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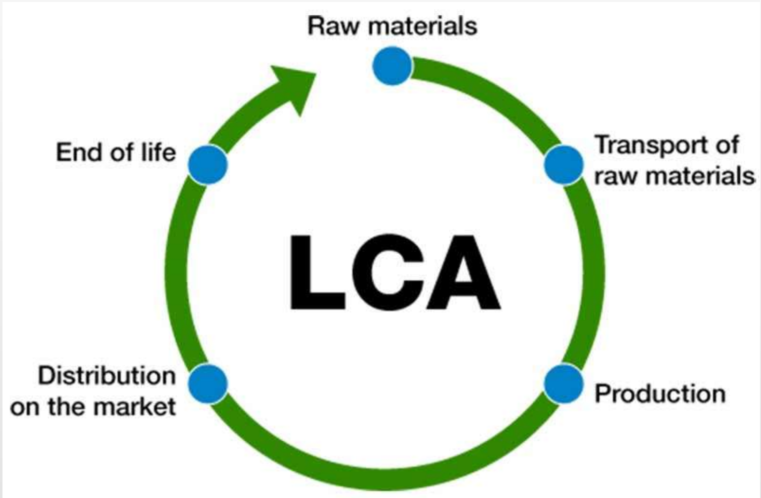
Agriculture, Environment and Bioenergy PhD Course

Life Cycle Assessment of environmental impact of animal production chains: methodological approaches and application cases

Luciana Bava

Life Cycle assessment: what is it?

Life cycle assessment is a cradle-to-grave or cradle-to-cradle analysis technique to assess environmental impacts associated with all the stages of **a product's life**, which is from raw material extraction through materials processing, manufacture, distribution, and use.



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Life Cycle assessment: what is it?

LCA evaluates all stages of a product's life:
-all stages are **interdependent**, meaning that decisions made at one point along the life cycle can have consequences somewhere else
-the environmental impacts resulting from all stages in the product life cycle is **cumulative** (often including impacts that go beyond the boundaries of traditional analyses)

LCA is a relative tool intended for **comparison and not absolute evaluation**, thereby helping decision makers compare all major environmental impact when choosing between alternative courses of action (Curran, 2008)

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Life Cycle assessment: what is it?

The LCA methodology was standardized through a standard of the International Organization in 1997, last revision of 2006 : ISO 14000

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Life Cycle assessment: example

Improve sustainability trough:

-choice of raw material

-improve packaging

-reduce use of energy

-reduce use of water

-improve waste recycling

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Life Cycle assessment: example from scientific literature

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Life cycle assessment of lithium oxygen battery for electric vehicles

Fenfen Wang [a], Yelin Deng [b, **], Chris Yuan [a, *]

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https://doi.org/10.1007/s11367-020-01735-7

LCA FOR MANUFACTURING AND NANOTECHNOLOGY

Environmental impact assessment of galvanized sheet production: a case study in Shandong Province, China

Changxing Ji [1] · Xiaotian Ma [1] · Yijie Zhai [1] · Ruirui Zhang [1] · Xiaoxu Shen [1] · Tianzuo Zhang [1] · Jinglan Hong [1]

Received: 4 September 2019 / Accepted: 16 January 2020 / Published online: 12 February 2020
Springer Nature 2020

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

journal homepage: www.elsevier.com/locate/solmat

Life Cycle Assessment of an innovative recycling process for crystalline silicon photovoltaic panels

Cynthia E.L. Latunussa [a], Fulvio Ardente [a,*], Gian Andrea Blengini [a,b], Lucia Mancini [a]

[a] European Commission, Joint Research Centre (JRC), Institute for Environment and Sustainability (IES), via Enrico Fermi 2749, 21027 Ispra, VA, Italy
[b] Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Torino, TO, Italy

Life Cycle assessment: example from scientific literature

Meat Science

journal homepage: www.elsevier.com/locate/meatsci

Environmental impact of rabbit meat: The effect of production efficiency

Cesari V.*, Zucali M., Bava L., Gislon G., Tamburini A., Toschi I.

Department of Agricultural and Environmental Sciences, Production, Landscape, Agroenergy, Università degli Studi di Milano, via Giovanni Celoria 2, 20133 Milan, Italy

Food and feed production

The International Journal of Life Cycle Assessment
https://doi.org/10.1007/s11367-020-01759-z

LCA FOR ENERGY SYSTEMS AND FOOD PRODUCTS

Fishmeal partial substitution within aquafeed formulations: life cycle assessment of four alternative protein sources

Silvia Maiolo[1] · Giuliana Parisi[2] · Natascia Biondi[2] · Fernando Lunelli[3] · Emilio Tibaldi[4] · Roberto Pastres[1]

Received: 26 September 2019 / Accepted: 13 April 2020

Journal

journal homepage: www.elsevier.com/locate/jclepro

Life cycle assessment of the chicken meat chain

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[a] Faculty of Agriculture, University of Belgrade, Nemanjina 6, 11080, Belgrade, Serbia
[b] Department of Animal Source Food Technology, Faculty of Agriculture, University of Belgrade, Nemanjina 6, 11080, Belgrade, Serbia
[c] Institute of Meat Hygiene and Technology, Kacanskog 13, 11040, Belgrade, Serbia
[d] Faculty of Technology, University of Novi Sad, Bulevar cara Lazara 1, 21000, Novi Sad, Serbia
[e] Department of Food Safety and Quality Management, Faculty of Agriculture, University of Belgrade, Nemanjina 6, 11080, Belgrade, Serbia

Life Cycle assessment: attributional and consequential

The two Life cycle assessment approaches are defined (UNEP, 2011):

- attributional approach*:* system modelling approach in which inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system *according to a normative rule*.
- consequential approach: system modelling approach in which activities in a product system are linked so that activities are included in the product system to the extent that they are expected to change *as a consequence of a change in demand* for the functional unit.

Life Cycle assessment: attributional and consequential

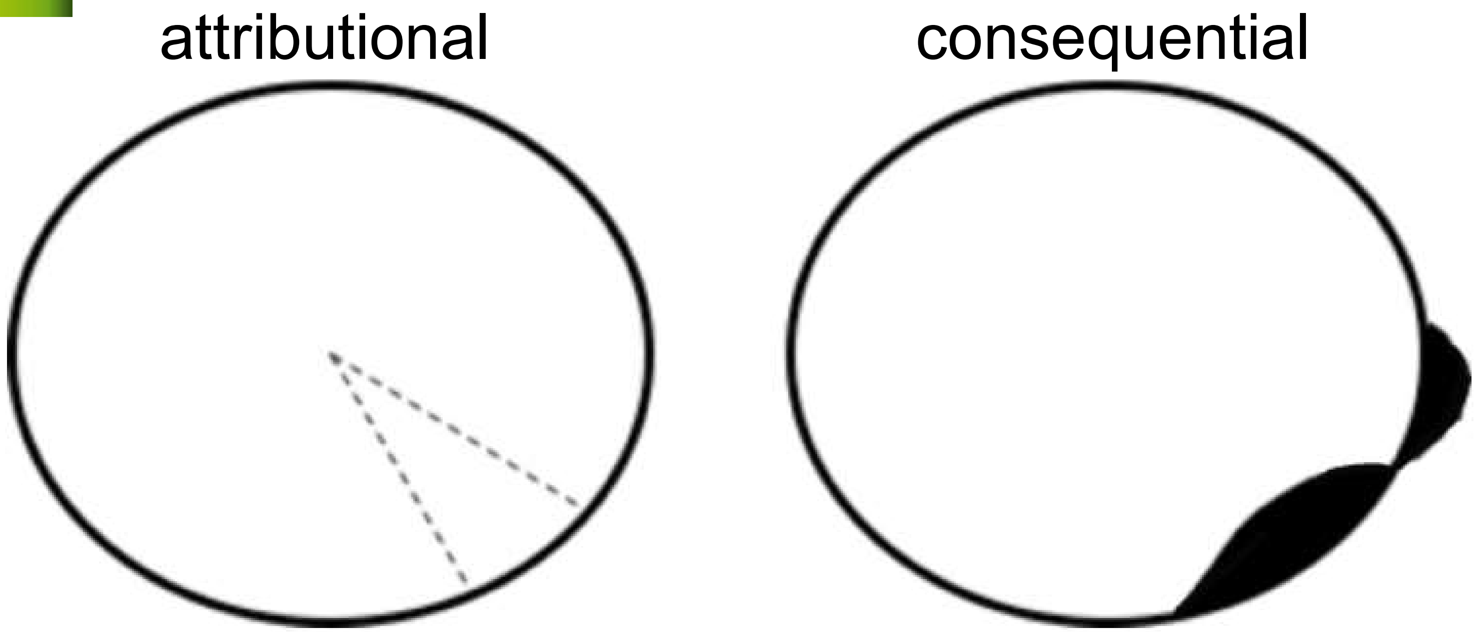


Figure: The conceptual difference between attributional and consequential LCA. The circles represent the total global environmental exchanges. In the left circle, attributional LCA seeks to cut out the piece with dotted lines that belongs to a specific human activity. In the right circle, consequential LCA seeks to capture the change in environmental exchanges that occur as a consequence of adding or removing a specific human activity. Source: (Weidema 2003).

Life Cycle assessment: attributional and consequential

"Attributional" vs. "Consequential" LCA Approaches

Framing your question

> What are the environmental impacts of producing 1 litre of bioethanol from wheat?

Spot the difference

> What are the environmental impacts of producing bioethanol from wheat?

Attributional LCA

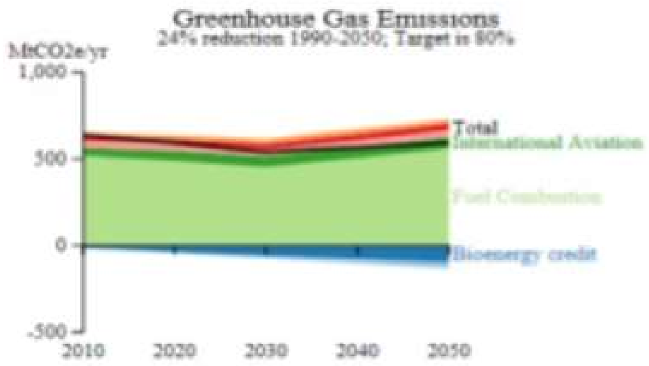
- Looks at a single unit of production
- Provides a snap shot of impacts
- **Attributes responsibility of emissions**

Specific supply chains = Regulation

Consequential LCA

- Looks at knock on effects
- Considers changes in production levels
- **Considers interactions between markets**

Networks/Markets = Policy analysis



Richter, 2016

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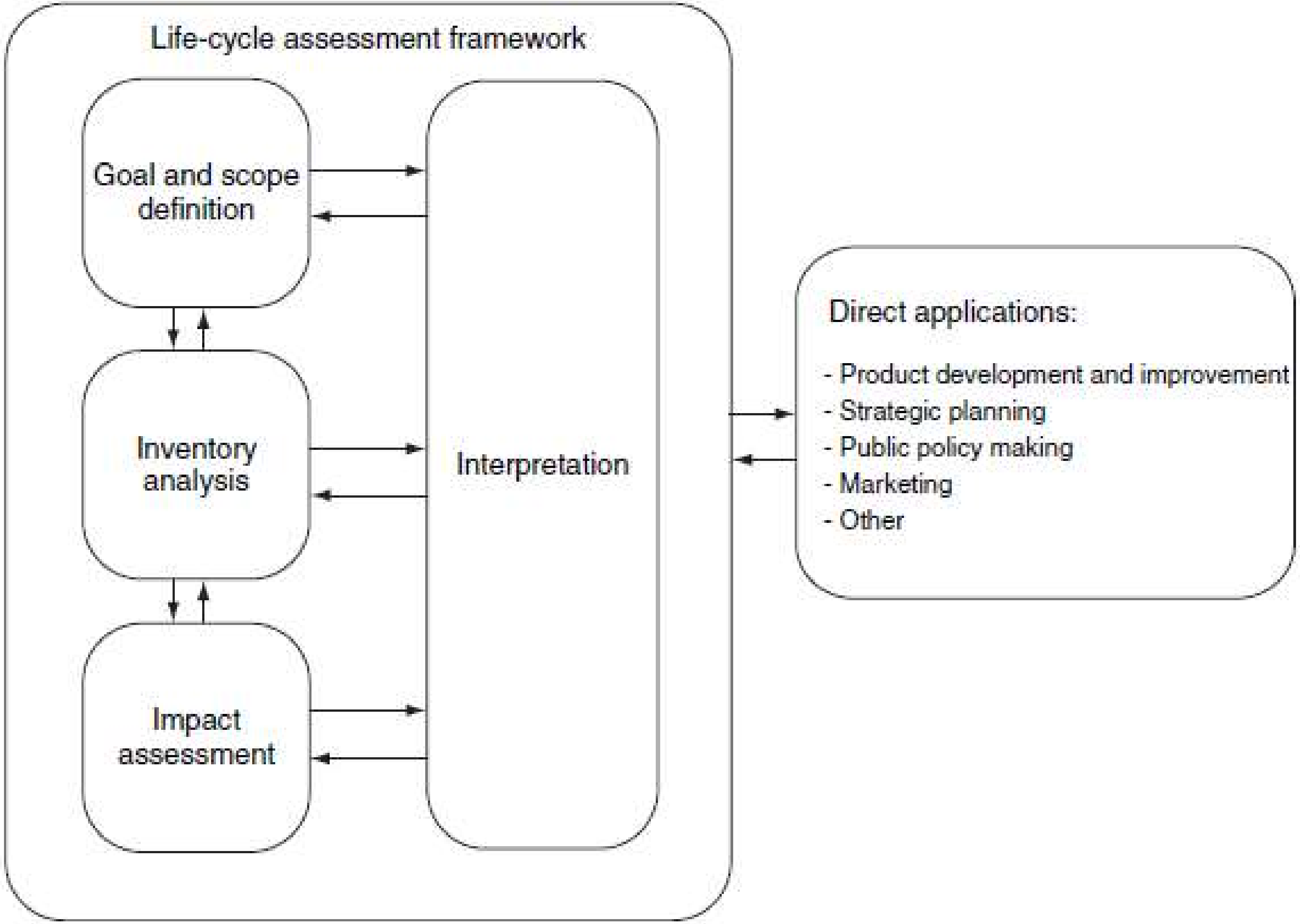
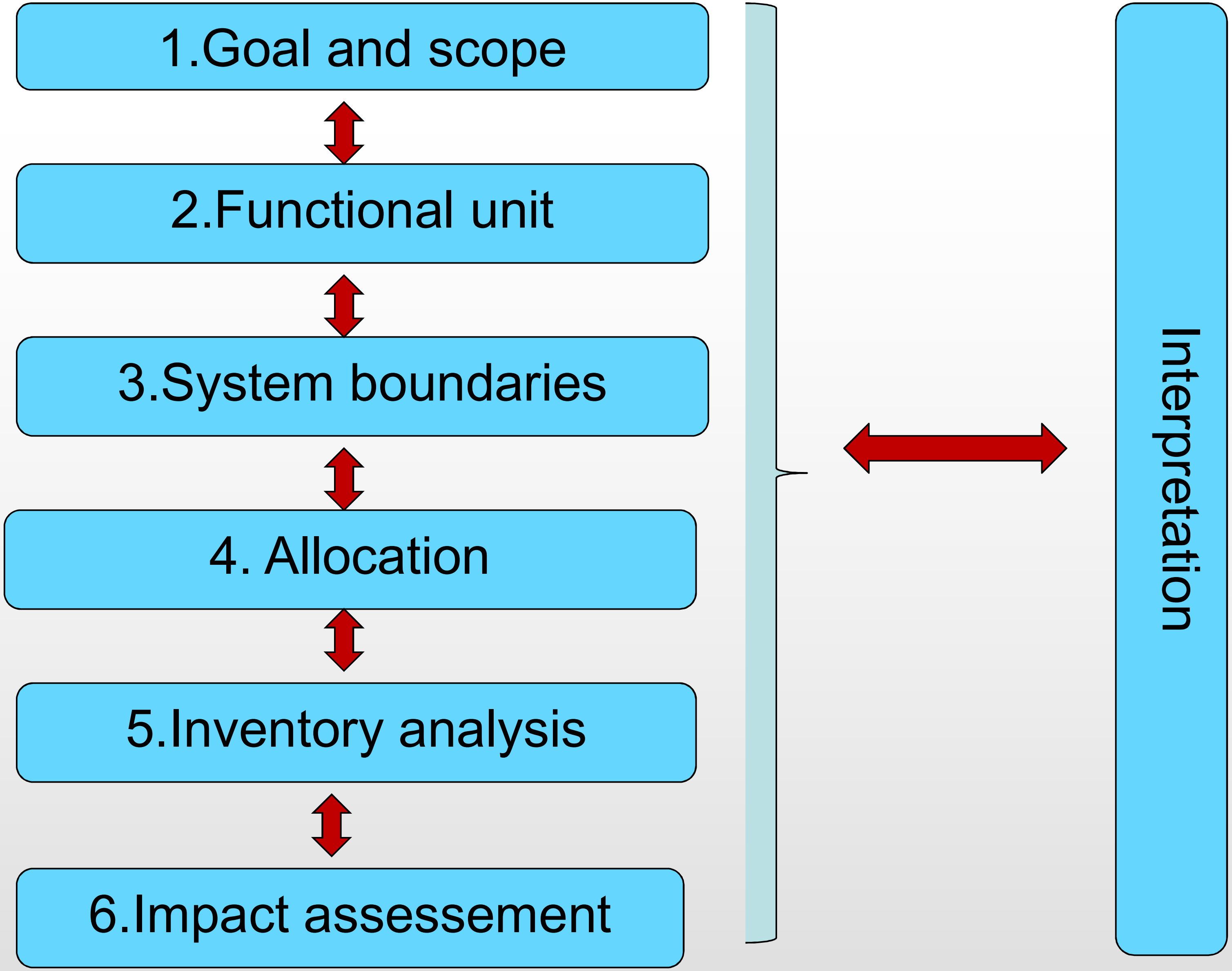
Life Cycle assessment: the phases according to EN ISO 14040



Life Cycle assessment: the phases according to EN ISO 14040 - modification



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LCA: stage 1

Stage 1: Goal and scope

They aims is to define how big a part of product life cycle will be taken in assessment and to what end will assessment be serving

Examples:

- quantify the potential environmental impact of rice production;
- estimate the total global warming potential (GWP) of milk and meat productions in Lombardy

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LCA: stage 1

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Stage 1: Goal and scope

Our example:

- **quantify the environmental impact of cow milk production**
- **Menozzi farm is the case study**

LCA: stage 2

Stage 2. Functional unit

- It is the basis for calculation of LCA
- this may be a unit of material (e.g. a kg of steel of given composition and quality), a unit of energy (e.g. a kW hour of electricity), or a unit of service (e.g. packaging one liter of milk)

- Example: live weight, carcass weight, protein content, lipid content, essential aminoacids content…

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LCA: stage 2

Stage 2. Functional unit

Our example:

Quantify the environmental impact of cow milk production

- **FU: 1 kg of fat and protein corrected milk (IDF, 2015)**

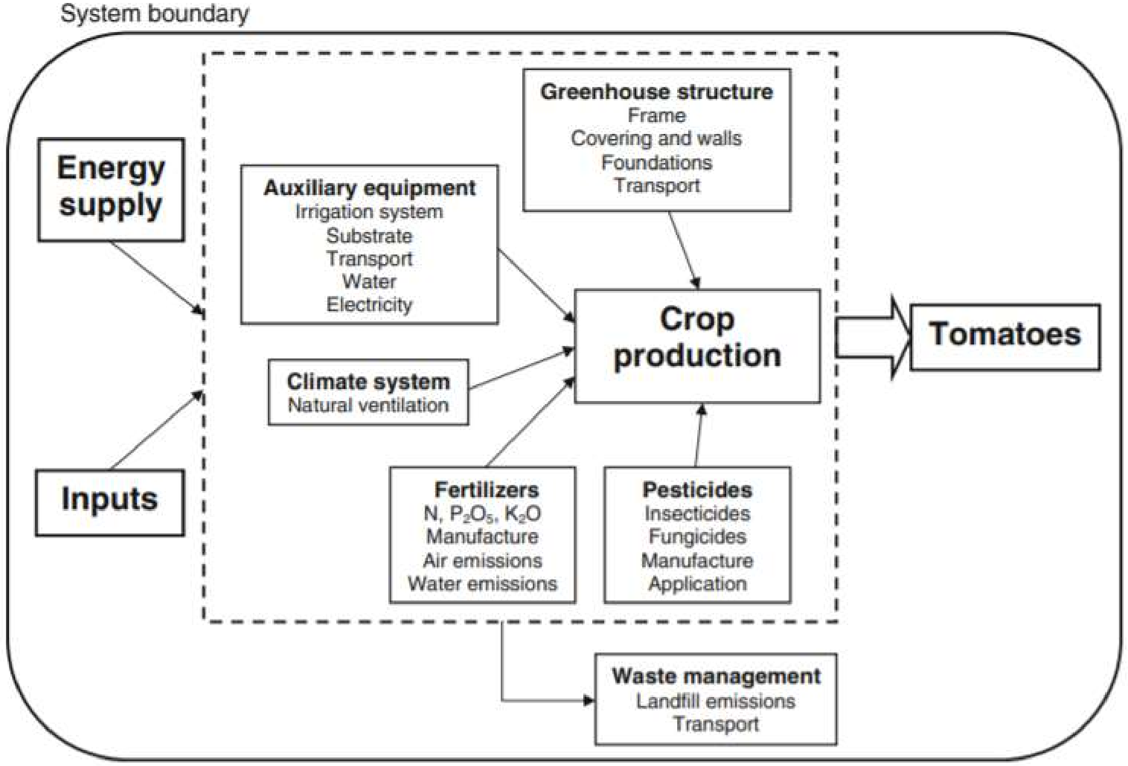
1 kg FPCM = total milk* (0.2534+0.1226 * % fat + 0.776 * % protein)

LCA: stage 3

Stage 3. Definition of system boundaries

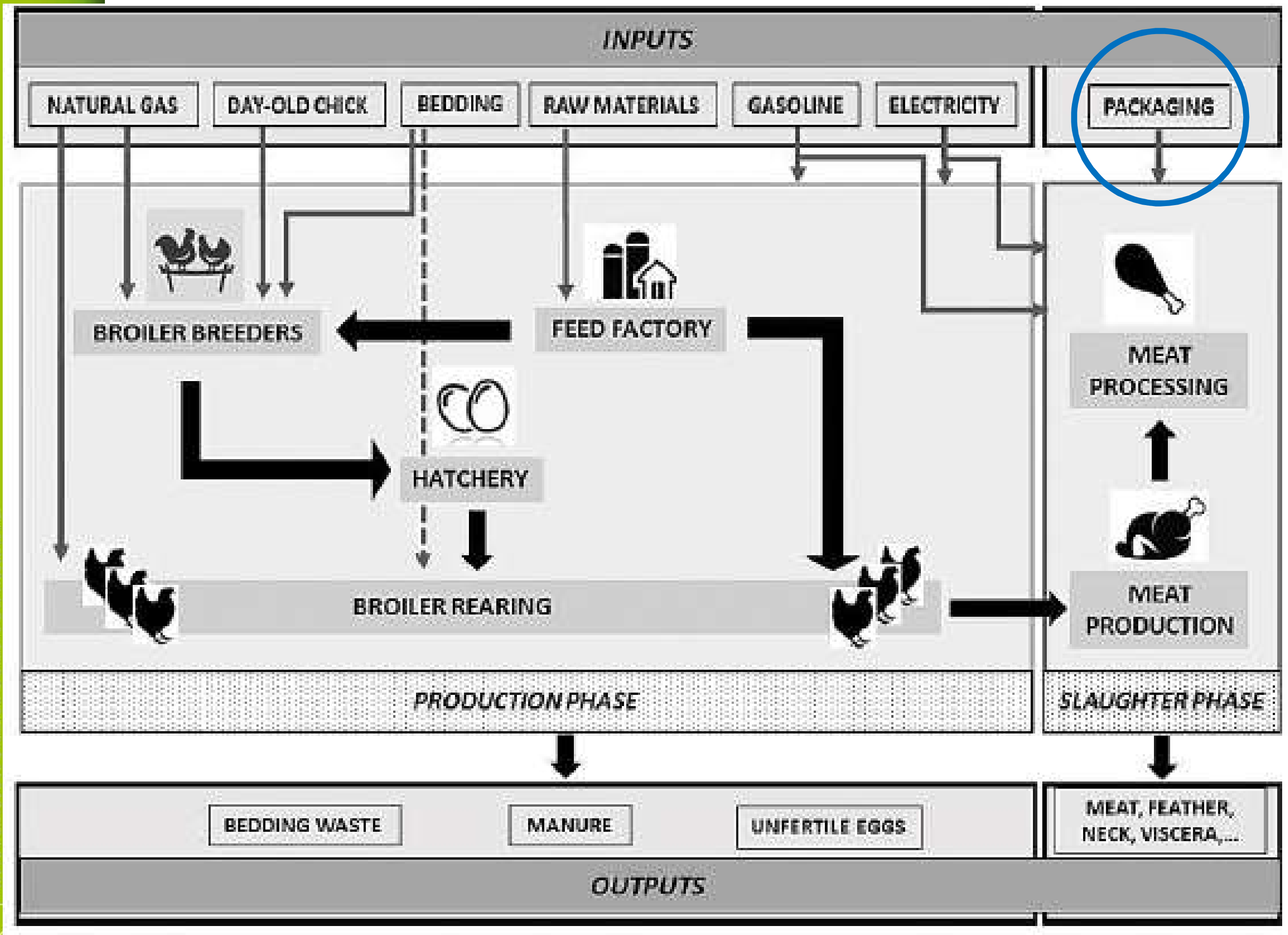
Define the boundaries for which processes in the products life cycle that is included in the LCA

Fig. 1 Flow diagram for tomato production system in a multi-tunnel greenhouse



Torrellas et al., 2012

LCA: system bundary of chicken meat production



System boundary

Cesari et al., 2017

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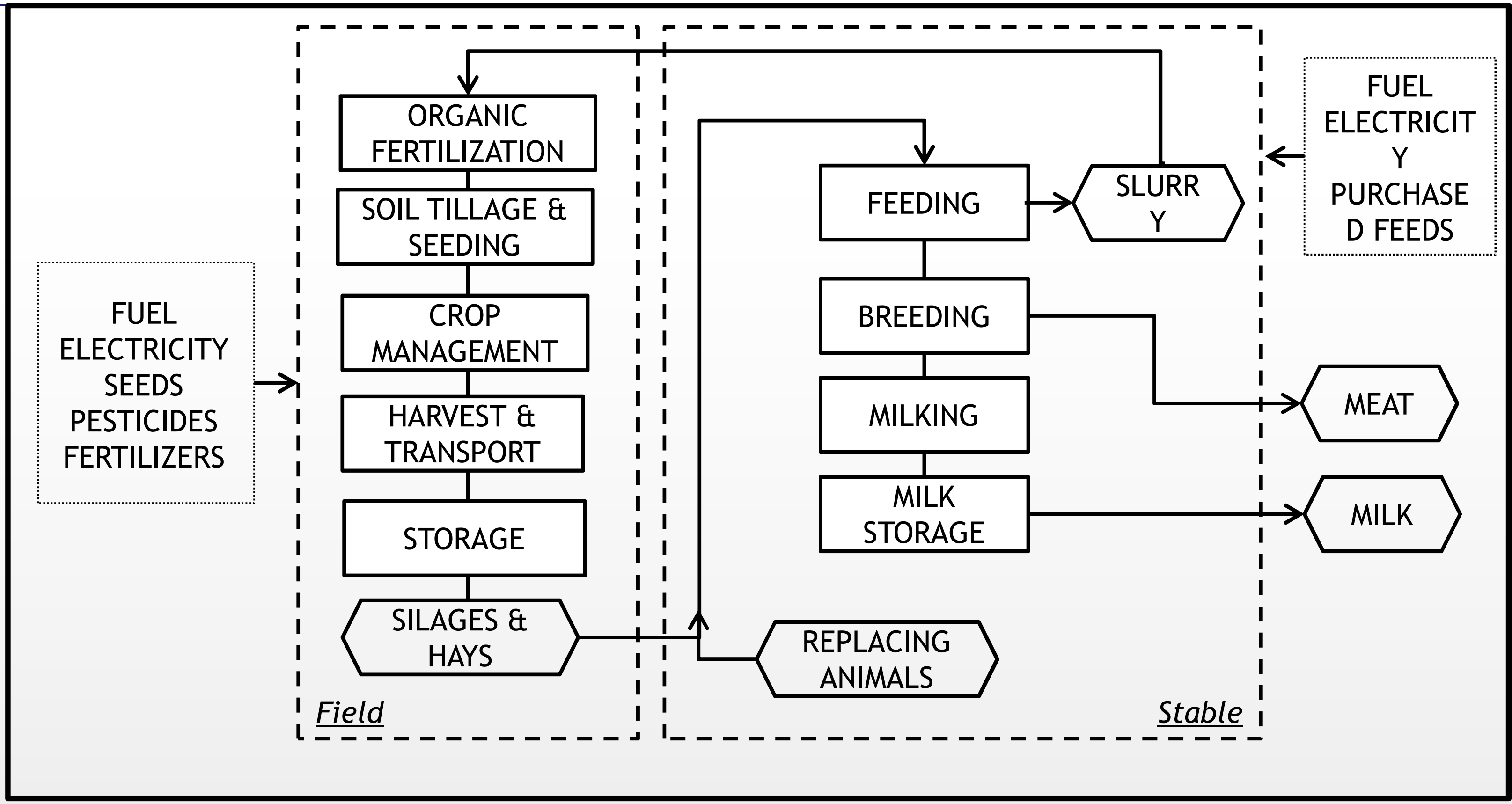
LCA: stage 3

Stage 3. Definition of system boundaries

Our example:

Quantify the environmental impact of cow milk production

Solution



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LCA: system boundary for Grana Padano PDO

System boundary

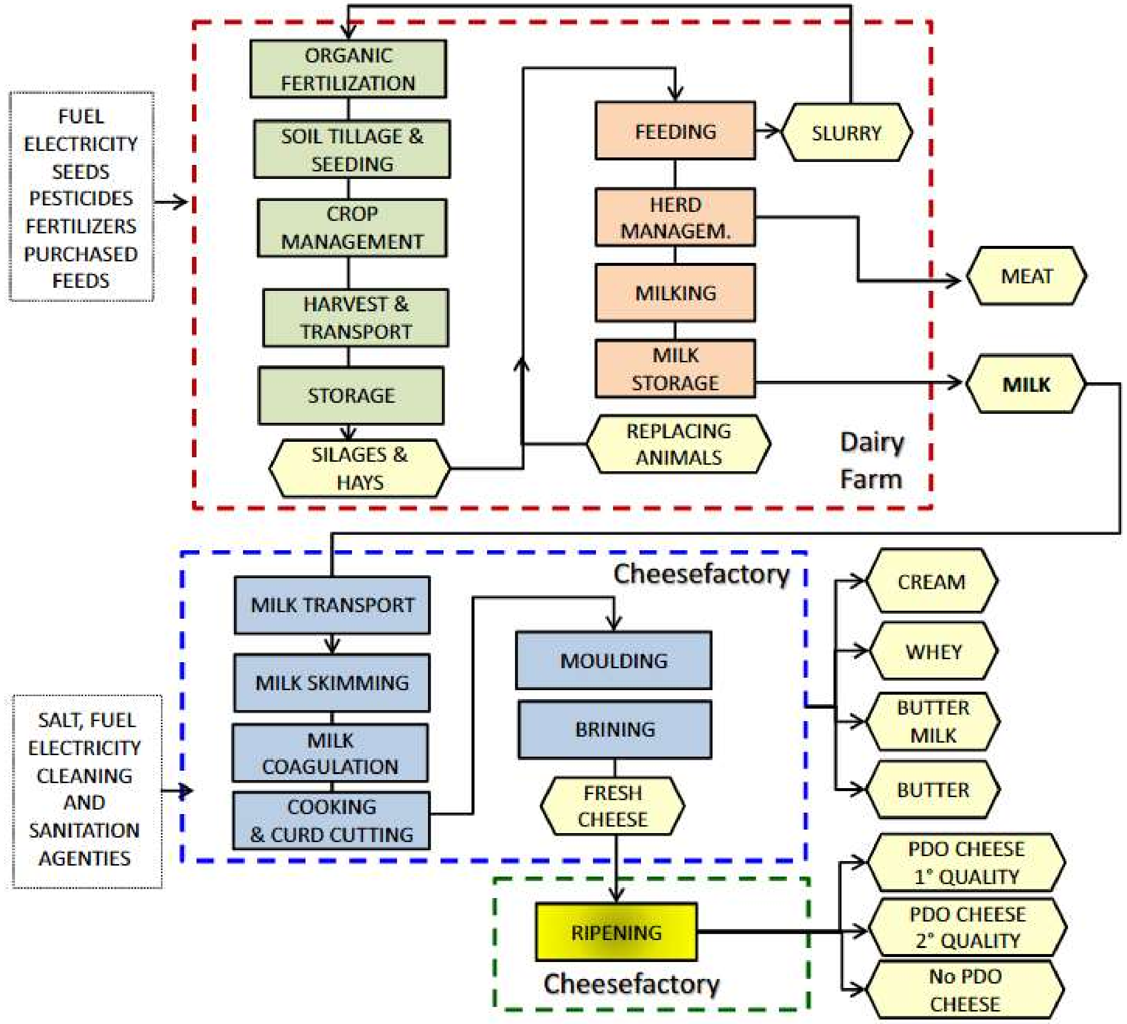

Fig. 2. System boundariy of the Grana Padano PDO production system.

Bava et al., 2018

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LCA: system bundary problems

Sometimes define the system boundary is not easy: how far back should we go?

R. Salomone et al. / Journal of Cleaner Production 140 (2017) 890–905 89

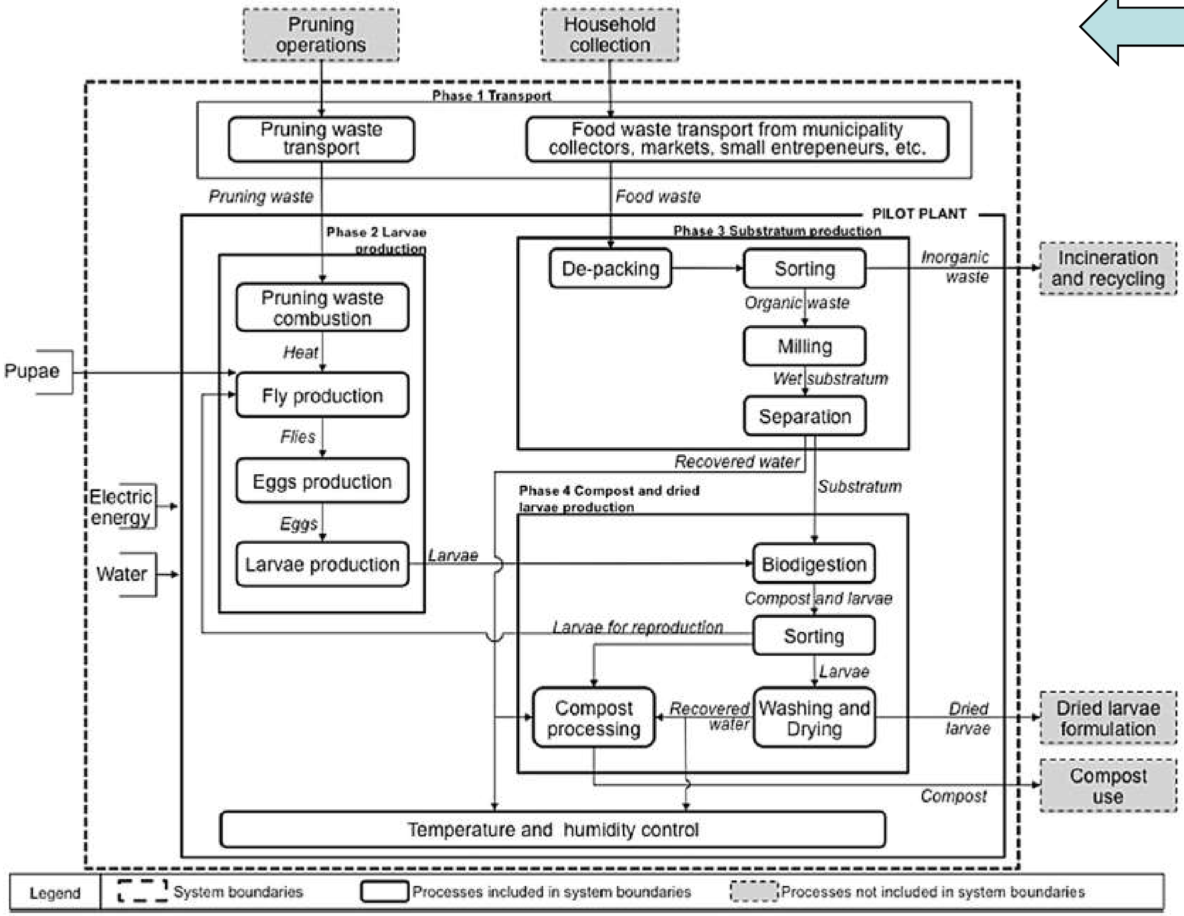


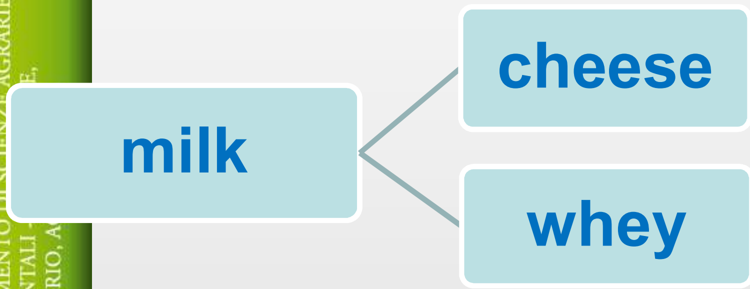
Fig. 2. System boundaries – Food waste bioconversion process.

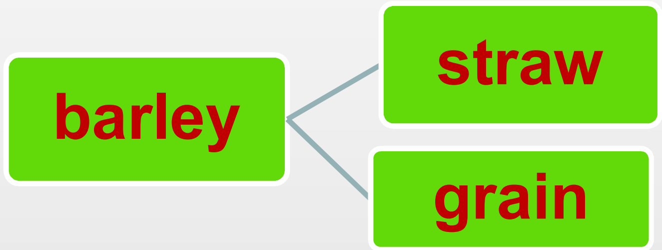
For example when the inclusion of by-products or food waste in a secondary products are considered

LCA: stage 4

Stage 4. Allocation: how to share the impact among product and co-products in multi-ouput processes

Co-product allocation is defined in the ISO standards on LCA as “partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems”





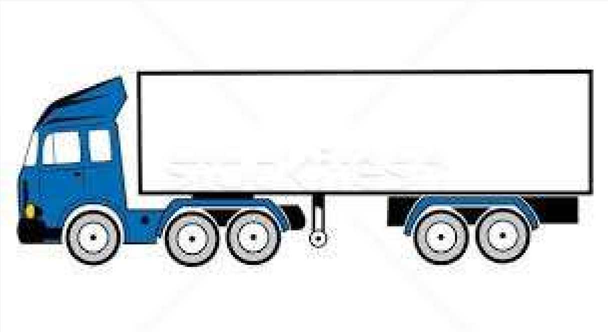
At cheesefactory

At mill

LCA: stage 4

Stage 4.1. Physical allocation

- It is based on physical characteristics, such as mass, dry mass, volume, energy content, and energy input associated with each co-product
- It is useful only for similar products



Problem: evaluate the environmental impact of the transport of 100 cans of beer. If the beer cans are transported together with other beverages, it is possible to divide the burdens related to transport by the relative volume of each type of beverage in the truck.

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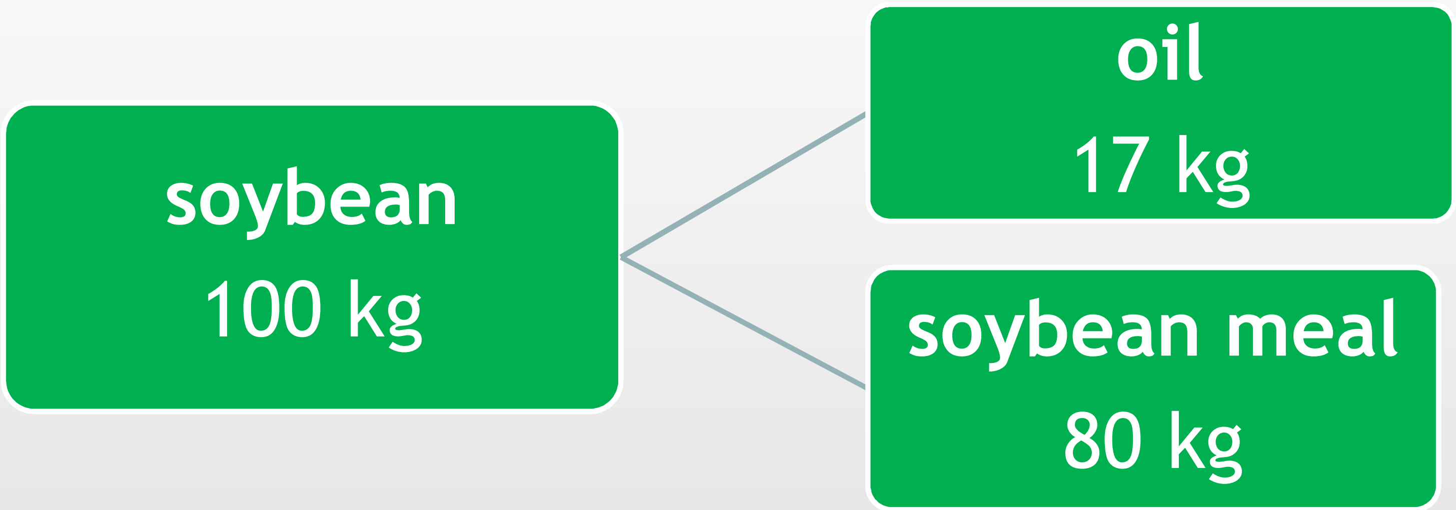
LCA: stage 4

Stage 4.2. Economic allocation

- It is raccomanded method by ISO standard
- Share the impact among product and secondary product based on real price and relative mass



LCA: stage 4

Stage 4.2. Economic allocation (IDF, 2015)

- Equation to calculate economic allocation of

$$AF_{meal} = (X \times A) / (X \times A + Y \times B)$$

AF= allocation factor
X= kg of meal
A= price of meal €/kg
Y= kg of oil
B= price of oil €/kg

AF % = ((80*0.34)/(80*0.34 +17*0.71))*100 = 69

LCA: stage 4

Stage 4.3. Biophysical allocation

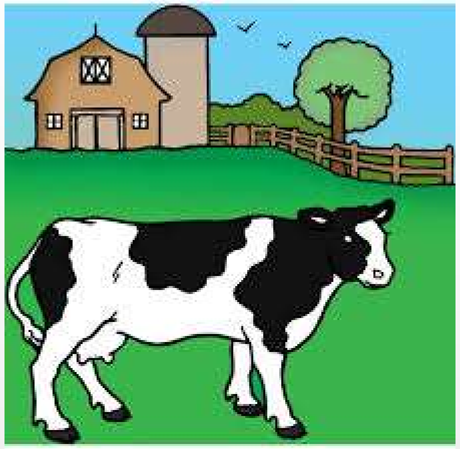
- It is based on underlying physical relationships between the material flows of a system and its products or functions

For milk production IDF (2015) suggest to consider an equation based on the «use of feed energy by dairy animals and physiological feed requirements of the animals to produce milk and meat»

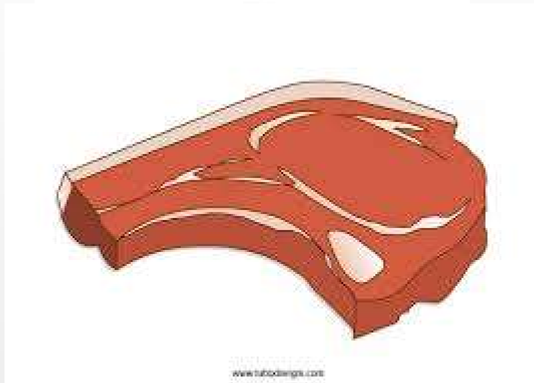
LCA: stage 4

Stage 4.3. Biophysical allocation

Example: milk production



Dairy farm



Meat from calves and culled cows sold or dead

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LCA: stage 4

Stage 4.3. Biophysical allocation

Our example:

Quantify the environmental impact of cow milk production

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LCA: stage 4

Stage 4.3. Biophysical allocation

Example: milk production (IDF, 2015)

$$AF_{milk} = 1 - 6.04 \times BMR$$

Figure 10: Formula for the allocation of milk and meat

AF is the allocation factor for milk; BMR is the ratio M_{meat}/M_{milk}; M_{meat} is the sum of live weight of all animals sold (including bull calves and culled mature animals); and M_{milk} is the sum of milk sold corrected to 4% fat and 3.3% protein (FPCM)

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LCA: stage 4

Stage 4.4 Nutritive allocation

- It is based on nutritive content of product and co-products

	% fat	% protein
Grana Padano PDO before ripening	27	29.7
Butter	83.4	0.8
Whey	0.09	0.75
Butter milk	0.6	3.2
Cream	22	2.6

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LCA stage 4: environmental impact of Grana Padano cheese

- Allocation of cheese and coproducts: three different methods based on dry matter content, economic or nutritive value of cheese

	Unit	Fresh cheese	Whey	Cream	Butter	Buttermilk
Dry matter content[a]	%	61.0	6.0	29.0	82.0	9.0
Dry matter allocation factor (DM_All)	%	46.3	37.9	13.0	1.7	1.0
Market Price	€/kg	5.19[c]	0.04[c]	2.01[d]	3.34[d]	0.18[d]
Economic allocation factor (ECON_All)	%	76.2	4.84	17.3	1.34	0.39
Fat content[b]	%	27.0	0.6	22.0	83.4	0.6
Protein content[b]	%	29.7	0.75	2.60	0.80	3.20
Nutritive allocation factor (NUTR_All)	%	68.7	8.40	19.4	2.80	0.68

[a] Dry matter contents from: fresh cheese and whey (personal communication); cream and buttermilk (Salvadori dal Prato, 2005); butter (CREA, 2016).
[b] Fat and protein contents: fresh cheese and whey (personal communication); cream (Salvadori dal Prato, 2005); butter (CREA, 2016); buttermilk (Mucchetti and Neviani, 2006).
[c] Cheese factory owner communication.
[d] Clal (2017).

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Environmental impact of Grana Padano cheese: results

Results

Environmental impacts of 1 kg of Grana Padano considering different allocation methods.

Impact category	Unit	Allocation		
		DM_All	ECON_All	NUTR_All
Climate change	kg CO_2 eq	10.3	16.9	15.2
Ozone depletion	g CFC-11 eq	0.00094	0.00154	0.0014
Particulate matter formation	g PM2.5 eq	5.669	9.312	8.406
Photochemical ozone formation	kg NMVOC eq	0.023	0.037	0.03
Terrestrial acidification	molc H+ eq	0.190	0.312	0.28
Terrestrial eutrophication	molc N eq	0.823	1.353	1.22
Freshwater eutrophication	g P eq	0.820	1.341	1.21
Marine eutrophication	g N eq	63.25	104.0	93.87
Freshwater ecotoxicity	CTUe	29.20	48.0	43.3
Mineral, fossil & ren resource depletion	g Sb eq	0.065	0.11	0.096

Milk production was the most important contributor to all impact categories: from 93.5% for freshwater eutrophication to 99.6% for terrestrial eutrophication. For climate change, milk production represented 95.6% of the total impact of cheese

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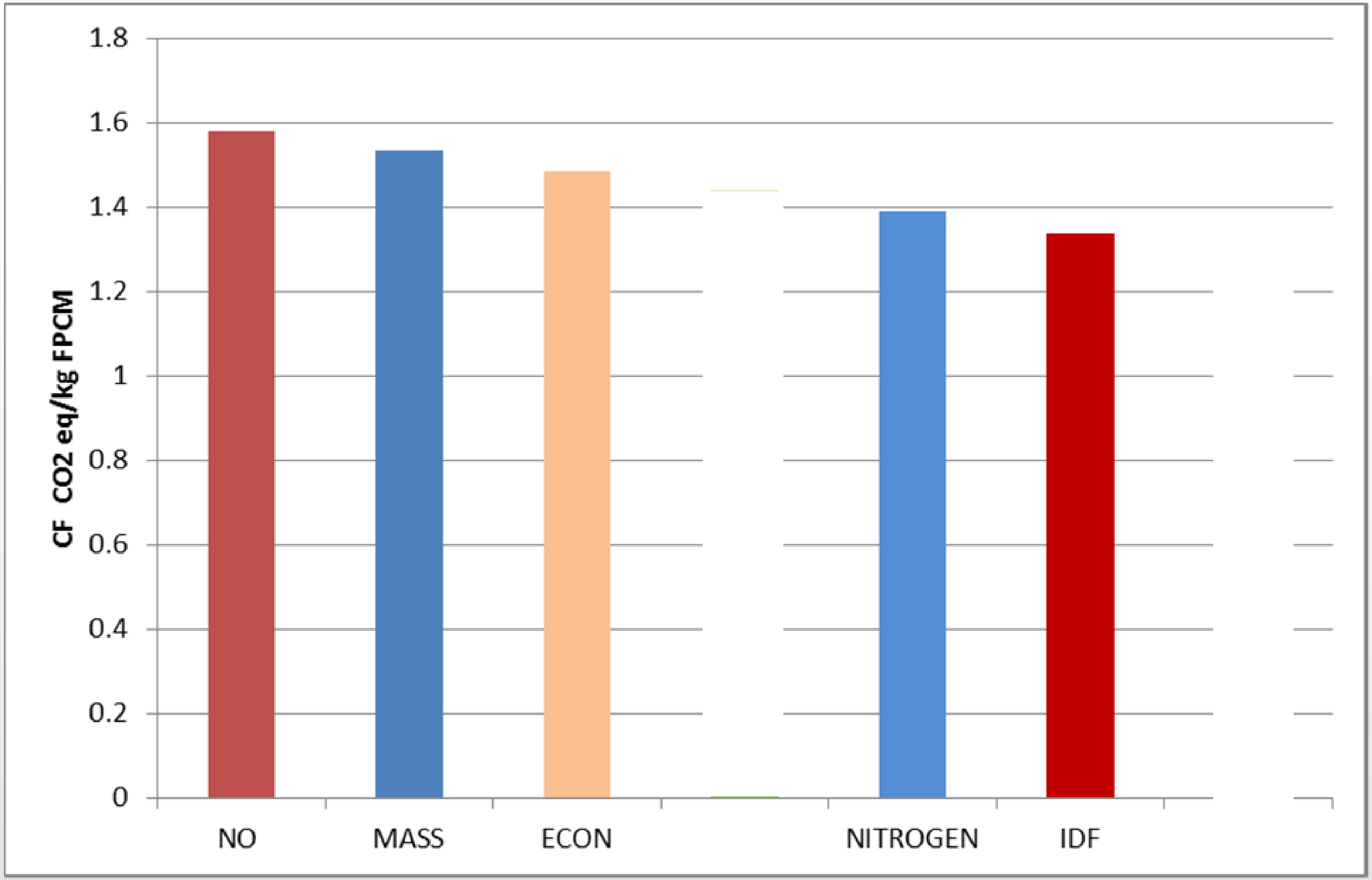
Carbon footprint of milk production change considering different allocation methods



LCA: stage 4

To know more about allocation methods:

https://www.pre-sustainability.com/news/finding-your-way-in-allocation-methods-multifunctional-processes-recycling

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LCA: stage 5

Stage 5. Inventory analysis

Inventory analysis gives a description of material and energy flows within the product system and especially its interaction with environment, consumed raw materials, and emissions to the environment. All important processes and subsidiary energy and material flows are described

More accurate the collection of inventory data, more accurate the impact estimate will be

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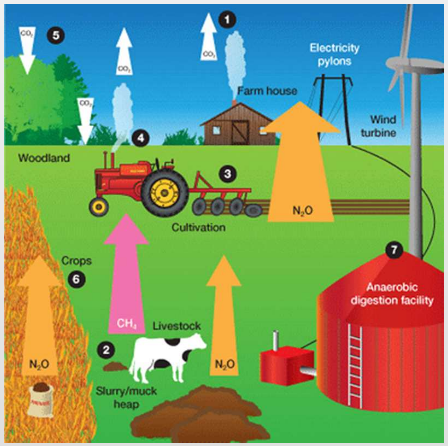
LCA: stage 5- Emissions

For calculation of emissions (CH_4, NO_2, NH_3…) from animals and manure:

-equation of IPCC
-equation of EEA
-other equations specially for enteric methane emission based on feed intake and feed ration composition

IPCC considered three different levels of complexity



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LCA: stage 5- Emissions

Equation of IPCC

IPCC considered three different level of methodological complexity

Tier 1 is the basic method

Tier 2 intermediate

Tier 3 the most demanding in terms of complexity and data requirements

Tiers 2 and 3 are generally considered to be more accurate on condition that adequate data are available to develop, evaluate and apply a higher tier method

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LCA: stage 5

Stage 5. Inventory analysis

Our example:

Quantify the potential environmental impact of cow milk production

LCA: stage 5 inventory analysis for milk production

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Input

- forage and crop production: land and yield
- manure and livestock management (type of housing, bedding material)
- purchased feed: type and quantity (forages and raw feed materials, compound feeds)
- external inputs fertilisers, pesticides
- energy and fuels consumption
- purchased animals
- transport of the inputs
- …

Output

- milk
- meat
- energy
- …

Inventory analysis for LCA of organic and conventional milk production

Overview inventory data used in inventory analysis

	Element	Computation method[a]	Included factors	References[b]
Off farm[c]	Purchased pesticides	$Q *$ LCI/kg active matter	Production/ transport	Brand and Melman (1993)
	Purchased artificial fertilizer	$Q *$ LCI/kg artificial fertilizer	Production/ transport	Davis and Haglund (1999)
	Purchased concentrates	$Q *$ LCI/kg concentrates	Crop cultivation[d]	FAO (2002/2003), Cederberg (1998), CVB (2000)
			Crop processing	Brand and Melman (1993), Cederberg (1998)
			Transport	Cederberg (1998), Michaelis (1998), WPD (2003)
	Purchased roughage and bedding material	$Q *$ LCI/kg roughage	Crop cultivation	Dekkers (2001), LEI (2004), Koroneos et al. (2005)
			Transport	Cederberg (1998), Michaelis (1998)
	Purchased animals	$Q *$ LCI/animal	Breeding[e]	Tamminga et al. (2000), Oenema et al. (2000)
			Transport	Cederberg (1998), Michaelis (1998)
	Purchased animal manure	$Q *$ LCI/kg manure	Transport	Brand and Melman (1993)
	Contract work	$Q *$ LCI/litre diesel	Diesel use	Brand and Melman (1993), Hanegraaf et al. (1996)
On farm	Use of diesel	$Q *$ LCI/litre diesel	Supply and use	Michaelis (1998)
	Use of electricity	$Q *$ LCI/kW h electricity	Supply and use	Michaelis (1998), EnergieNed (2002), CertiQ (2003)
	Use of gas	$Q *$ LCI/m^3 gas	Supply and use	Michaelis (1998)
	Use of water	$Q *$ LCI/m^3 water	Electricity supply	Michaelis (1998), EnergieNed (2002)
On/off	Emissions of CH_4	Fixed values animals	Enteric + manure	Schils et al. (2006)
	Emissions of NH_3 and NO_x	Fixed values animals[f] and spreading of fertilizer	Stable/pasture/ deposit/spreading	Oenema et al., 2000, Van Geel (2004), Van der Hoek (2002), Mosier et al. (1998)
	Emissions of N_2O	Fixed values animals/soil	Direct and indirect	Mosier et al. (1998), Oenema et al. (2000)
	Leaching of NO_3 and PO_4	Farm-gate balance and soil surface balance	Net N-leaching factors	Schröder et al. (2005)
			Inputs and outputs	Van Eerdt and Fong (1998)

Thomassen et al., 2008

LCA: stage 5 inventory analysis for goat milk production

Main inventory data of the studied farms.

Variable	Unit	Mean	SD	Min	Max
Input					
Dairy goats	n	200	108	62	450
Straw purchased	t DM/year	33.3	21.9	0	80
Forages purchased	t DM /year	80.1	112.5	0	380
Concentrate feed purchased	t DM /year	78.7	75.3	0	330
Mineral fertiliser	t/year	2.54	6.92	0	27
Diesel	l/year	4993	4932	0	18,000
LPG	l/year	612.5	2021	0	8000
Electricity	kWh/year	31,676	13,950	15,000	60,000
Output					
Milk sold	kg FPCM/ year	138,506	81,088	28,245	363,971
Individual milk sold	kg FPCM/ year	711	269	302	1144
Fat	%	3.85	0.22	3.4	4.38
Protein	%	3.60	0.24	3.15	4.00
Meat sold	kg/year	2842	1496	540	5400

Zucali et al., 2020

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LCA: stage 6

Stage 6. Impact assessement

“The life cycle impact assessement is the evaluation of potential human health and environmental impacts of the environmental resources and releases identified during the inventory”

Environmental impact = consequences of pollution, e.g. eutrophication and depletion of stratospheric ozone

The indicator of results are impact categories that summerize and categorize the environmental impact

Characterization factors help to convert emission into categories → characterization

LCA: stage 6

Stage 6. Impact assessement example

Global warming potential (GWP): indicator of potential global warming due to emissions of greenhouse gases to air

Unit of measure of GWP: kg CO_2 eq

100-Year Global Warming Potential

1 kg of substance	GWP* (CO_2-eq)
Carbon Dioxide	1
Carbon Tetrachloride	1400
CFC 12	10,900
Chloroform	31
Methane	25
Methyl Bromide	5
Nitrous Oxide	298
1,1,1-Trichloroethane	146

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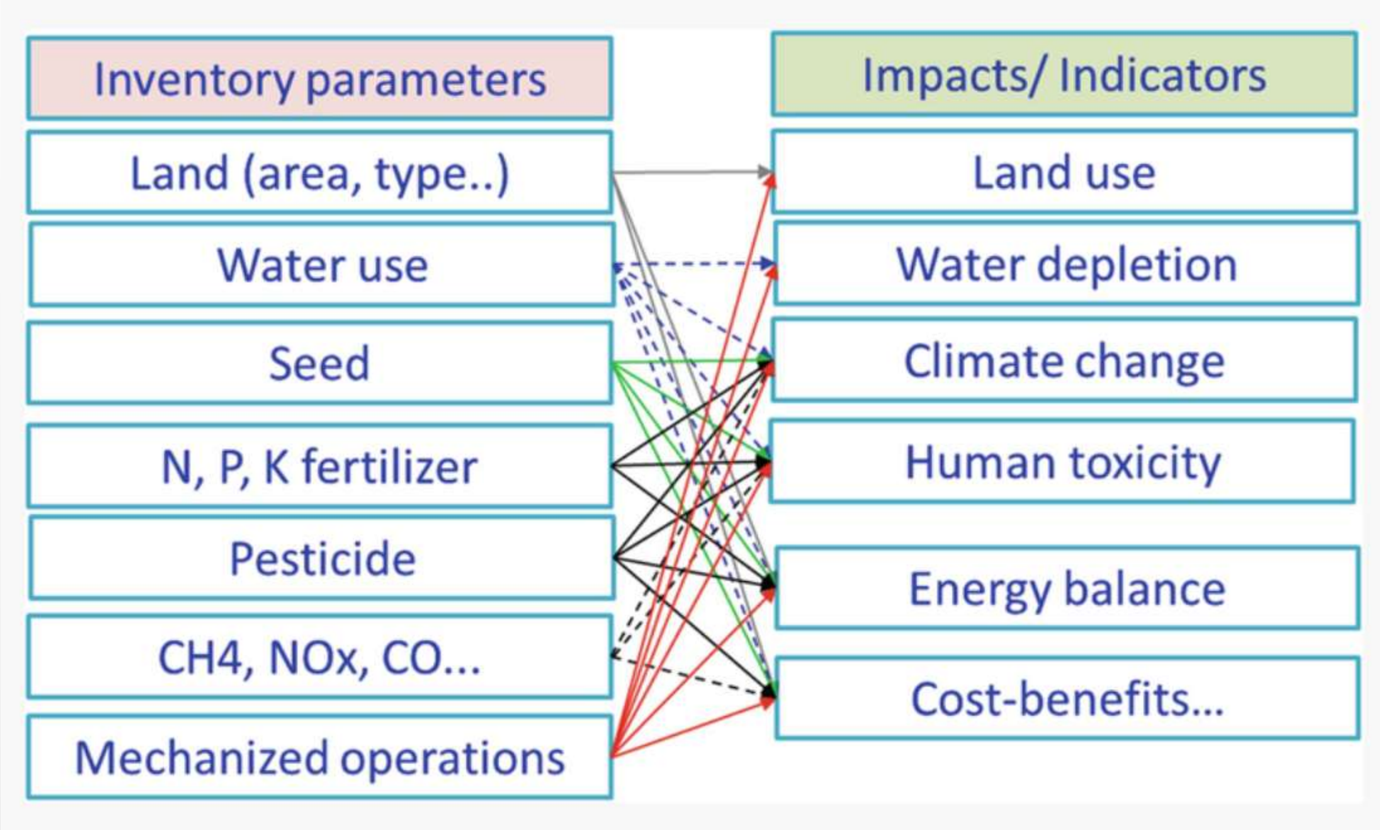
LCA: stage 6

Stage 6. Impact assessement



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LCA: stage 6

Stage 6. Impact assessement example

Acidification potential (kg SO_2 eq.)	AP, CML 2001 **non-baseline** (fate not included), Version: January 2016. *Please notice the use of non-baseline characterisation factors for acidification potential.*	Hauschild & Wenzel (1998)	1 kg ammonia = 1.88 kg SO_2 eq. 1 kg nitrogen dioxide = 0.7 kg SO_2 eq. 1 kg sulphur dioxide = 1 kg SO_2 eq.
Eutrophication potential (kg PO_4^{3-} eq.)	EP, CML 2001 **baseline** (fate not included), Version: January 2016.	Heijungs et al. (1992)	1 kg phosphate = 1 kg PO_4^{3-} eq. 1 kg ammonia = 0.35 kg kg PO_4^{3-} eq. 1 kg COD (to freshwater) = 0.022 kg kg PO_4^{3-} eq.

https://www.environdec.com/

LCA: stage 6

Stage 6. Impact assessement

There are different methods to calculate the impact categories, each methods could give a different weight to substance and could assume different categories

Software to calculate impact categories:
Simapro
Gabi
C calculator…

https://www.environdec.com/

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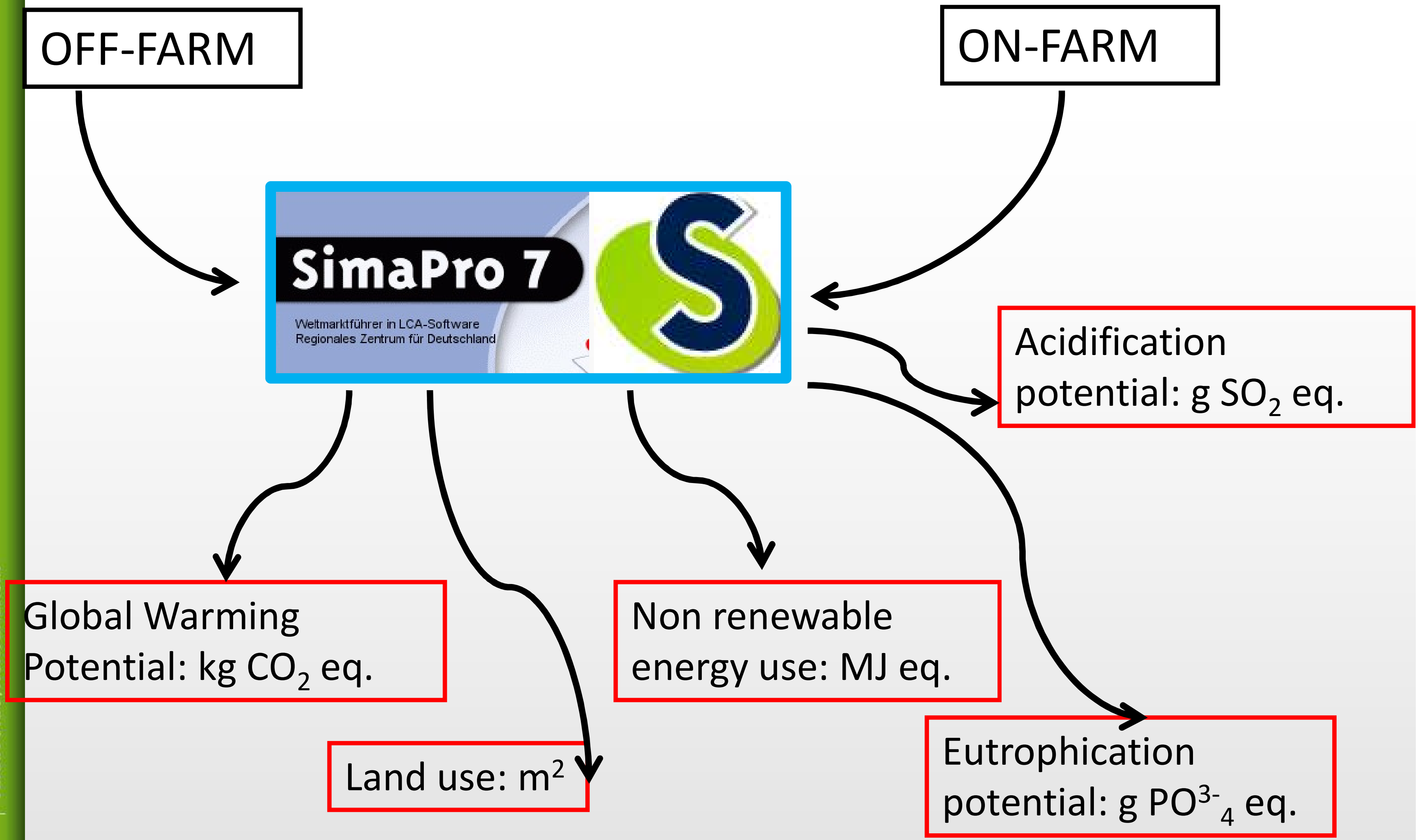
Impact assessement



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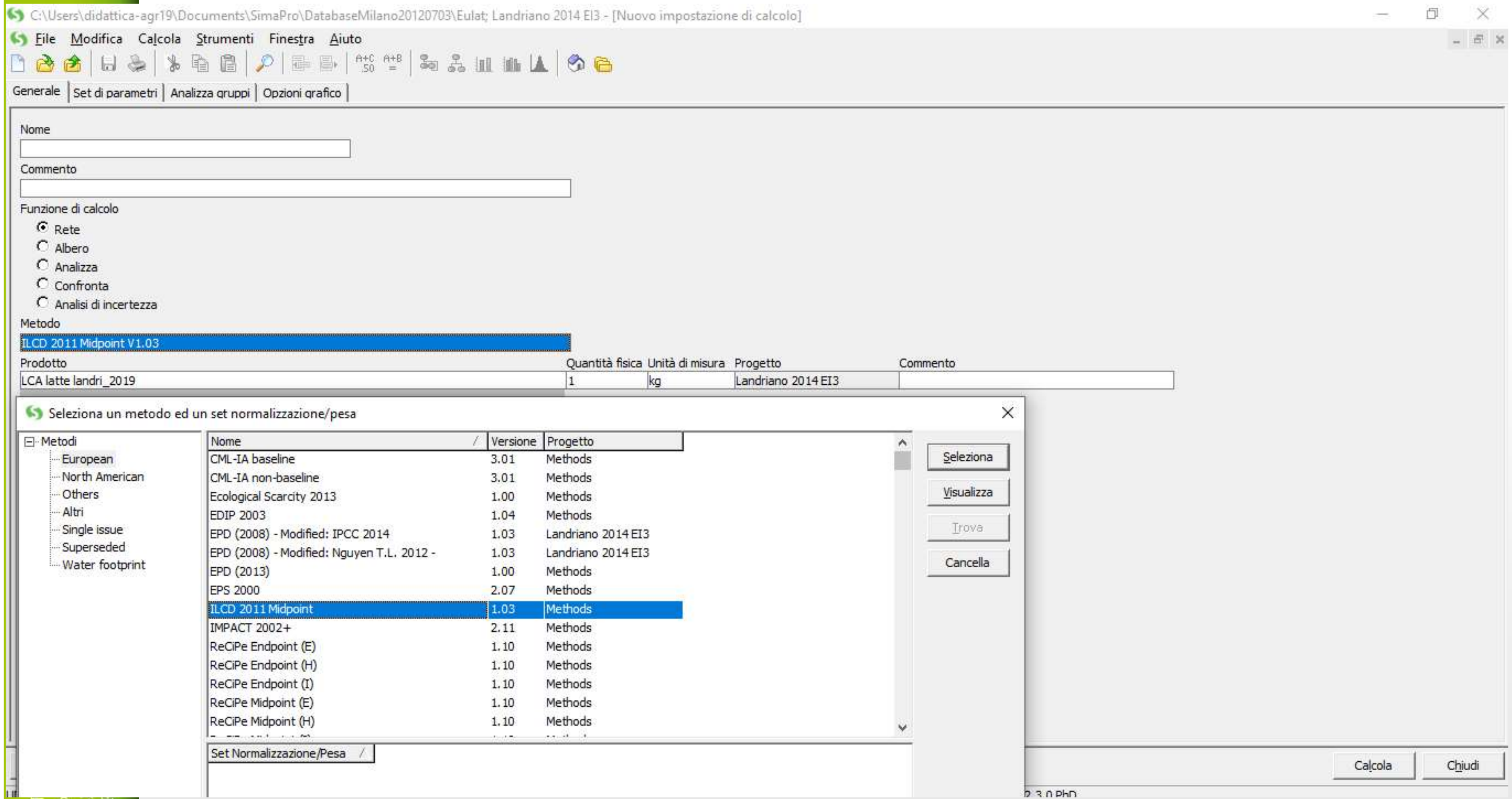
Methods implemented into Simapro Software



LCA: stage 6

Stage 6. Impact assessement

Simapro

A video tutorial

https://www.youtube.com/watch?v=rV6pkNimP9k 2.49

https://www.youtube.com/watch?v=ruL0IaNNmWY 3

https://www.environdec.com/

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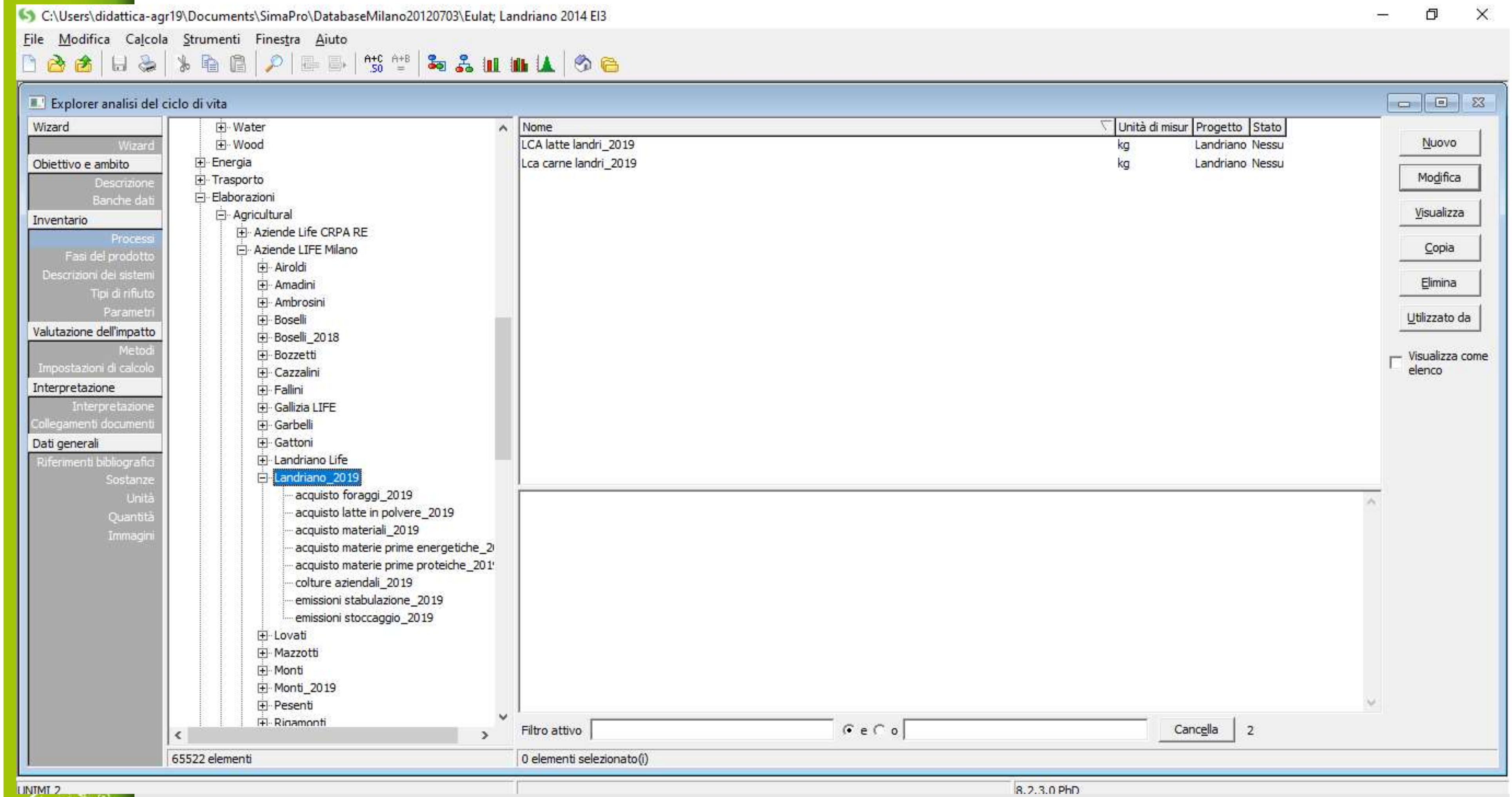
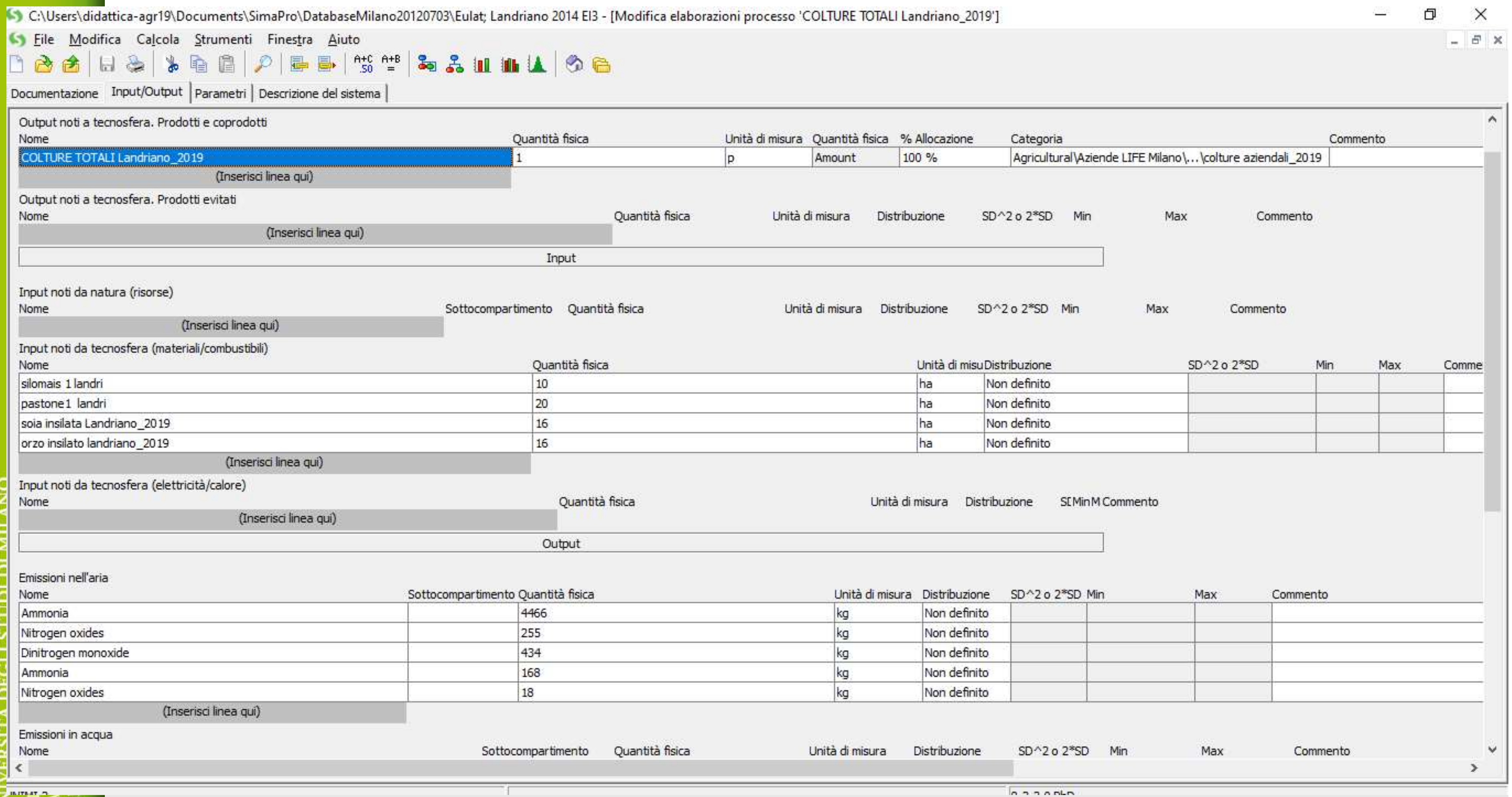
Quantify the potential environmental impact of cow milk production: create the project



Quantify the potential environmental impact of cow milk production: data entry



Quantify the potential environmental impact of cow milk production: details of a specific crop

C:\Users\didattica-agr19\Documents\SimaPro\DatabaseMilano20120703\Eulat; Landriano 2014 EI3 - [Modifica materiali processo 'silomais 1 landri']

File Modifica Calcola Strumenti Finestra Aiuto

Documentazione | Input/Output | Parametri | Descrizione del sistema

Output noti a tecnosfera. Prodotti e coprodotti

Nome	Quantità fisica	Unità di misura	Quantità fisica	% Allocazione	Tipo rifiuto	Categoria	Commen
silomais 1 landri	1	ha	Area	100 %		Agricultural\LIFE Forage4Climate\Milano\colture\mais	Landriar
(Inserisci linea qui)							

Output noti a tecnosfera. Prodotti evitati

Nome	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
(Inserisci linea qui)							

Input

Input noti da natura (risorse)

Nome	Sottocompartimento	Quantità fisica	Unità di misura	Distribuzione	SD^2 o 2*SD	Min	Max	Commento
Occupation, arable	in ground	1	ha a	Non definito				
(Inserisci linea qui)								

Input noti da tecnosfera (materiali/combustibili)

Nome	Quantità fisica	Unità di misu	Distribuzione	SD^2 o 2*SD	Min	Max	Comme
Tillage, ploughing Landriano	1	ha	Non definito				
Tillage, harrowing, by rotary harrow Landriano	1	ha	Non definito				
Maize seed IP, at regional storehouse/CH U	20	kg	Non definito				Bocchi
Sowing Landriano	1	ha	Non definito				
Tillage, currying, by weeder/CH U	1	ha	Non definito				
Fertilising, by broadcaster Landriano	1	ha	Non definito				
Urea, as N, at regional storehouse/RER U	150*46/100 = 69	kg					
Di ammonium phosphate, as 100% (NH3)2HPO4 (NPK 22-57-0), at plant/RER Economic	0	kg	Non definito				
Application of plant protection products, by field sprayer Landriano	1	ha	Non definito				Diserbo
Application of plant protection products, by field sprayer Landriano	0	ha	Non definito				
Acetamide-anillide-compounds, at regional storehouse/RER U	12000/12 = 1E3	g					
Triazine-compounds, at regional storehouse/RER U	1440/12 = 120	g					
Slurry spreading, sistema ombelicale Landriano	960/12 = 80	m3					
Irrigazione scorrimento con turbina Landriano	1.5	ha	Non definito				
Combine harvesting Landriano	1	ha	Non definito				
Transport, tractor and trailer Landriano	60*0.8 = 48	tkm					
Insilamento trincea Landriano	60	ton	Non definito				
(Inserisci linea qui)							

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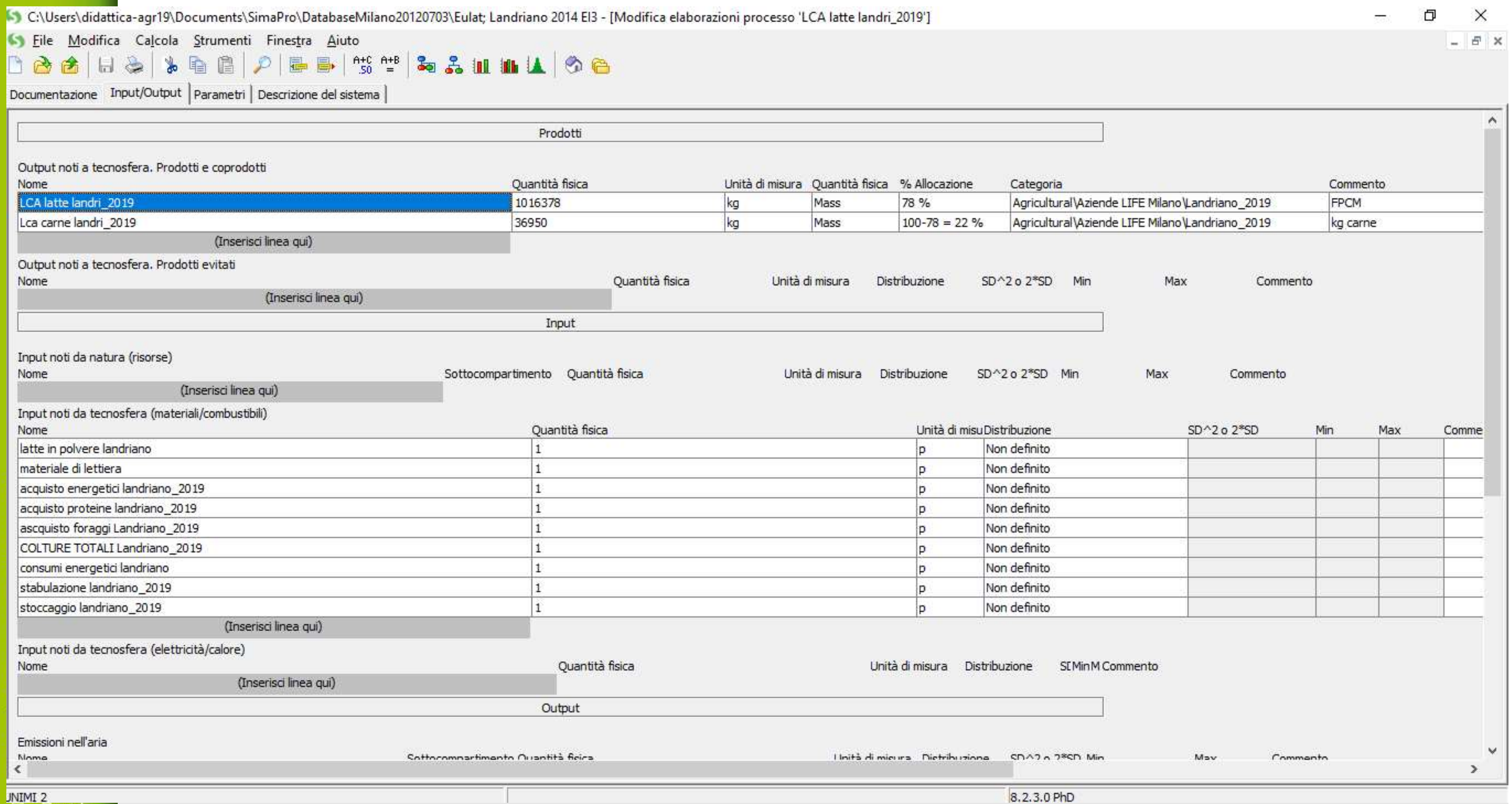
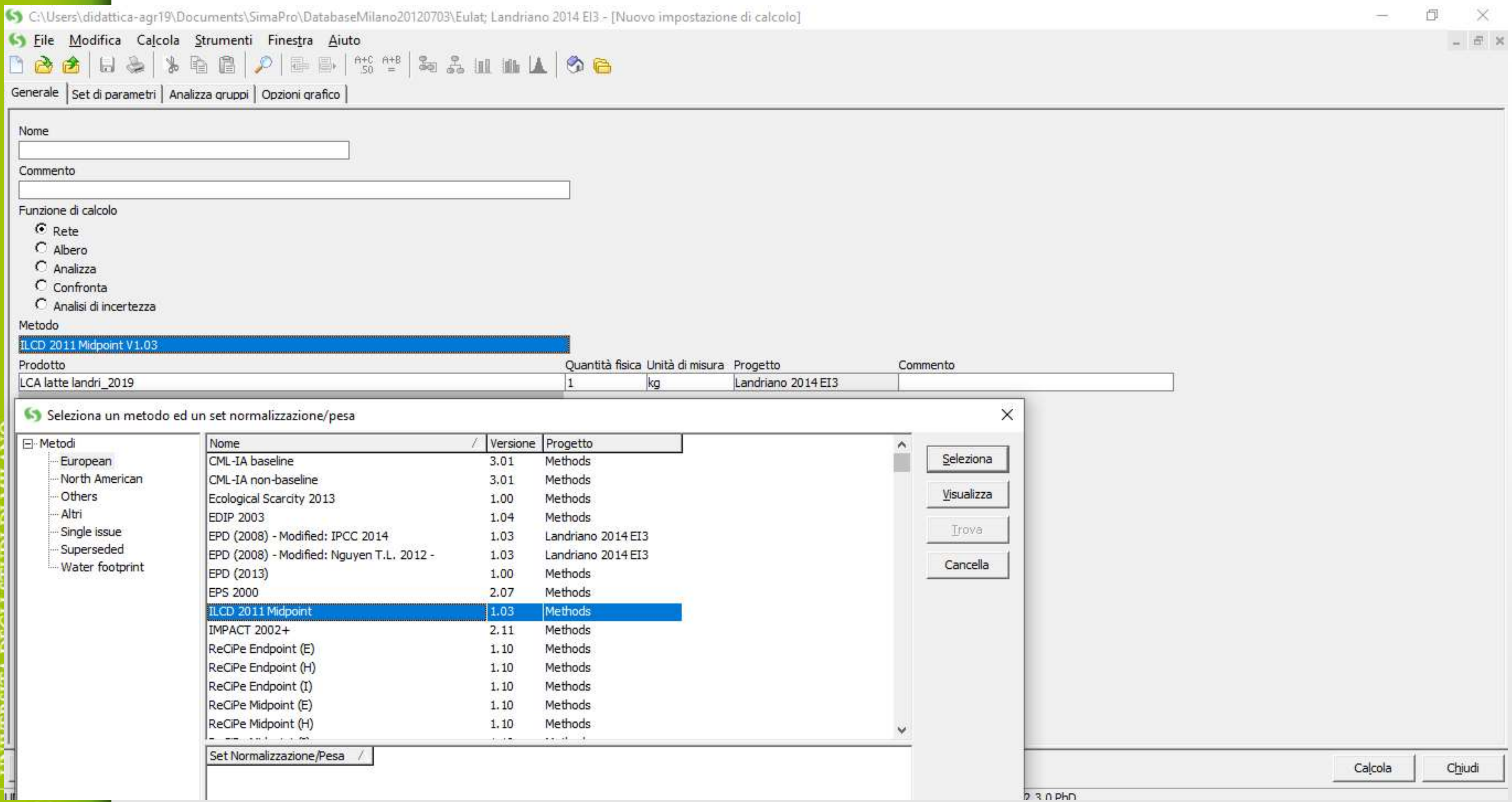
Quantify the potential environmental impact of cow milk production: final



Quantify the potential environmental impact of cow milk production: choice of method to calculate impact categories



Quantify the potential environmental impact of cow milk production: final results

Rete | Albero | Valutazione dell'impatto | Inventario | Contributo processo | Impostazione di calcolo | Controlli (633) | Panoramica del prodotto

Caratterizzazione

Ignora categorie: Mai

Standard / Gruppo

Unità predefinite
Escludere il lungo termine
Per ogni categoria d'impatto

Sele	Categoria d'impatto	Unità	Totale	LCA latte landri_2019	latte in polvere landriano	materiale di lettiera	acquisto energetici landriano_2019
☑	Climate change	kg CO2 eq	1.39	x	0.0315	0.00308	0.102
☑	Ozone depletion	kg CFC-11 eq	3.42E-8	x	4.19E-9	8.19E-11	8.3E-9
☑	Human toxicity, cancer effects	CTUh	1.14E-8	x	1.27E-11	6.76E-10	3.48E-9
☑	Human toxicity, non-cancer effects	CTUh	5.82E-7	x	1.45E-10	1.81E-9	1.11E-9
☑	Particulate matter	kg PM2.5 eq	0.000675	x	8.9E-6	1.35E-6	4.11E-5
☑	Ionizing radiation HH	kBq U235 eq	0.0182	x	0.000234	6.69E-5	0.00941
☑	Ionizing radiation E (interim)	CTUe	5.59E-8	x	4.38E-10	2.02E-10	2.8E-8
☑	Photochemical ozone formation	kg NMVOC eq	0.00188	x	5.07E-5	1.38E-5	0.00028
☑	Acidification	molc H+ eq	0.0283	x	0.000414	3.26E-5	0.00116
☑	Terrestrial eutrophication	molc N eq	0.125	x	0.00187	8.27E-5	0.00492
☑	Freshwater eutrophication	kg P eq	4.41E-5	x	1.93E-6	4.71E-7	1.54E-5
☑	Marine eutrophication	kg N eq	0.0088	x	0.000195	2.69E-5	0.00118
☑	Freshwater ecotoxicity	CTUe	1.1	x	0.00177	0.0147	0.284
☑	Land use	kg C deficit	16.4	x	0.134	0.34	1.19
☑	Water resource depletion	m3 water eq	0.0712	x	0.000216	0.000173	0.0278
☑	Mineral, fossil & ren resource depletion	kg Sb eq	4.12E-6	x	4.85E-8	1.81E-8	9.42E-7

Rete | Albero | Valutazione dell'impatto | Inventario | Contributo processo | Impostazione di calcolo | Controlli (633) | Panoramica del prodotto

Caratterizzazione

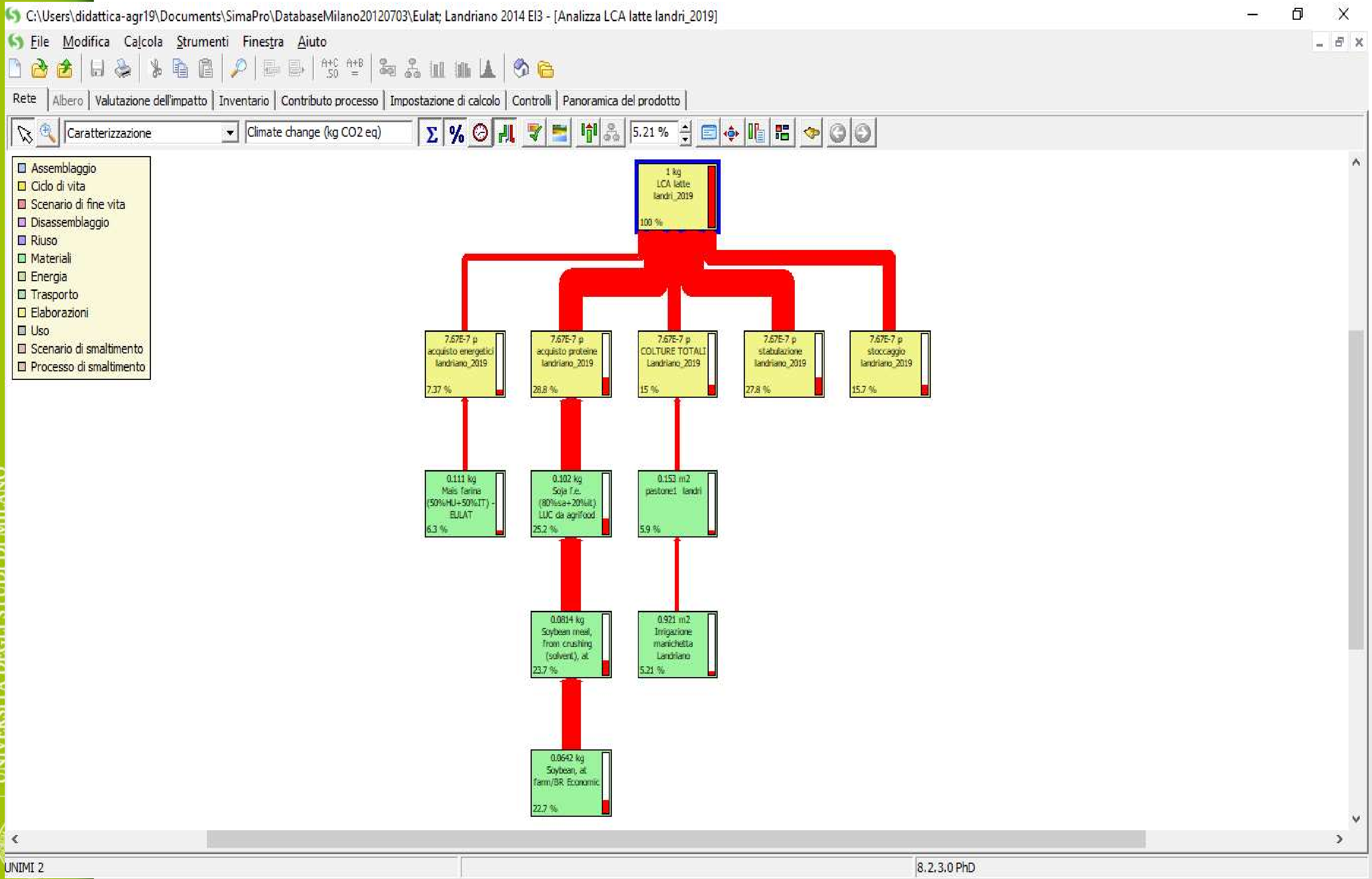
Ignora categorie: Mai

Standard / Gruppo

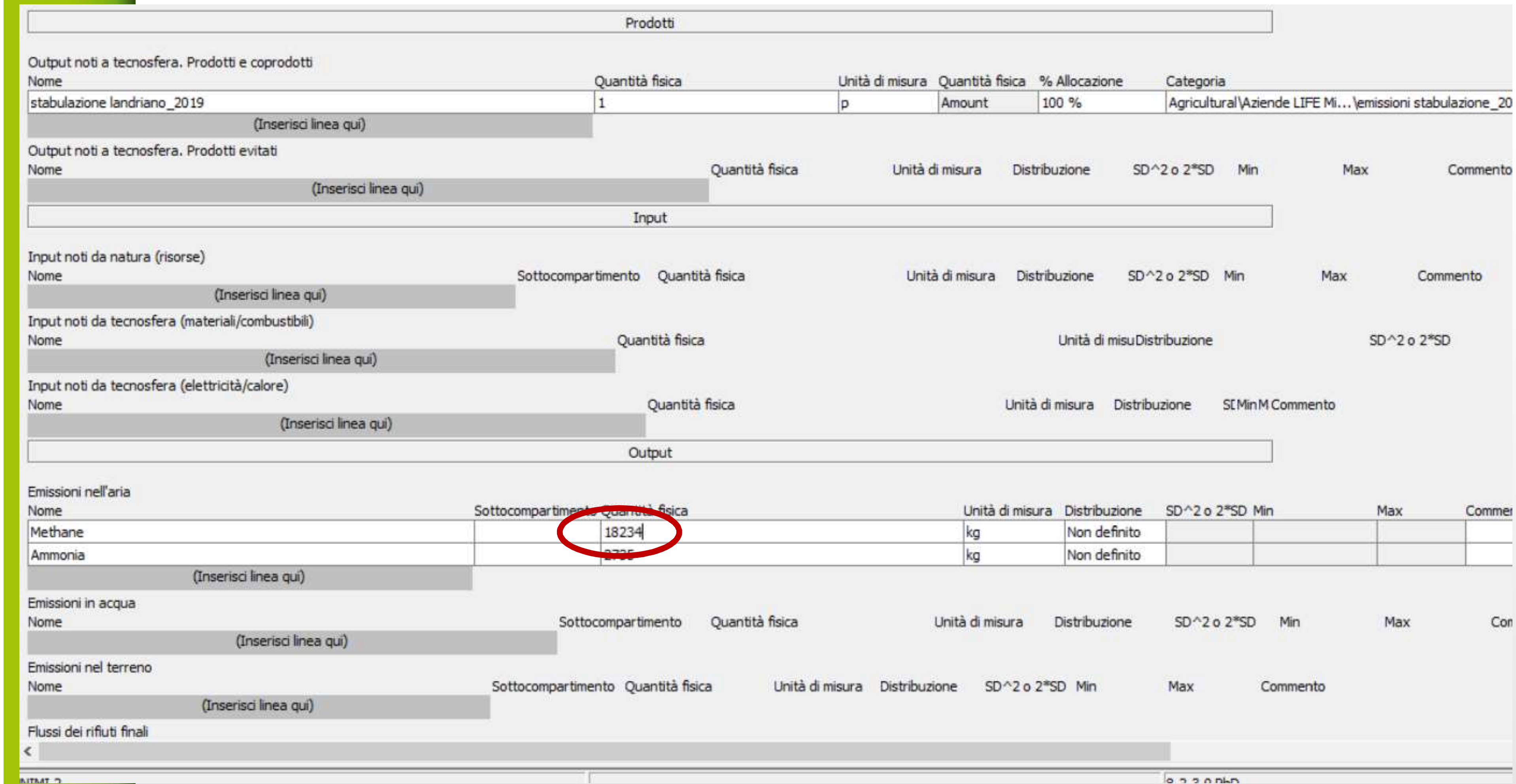
Unità predefinite
Escludere il lungo termine
Per ogni categoria d'impatto

materiale di lettiera	acquisto energetici landriano_2019	acquisto proteine landriano_2019	ascquisto foraggi Landriano_2019	COLTURE TOTALI Landriano_2019	consumi energetici landriano	stabulazione landriano_2019	stoccaggio landriano_2019
0.00308	0.102	0.401	0.0347	0.209	0.00362	0.386	0.218
8.19E-11	8.3E-9	4.17E-9	5.17E-9	9.48E-9	2.81E-9	x	x
6.76E-10	3.48E-9	4.83E-9	3.01E-10	1.97E-9	9.11E-11	x	x
1.81E-9	1.11E-9	4.98E-7	3E-9	7.77E-8	2.99E-10	x	x
1.35E-6	4.11E-5	7.39E-5	9.27E-6	0.000269	1.62E-6	0.00014	0.00013
6.69E-5	0.00941	0.00345	0.000562	0.00397	0.000535	x	x
2.02E-10	2.8E-8	1.23E-8	1.59E-9	1.21E-8	1.26E-9	x	x
1.38E-5	0.00028	0.000504	0.000106	0.000653	1.78E-5	0.000156	9.56E-5
3.26E-5	0.00116	0.00274	0.000378	0.0113	2.53E-5	0.00634	0.0059
8.27E-5	0.00492	0.0116	0.00166	0.0504	4.09E-5	0.0283	0.0264
4.71E-7	1.54E-5	7.06E-6	1.23E-6	1.77E-5	3.13E-7	x	x
2.69E-5	0.00118	0.00125	0.000563	0.0052	3.8E-6	0.000193	0.000193
0.0147	0.284	0.599	0.0156	0.178	0.00585	x	x
0.34	1.19	8.69	0.883	5.17	0.033	x	x
0.000173	0.0278	0.0238	0.00125	0.0174	0.000593	x	x
1.81E-8	9.42E-7	1.69E-6	1.96E-7	1.21E-6	1.42E-8	x	x

Quantify the potential environmental impact of cow milk production: final results, details of GWP



Environmental impact of milk production from Menozzi farm: choice of equation for methane emission



Environmental impact of milk production from Menozzi fa choice of equation for methane emission

File Modifica Calcola Strumenti Finestra Aiuto

Rete | Albero | Valutazione dell'impatto | Inventario | Contributo processo | Impostazione di calcolo | Controlli (633) | Panoramica del prodotto

Caratterizzazione

Ignora categorie: Mai

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☑	Ionizing radiation E (interim)	CTUe	5.59E-8	x	4.38E-10	2.02E-10	2.8E-8
☑	Photochemical ozone formation	kg NMVOC eq	0.00186	x	5.07E-5	1.38E-5	0.00028
☑	Acidification	molc H+ eq	0.0283	x	0.000414	3.26E-5	0.00116
☑	Terrestrial eutrophication	molc N eq	0.125	x	0.00187	8.27E-5	0.00492
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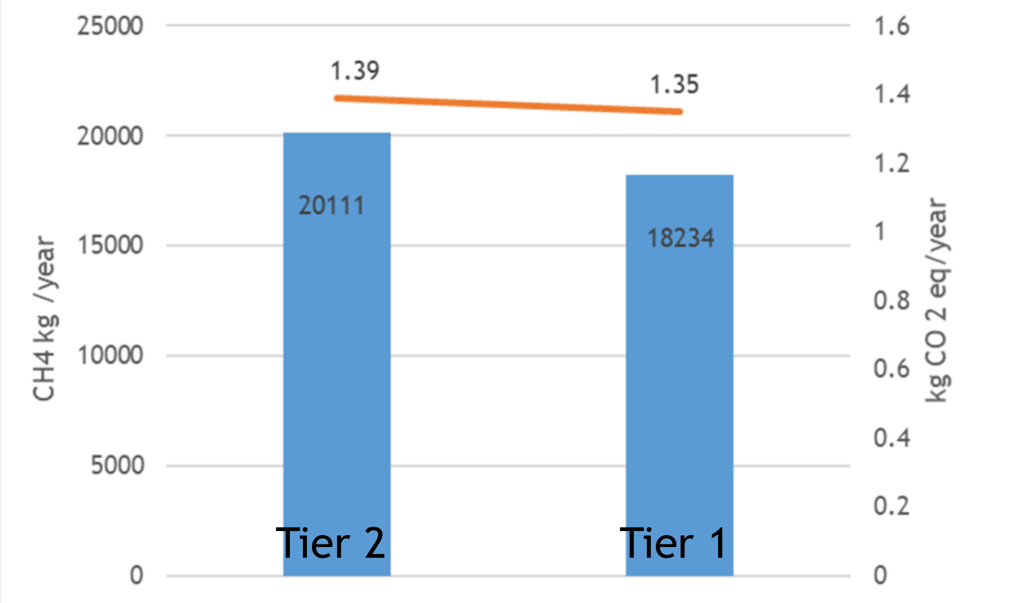

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Normalization

As defined in the ISO standard 14044, normalization is a process to calculate the magnitude of the results of impact category indicators, relative to some reference information. It is an optional process that can be done to complement a LCIA. The characterized results of each impact category are divided by a selected reference value, which brings all the results on the same scale

The reference system can be:

- The total inputs and outputs for a geographical given area over a given reference year (e.g. the impact of the European Union for 2010); •
- The total inputs and outputs for a geographical given area over a given reference year on a per capita basis (e.g. the impact of a European in 2010).

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Final: interpretation

Life-cycle interpretation, the last phase of the LCA process, is a systematic technique to identify, quantify, check, and evaluate information from the results of the life cycle inventory and the life cycle assesment, and communicate them effectively.

It is important :

- to communicate all decisions and choices assumed during evaluation
- to communicate the better solution among others (if it is possible…)

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Life Cycle assessment: final consideration

- LCA is a relative tool intended for comparison and not absolute evaluation, thereby helping decision makers compare all major environmental impact when choosing between alternative courses of action (Curran, 2008)

- LCA is an environmental management tool that informs decision makers, other decision criteria, such as cost and performance, should also be considered in order to make a well-balanced decision.

For agricoltural production for instance is important to include other aspect as biodiversity, ecoservices, cultural and traditional aspects…

Life Cycle assessment: limitations

- Performing an LCA can be very resource and time intensive
- The availability of data can greatly impact the accuracy of the final results
- There are a number of ways to conduct LCIA, a lot of choice has been made because the complexity of environmental systems that must be reported alongside the final results of the LCA project
- LCA will not determine which product or process is the most cost effective or works the best. Therefore, the information developed in an LCA study should be used as one component of a more comprehensive decision process assessing the tradeoffs with cost and performance.

Curran, 2008

The holistic approach to sustainability: the LCSA and the three pillar

In the first decade of the twenty-first century the LCA broadened itself from a merely environmental LCA to a more comprehensive **life cycle sustainability assessment (LCSA)**

LCSA= LCA + LCC + SLCA

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The holistic approach to sustainability: the LCSA and the three pillar

LCSA= LCA + LCC + SLCA

Life cycle costing (LCC) is an economic approach that sums up ”total costs of a product, process or activity discounted over its lifetime”. It is associated with cost in general rather than just environmental costs.

A social life cycle assessment (S-LCA) is a method that can be used to assess the social and sociological aspects of products, their actual and potential positive as well as negative impacts along the life cycle

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The holistic approach to sustainability: a case study in Italy (de Luca et al., 2018)

Aim: evalaute environmental, social and economic impact of 1 ha of cultivated surface with olive

Three scenario:

1) conventional and traditional farming system (CS);
2) a reduced use of chemical (LDNT);
3) organic farming system (ZCW)

The best scenario was 2

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The holistic approach to sustainability: a case study in Italy (de Luca et al., 2018)

Table 4
Environmental assessment.

Life Cycle tool	Impact Categories	Indicators	Unit of Measure	Positive or negative	Olive growing scenarios		
					CS	LDNT	ZCW
LCA	Climate change	GHGs	kg CO_2 eq ha^{-1} $50yr^{-1}$	−	3.65E+05	3.60E+05	3.82E+05
	Toxicity	Toxic emissions	kg 1,4-DB eq ha^{-1} $50yr^{-1}$	−	4.67E+08	4.64E+08	4.68E+08
	Land Use	Land occupation	m^2yr ha^{-1} $50yr^{-1}$	−	6.49E+05	5.00E+05	6.50E+05

Table 6
Economic impacts results.

Life Cycle tool	Impact Categories	Indicators	Unit of Measurement	Positive or negative	Olive growing scenarios		
					CS	LDNT	ZCW
LCC	Profitability	GM	€ ha^{-1} $50yr^{-1}$	+	141,391.04	143,727.28	141,006.35
	Life Cycle Costs	DLCC	€ ha^{-1} $50yr^{-1}$	−	184,174.96	181,838.72	184,559.65
	Investment feasibility	NPV	€ ha^{-1} $50yr^{-1}$	+	40,295.60	42,631.84	39,910.91

Table 8
Social indicators results.

Life Cycle tool	Impact Categories	Indicators	Unit of Measure	Positive or negative	Olive growing scenarios		
					CS	LDNT	ZCW
sLCA	Social health	Hours of risk exposure	hours ha^{-1} $50yr^{-1}$	−	58,801.90	52,913.65	54,276.90
	Job opportunities	Employment hours	hours ha^{-1} $50yr^{-1}$	+	12,103.08	11,758,33	12,103.08
	Contribution to national welfare	Fair employees treatment	dimensionless	+	0.665	0.646	0.665

The holistic approach to sustainability: a case study in Italy (de Luca et al., 2018)

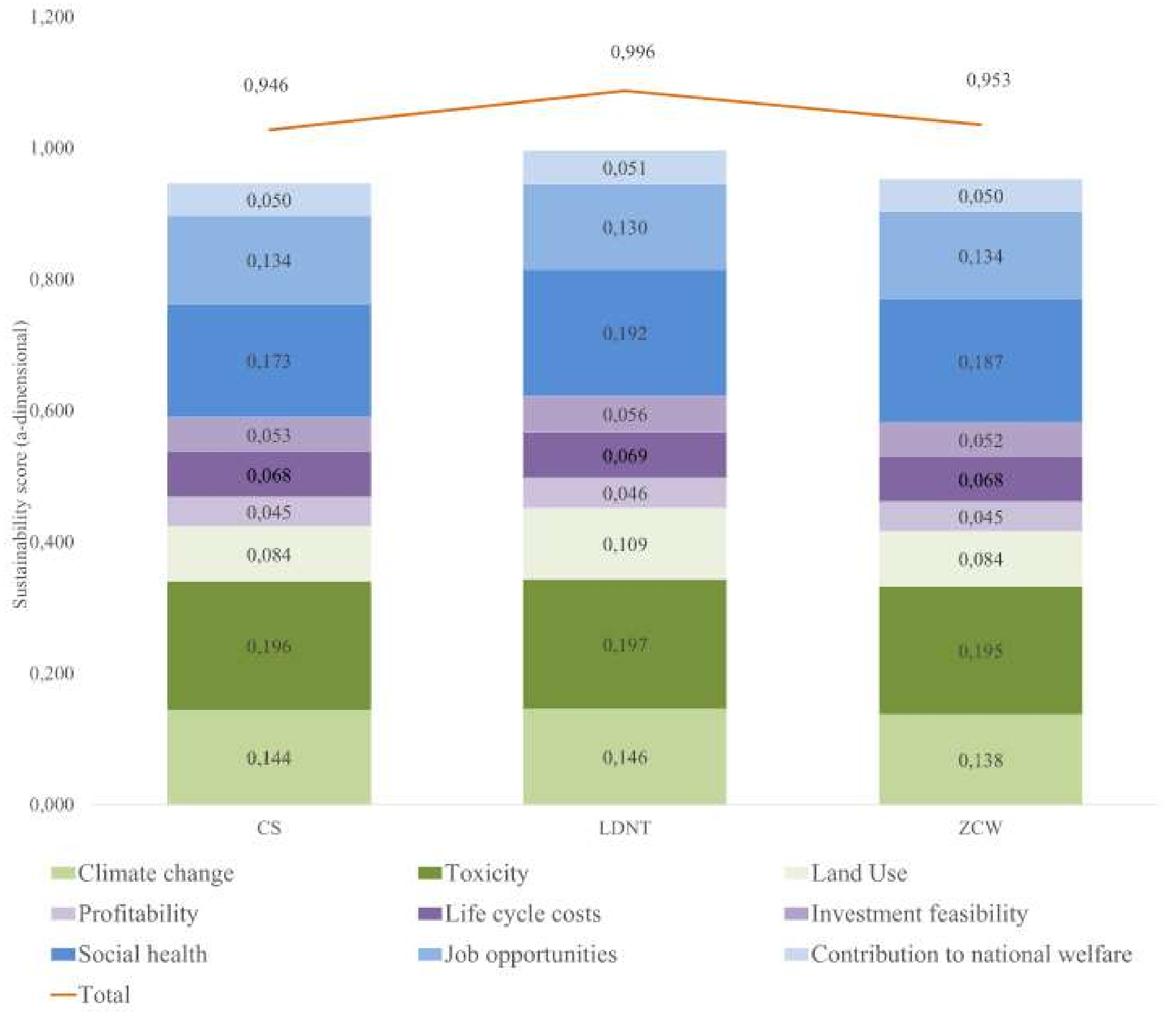

Fig. 3. Integrated sustainability performance of olive growing scenarios.

Environmental LCA and Life Cycle Costing: an example (Martínez-Blanco et al, 2014)

Comparison of three fertilizing alternatives for tomato

Table 6
Environmental Life Cycle Assessment (E-LCA) and Life Cycle Costing (LCC) results for the three fertilizing alternatives (units per ton of fertilized tomato).

Indicator	Unit	Compost	HNO_3	KNO_3
Environmental Life Cycle Assessment[a]				
Abiotic depletion	kg Sb eq	3,13E+00	2,61E-01	3,08E-01
Acidification	kg SO_2 eq	4,25E+00	6,63E-01	5,37E-01
Eutrophication	kg PO_4^{3-} eq	3,20E+00	1,55E-01	1,75E-01
Global warming (GWP100)	kg CO_2 eq	6,72E+02	1,39E+02	9,17E+01
Ozone layer depletion (ODP)	kg CFC-11 eq	7,02E-05	4,86E-06	5,04E-06
Human toxicity	kg 1,4-DB eq	3,44E+02	2,78E+01	3,43E+01
Fresh water aquatic ecotox.	kg 1,4-DB eq	4,06E+03	6,31E+00	8,78E+00
Marine aquatic ecotoxicity	kg 1,4-DB eq	1,46E+06	1,76E+04	2,11E+04
Terrestrial ecotoxicity	kg 1,4-DB eq	6,55E+00	3,48E-01	2,33E-01
Photochemical oxidation	kg C_2H_4	1,22E+00	5,24E-03	5,86E-03
Cumulative energy demand	MJ eq	7,64E+03	5,74E+02	6,76E+02
Life Cycle Costing[b]				
Fertilizer market price	€	14,31	24,01	27,94
Price of transportation	€	1,95	0,1410	0,1354
Extra application costs	€	21,35	0,00	0,00

[a] Data adapted from Martínez-Blanco et al. (2011b).
[b] Data adapted from Martínez-Blanco et al. (2013b).

Social Life Cycle: an example (Martínez-Blanco et al, 2014)

Comparison of three fertilizing alternatives for tomato

Table 2
Country scale – Social aspects (including risks and impacts) for countries involved in the foreground processes for fertilizer production.

STAKEHOLDER > Subcategory (shaded) > Social indicator (white)	Data	Spain	Israel
WORKER			
Freedom of association and collective bargaining			
Risk of not having freedom of association rights	S[a]	M	M
Risk of not having collective bargaining rights	S[a]	M	M
Risk of not having the right to strike	S[a]	M	M
Potential of country not passing labor laws (number of labor laws)	T[a]	L (1489)	H (135)
Potential of country not adopting labor conventions	S[a]	M	M
Child labor			
Risk of child labor	L[a]	L	L
Number of children out of school (%)	T[a]	L (0.33)	n.d.
Fair salary			
Potential of average wage being < minimum wage USD	T[a]	L	L
Potential of average wage being < non-poverty guideline USD	T[a]	L	L
Potential of minimum wages not being updated (year of last update)	S[a]	L (2010)	M (2008)
Working hours			
Risk of population working > 48 hours/week	T/L[a]	M	M
Average working hours per week	T	L (38.6[b])	M(40-43[c])
Maximum working hours per week in labor laws	T[c]	L (40)	M (48)
Forced labor			
Risk of forced labor	L[a]	M	M
Equal opportunities/Discrimination			
Overall fragility of gender equity	T[a, d]	L	M
Health and safety			
Occurrence of occupational lethal accidents per year (per 100,000 people)	T[e]	M (4.1)	L (2.9)
Occurrence of occupational non-lethal accidents per year (per 100,000 people)	T[e]	VH(5641)	H(2314)
LOCAL COMMUNITY			
Safe and healthy living conditions			
Deaths due to outdoor air pollution (deaths per million people)	T[f]	M (136)	H (216)
Population living on degraded land (%)	T[f]	L (1.4)	M (12.9)

Environmental LCA and Life Cycle Costing: an example (Martínez-Blanco et al, 2014)

Fig. 2 Social performance of Irish dairy farm