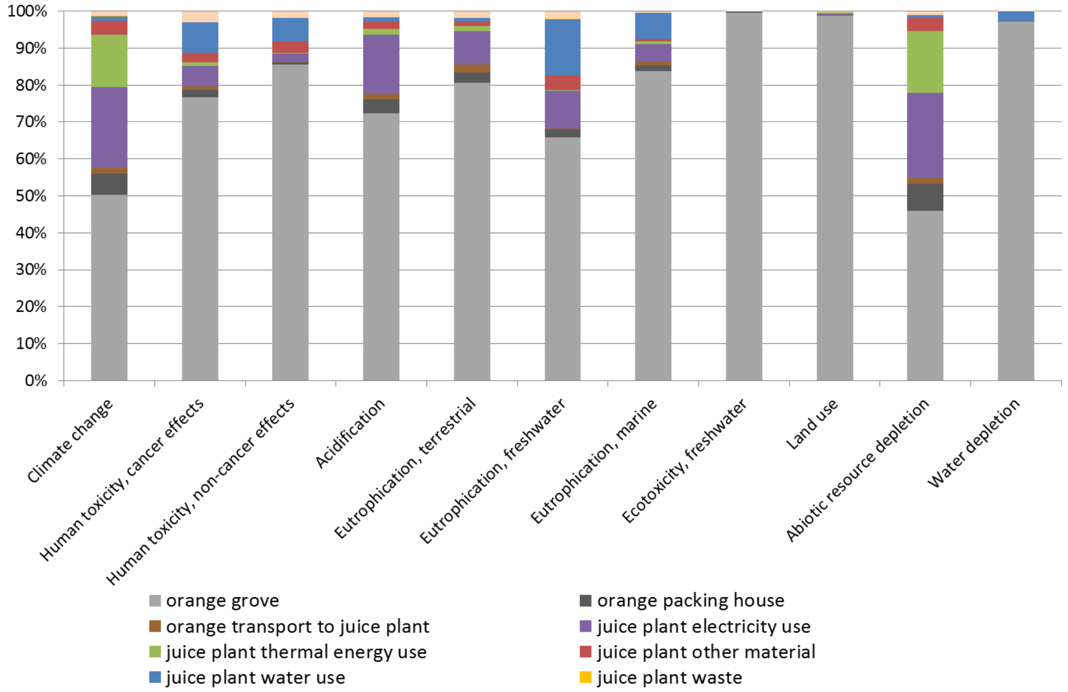

Figure 2-3 Analysis of the environmental impacts of orange juice at juice processing plant. The relative scale (100%) shows the contribution of different inputs and outputs

Table 2.10 Legend explanation of Figure 2-3

Legend	**Included processes**
Orange grove	Orange cultivation (fertilisers, pesticide, diesel, electricity…)
Orange packing house	Transport by truck to packing house, electricity and detergents use for washing
Orange transport to juice plant	Transport by truck 25 t from grove (40 %) and packing house (60 %)
Juice plant electricity use	Electricity for pasteurization, blending, chilling
Juice plant thermal energy use	Natural gas
Juice plant other material	Detergents and cooling material (liquid nitrogen)
Juice plant water use	Water delivery and municipal wastewater treatment
Juice plant waste	Municipal solid waste, hazardous waste (solvents packaging), cardboard
Juice plant buildings	Office building, factory hall and facilities included

2.3.3 Bottling process

The relative contribution of the bottling process to each impact category is illustrated in Figure 2-4. The grey bars represent the contribution of the previous life cycle steps: the production of oranges at the orange grove, the packing house and the juice processing respectively. The focus is on the contribution of the bottling process to the production of orange juice. The main contributor to all impact categories is the PET bottle, more specifically the PET material. All steps related to the PET bottle production are shown with a red gradation. The injection moulding process to transform PET granulates into PET preforms is also an important contributor to the environmental impacts. Apart from PET itself other materials are included in a PET bottle too (e.g. inner layer, cap, label, secondary packaging, and tertiary packaging). The production of these materials is also considered in the inventory and is responsible for 5 % of the impacts in all impact categories. The PET bottle disposal contributes 10 % to the climate change. The other processes, e.g. transport, water use, buildings, materials, are negligible.

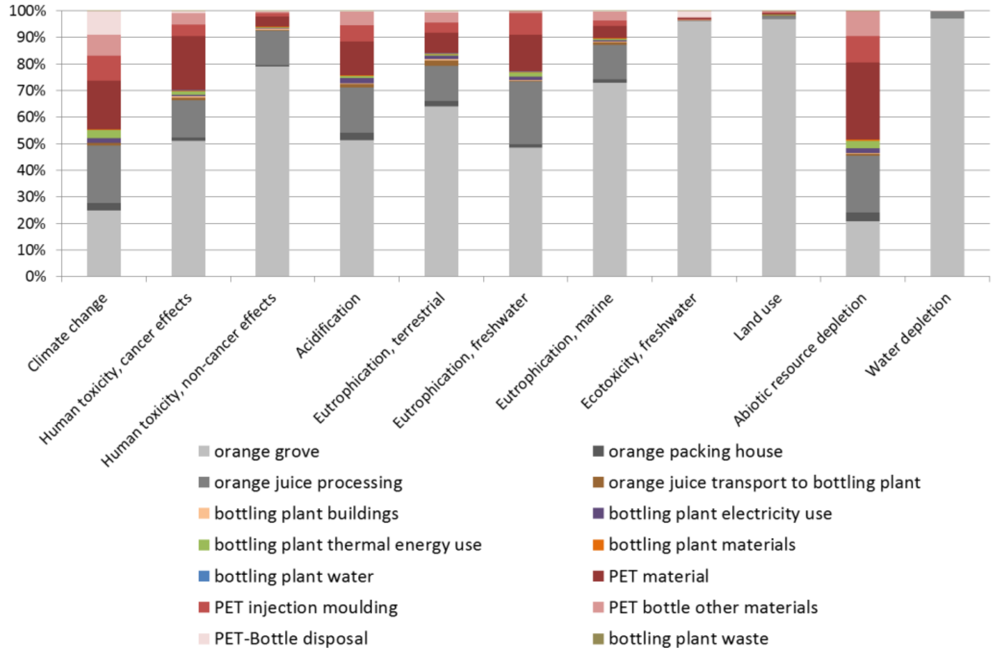

Figure 2-4 Analysis of the environmental impacts of orange juice at bottling plant. The relative scale (100%) shows the contribution of different inputs and outputs

Table 2.11 Legend explanation of Figure 2-4

Legend	Included processes
Bottling plant buildings	Office building, factory hall and facilities included
Bottling plant thermal energy use	Natural gas, cooling energy, compressed air
Bottling plant materials	Cleaning products and cooling material (liquid nitrogen)
Bottling plant water	Tap water and effluent treatment
PET material	PET granulate
PET injection moulding	Injection moulding process to produce PET preforms
PET bottle other materials	Nylon for Bottle, Polystyrene for label PE for secondary and tertiary packaging for PET bottles.
PET-bottle disposal	Disposal of PET bottle by consumers after use phase (average European recycling rates)
Bottling plant waste	Municipal solid waste and cleaning products packaging

The LCIA results for each life cycle stage are shown in digits in Table 2.12. The GWP of 1 l orange juice in a 1.0 l PET bottle is 0.67 kg CO_2-eq.

Table 2.12 LICA results for 1 l of orange juice in a 1.0 l PET bottle

Impact category	**Unit**	**Orange cultivation**	**Orange juice processing**	**Bottling process**	**Total**
Climate change	kg CO_2 eq	1.65E-01	1.45E-01	3.39E-01	6.68E-01
Human toxicity, cancer effects	CTUh	5.34E-09	1.49E-09	3.51E-09	1.05E-08
Human toxicity, non-cancer effects	CTUh	1.34E-07	2.17E-08	1.27E-08	1.69E-07
Acidification	molc H+ eq	2.03E-03	6.72E-04	1.14E-03	3.94E-03
Eutrophication, terrestrial	molc N eq	7.08E-03	1.46E-03	2.28E-03	1.11E-02
Eutrophication, freshwater	kg P eq	2.07E-05	1.00E-05	1.13E-05	4.27E-05
Eutrophication, marine	kg N eq	1.27E-03	2.23E-04	2.24E-04	1.74E-03
Ecotoxicity, freshwater	CTUe	9.77E+00	3.36E-02	3.60E-01	1.02E+01
Land use	kg C deficit	7.85E+00	9.67E-02	1.48E-01	8.10E+00
Abiotic resource depletion	kg Sb eq	1.09E-03	1.11E-03	2.85E-03	5.22E-03
Water depletion	m^3 water eq	3.50E-01	9.84E-03	6.24E-04	3.60E-01

In Figure 2-5 the main substances contributing to the climate change are shown per life cycle stage. A difference is made between the substances that are emitted in the foreground system, e.g. orange grove, juice processing plant, bottling plant and the substances that are emitted in the background system, e.g. electricity production, pesticides production, PET production etc. Therefore the emissions occurring in the background system are labelled with the name “background system”. The legend “background system aggregated” refers to the emissions that were too small to be differentiated between the substances emitted. The bar named “other processes” refers to the remainder processes from the life cycle, whose single contribution is too small to be assessed individually. The main GHG emissions occur in the background system, which is actually not under the direct influence of SMEs. The main contributors are the PET bottle production followed by the electricity use at the juice processing plant and at the orange grove. The only direct emissions are the N_2O emissions from the use of fertiliser and the CO_2 emissions due to the combustion of natural gas at the juice processing plant (labelled with the name “juice plant thermal energy use”). The diesel use at the orange grove, the use of fertilisers and the production of pesticides are only minor contributors. Transports until the bottling plant are also not an important contributor in this case study.

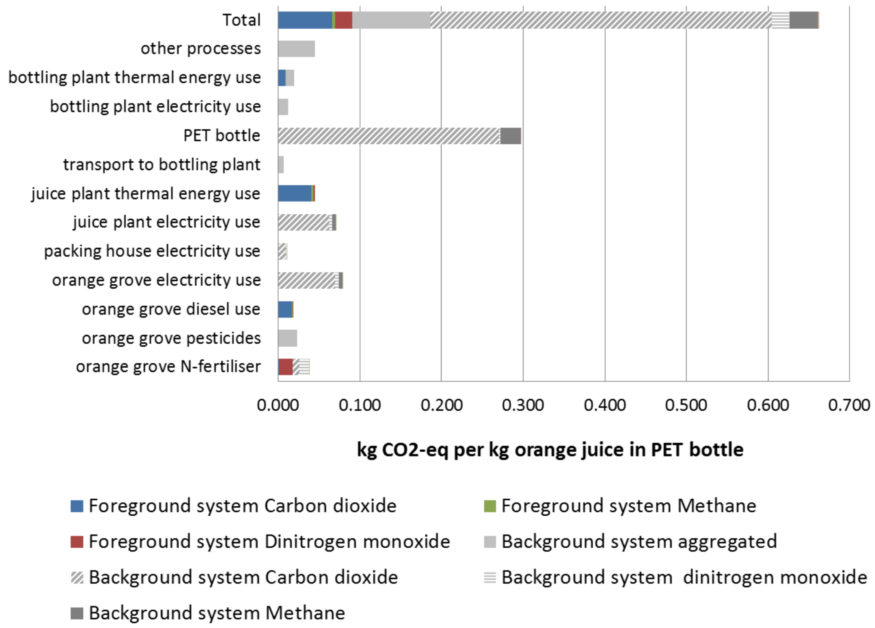

Figure 2-5 Main substances in the foreground system and emissions in the background system per life cycle stage contributing to the climate change

In Figure 2-6 the main substances per life cycle step contributing to the acidification potential are illustrated. The same legend used in the previous Figure 2-5 is applied. The contribution of the foreground system to the acidification potential is higher than its contribution to the climate change. The two main contributors are the use of fertilisers in the foreground system and the PET bottle production in the background system. The electricity use at the orange grove and the juice processing plant are also important steps. The main emissions occurring in the foreground system are the NH_3 and NO_x emissions due to the application of N-fertiliser. The background emissions of SO_2, NH_3 and NO_x resulting from the electricity use at the orange grove and juice processing plant are important contributors. The production of pesticides generates SO_2 emissions. The SO_2 and NO_x emissions due to the PET bottle manufacture are the second largest contributor after the emissions from the N-fertiliser application. The label "background system aggregated" refers to other processes, e.g. land use, materials use at the juice processing plant, waste infrastructure, etc. whose emissions were aggregated and not differentiate between sulphur dioxide, ammonia and nitrogen oxides due to their small amounts. Transport is negligible in this case study.

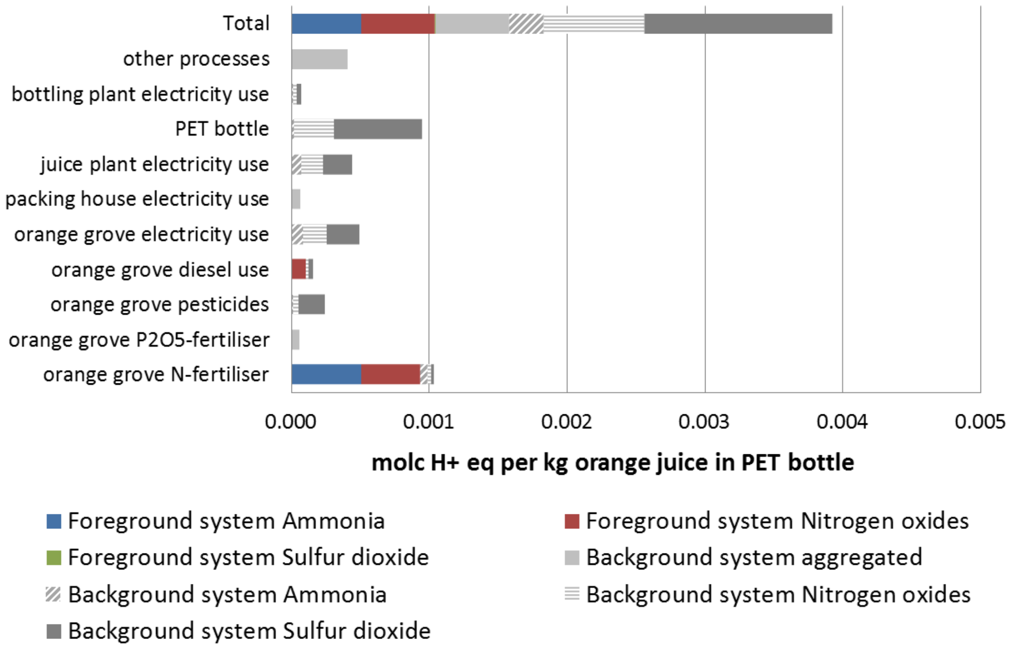

Figure 2-6 Main substances responsible for the acidification identified per life cycle stage

2.4 Discussion

2.4.1 Most relevant stages

The most relevant stage depends on the impact category assessed. The share of each life cycle step to the overall environmental impacts is shown in Table 2.13. The bottling process contributes at least 50 % to the climate change and abiotic resource depletion. The other categories are dominated by the orange cultivation. The shares of the orange cultivation in the total results show that the human toxicity, marine eutrophication, freshwater ecotoxicity, land use and water depletion are dominated by the agriculture step (more than 70 %).

Table 2.13 Share of the different life cycle stages to the overall environmental impacts

Impact category	**Share orange cultivation**	**Share packing house**	**Share orange juice processing**	**Share bottling process**
Climate change	25%	3%	22%	51%
Human toxicity, cancer effects	51%	1%	14%	34%
Human toxicity, non-cancer effects	79%	0%	13%	8%
Acidification	51%	3%	17%	29%
Eutrophication, terrestrial	64%	2%	13%	21%
Eutrophication, freshwater	48%	1%	24%	27%
Eutrophication, marine	73%	1%	13%	13%
Ecotoxicity, freshwater	96%	0%	0%	4%
Land use	97%	0%	1%	2%
Abiotic resource depletion	21%	3%	21%	55%
Water depletion	97%	0%	3%	0%

2.4.2 Comparison with literature values

The key environmental challenges for the fruit juice supply chain were identified in task 1.1 of the SENSE project based on literature review (Landquist et al. 2013). Hence, the inventory from this case study can be compared with literature data provided in this review.

Orange production

The comparison of the GWP of 1000 kg orange harvested is shown in Table 2.14. This case study has the lower GWP with 71 kg CO2-eq per ton while the other literature values are more in the range of 100-300 kg CO2-eq. The low amount of fertilisers and diesel use as well as the high orange yield could explain the low GWP (see Table 2.3). The high value reported by Dwivedi (2012) could be attributed to the use of fertilisers and energy inputs. The values from Jungbluth et al (2013) are based on published literature source with some adjustment to the ESU database, harmonization of all assumptions and background datasets from the ecoinvent database. This explains the main difference with the results given in Knudsen et al. 2011b due to difference in the organic N-fertiliser model.

Table 2.14 Comparison of LCA studies on orange cultivation GWP (Landquist et al. 2013)

References	**Region**	**Production method**	**Orange cultivation kg CO_2-eq/tons oranges**
Case study	Spain	Integrated production	71
Ribal et al. 2009	Spain	Integrated production	222-450
Ribal et al. 2009	Spain (Valencia)	Organic farming	100-350
Sanjuan et al. 2005	Spain (Valencia)	Integrated production	220-280
Jungbluth et al. 2013	Spain (Valencia)	Integrated production	193[1]
Beccali et al. 2009	Italy		100
Dwivedi et al. 2012	USA (Florida)	Conventional production	312
Jungbluth et al. 2013	USA (Florida)	Conventional production	266[2]
Knudsen et al. 2011a	Brazil (S.Paulo)	Organic: Small scale	84
Jungbluth et al. 2013	Brazil	Organic small scale	111[3]
Knudsen et al. 2011a	Brazil (S.Paulo)	Organic: Large scale	114
Jungbluth et al. 2013	Brazil*	Organic large scale	149[3]
Knudsen et al. 2011a	Brazil (S.Paulo)	Conventional: Small scale	112
Jungbluth et al. 2013	Brazil*	Conventional	140[3]

[1] inventory of Sanjuan et al. 2005 re-modeled by ESU-services
[2] inventory of Dwivedi et al. 2012re- modeled by ESU-services
[3] inventory of Knudesen et al. 2011 re-modeled by ESU-services

Orange juice

The NFC orange juice production investigated has also one of the lowest GHG emissions when it is compared with other literature value on NFC orange juice. The literature values for orange juice in different studies are in the range of 0.4 to 1.1 kg CO_2-eq per litre. On the one hand, the low GWP of the orange cultivation implies that the orange juice has also a low GWP. On the other hand, Zuvamesa is a new factory designed with the latest standards on processing equipment and can easily provide exact and detailed numbers on consumption[4].

---

[4] Communication with Susanne Koswig on 15.05.2013, SGF International

Table 2.15 Comparison of LCA studies on GWP of NFC orange juice and FCOJ (Landquist et al. 2013)

References		**Region**	**GWP** **kg CO_2 eq/l**
Case study	NFC orange juice in PET bottle	Spain (Valencia)	0.67
Beccali et al. 2009	NFC orange juice	Italy (Sicily)	1.00
Dwivedi et al. 2012	NFC orange juice in tetra brick	USA (Florida)	0.85
Jungbluth et al. 2013	NFC orange juice in tetra brick	USA (Florida)	0.97[1]
Tesco. 2009	NFC orange juice	Brazil	1.09
Tropicana. 2009	NFC orange juice	Brazil	0.94
Munasinghe et al. 2009	NFC orange juice	Brazil	0.96
PepsiCo. 2008	NFC orange juice	Brazil	1.10
Beccali et al. 2009	FCOJ (not included final package)	Italy (Sicily))	0.84
Knudsen et al. 2011b	FCOJ	Brazil	0.42
Tesco 2009	FCOJ	Brazil	1.04
Jungbluth et al 2013	FCOJ in tetra brick	Brazil	0.60[2]
Jungbluth et al 2013	FCOJ organic in tetra brick	Brazil	0.71[2]

[1] inventory of Dwivedi et al. 2012 re-modeled by ESU-services

[2] inventory of Knudsen et al. 2011 re-modeled by ESU-services

2.4.3 Allocation rules

At the orange grove, no allocation is required since only oranges are produced on field. On the other hand, the juice processing plant and the bottling plant do not only process oranges but other citrus fruits. In this case study, the energy and material flows at both plants can be given on a product-basis. Hence, no allocation is required to allocate the energy use to clementine and oranges. However, there are also by-products from the orange juice extraction such as orange pulp, essential oils, D-limonene and orange peels. An economic allocation should be chosen only if a physical relationship between the different products cannot be established (International Organization for Standardization (ISO) 2006b). Since no physical relationships can be identified, the allocation between the different products follows an economic allocation approach based on the shares of products in the turnover. All energy and material flows are allocated to each product using these allocation factors. The infrastructure is allocated to both clementine and oranges processed using their shares in the total weight processed.

The same approach is applied to the bottling plant, which processes also clementines and oranges with orange pulp. The energy and material flows are given for the orange juice bottling directly. The infrastructure is allocated to clementines and oranges using their shares in the total weight processed.

2.4.4 KEPIS

On the basis of the impact assessment, the most relevant sources of impacts are identified and the key environmental performance indicators are selected. This simplified approach aims to estimate about 80% of the environmental impacts and its possible variation based on plant specific data while the rest of the life cycle inventory can be modelled with average background data. They cover the following life cycle steps: orange cultivation, orange juice production and bottling process. In Table 2.16, the list of KEPIS is displayed horizontally in below the production step and the impact categories are listed vertically on the left. If one KEPI contributes substantially to an impact category, the cell is coloured in red. If there is no contribution, the cell is green. The cell sometimes includes the main pollutant concerning a specific impact category and influenced by a specific KEPI.

Orange grove

The first KEPI to be provided at the orange grove is the **orange yield**. All data can be provided per hectare and then they are divided by the yield to have them per kg orange harvested.

The KEPIs "**N-fertiliser use**" and "**P_2O_5-fertiliser use**" refer to the production and use of these fertilisers. The quantities of N-fertiliser and P_2O_5-fertiliser applied must be asked separately since each fertiliser contributes to different impact categories. On the one hand, ammonia (NH_3) and nitrate (NOx) are emitted during the application of N-fertiliser and contribute to the acidification and terrestrial eutrophication. The emissions of nitrate (NO_{3-}) contribute to the marine eutrophication. The emissions of dinitrogen monoxide (N_2O) affect the climate change. On the other hand, the emissions of heavy metals (HM) due to the application of P_2O_5-fertiliser cause human toxicity effects and affect the freshwater ecotoxicity. The phosphate emissions due to the production and application of P_2O_5-fertiliser contribute to the freshwater eutrophication.

The KEPI "**Pesticide and active substance content**" includes the production of pesticides, i.e. plant protection products (PPP), and the emissions from the active substances contained in the pesticides applied. It is important that the farm provides the pesticide name and the content of active substance. If the latter is not known, it can be found in literature. The active substances are necessary to estimate the type of emissions that affect the ecotoxicity. In a similar way as for the fertilisers, the production of pesticides is included in the background system. Moreover, pesticides use will also depend on whether biological control is also used at the orange grove. The biological control is not included in the inventory but it reduces the amounts of pesticide applied.

The KEPI "**diesel use incl. machineries**" refers to the diesel consumption including its production and the agricultural machineries used. The CO_2 emissions due to the diesel combustion contribute to the climate change. The NO_x emissions affect the acidification, terrestrial and marine eutrophication. The diesel production causes abiotic resource depletion. The manufacture of the agricultural machineries contributes to the human toxicity and ecotoxicity impacts as well as the freshwater eutrophication due to the steel production. It is suggested to have an estimation of the agricultural machinery as a background process linked to the diesel consumption, as it was done also for this case study. Indeed, the diesel use for the agricultural processes is modelled with a dataset that includes the diesel fuel consumption, the corresponding amount of agricultural machinery needed (tractor, trailer, harvester, tillage) and its production and the shed corresponding to the machinery use.

The KEPI "**electricity use (irrigation)**" includes the production of electricity. The main environmental impacts are the climate change due to the CO_2 emissions and the abiotic resource depletion due to the fossil fuel extracted. Irrigation methods may vary depending on local rainfalls, soil characteristics and hydrological factors (Landquist et al. 2013). For example, diesel use can also be used for irrigation (see Table 2.3) and will decrease the contribution of the electricity use for irrigation.

The **land use** is a KEPI for the land use impact category. The land use includes the emissions of phosphorus to water that affect the freshwater eutrophication. The **direct water use** is also a KEPI related to the water depletion impact category.

Orange Juice processing

In order to build the life cycle inventory, the juice processing plant must provide the input mass (kg) of oranges needed to produce 1 l of orange juice.

The **electricity use**, the **thermal energy use** and the **water use** are the three main KEPIs. In our case, thermal energy corresponds to natural gas, which was given in Nm^3 and converted into MJ. Both electricity and thermal energy contribute to the abiotic resource depletion and the climate change. The water use determines the amount of wastewater that will be treated. The phosphate emissions resulting from the wastewater treatment affect the freshwater eutrophication.

There are by-products from the orange juice processing, e.g. peels, pulp, and essential oils. An allocation approach is necessary to allocate the energy and material flows to the orange juice. In our case study, the allocation factors were computed on the basis of the shares of the different output products in the turnover, which were given by the plant. Hence, the “**shares of products in turnover**” is a KEPI.

Bottling process

In most cases, the bottling plant does not only bottle orange juice. Therefore, the **share of orange juice in the total amount of juice processed** is a KEPI necessary to allocate the energy and material flows to the orange juice. The KEPIs **electricity use** and the **thermal energy use** cover the energy consumption of the bottles dryers and blowers, compressors, labelling machines, palletizers etc. The thermal energy use has to distinguish between natural gas, steam, cooling energy and compressed air (if not included in electricity use).

The environmental impacts of the KEPI “**type of container**” depend on the packaging investigated. In our case study, the packaging investigated is a PET bottle. The KEPI includes the PET material production, the PET granulates injection moulding into PET preforms and the production of other materials that are included in the PET bottle e.g. secondary packaging, intermediate layer etc. It is relevant for the abiotic resource depletion, the human toxicity, the climate change, the acidification and the freshwater eutrophication. All these processes are included in the background system but the weight of the PET bottle and the other materials must be provided by the bottling plant. Another packaging could not be investigated because the energy use at the bottling plant is connected to the packaging, e.g. blowing of PET preforms. Moreover, it is difficult to gather data on packaging weight. In our inventory, data was not given in the questionnaire and were taken from a previous study. Nonetheless, PET bottles, glass bottles as well as tetrabrick are standard packages that follow healthy and quality guidelines. It is suggested to have different types of packages or packaging materials in the background database for the SENSE tool.

Table 2.16 List of proposed KEPIs for each impact category concerning the environmental impacts of the production of orange juice

Impact category	Orange cultivation								Orange juice processing					Bottling				Main pollutants
Unit	kg orange/ha	kg N/ha	kg P2O5/ha	kg/ha	l/ha	kWh/ha	ha	m3/ha	%	kg orange/l orange juice	kWh/l orange juice	MJ/ l orange juice	m3/ha	% (orange juice/ total juice)	kWh/l orange juice	MJ/ l orange juice	type/l orange juice	
Key Environmental Performance Indicator (KEPI)	Yield	N-fertiliser use	P2O5-fertiliser use	Pesticide and active substance content	Diesel use incl. machineries	Electricity use (irrigation)	Land use	Water use	Share of products in turnover	Yield	Electricity use	Thermal energy use	Wastewater treatment	Share of orange juice in total juice processed	Electricity use	Thermal energy use (natural gas, steam, cooling energy, compressed air)	Type of container (e.g. PET, glass, Tetrapack)	
All impact categories	x								x	x								
Climate change		N2O			CO2	CO2					CO2	CO2			CO2	CO2	CO2	CO2, CH4, N2O
Human toxicity			HM		HM												HM	Heavy metals (HM)
Acidification		NH3			NOx												SO2	SO2, NOx, NH3
Eutrophication, terrestrial		NOx			NOx													NO3, NH3
Eutrophication, freshwater			PO4				PO4						PO4				PO4	PO4
Eutrophication, marine		NO3			NOx													NO3 (Nitrate), NOx
Ecotoxicity, freshwater			HM	PPP	HM													Heavy metals (HM) Plant Protection Products (PPP)
Land use							x											Land use (m2a and type)
Abiotic resource depletion					x	x					x				x	x	x	Fossil resources (oil, gas, coal)
Water depletion								x					x					Water use

The KEPIs proposed in Table 2.16 cover in average 95% of the environmental impacts of our case study (see Figure 2-7).

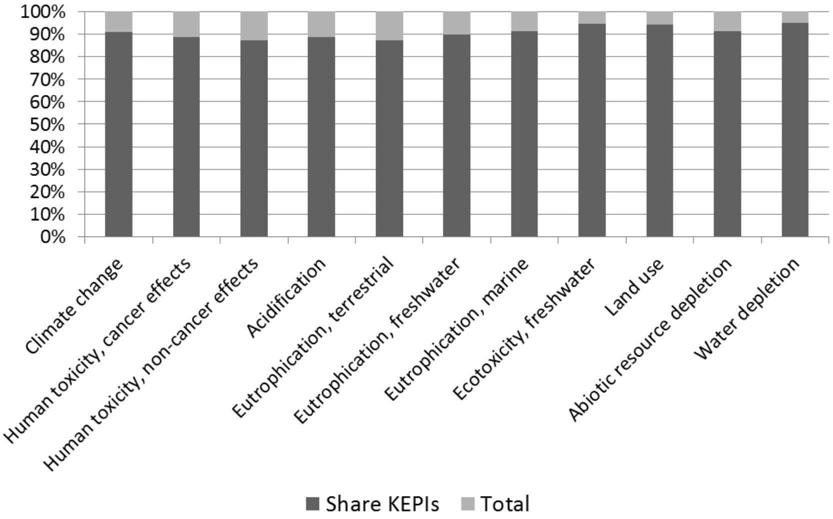

Figure 2-7 Share of the environmental impacts in this case study covered by the KEPIs selected

In our case study, the transport between the life cycle stages does not play a significant role for any impact categories since no refrigerated transport is required for a pasteurised NFC orange juice. Moreover, transport distances are short between the orange grove, the juice processing plant and the bottling plant. This is specific to the Spanish orange juice and can be different if a frozen concentrated orange juice (FCOJ) produced in Brazil and diluted in Europe is assessed (Landquist et al. 2013).

Some dataset used in this case study could be better investigated in future studies. First of all, it would be necessary to take into account the method of application of the fertilisers since the fertigation is only considered by having a lower amount of fertilisers used. The emissions resulting from the application of fertilisers depends on the type of fertilisers use and the way how it is applied. The share of different types of fertilisers is modelled according to use rate in Switzerland. These might be different in a European context. Furthermore emissions have been calculated with a model developed for the application by tractor. It can be assumed that the emission rates with fertigation should be lower than assumed here.

The agricultural machineries and installations used for the fertigation would also be different. The agricultural machineries, which are modelled with the amount of diesel used, are based on measurements made by a Swiss agricultural research institute. A detailed description of the work processes at farm, e.g. preliminary work, hours on field etc. and the type and weight of machinery would be necessary to make this dataset more accurate.

2.4.5 Regionalisation

An important question of the project is the adjustment of the SENSE model to regional characteristics. For each impact category, the KEPIs have already been identified in Table 2.16. Depending on this, it can be evaluated whether a regionalised impact assessment, a regional emission model or regional background data is needed, available and feasible to provide a regionalised assessment.

The regionalisation of the **impact assessment method** (LCIA) means that different characterization factors are used for each country or for a specific region. The characterisation factors of ammonia, nitrogen oxides and sulphur dioxides for acidification for example are available for Spain. They are smaller than the weighted average characterisation factors used in this case study. The characterisation factors of ammonia and nitrogen oxides for terrestrial eutrophication in Spain are smaller than the weighted average implemented in SimaPro (Posch et al. 2008). Thus, this would reduce the contribution of direct impacts in these impact categories compared to the contribution of background processes. In this case study, a regionalised approach was applied for water depletion (Frischknecht et al. 2009).

Calculations for direct emissions due to the application of fertilizers are based on scientific **emission models** and not on real measurements. In these models regional differences such as rainfall, soil quality, slope of fields, average temperatures, irradiation, etc. could be taken into account. However, this would implicate that these models need to be adapted accordingly. In this case study, most of the models applied are based on Swiss circumstances. Such easy-to-apply models for all different European regions are so far not available. A quite relevant question for a regionalised model would be the calculation of phosphorus emissions to water due to the land erosion and run-off as well as different type of nitrogen emissions and phosphate emissions due to N-fertilizer and P_2O_5-fertiliser. These will further depend on the type of fertiliser and the way how it is applied. The modelling of NO_x emissions from fuel combustion, which depends e.g. on the technology standards applied in a specific region, could be another issue for a regionalized model.

The **background system** is not under the direct influence of the SME but it is the basis of the SENSE tool. In many cases LCI background data are just available for a global or a European production mix. But, in practice the markets in different regions might be supplied with a different mix of products. Thus, also LCI data can be adapted to the market situation in a specific region. The easiest regionalisation of background LCI data is the application of a country-specific electricity mix. Datasets are publicly available and can be easily implemented (Itten et al. 2012). Tap water use can also be inventoried country-specific. However, the wastewater treatment was modelled for an average municipal wastewater treatment plant in Switzerland. The treatment technology actually differs within European countries. It would be interesting to have a regionalised inventory for different type of land occupation in different countries.

The packaging investigated is a PET bottle. So far, European averages for the PET bottle production are applied in the inventory. Indeed, a European average electricity mix was used in the inventory for the PET preform production and a European average recycling rate of 51 % was used for the PET bottle disposal. The rest of the PET bottles are assumed to be incinerated. The recycling rate and recycling routes depend on the country. In some countries, the recycling rate is high while in some other countries landfill might be more important. The energy use for the packaging production depends on the country and this must be taken into account in the SENSE tool.

For others background data we do not expect major differences (diesel, natural gas, fuel oil) in the environmental impacts or it might be very time consuming to further elaborate such regionalized data e.g. for machinery production and buildings.

Table 2.17 Identification of regionalisation potentials in impact assessment methods, emissions model and background data based on the case study for Spanish orange juice

Impact category	Regional impact assessment methods	Emission model	Background data
Climate change	Not relevant	CO_2 emissions diesel use CO_2 emissions thermal energy N_2O-emissions N-fertiliser	Electricity mix Packaging production Packaging disposal
Human toxicity	Not available	Not relevant	Electricity mix Chromium content in P_2O_5-fertiliser Wastewater treatment technology
Acidification	Regional characterisation factors available	NH_3 and NO_x-emissions NO_x emissions diesel use	Electricity mix
Eutrophication, terrestrial	Regional characterisation factors available	NH_3 and NO_x-emissions N-fertiliser NO_x emissions diesel use	Electricity mix
Eutrophication, freshwater	Not available	Phosphorus emissions by arable land use	Electricity mix
Eutrophication, marine	Not available	NO_3 emissions N-fertilizer use NO_x emissions diesel use	Not relevant
Ecotoxicity, freshwater	Not available	Active substance emissions to soil (pesticide use)	Electricity mix
Land use	No LCIA method yet	Type of land occupation	Land use
Abiotic resource depletion	Not relevant	Not relevant	Electricity mix Thermal energy production Packaging production Packaging recycling rate and recycling routes
Water depletion	Regional characterisation factors used	Direct water use	Regionalized data for tap water

Copyright

References

Aronsson A., Landquist B., Pardo G., Esturo A., Ramos S., Jungbluth N., Flury K. and Stucki M. (2013) Environmental assessment methodology and sustainability indicators for products and supply chains. SENSE - Harmonised Environmental Sustanainability in the European food and drink chain, Seventh Framework Programme: Project no. 288974. Funded by EC. Deliverable D 1.3 SIK, Gothenburg.

Beccali M., Cellura M., Iudicello M. and Mistretta M. (2009) Resource consumption and environmental impacts of the agroffod sector: life cycle assessment of italian citrus-based products. In: Environmental Management, 43(4), pp. 707-724.

Coltro L., Mourad A. L., Kletecke R. M., Mendonca T. A. and Germer S. P. M. (2009) Assessing the environmental profile of orange production in Brazil. In: Int J LCA, 14(7), pp. 656-664.

de Beaufort-Langeveld A. S. H., Bretz R., van Hoof G., Hischier R., Jean P., Tanner T. and Huijbregts M. A. J. (2003) Code of Life-Cycle Inventory Practice (includes CD-ROM). SETAC, ISBN ISBN 1-880611-58-9, retrieved from: www.setac.org.

Doublet G. (2012) LCA of Rivella and Michel soft drink packaging. Institute of Environmental engineering (IFU), Chair of Ecological System Design (ESD), ETH, Zürich, retrieved from: http://www.esu-services.ch/address/genevieve/.

Dwivedi P., Spreen T. and Goodrich-Schneider R. (2012) Global warming impact of Florida's Not-From-Concentrate (NFC) orange juice. In: Agricultural Systems, 108(0), pp. 104-111, 10.1016/j.agsy.2012.01.006, retrieved from: http://www.sciencedirect.com/science/article/pii/S0308521X12000145.

ecoinvent Centre (2010) ecoinvent data v2.2, ecoinvent reports No. 1-25. Swiss Centre for Life Cycle Inventories, Duebendorf, Switzerland, retrieved from: www.ecoinvent.org.

Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Dones R., Heck T., Hellweg S., Hischier R., Nemecek T., Rebitzer G. and Spielmann M. (2007) Overview and Methodology. ecoinvent report No. 1, v2.0. Swiss Centre for Life Cycle Inventories, Dübendorf, CH, retrieved from: www.ecoinvent.org.

Frischknecht R., Steiner R. and Jungbluth N. (2009) The Ecological Scarcity Method - Eco-Factors 2006: A method for impact assessment in LCA. Federal Office for the Environment FOEN, Zürich und Bern, retrieved from: www.bafu.admin.ch/publikationen/publikation/01031/index.html?lang=en.

Goedkoop M., Heijungs R., Huijbregts M. A. J., De Schryver A., Struijs J. and van Zelm R. (2009) ReCiPe 2008 - A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. First edition. Report I: Characterisation, NL, retrieved from: lcia-recipe.net/.

International Organization for Standardization (ISO) (2006a) Environmental management - Life cycle assessment - Principles and framework. ISO 14040:2006; Second Edition 2006-06, Geneva.

International Organization for Standardization (ISO) (2006b) Environmental management - Life cycle assessment - Requirements and guidelines. ISO 14044:2006; First edition 2006-07-01, Geneva.

Itten R., Frischknecht R. and Stucki M. (2012) Life Cycle Inventories of Electricity Mixes and Grid. ESU-services Ltd., Uster, Switzerland, retrieved from: http://www.esu-services.ch/data/public-lci-reports/.

Jungbluth N., Flury K., Doublet G., Leuenberger M., Steiner R., Büsser S., Stucki M., Schori S. and Itten R. (2013) Life cycle inventory database on demand: EcoSpold LCI database of ESU-services. ESU-services Ltd., Zürich, CH, retrieved from: www.esu-services.ch/data/data-on-demand/.

Knudsen M., Fonseca de Almeida G., Langer V., Santiago de Abreu L. and Halberg N. (2011a) Environmental assessment of organic juice imported to Denmark: a case study on oranges from Brazil. In: Organic Agriculture, 1(3), pp. 167-185, 10.1007/s13165-011-0014-3, retrieved from: http://dx.doi.org/10.1007/s13165-011-0014-3.

Knudsen M., Fonseca de Almeida G., Langer V., Santiago de Abreu L. and Halberg N. (2011b) Environmental assessment of organic juice imported to Denmark: a case study on oranges (Citrus sinensis) from Brazil. In: Organic Agriculture, 1(3), pp. 167-185, 10.1007/s13165-011-0014-3, retrieved from: http://dx.doi.org/10.1007/s13165-011-0014-3.

Landquist B., Aronsson A., Esturo A., Ramos S., Pardo G., Ólafsdóttir G., Viera G., Larsen E., Nielsen T., Ingólfsdóttir G. M. and Yngvadóttir E. (2013) Key environmental challenges for food groups and regions representing the variation within the EU. SENSE - Harmonised Environmental Sustanainability in the European food and drink chain, Seventh Framework Programme: Project no. 288974. Funded by EC. Deliverable D 1.1. SIK, Gothenburg.

LC-inventories (2013) Corrections, updates and extensions of ecoinvent data v2.2. ESU-services Ltd., retrieved from: www.lc-inventories.ch.

Posch M., Seppälä J., Hettelingh J. P., Johansson M., Margni M. and Jolliet O. (2008) The role of atmospheric dispersion models and ecosystem sensitivity in the determination of characterisation factors for acidifiying and eutrophying emissions in LCIA. In: Int J LCA(13), pp. 477-486.

Ribal J., Sanjuan N., Clemente G. and Fenollosa M. L. (2009) Medicion de la ecoeficiencia en procesos productivos en el sector agrario. Caso de estudio sobre produccion de citricos. . In: Economia Agraria y Recursos Naturales 9(1), pp. 125-148.

Sanjuan N., Ubeda L., Clemente G., Mulet A. and Girona F. (2005) LCA of integrated orange production in the Comunidad Valenciana (Spain). In: International Journal of Agricultural Resources, Governance and Ecology, 4(2), pp. 163-177, retrieved from: http://inderscience.metapress.com/content/NB9DRUQB7X7UGLY6.

Solomon S., Qin D., Manning M., Alley R. B., Berntsen T., Bindoff N. L., Chen Z., Chidthaisong A., Gregory J. M., Hegerl G. C., Heimann M., Hewitson B., Hoskins B. J., Joos F., Jouzel J., Kattsov V., Lohmann U., Matsuno T., Molina M., Nicholls N., Overpeck J., Raga G., Ramaswamy V., Ren J., Rusticucci M., Somerville R., Stocker T. F., Whetton P., Wood R. A. and Wratt D. (2007) Technical Summary. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Spielmann M., Roberto Dones, Bauer C. and Tuchschmid M. (2007) Life Cycle Inventories of Transport Services. ecoinvent report No. 14, v2.0. Swiss Centre for Life Cycle Inventories, Dübendorf, CH, retrieved from: www.ecoinvent.org.

Annex Life Cycle Assessment (LCA) Methodology

The life cycle assessment (LCA) – sometimes also called ecobalance – is a method to assess the environmental impacts of a product[5] encompassing the whole life cycle (cradle to grave). Hence, the environmental impacts of a product are evaluated from resource extraction to material production, product manufacturing, use of the product up to the disposal of the product and also the production wastes.

The general procedure of conducting an LCA is standardised in ISO 14040 (International Organization for Standardization (ISO) 2006a) and ISO 14044 (International Organization for Standardization (ISO) 2006b)

An LCA consists of the following four phases (Figure 1):

1. Goal and Scope Definition
2. Inventory Analysis
3. Impact Assessment
4. Interpretation

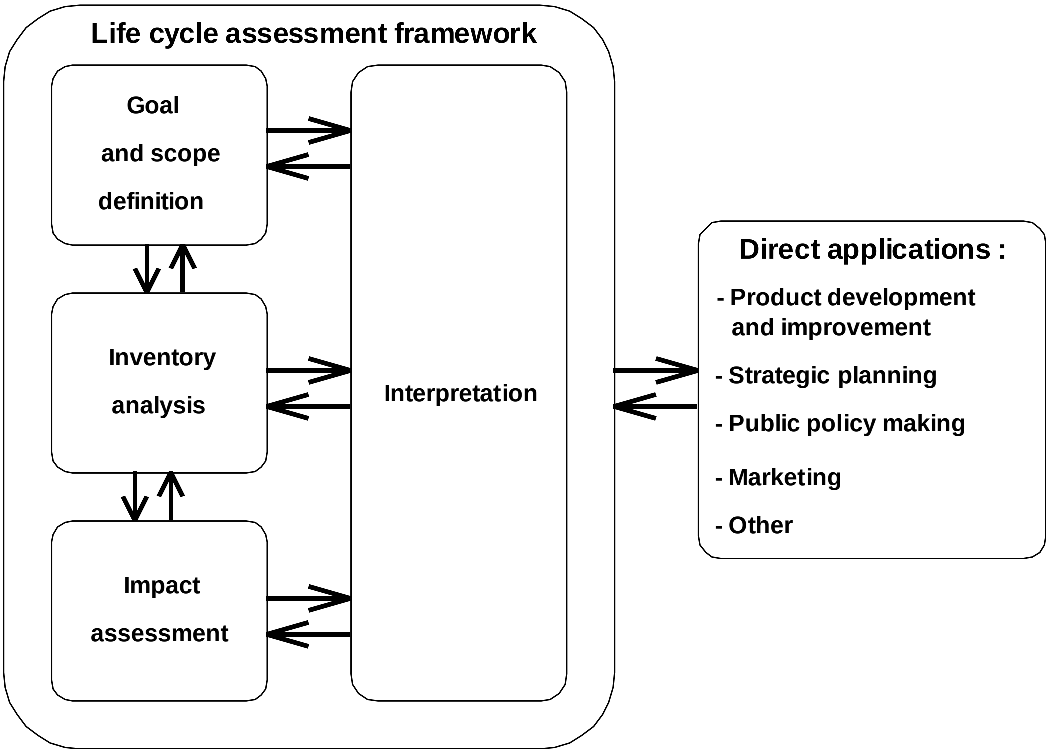

Figure A.1 The four phases of the life cycle assessment (LCA) framework according to International Organization for Standardization

---

[5] The term product also encompasses services

The *Goal and Scope Definition* (phase 1) includes a description of the goal of the study and covers the description of the object of investigation. The intended audience is determined. The environmental aspects to be considered in the impact assessment and the interpretation and the functional unit, to which all emissions and resource uses are referred to and which determines the basis for the comparison, are defined.

The elementary flows[6] occurring in a process, the amount of semi-finished products, auxiliary materials and energy of the processes involved in the life cycle are determined and inventoried in the *Inventory Analysis* (phase 2). These data are set in relation to the object of investigation, expressed by the functional unit. The final outcome consists of the cumulative resource demands and the cumulative emissions of pollutants.

The Inventory Analysis provides the basis for the *Impact Assessment* (phase 3). Applying current impact assessment methods, such as climate change impact according to IPCC (2007), on the inventory results leads to impact indicator results that are used and referred to in the interpretation.

The results of the inventory analysis and the impact assessment are analysed and commented in the *Interpretation* (phase 4) according to the initially defined goal and scope of the LCA. Final conclusions are drawn and recommendations stated.

---

[6] Resource extraction and emission of pollutants