Final report, Task 2.2:

Report on Life Cycle and Emergy Assessment

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Executive summary

This report is a part of WP2 Foodlever project task “Holistic sustainability assessment”. Environmental assessment is conducted following a life cycle perspective, specially using the Life Cycle Assessement (LCA) and Emergy Assessement. A cradle-to-grave LCA determines the overall sustainability of the innovative organic farms compared to mainstream organic systems, separated into three phases: farm, farm to consumer and consumer. However, being aware of the limitations of LCA tools in its ability to assess the comprehensive sustainability of organic production systems, next to the ‘standard’ Life Cycle Impact Assessment (LCIA) methods, additional indicators for human nutrition, biodiversity, social wellbeing and animal welfare were introduced.

The main aim of the research was to examine the sustainability of innovative farms and enable the identification of leverage points for the further transition.

The research covers a variety of products, depending on the country of the Foodlevers project partners:

- vegetables (Brussel sprouts, DE; zucchini, BE)
- milk (RO)
- beef (UK; PL)
- eggs (IT)
- shiitake mushrooms (FI)

Section 2 contains a brief description of the methodology used (more detailed information can be found in the M2.2 report).

Then Section 3 introduces the main results for each product. Life Cycle Inventory (LCI) data from innovative farms were collected directly in surveys conducted on farms; the description of reference systems (mainstream organic) was carried out either through surveys, interviews with experts or reference to statistical data or other studies.

The results are presented in the following order:

- Description of the production systems
- Main LCI data
- LCIA results and interpretations (including SLCA)
- Conslussions
- Results of the analysis of additional indicators (beyond the ‘classic’ LCA impact categories)

Section 4 presents the results and limitations of the used methodology. Although the study is not primarily methodological in nature but practical, it aims to draw attention to the weaknesses of the LCA methodology in the context of assessing organic products, and to propose solutions for a better assessment of the overall sustainability of organic farms.

In conclusion, through the environmental assessments conducted in Task 2.2 we can conclude that:

- This study is probably the first attempt to compare innovative organic farms with mainstream organic systems.
- Inventory data describing mainstream organic systems are highly uncertain; the question of how to define a mainstream organic system is challenging due to the variability of organic farms.
- The LCA methodology is useful for assessing the environmental impact of food products, but in the context of organic products further development is needed to capture the

specificity of organic production, in particular the chemicals used, natural fertilisers (purchased) and other soil amendments.

- Additional indicators tested (beyond the 'classic' LCA impact categories): social LCA, biodiversity, animal welfare and nutritional indices have their limitations and do not allow innovative farms to be compared with mainstream farms in all cases. They need to be further developed to be objective and scalable.
- The results of our research indicate that the farm phase is usually the most significant for most of the main impact categories (exception: courgettes - most emissions occur beyond farm).
- Vegetables and shiitake mushrooms from innovative farms had lower environmental impacts than products from mainstream farms in most of the impact categories.
- Animal products (milk, eggs) from innovative farms have similar environmental impacts to those from mainstream farms.
- Meat from mainstream farms has a lower carbon footprint than that from case study farms (similar results in both countries: Poland and the UK).

Introduction

The objective of the Foodlevers project is to identify innovative and sustainable organic farming systems, compare them with mainstream organic systems and determine how they can contribute to more efficient resource use from farm to fork. Life Cycle Assessment extended beyond farm-gate (including farm to consumer and consumer phase) allows determining trade-offs and synergies between production stages and the dependence of individual farming systems on non-renewable resources.

This document presents results of the Task 2.2 Life Cycle and Emergy Assessement. The main goal of the study is to evaluate an environmental impact of the innovative case study farms compared to mainstream organic systems, using an integrated holistic life cycle assessment (LCA). The LCA focuses on common impact categories (climate change, acidification, eutrophication, water demand, land and energy use) and incorporates novel indicators for human nutrition, biodiversity and social well-being. Extending LCA beyond the farm gate (i.e. including the processing, transport and consumer stages) also allows the identification of trade-offs/synergies between production, distribution and use stages.

This document describes the outline methodology (LCI phase is discussed in more detail in the Milestone 2.2 Report) and covers:

- Goal and scope definition
- System boundary and functional unit
- Life cycle inventory (LCI) phase
- Life Cycle Impact Assessment (LCIA)
- Interpretation of results

Methods

Goal of the LCA

The goal of the study is to compare the environmental impacts of fresh food produced by innovative localised food production systems with the impacts generated by mainstream organic production. Raw or low processed products and a short post farm supply chain are features of production in our case studies. Global warming potential (GWP, kg CO2-eq), acidification (AC, H+eq), freshwater eutrophication (FE, kg P-eq), land occupation (LO, m2y), water depletion (WD, m3), fossil depletion (FD, kg oil-eq) were included as impact categories. Additional work was carried out to include impacts on biodiversity, social aspects and human nutrition using data collected during the Public Goods Tool assessment for each case study farm in T2.1.

Functional unit

The functional unit used for each LCA is 1 kg of fresh/low processed product purchased by the consumer.

Overview of organic production systems and key LCI data

System boundaries are considered from cradle to grave. Depending on availability, data averaged over several years or data over a shorter period (at least 1 year) were used for the analyses. All on-farm operations such as fodder production, composting and organic fertiliser management were included as primary data, and the corresponding emissions were considered. The analyses also take into account indirect consumption and emissions related to the production of purchased fertilisers, fuel and the use of equipment and machinery. Depending on the product analysed and the length of the post-farm supply chain (some farms sell raw or low processed products directly), either primary or secondary data were used at this stage. The consumer phase (storage and cooking) is based on secondary data (mainly energy and water consumption assumed). The summary of investigated products and farms is given in Table 1.

Table 1: Description of innovative case study farms and mainstream organic systems.

Country (project partner)	Case study farm	LCA product (FU)	System boundary	Comparative system
Romania (USAMVCJ)	Ferma Ecologica Topa: biodynamic mixed farm	1 kg fresh milk	cradle to grave	typical organic milk system
Italy (CNR)	Fattoria Cupidi: silvopastoral farm (walnuts, olive orchard, laying hens grazing)	1 kg fresh eggs	cradle to grave	typical organic egg system
Belgium (EV ILVO)	Het Polderveld: organic mixed farm	1 kg fresh courgette (zucchini)	cradle to grave	typical organic zucchini
Germany (UMR)	Die Kooperative Frankfurt am Main: biodynamic mixed farm	1 kg Brussel sprouts (fresh on stalk)	cradle to grave	typical organic Brussel sprouts cultivation
Poland (IUNG-PIB)	OIKOS Farm: organic beef farm	1 kg bone free beef	cradle to grave	organic beef system
Finland (EFI)	Mushroom cultivation in forests	1 kg fresh mushrooms (shiitake)	cradle to grave	indoor shiitake cultivation
UK (RAU/UoR)	Stroud CSA: biodynamic mixed farm	1 kg bone free beef	cradle to consumer home	typical lowland livestock farm (organic)

Data collection process

As the objective of this study was to compare the environmental impacts of innovative production systems with the mainstream equivalent, significant effort was put into collection of farm scale data. Data collection for the Life Cycle Inventory (LCI) took place alongside data collection for the Public Goods Tool assessment (T2.1) based on face to face interviews with the case study farmers. The data collection process was an iterative process with input from the case study farmers throughout the process. Background data from LCA databases (e.g. Ecoinvent, Agribalyse, Agri-footprint) or published studies were used where farm specific data was not available.

General activities and data

The analyses used primary data collected in excel sheet template adapted to the specific characteristics of the investigated innovative organic farms. The description below focuses on the data sources for the background system processes and the assumptions made in the absence of primary data.

Capital goods

Capital goods include the production of machinery, buildings and infrastructure. The environmental impact of machinery used on farms was determined using the Ecoinvent database. As the foreground systems studied are based on unprocessed food with minimal storage time or even direct harvest by the consumer, buildings and other infrastructure were generally not included in the study.

Fertilizers and other chemicals

In organic farming, only a limited number of fertilisers and plant protection products are allowed (e.g. lime to correct pH imbalances). Processes from the Ecoinvent database were used for all chemicals used (or proxy processes).

Electricity (country mix)

Country specific system processes based on the Ecoinvent database were used. Low voltage electricity mixes for all countries were applied: *Electricity, low voltage {...}| market for | Cut-off, U*; where in curly brackets country abbreviation is pasted.

Fuels and burning of fuels

Background system process from Ecoinvent database for diesel fuel:
Diesel, low-sulfur {Europe without Switzerland}| market for | Cut-off, U
was used.

Transport

Primary data about transport from farm gate to consumer (via processor/retailer) were collected for each case study. Published data was used for the comparative systems. Background data origin from Ecoinvent database separately for consumer cars, separately for vans and trucks (without or with cooling).

Slaghterhouse / Processing

In the case studies analysed, generally, an unprocessed product reaches the consumer. In the case, where the product under consideration is beef meat: for Poland PEF compliant economic allocation for slaughtering was used; for UK country-specific allocation factors were used.

Packaging

In this study only B2C (business-to-consumer) packaging is considered due to:

- the fact in considered case studies farms the supply chains are short, often based on direct sales
- in general, business to business packaging are negligible in comparison to primary packaging regarding environmental impacts [1]

Primary data about packaging materials were collected for each case study farm. Background processes representing packaging materials are taken from the Ecoinvent database.

Home cooking

Home cooking assumption are based on median preparation time and different preparation method described by Frankowska et al. [2] (see Table2). Energy amount for cooking and water use were taken from Agribalyse database. Two datasets are used to model the energy input needed to prepare food at consumer stage:

- *Electricity: Electricity, low voltage {...}| market for | Cut-off, U,* where in curly brackets country abbreviation is inserted
- *Thermal energy: Heat, central or small-scale, natural gas {Europe without Switzerland}| market for heat, central or small-scale, natural gas | Cut-off, U.*

Detailed assumptions are provided for all products in Section 4.

Table 2. Assumption for home cooking taken in the study.

Product	Preparation methods
Eggs	36% boil, 56% pan frying, 6% microwave, 3% deep fry
Beef	2% without cooking, 63% oven, 16% pan frying, 11% slow cooking
Milk	88% without cooking, 12% boilling
Mushrooms (Shiitake)	4% without cooking, 9% boil, 2% microwave, 4% deep fry, 72% pan frying, 2% steam , 6% oven
Vegetables	7%without cooking, 66% boil on stove, 19% steam, 9% oven

Source: [2]

Methodology for calculations (emissions and other impacts)

This report covers organic production of the studied innovative farms. The sources of the methodology used to calculate the environmental impacts (emissions and other indicators) of the products considered are outlined below. For the calculation of CH_4 emissions from enteric fermentation and manure management, N_2O emissions from soil and manure management, and CO_2 emissions from soil, methods and emission factors, the IPCC Guidelines for National Greenhouse Gas Inventories (2006, 2019) were used [3,4]. Ammonia (NH_3) and nitric oxide (NO, NO_2) emissions were calculated according to the EEA guidelines [5]. Where possible, national or farm level indicators and coefficients have been used, as reported in detail in the M2.2 report. For additional (non-standard) indicators, more detailed information on the methodology for their calculation is provided.

Emissions to air

Methane (CH_4) from enteric fermentation

Calculated using annual dry matter intake (DMI) and livestock metabolizable energy (ME) requirements of the whole herd. A standard figure of 23.3 $gCH_4\ kg^{-1}$ DMI ([4], Table 10.12) was used for methane yield (MY) for non-dairy cows with a diet of >75 % forage. The IPCC (2019) Tier 2 equation 10.21a [4] gave a methane emission factor (EF) which was then used to calculate methane emissions for the entire herd. Detailed description is included in each case study result.

CH_4 emissions from manure management

CH_4 emissions from the manure management systems present on each case study and comparative farm were calculated using IPCC Tier 2 methods (Equation 10.23,[4]). Country specific Volatile Solid (VS) content was calculated from annual manure production figures for each animal class (e.g. NVZ guidance, 2013 for UK). The Methane Conversion Factor (MCF) was obtained for each Animal Waste Management System (AWMS) (2 % for manure composted using passive windrow and 0.47 % for manure deposited on pasture (Table 10.17, [4]). Default methane producing potential values (Bo) for each AWMS were used (for Western Europe 0.18 for manure composted using passive windrows and 0.19 for manure deposed on pasture) (Table 10.16, [4]).

Direct N_2O emissions from manure management

Calculated using Equation 10.25 [4]. Country specific excretion rates for all livestock were used to give the annual average N excretion rates for each livestock category. Default emission factors for each AWMS were taken from Table 10.21 [4].

Indirect N_2O emissions from volatilisation of N from manure management in forms of Ammonia (NH_3) and atmospheric nitrogen oxides (NOx) were estimated using the IPCC Tier 2 approach (Equation 10.28, [4]). Country specific total nitrogen excretion values for all livestock categories were used, along with default emission factors (Table 11.3) and figures for the fraction of nitrogen from manure in each AWMS that volatilizes were obtained from Table 10.22.

Indirect N_2O emissions from leaching and run off of nitrates (NO_3) from each manure management system were calculated using equation 10.29 which uses country specific total nitrogen excretion rates. Default values for the fraction of N leached from each AWMS and default emission factors for leaching and run-off have been assumed (Table 10.22).

Direct emissions of N_2O from soils: Calculated using Equation 11.2. Farm/country specific volumes of N added to the soils for each crop as organic fertiliser were calculated using Equation 10.34a from: annual N excretion rates of the whole herd; N in animal bedding; taking into account the fraction lost to volatilisation, leaching (Table 10.22) and as N_2 (Equation 10.34b) for each AWMS. The N from crop residues were calculated for each crop and summed using Equation 11.6. Farm/country specific values for areas of harvested annual dry matter for each fodder crop and crop yield data and default values for the N content of residues and the ratio of above to below ground crop biomass are used (Table 11.1a).

Indirect emissions of N_2O from soils and crop residues: N volatilisation/deposition calculated using Equation 11.9 (IPCC, 2019) and N leaching Equation 11.10 [4] with farm/country specific data for amount of N applied in manure and deposited on pasture by grazing animals

Emissions *from transport and on-farm energy use*: Country-specific emission factors from Ecoinvent database were used where possible. For the United Kingdom the emission factors for CO_2, CH_4 and N_2O from diesel used in machinery operations and transportation were obtained from the UK Government GHG Conversion Factors (2022).

Ammonia

The EMEP/EEA guide from the European Environment Agency, was used to calculate ammonia emissions [5]. Tier 2 emission factors for calculation of the NH_3-N emissions from manure management and grazing were used (Table 3.9, EEA, 2019, 3B). Country specific emissions factors for animal production were used where they were available (Nex, proportion of TAN). UK specific EFs were used to calculate NH3 emissions from the different systems based on the total N excretion values for the whole herd [6]. Conversion factor 17/14 is used to express results in kg NH_3. Tier 1 method with emission factors per kg applied N from organic fertilizers for crop cultivation was used.

Nitrogen oxides (NOx, NO, NO_2)

The nitrogen oxides emissions from manure or excreta deposited during grazing are calculated following EMEP/EEA guide using default emission factor for NO_2-N 0.04 NO_2 kg^{-1} N applied in fertilizer, manure and excreta (Table 3.1, Crop production and agricultural soils, Chapter 3.D) [5]. Conversion factor of 46/14 is used to express NO_2-N emissions in kg NO_2.

Concentrates and compound feeds

Most of the analysed farms engaged in animal production rely on fodder grown on the farm. Assumptions regarding purchased products and feed come from the Ecoinvent database. Where possible, processes relating to organic feed were used, otherwise processes describing traditional feed were used. An emission factor of 0.4650 CO_2e kg^{-1} was used to calculate the GHG emissions from bought in concentrates and compound feed (Simmons et al. 2006) in the UK case.

Emissions to water

Nitrates

Nitrate leaching as NO_3 was calculated at a farm level using a method adapted from Brentrup et al. (2000) based on: the farm nitrogen balance in kgN ha^{-1} yr^{-1} which is calculated in the PGTool.

Phosphorus

Phosphorus emission to water was calculated using a method from the Agri-footprint 5.0 database. A standard emission factor of 0.05 kg of P emitted to the soil when one 1 kg of fertilizer is applied to the soil was used following the methodology used in Agri-footprint 5.0 [7]. The country/farm specific values of P_2O_5 content for manure other organic fertilizers were used.

Water use

As water consumption for animals drinking was not measured default values were used (Agri-footprint 5.0; 2019) [7]. Water amount for irrigation was measured or assumed due to experts' opinions.

Chosen Life Cycle Impact Assessment method

'Standard' impact categories

Life Cycle Impact Assessment (LCIA) is the phase of the LCA analysis aimed to understand and evaluate the magnitude and significance of the environmental impact of a production system. Impact models are used to connect flows (emissions and resource consumptions) to the corresponding impact in different aspects. In line with the goal of the study ReCiPe Midpoint (H) v1.13 / World as a commonly accepted impact assessment method was used during the LCIA phase. For comparisons, especially regarding the Global Warming Potential (GWP) other impact assessment methods, like: ILCD Midpoint, IPCC 2013, IPCC 2021 have also been applied. The characterization of main impact categories is shown in Table 3.

Table 3. ReCiPe 2016 (updated 2020) midpoint impact categories characterisation.

Impact category	Unit	Metric	Main contributors/Comments
Climate change	kg CO2 eq	Radiative forcing as Global Warming Potential (GWP 100)	CO2, CH4, N2O
Ozone depletion	kg CFC-11 eq	Ozone Depletion Potential (ODP)	CFCs, HCFCs
Terrestrial acidification	kg SO2 eq	Acidification Potential (AP)	NH3, NOx, SO2, particulates
Freshwater eutrophication	kg P eq	Fraction of nutrients reaching freshwater	P, PO3
Marine eutrophication	kg N eq	Fraction of nutrients reaching marine water	N
Human toxicity	kg 1,4-DB eq	Human Toxicity Potennial (HTP)	See documentation (long list of chemicals)
Photochemical oxidant formation	kg NMVOC	Photo-chemical oxidant formation potential	CO, SO2, CH4
Particulate matter formation	kg PM10 eq	Particulate matter formation potential	NH3, NOx, SO2, particulates
Terrestrial ecotoxicity	kg 1,4-DB eq	Terrestial cotoxicity Potential (TE)	Cu, S, Pesticides, heavy metals, Oil crude
Freshwater ecotoxicity	kg 1,4-DB eq	Freshwater Exotoxicity Potential (FE)	Cu, S, Pesticides, heavy metals, Oil crude
Marine ecotoxicity	kg 1,4-DB eq	Marine Ecotoxicity Potential (ME)	Cu, S, Pesticides, heavy metals, Oil crude
Ionising radiation	kBq U235 eq	Ionising radiation Potential (IR)	nuclear source of electricity
Agricultural land occupation	m2a	Agricultural land occupation Potential (ALOP)	crop/pasture occupation
Urban land occupation	m2a	Urban land occupation Potential (ULOP)	urban land occupation
Natural land transformation	m2	Natural land transformation Potential (NLOP)	transformation of natural land
Water depletion	m3	Water depletion Potential (WD)	use of water (without rainfall)
Metal depletion	kg Fe eq	Metal depletion Potential (MD)	use of ores
Fossil depletion	kg oil eq	Fossil depletion Potential (FD)	coal, gas, oil crude, 1 kg oil eq = 41.868 MJ

Source: ReCiPe 2016 Midpoint (H) v 1.08 SimaPro documentation and [8].

Emergy assessement

This report presents the total inflow emergy calculations as done with the python based *emergypy* tool from LIST, based on inventories from the Foodlevers project.
The emergy calculations were done based on life-cycle inventories, as produced with the SimaPro 9.5 software, and using several background databases, including ecoinvent 3.9.1 and AgriFootprint among others.
The salient feature of the emergypy software, is that it can derive the emergy calculations based on such life cycle inventories, without the need to do an explicit emergy flow model.

For each product, we analyzed 2 different scenarios: the use case and the mainstream. Each scenario had a different functional unit, always for 1kg of product.

The calculations where run using the same algorithm as presented in [Arbault et al, 2014] but with a new implementation of the software. This new implementation of the SCALEM software is now entirely rewritten in python, but without a graphical user interface, and is compatible with using newer versions of the ecoinvent database. It must be taken into account that the results provided, comply with all rules of emergy algebra, but since the database used in the original creation of the inventories was not reallocated to take into account 100% of the emergy burden by multi-output life-cycle inventories, the results found are to be considered as a "minimal" value of Solar equivalent Joules of emergy. The reallocation of the said multi-outuput processes must be done in the original life-cycle inventory modelling software (SimaPro in this case) prior to exporting the inventories to be processed by the "emergypy" tool. The original software "SCALEM" only took into account the ecoinvent version 2 database, this new version called "emergypy" is compatible with ecoinvent 3.9.1 datasets that have not yet been re-allocated, but hence produce only "minimal" estimation of emergy. The calculations where done using a minflow value of 0.01 (See Arbault et al., 2014 for the meaning of the minflow value). The value refers to the threshold to consider as the stop condition to continue evaluating the graph generated from the life-cycle inventory.

Additional categories

Human nutrient index

Nutrient indices NRFn.3 (where n = 6–15) composed by Fulgoni et al. (2009) are based on weighted sums, means, and ratios of percent daily values for nutrients to encourage (n) and for nutrients to limit (LIM) [9]. Scores are calculated based of 100-kcal units. NRF9.3 index was used to measure nutritional quality of foods and expressed as below:

NRF9.3 *= (protein g/50 g + fiber g/25 g + vitamin A IU/5000 IU + vitamin C mg/60 mg + vitamin E IU/30 IU + calcium mg/1000 mg + iron mg/18 mg + magnesium mg/400 mg + potassium mg/3500 mg – saturated fat g/20 g – added sugars g/50 g – sodium mg/2400 mg) *100*

The nutrient content per 100 kcal of products has been calculated on the grounds of the USDA database (https://fdc.nal.usda.gov/fdc-app.html#/food-details/170383/nutrients) or, if carried out, on the basis of product composition analyses.

Social Life Cycle Assessment (SLCA)

A social life cycle assessment (SLCA) has been developed to assess the social impacts along the life cycle of a product or service. There is not a standardised methodology for assessing SLCAs yet, mainly because it is a contextual assessment and there are no generally accepted impact categories and their importance (in terms of weighting). A similar contextualisation is evident in the assessment of social impacts depending on the choice of the actor (producer, worker, community member, consumer) [10]. Since 2009, the UNEP/SETAC has published a number of methodological papers on S-LCA, which can be considered as a standard (last update 2020 [11]). It should be noted, however, that the UNEP/SETAC methodology is adapted to developing countries and that the postulated categories (and subcategories) of impact should be adapted to local conditions, including labor law in developed countries [12].

We consider three actors: farm workers, the local community and consumers. Similar approaches have been proposed by, among others Petti et al. (2018) [13] and Wei et al. (2022) [14]. A detailed description of the data collection form (based on PGTool) can be found in report M2.2.

Table 4. PGTool based questionnaire for SLCA assessment

	Category	Question	unit	min	max	Source	FARM SCORE
Worker	Health and Safety	Skills and knowledge	Qualit. : # transformed	1	5	PGTool	
		Have you carried out a COSHH assessment?	Qualit.	1	5	PGTool	
		How rigorously is health and safety enforced on the farm?	Qualit.	1	5	PGTool	
		Are staff who handle potentially hazardous substances/machinery (e.g pesticides, heavy plant machinery) given training?	Qualit.	1	5	PGTool	
		How would you describe the working environment at your farm in terms of health and safety?	Qualit.	1	5	PGTool	
	Working hours	Number of working hours per week per employee	Quant. : # transformed	1	5	PGTool	
		How onerous (tough) is the workload on your farm?	Qualit.	1	5	PGTool	
		Are you happy with the amount of holiday period you can take over a year?	Qualit.	1	5	PGTool	
Local community	Access to material and immaterial resources	How many environmental management options do you undertake on your farm?	Qualit.	1	5	PGTool	
		Habitat and conservation planning	Qualit.	1	5	PGTool	
		Richness of landscape	Qualit.	1	5	PGTool	
	Community engagement	Do you promote public access?	Qualit. :1,5	1	5	PGTool	
		How many community events do you attend/ host as a farm per year (this excludes events just for sales, like many farmers markets)?	Qualit.	1	5	PGTool	
		Any awards for staff welfare/community engagement?	Qualit.	1	5	PGTool	
		Approximately what percentage of your produce (by weight) is sold to the local sales (<16km)	Qualit.	1	5	PGTool	
	Cultural heritage	How much maintenance/care do you give to historic features present on the farm?	Qualit.	1	5	PGTool	
		Do you farm any Rare Breeds Survival Trust watchlist breeds? https://www.rbst.org.uk/Our-Work/Watchlist/Watchlist2	Qualit.	1	5	PGTool	
		Does the farm produce Produce of Designated Origin (PDO), Protected Geographical Status (PGS) or Traditional Specialities Guaranteed (TSG)?	Qualit.	1	5	PGTool	

		Do you farm using heritage varieties of crops?	Qualit.	1	5	PGTool	
	Safe and healthy living conditons	How many of these routes are local markets (e.g. farm shop, local delivery, local market, local shops)	Qualit.	1	5	PGTool	
		Do you sell produce direct to customers on-farm?	Qualit.	1	5	PGTool	
		Herbicide and other pesticide use	Qualit.	1	5	PGTool	
		Water management score	Qualit.	1	5	PGTool	
		Nitrogen surplus score	Qualit.	1	5	PGTool	
		Phosphorus and Potassim surplus score	Qualit.	1	5	PGTool	
		Are animals correctly identified and is product traceability ensured through animal identification tags (e.g. eat tags, ID tatoo)?	Qualit.	1	5	PGTool	
Consumer	Health and safety	Have you received any 3rd party endorsement for food quality/local food production (including awards but excluding certifications)? None, local, regional, national	Qualit.	1	5	PGTool	
		How many environmental management options do you undertake on your farm?	Qualit.	1	5	PGTool	
	Feedback mechanism	Do you have any evidence of consumer satisfaction?	Qualit.	1	5	PGTool	
		Do you sell produce direct to customers on-farm?	Qualit.	1	5	PGTool	
		How many of these routes are local markets (e.g. farm shop, local delivery, local market, local shops)	Qualit.	1	5	PGTool	
	Transparency	What level of food quality certification do you have? E.g. Basic farm assured, Global GAP/ Europe GAP, full organic certification	Qualit.	1	5	PGTool	

Reference scales for impact assessment are ordinal scales in range from 1 to 5. For each subcategory in Table 4 the score is the average obtained from the questions in that subcategory. Each level of the scale corresponds to the respective interval and is context- dependent (based on local standards and regulations or best known practices). Similarly to PGTool, it has been assumed that a score of 0 (interval 2.6 - 3.5) represents compliance with these standards.

Table 5. Ascending reference scale and score interval for social performance evaluation. Source: [15]

Scale	Score Interval	Description
+2	4.6 - 5	Ideal performance. Best in class
+1	3.6 - 4.5	Beyond compliance/standard
0	2.6 - 3.5	Compliance
-1	1.6 - 2.5	Slightly below compliance
-2	1 - 1.5	Below compliance

Biodiversity assessement

FOODLEVERS aims to identify key practices and innovations from the case study farms that are contributing to best practice from multiple perspectives including biodiversity. The use of Life Cycle Assessment (LCA) methods to assess impact on biodiversity, for example using Biodiversity Potential Damage [16] or ReCiPe 2016 methods [17] to give a biodiversity damage score for farm outputs in potential species loss per area, presents difficulties when applied at a farm level.

An evaluation of farm biodiversity was carried out in two ways. Since it was not practicable to obtain inventory data from reference farms using PGTool surveys, the Biodiversity Potential Damage metric developed by Chaudhary et al. (2015) [18] was used to compare biodiversity between case study and mainstream farms. This method is recommended by the UNEP-SETAC Life Cycle Initiative and is suitable for regionalised data inventory. The results obtained should therefore be treated with great caution. The land use categories used in this approach are too broad to enable meaningful comparisons to be made at the scale of an individual farm. For this reason, an additional biodiversity index was used to assess the case study farms. A brief description of the methodology is given below.

The PG Tool has been applied to the case study farms FOODLEVERS to assess whole farm sustainability. The Tool collects qualitative and quantitative data at a farm scale, this data can also be used in the development of a biodiversity indicator that enables assessment of the impact of different farming systems on biodiversity. The index assesses biodiversity based on three pillars: species diversity, ecosystem diversity and land use changes (See Table 6). We standardised farm metric data against target (average) values to give an overall score for each category centred around one, with higher values (>1) reflecting better performance and lower values (<1) below average performance. Weighting was used to combine sub categories from within the PGTool e.g. data from livestock species diversity was combined with livestock breed/crossbreed diversity.

Table 6. Selection of data from the PGTool to develop the Biodiversity Index.

	PG Tool
Species diversity	Diversity of crop species and varieties
	Diversity of livestock species and breeds
	Evidence of rare species
Ecosystem diversity	Richness of landscape elements
	Habitat and conservation planning and AES participation
Land use change	Land use change from arable to woodland/ grassland or visa versa

Animal welfare

Animal welfare is assessed according to the method proposed by Scherer et al (2018) [19]. The animal welfare loss index describes the life quality of an animal such as space allowance, the slaughter age lifetime fraction, and the number of animals affected for providing a unit of product. This indicator was calculated for case studies with animal production

Results

The results of the Life Cycle Inventory for selected products are presented as follows: a short description of the production systems (innovative farm and reference farm/mainstream organic system), tables with main inventory data, LCIA results, and conclusions. The detailed inventory data and assumptions are mostly omitted for clarity in this part of the document but available in Annexes or in the M2.2 Report.

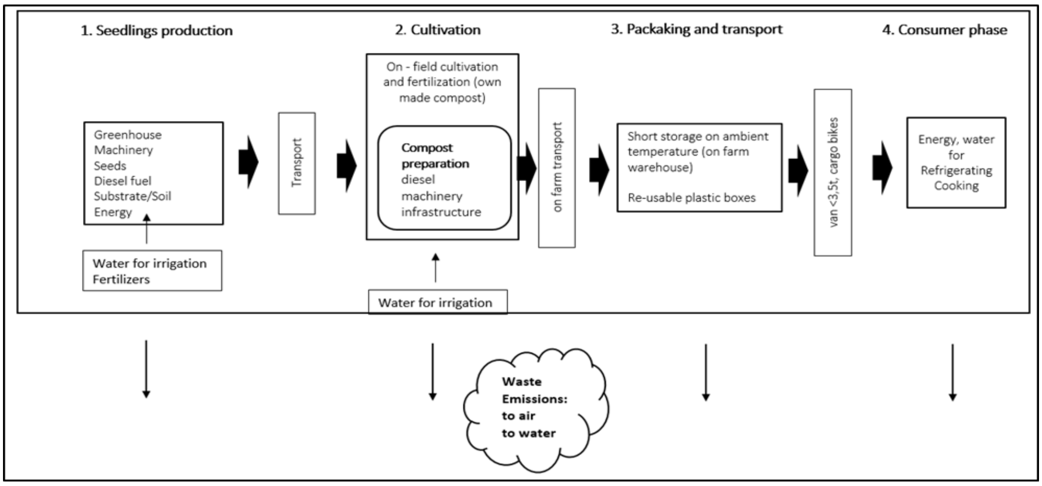
Germany, brussels sprouts

Systems overview

The innovative farm is located in Frankfurt am Main and is a biodynamic urban farm that cooperates with a large network of regional organic farms. Brussels sprouts are grown on a small scale on an area of approximately 0.6 ha. The average yield of fresh sprouts was 7.2 t per hectare. Fermented compost is used for fertilization. The nitrogen and potassium contents were measured and are 4.375 and 2.8 kg m^{-3}, respectively. The dry matter content of the main crop, the ratio of yield to above-ground parts, root weight, and the nitrogen content of above-ground and below-ground parts were taken from Wheeler (2018) [20]. The 30% of the crop residues are left in the field and mulched, the rest is harvested and composted. Products are delivered to consumers by cargo bike and van <3.5t. The production system is presented in Figure 1. Inventory phase for seedlings preparation, on-farm compost production, and brussel sprouts cultivation from cradle to consumer gate are described more precisely in M2.2 Report (See Tables 6-8, M2.2 Report).

Reference system describes small-scale outdoor cultivation on medium level yield and medium soil and is based on data from Kuratorium für Technik und Bauwesen in der Landwirtschaft (https://daten.ktbl.de/dslkrpflanze/postHv.html#anleitung) and experts opinions. Detailed information of the cultivation system can be found in Table A1 (Appendix).

Figure 1 . Brussels sprouts production system. The diagram shows the main phases of cultivating organic Brussels sprouts from seedlings production to consumer use. Die Kooperative Frankfurt am Main.



Main LCI data

Table 7. Main data of LCI for organic brussels sprouts cultivation in Germany. Comarision between innovative farm (case study) and mainstream organic system. The inventory contains all stages from cradle do fork (including consumer cooking).

Item	Unit	Case study	Mainstream	Comments/Assumptions
Functional unit		1kg	1kg	Brussels sprouts purchased by consumer

Time coverage		2018-2020		2019-2021		
Area of cultivation	ha	0.6		1		
Data inventory		farm survey		averaged values for Brussels sprouts cultivation in Germany *		*based on: Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL): https://daten.ktbl.de/dslkrpflanze/postHv.html#anleitung and experts opinons (Bioland e.V.; Department of Horticulture, Service centre for rulal area Rhineland-Palatinate)
Localisation		Frankfurt am Main		small-scale outdoor cultivation *		* based on experts opinion (See above)
Residue incorporation into soil	%	30%*		100%		* rest of residues is composted and then incorporated into soil
Main similarities and differences	Both systems use purchased seedlings and obtain a similar yield per 1 ha; fertilization is based on compost (case study) or mulch and purchased organic fertilizers (mainstream). The main differences throughout the life cycle are in packaging and transportation to the customer.					
Output to technosphere		per 1 ha	per 1kg	per 1 ha	per 1kg	
Brussel sprouts, total yield	kg	*		10000		*not measured (left on the field)
Brussel sprouts, marketable yield	kg	7200		8000		
Inputs						
Transport of inputs: Van (<3.5t)	km	173	0.024028	33	0.004125	
Seedlings	#	30000	4.166667	33000	4.125	Additional process, See Report M2.2, the same assumption for both cases
Diesel fuel	l	439	0.060972	174.44	0.021805	
Machinery time	h	55	0.007639	40.76	0.005095	
Water for irrigation	m3	2220	0.308333	4001.8	0.500225	
Fertilizing						
On-farm compost	m3	140	0.019444			Additional process, See Report M2.2
Hairflour pellets (14% N)	kg			1200	0.15	
Kali-Magnesia (30% K20, 10% MgO)	kg			680	0.085	
Farm-grown mulch (mainly clover grass)	kg			35000	4.375	
Micro-organisms (bacteria, viruses and fungi)	kg			1.8	0.000225	*Bacillus Thuringiensis*
Crop protection net	m2			10000	1.25	
Inputs from technosphere: electricity/heat						
Electricity, low voltage {DE}| market for electricity, low	kWh	0.53	7.36E-05	177.14	0.0221425	

voltage | Cut-off, U						
Emissions to air						
Dinitrogen monoxide (direct)	kg N2O	6.38	0.000886	7.28E+00	0.00091	
Dinitrogen monoxide (indirect)	kg N2O	4.36	0.000606	4.12E+00	0.000515	
Nitrogen oxides	kg NO2	78.86	0.010953	1.22E+02	0.015235	
Ammonia	kg NH3	58.29	0.008096	9.01E+01	0.01126125	
Emissions to water						
Nitrate leaching and run-off	kg NO3	226.52	0.031461	2.87E+02	0.03592125	
Phosphorus leaching and run-off	kg P2O5	112	0.015556	2.10E+01	0.002625	
Processing on farm						
Cut, sort, weigh and pack Brussels sprouts	h	no processing		65.38	0.0081725	1.2 t/h; 7 workers
Packaging						
Re-usable plastic boxes 40x30x18cm	#	3.6	0.0005	4	0.0005	10-year lifetime and are used in 20 rotation a year, carry 10 kg
Plastic nets (polyethylene)	kg			8	0.001	1 g of net to pack 1kg of vegetables
Transport into consumer						
Transport, passenger car, EURO 5 {RoW}| transport, passenger car, EURO 5 | Cut-off, U	km	420	0.058333	3200*	0.4	For mainstram system: distance of 10km assumed; allocation factor=2dm3/200dm3 per 1kg of brussels sprouts
Electric bike	km	420	0.058333			
Consumer phase						Same assumptions for both products
Electricity	kWh		0.2336		0.2336	Electricity, low voltage {DE}| market for electricity, low voltage | Cut-off, U
Natural gas	MJ		1.2614		1.2614	
Water	l		0.7		0.7	

Results

Table 8. Results of impact assessment , 1kg of Brussels sprouts, ReCiPe Midpoint (H) V1.13 / World Recipe H

Impact category	Unit	Case study farm				Mainstream system			
		Total	farm	farm to consumer	consumer	Total	farm	farm to consumer	consum
Climate change	kg CO2 eq	0.768619	0.634408564	0.019743	0.114467	0.858377	0.619974	0.135383	0.10302
Ozone depletion	kg CFC-11 eq	1.01E-08	5.44492E-09	4.04E-10	4.25E-09	1.01E-08	3.54E-09	2.77E-09	3.83E-0

Terrestrial acidification	kg SO2 eq	0.026941	0.026653431	5.42E-05	0.000233	0.037494	0.036913	0.000371	0.00021
Freshwater eutrophication	kg P eq	0.010938	0.010798182	2.75E-06	0.000137	0.002902	0.00276	1.89E-05	0.00012
Marine eutrophication	kg N eq	0.006422	0.006382609	3.48E-06	3.59E-05	0.010004	0.009948	2.39E-05	3.23E-0
Human toxicity	kg 1,4-DB eq	0.20624	0.108782882	0.004803	0.092655	0.228164	0.111843	0.032932	0.08338
Photochemical oxidant formation	kg NMVOC	0.012292	0.011920896	8.42E-05	0.000287	0.017086	0.01625	0.000578	0.00025
Particulate matter formation	kg PM10 eq	0.0055	0.005385659	2.75E-05	8.66E-05	0.007653	0.007387	0.000188	7.79E-0
Terrestrial ecotoxicity	kg 1,4-DB eq	4.17E-05	2.89803E-05	2.82E-06	9.94E-06	6.76E-05	3.93E-05	1.94E-05	8.94E-0
Freshwater ecotoxicity	kg 1,4-DB eq	0.018325	0.009693335	0.000998	0.007634	0.023235	0.009522	0.006843	0.00687
Marine ecotoxicity	kg 1,4-DB eq	0.016465	0.008763711	0.00087	0.006831	0.020758	0.008642	0.005968	0.00614
Ionising radiation	kBq U235 eq	0.042817	0.020421099	0.000438	0.021958	0.043625	0.020862	0.003002	0.01976
Agricultural land occupation	m2a	0.011184	0.006543935	0.000206	0.004435	0.01216	0.006758	0.001411	0.00399
Urban land occupation	m2a	0.00398	0.002338607	0.000539	0.001103	0.009012	0.004325	0.003695	0.00099
Natural land transformation	m2	0.000177	0.000117759	7.63E-06	5.19E-05	0.000172	7.29E-05	5.23E-05	4.67E-0
Water depletion	m3	0.3079149	0.307058929	0.00011	0.000746	0.507567	0.499096	0.00078	0.00067
Metal depletion	kg Fe eq	0.065415	0.054696804	0.002275	0.008443	0.071192	0.047991	0.015602	0.00759
Fossil depletion	kg oil eq	0.166733	0.103591042	0.006146	0.056995	0.166256	0.072815	0.042146	0.05129

Figure 2. GWP through all life cycle stages: on-farm cultivation, post farm activities (including transport and packaging) and home cooking.

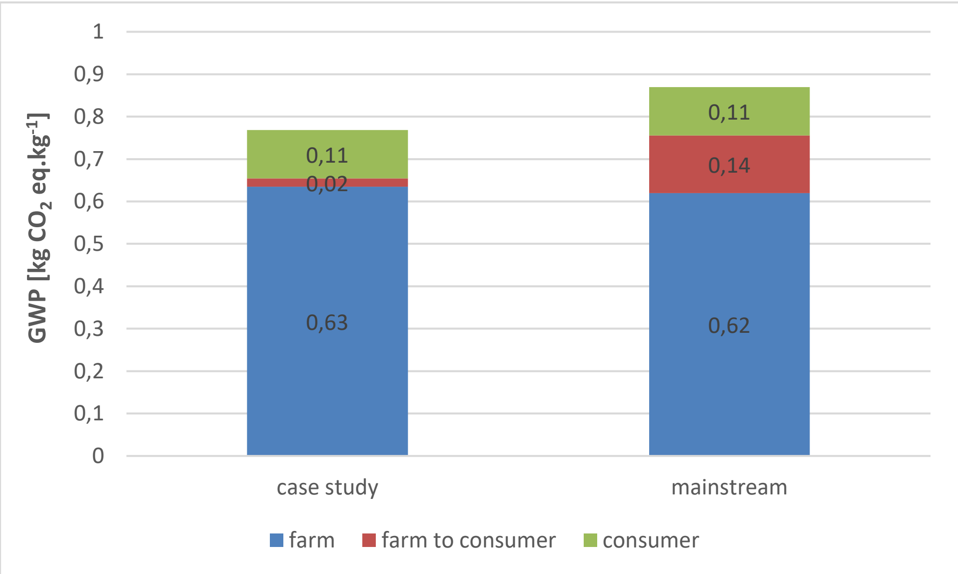


Figure3. Contribution, %, of the mains stages for each impact category of 1kg Brussels sprout purchased by consumer (innovative farm). Impact assessment method used: ReCiPe 2016 Midpoint (H) V1.13 / World (2016) H.

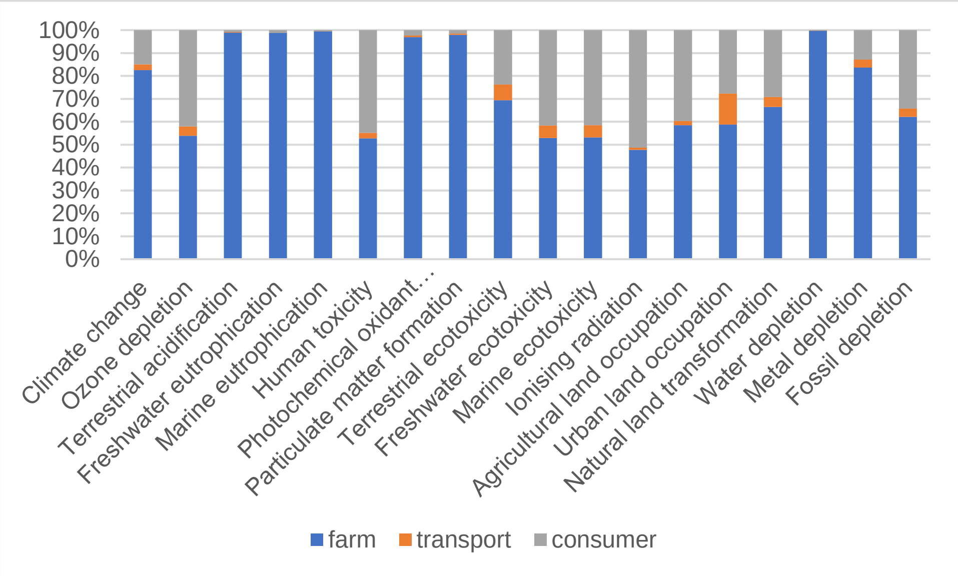


Figure 4. Contribution, %, of the mains stages for each impact category of 1kg Brussels sprout purchased by consumer (mainstream organic). Impact assessment method used: ReCiPe 2016 Midpoint (H) V1.13 / World (2016) H.V1.13 / World (2016) H.

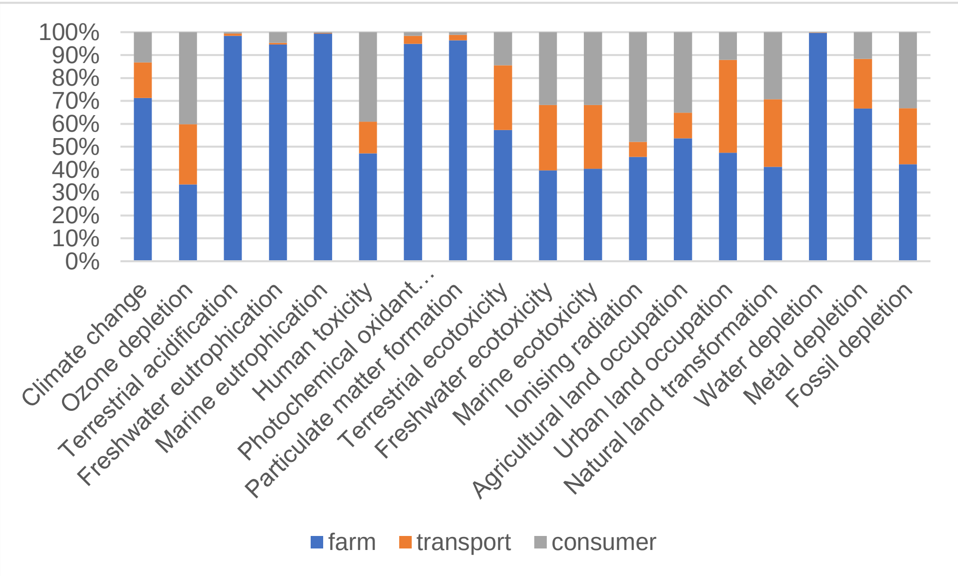


Figure 5. Share, %, of individual emission sources in Brussels sprouts cultivation (farm, case study). Field emissions mean GHG emissions caused mainly by fertilization, including leaving plant residues; On farm operations include the use of machinery and fuel.

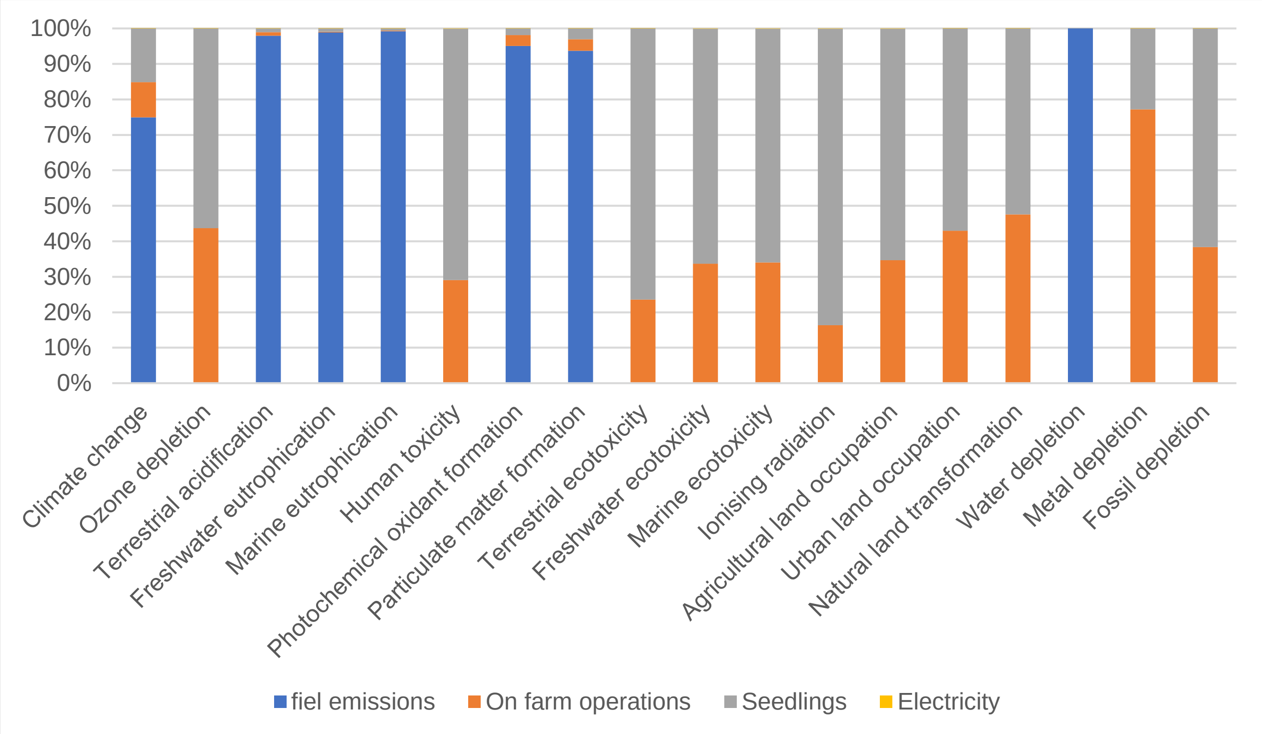
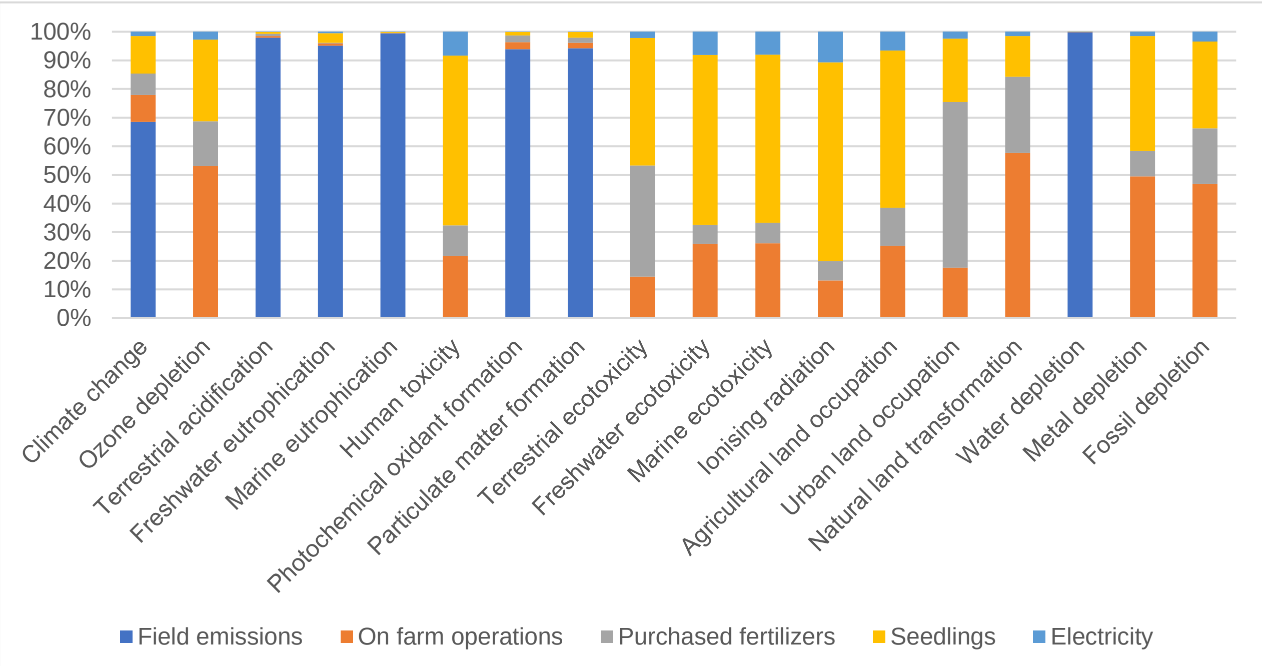


Figure 6. Share, %, of individual emission sources in Brussels sprouts cultivation (farm, mainstream system). Field emissions mean GHG emissions caused mainly by fertilization, including leaving plant residues; On farm operations include the use of machinery and fuel.



The results of SLCA analyzes are shown in Figure 7 and Table 9. The employee's category scores indicate a level above acceptable in terms of health and safety and life balance. Due to the fact that the examined farm is located within the city, in a relatively small area, it is not possible to introduce various environmental management options and there are no cultural heritage objects on the farm, the impact on the local community was determined to be acceptable. In the consumer category, the farm was rated above average due to its transparency and feedback mechanism high scores.

Figure 7. Results of SLCA analysis for each subcategory, Brussels sprouts, case study farm, Germany.

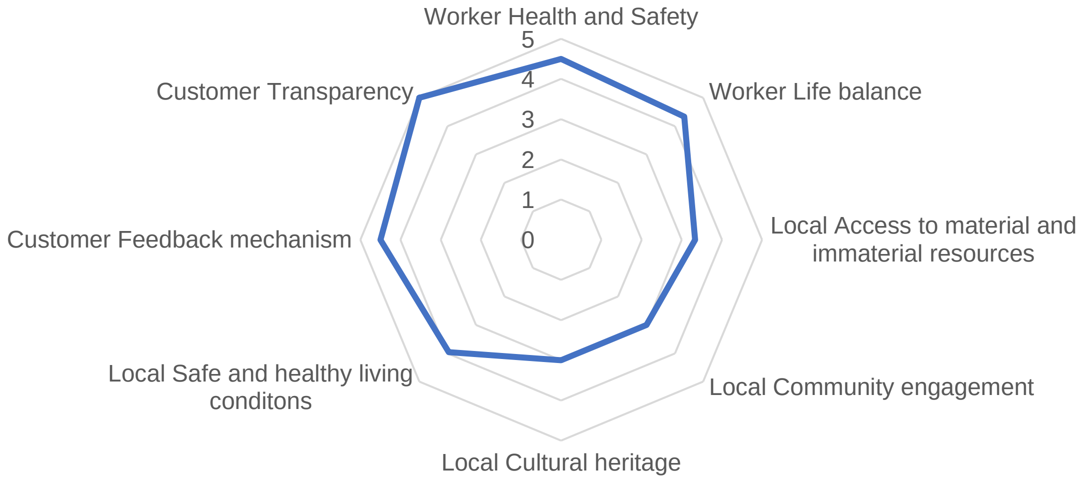


Table 9. Detailed results for SLCA analysis, Brussels sprouts, case study, Germany.

	Category	Question	FARM SCORE
Worker	Health and Safety	How many training days have staff (including the farmer) had per year in total - number of days per person	3
		Have you carried out a COSHH assessment?	N/A
		How rigorously is health and safety enforced on the farm?	5
		Are staff who handle potentially hazardous substances/machinery (e.g pesticides, heavy plant machinery) given training?	5
		How would you describe the working environment at your farm in terms of health and safety?	5
	Working hours	Number of working hours per week per emploee	5
		How onerous (tough) is the workload on your farm?	3
		Are you happy with the amount of holiday period you can take over a year?	5
Local community	Access to material and immaterial resources	How many environmental management options do you undertake on your farm?	2
		Habitat and conservation planning	3
		Richness of landscape	5
	Community engagement	Do you promote public access?	1
		How many community events do you attend/ host as a farm per year (this excludes events just for sales, like many farmers markets)?	5
		Any awards for staff welfare/community enagagement?	1

		Approximately what percentage of your produce (by weight) is sold to the local sales (<16km)	5
	Cultural heritage	How much maintenance/care do you give to historic features present on the farm?	N/A
		Do you farm any Rare Breeds Survival Trust watchlist breeds? See list below or access https://www.rbst.org.uk/Our-Work/Watchlist/Watchlist2	N/A
		Does the farm produce Produce of Designated Origin (PDO), Protected Geographic Status (PGS) or Traditional Specialities Guaranteed (TSG)?	1
		Do you farm using heritage varieties of crops?	5
	Safe and healthy living conditons	How many of these routes are local markets (e.g. farm shop, local delivery, local market, local shops)	N/A
		Do you sell produce direct to customers on-farm?	5
		Herbicide and other pesticide use	4
		Water management score	2.8
		Nitrogen surplus score	5
		Phosphorus and Potassim surplus score	3
		Are animals correctly identified and is product traceability ensured through animal identification tags (e.g. eat tags, ID tatoo)?	N/A
Consumer	Health and safety	Have you received any 3rd party endorsement for food quality/local food production (including awards but excluding certifications)? None, local, regional, national	5
		How many environmental management options do you undertake on your farm?	2
	Feedback mechanism	Do you have any evidence of consumer satisfaction?	4
		Do you sell produce direct to customers on-farm?	5
		How many of these routes are local markets (e.g. farm shop, local delivery, local market, local shops)	N/A
	Transparency	What level of food quality certification do you have? E.g. Basic farm assured, Global GAP/ Europe GAP, full organic certification	5

Conclusions

- Importance of on-farm emissions for some of the impact categories: climate change, acidification, eutrophication for both compared systems
- Purchased seedlings have a big impact on many categories, in the CC category they are responsible for 14 and 13% of greenhouse gas emissions, respectively, for case study and mainstream
- Throughout the life cycle of 1 kg of zucchini, 307 and 508 liters of water are used (irrigation), respectively for innovative farm and mainstream cultivation sytem, respectivily
- Most of farm GHG emissions are N2O field emissions (~70%) for both compared systems caused by N fertilization
- Main differences between impact of Brussels sprouts are due to post farm activities (distribution, retail), for GWP over all stages is 10% difference (0.77 vs. 0.86 kg CO_2eq. kg^{-1})

Romania, Topa farm (Ferma Ecologica Topa), Organic milk production

Overview

This LCA case study focuses on organic milk production, which is the main product of this case study. On the farm they also produce vegetables, black currants, and medicinal plants, which they use for pickles, jams, various syrups and tea mix, the classic zacusca (vegetable mix) and the famous salt with greens from dried vegetables. At the Țopa Organic Farm, all plots of land are organic certified. All these products are capitalized through a variety of short distribution chains like: buying directly from the farm, order based for individuals as well for restaurants, trailer stores (especially useful during the pandemic) but also through an organic store where more organic producers sell their products.

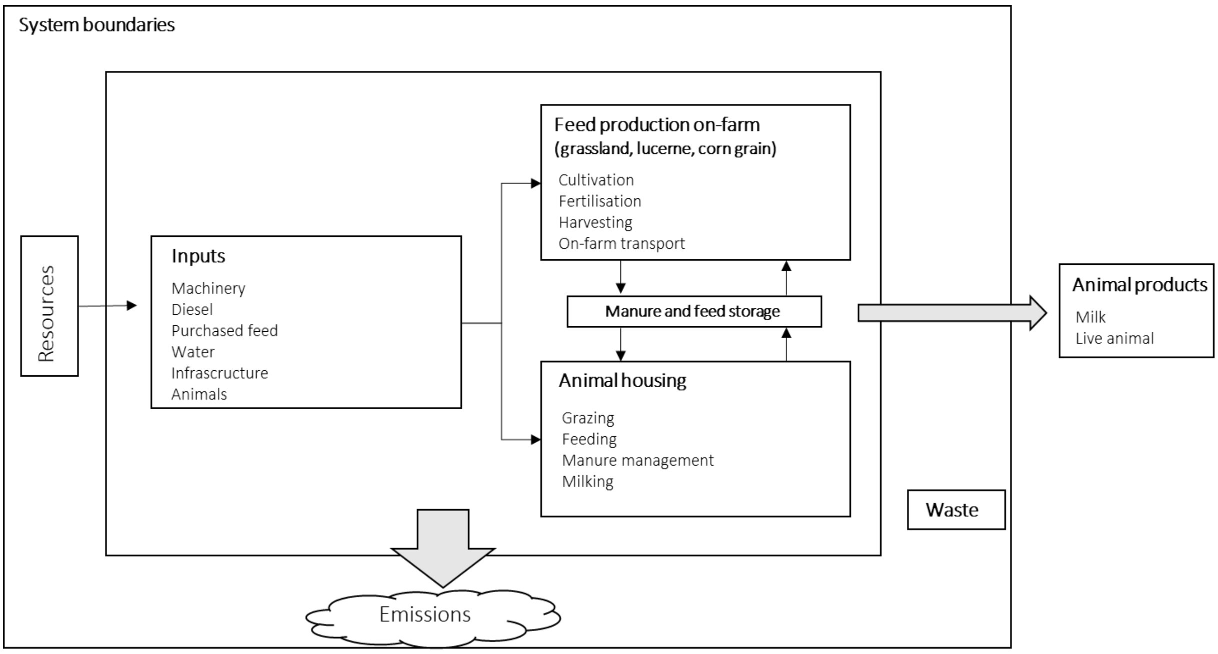
The milk production system is based half on grazing and fodder produced on the farm, the average milk yield of cow is approx. 4000 liters (fat and protein corrected milk (FPCM); 4% fat, 3.3% true protein content FPCM milk) per year (see Figure 8). Grazing takes place on 20 ha of pasture with an average clover content, additionally lucerne (7 ha) and corn for grain (4.3 ha) are grown for feed.

The production system is shown in Figure 8. The main primary data collected from the farm, as well as inventory for on-farm feed production and assumed emission factors can be found in M2.2 Report (See Tables 15 – 19 , M2.2 Report).

Description of reference system (organic dairy farm) is based on 'Harmonised Environmental Sustainability in the European food and drink chain, Life cycle assessment of Romanian beef and dairy products' (2013) and experts opinions (Detailed information can be found in Table A6, Appendix).

A brief comparative inventory between the systems is presented in Table 10.

Figure 8. Organic milk production system, Topa farm, Romania



Main LCI data

Table 10. Life Cycle Inventory of milk production systems, Romania.

Milk production system	Unit	Case study	Mainstream*	Source/Comments
Functional unit		1kg of FPCM milk*	1kg of FPCM milk*	A small amount of milk (about 10%) from the case study farm is sold directly (unpasteurised), but for comparison purposes it was assumed that all milk goes to the dairy plant and is sold as pasteurised. FPCM(fat, protein corrected milk: 4%, 3,3%)
Time coverage		2021	2011	
Localisation		Topa Ecological Farm, RO	RO	
Source of data		farm survey	typical milk farm*	*based on experts opinion and „Harmonised Environmental Sustainability in the European food and drink chain, Life cycle assessment of Romanian beef and dairy products", 2013
Farm type		mixed farm (fruits, vegetables, milk)	dairy farm	
Main similarities and differences	Mainstream system is a typical organic dairy farm, whereas a case study farm is a mixed farm. The feeding system is very similar (based on on-farm cultivation) as well as the milk yield per cow (~4000l vs 4500 l/cow/year). The assumptions regarding the impact of milk processing in the dairy are the same in both systems. The differences concern transport from the dairy to the consumer, because in the case study it is nearby dairy plant sales while 'normal' supply chain assumed for mainstream milk.			
Output				
Milk production	kg	88000	279130	Economic allocation to milk = 0.782
Exported animals for raising, live weight	kg	7500	7670	
Herd description				
Dariy cows	#	22	60	
Dairy heifer	#	10	30	
Dairy calf (0-6 months)	#	30	40	
Feeding				
Pernament grassland	ha	20	72	
Annual crops (cereals, maize)	ha	11.3	17.5	
Inputs from technosphere				
Diesel use	l	1612	16380	
Electricity	kWh	1500	16260	
Emissions to air				
Methane	kg	3723.47	10012	
Dinitorgen monoxide	kg	52.75	100	

Ammonia	kg	173.5429545	397	
Nitrogen oxides	kg	76.685	197.67	
Emission to water				
Phosphorus	kg	54	120	
Nitrates	kg	0	0	Negative N balance
Transport of raw milk to dairy plant	km	20	22	
Milk Plant/Packaging*				
Water	l	0.98	0.98	
Heat, natural gas	MJ	2.01	2.01	
Electricity	kWh	0.16	0.16	
packaging	kg of glass	0.0221	0.0221	20 reuse of 442g glass bottle, PEF
Transport				
Transport to retailer	kgkm		56	lorry with refrigeration, PEF transport matrix
	kgkm		34	rail
	kgkm		11	barge
Transport to consumer/by consumer	km	0.2	0.2	assumed 20 km with 1/100 trunk share

Results

Table 11. Results of impact assessment , 1kg of FPCM milk, Romania, ReCiPe Midpoint (H) V1.13 / World Recipe H

		case study				mainstream			
Impact category	Unit	Total	farm	transport, packaging, retail	consumer	Total	farm	transport, packaging, retail	consumer
Climate change	kg CO2 eq	1.282797	1.038423	0.237258	0.007116	1.30248	1.031595	0.26377	0.007116
Ozone depletion	kg CFC-11 eq	4.78E-09	1.04E-09	3.57E-09	1.67E-10	7.21E-09	3.11E-09	3.94E-09	1.67E-10
Terrestrial acidification	kg SO2 eq	0.012876	0.012048	0.000791	3.73E-05	0.005455	0.004508	0.00091	3.73E-05
Freshwater eutrophication	kg P eq	0.000686	0.000518	0.000155	1.23E-05	0.000394	0.000224	0.000158	1.23E-05
Marine eutrophication	kg N eq	0.00057	0.000511	5.61E-05	3.2E-06	0.000289	0.000221	6.45E-05	3.2E-06
Human toxicity	kg 1,4-DB eq	0.133812	0.012206	0.113611	0.007996	0.205765	0.078148	0.119621	0.007996
Photochemical oxidant formation	kg NMVOC	0.004282	0.00353	0.000729	2.26E-05	0.00413	0.003166	0.000941	2.26E-05
Particulate matter formation	kg PM10 eq	0.002446	0.002051	0.000377	1.83E-05	0.001766	0.001312	0.000436	1.83E-05
Terrestrial ecotoxicity	kg 1,4-DB eq	2.07E-05	2.34E-06	1.79E-05	4.37E-07	6E-05	3.43E-05	2.52E-05	4.37E-07
Freshwater ecotoxicity	kg 1,4-DB eq	0.011507	0.001054	0.009923	0.00053	0.017664	0.006713	0.010421	0.00053
Marine ecotoxicity	kg 1,4-DB eq	0.01027	0.000948	0.008844	0.000477	0.015843	0.006041	0.009324	0.000477
Ionising radiation	kBq U235 eq	0.067583	0.005364	0.057408	0.004812	0.082242	0.019444	0.057987	0.004812
Agricultural land occupation	m2a	0.008106	0.000369	0.007584	0.000153	0.050543	0.042552	0.007838	0.000153
Urban land occupation	m2a	0.002995	0.00034	0.002618	3.73E-05	0.013039	0.009406	0.003596	3.73E-05
Natural land transformation	m2	0.000113	2.69E-05	8.28E-05	3.05E-06	0.000175	7.85E-05	9.38E-05	3.05E-06

Water depletion	m3	0.012309	0.006156	0.004743	0.00141	0.008177	0.001867	0.004901	0.00141
Metal depletion	kg Fe eq	0.019456	0.003022	0.0159	0.000533	0.043938	0.02612	0.017284	0.000533
Fossil depletion	kg oil eq	0.099022	0.01981	0.075652	0.00356	0.160409	0.072485	0.084364	0.00356

Figure 9. GWP through all life cycle stages: on-farm cultivation, post farm activities (including transport, milk plant, and packaging) and home cooking.

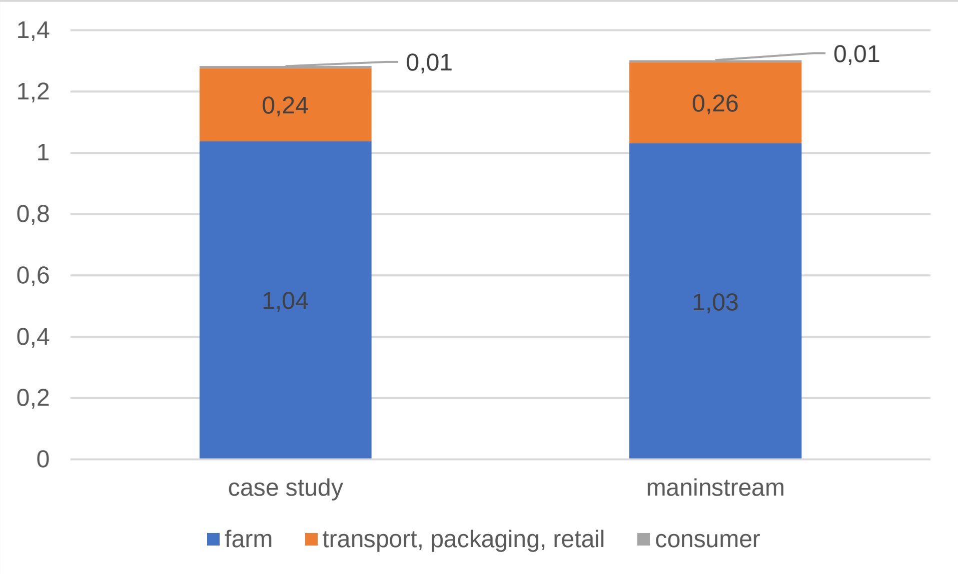


Figure 10. Contribution, %, of the main stages for each impact category of 1kg FPCM milk purchased by consumer (case study). Impact assessment method used: ReCiPe 2016 Midpoint (H) V1.13 / World (2016) H.V1.13 / World (2016) H.

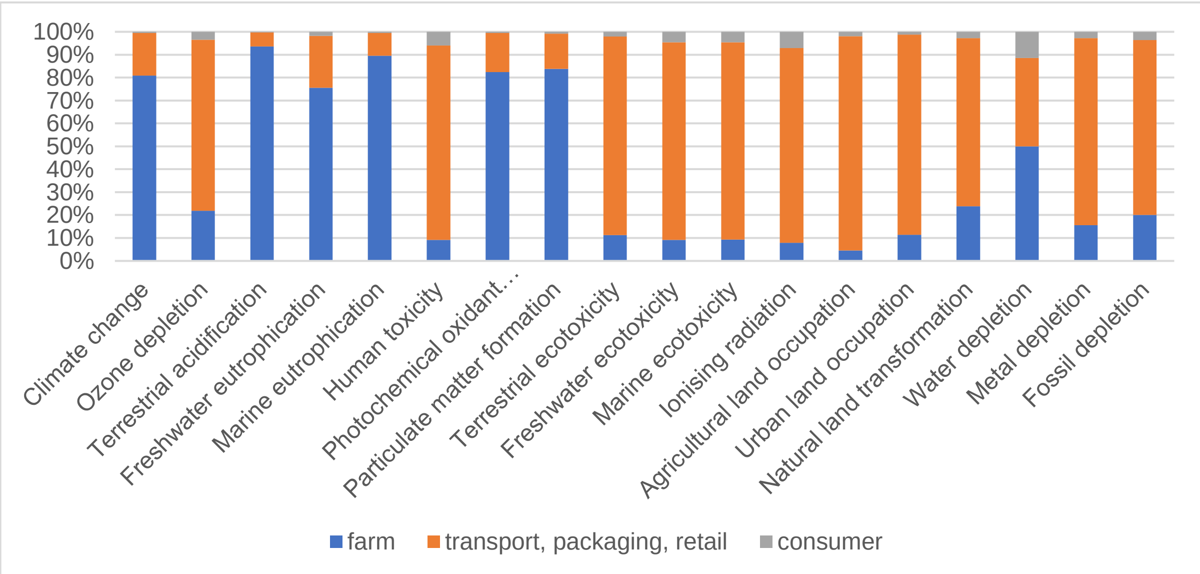


Figure 11. Contribution, %, of the main stages for each impact category of 1kg FPCM milk purchased by consumer (mainstream). Impact assessment method used: ReCiPe 2016 Midpoint (H) V1.13 / World (2016) H.V1.13 / World (2016) H.

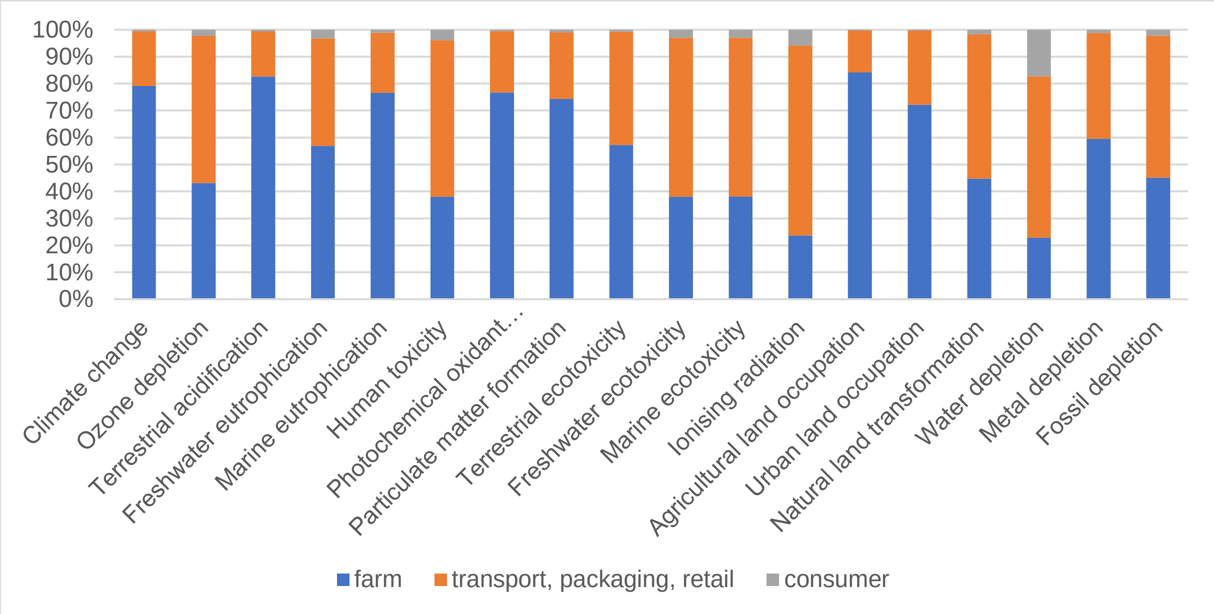
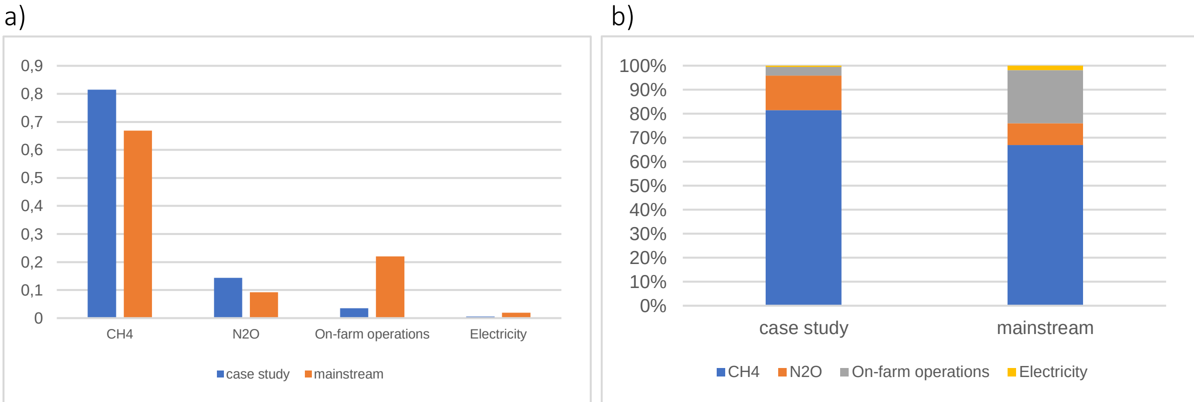


Figure 12. Greenhouse gas emissions at the farm stage are divided into main sources: CH4 means emissions from enteric fermentation and animal excrements, N2O - soil emissions mainly from grazing, additionally showing the share of agrotechnical operations (expressed in CO2) and additional sources such as electricity. Figure a) shows the absolute share and figure b) shows the percentage share.



The results of the SLCA analyzes are presented in Figure 13 and Table 12. The employee's results in individual categories indicate a level above acceptable in terms of occupational health and safety and life balance. The impact on the local community was assessed as acceptable. In the consumer category, the farm was rated below the median, mainly due to the fact that it did not renew its organic certificate (what happened during the Foodlevers project).

Figure 13. Results of SLCA analysis for each subcategory, organic milk, case study farm, Romania.

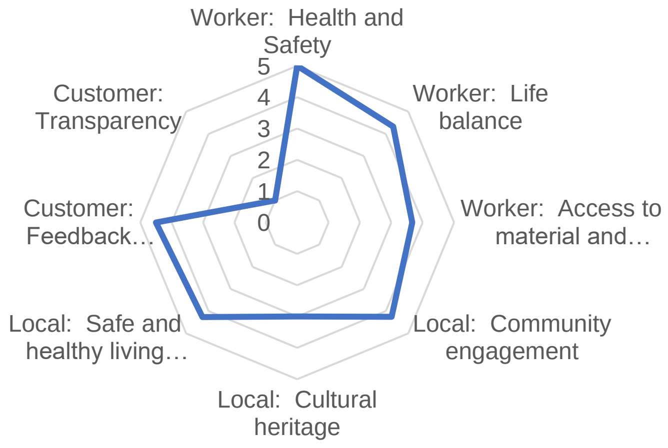


Table 12. Detailed results for SLCA analysis, milk, case study, Romania.

	Category	Question	unit	FARM SCORE
Worker	Health and Safety	How many training days have staff (including the farmer) had per year in total - number of days per person	Qualit. : # transformed	5
		Have you carried out a COSHH assessment?	Qualit.	N/A
		How rigorously is health and safety enforced on the farm?	Qualit.	5
		Are staff who handle potentially hazardous substances/machinery (e.g pesticides, heavy plant machinery) given training?	Qualit.	N/A
		How would you describe the working environment at your farm in terms of health and safety?	Qualit.	5
	Working hours	Number of working hours per week per emploee	Quant. : # transformed	5
		How onerous (tough) is the workload on your farm?	Qualit.	3
		Are you happy with the amount of holiday period you can take over a year?	Qualit.	5
Local community	Access to material and immaterial resources	How many environmental management options do you undertake on your farm?	Qualit.	3
		Habitat and conservation planning	Qualit.	3
		Richness of landscape	Qualit.	5

	Community engagement	Do you promote public access?	Qualit. :1,5		5
		How many community events do you attend/ host as a farm per year (this excludes events just for sales, like many farmers markets)?	Qualit.		5
		Any awards for staff welfare/community enagagement?	Qualit.		2
		Approximately what percentage of your produce (by weight) is sold to the local sales (<16km)	Qualit.		5
	Cultural heritage	How much maintenance/care do you give to historic features present on the farm?	Qualit.	N/A	
		Do you farm any Rare Breeds Survival Trust watchlist breeds? https://www.rbst.org.uk/Our-Work/Watchlist/Watchlist2	Qualit.		3
		Does the farm produce Produce of Designated Origin (PDO), Protected Geographic Status (PGS) or Traditional Specialities Guaranteed (TSG)?	Qualit.		1
		Do you farm using heritage varieties of crops?	Qualit.		5
	Safe and healthy living conditons	How many of these routes are local markets (e.g. farm shop, local delivery, local market, local shops)	Qualit.	N/A	
		Do you sell produce directly to customers on-farm?	Qualit.		5
		Herbicide and other pesticide use	Qualit.		5
		Water management score	Qualit.		2.6
		Nitrogen surplus score	Qualit.		3
		Phosphorus and Potassim surplus score	Qualit.		5
		Are animals correctly identified and is product traceability ensured through animal identification tags (e.g. eat tags, ID tatoo)?	Qualit.		5
Consumer	Health and safety	Have you received any 3rd party endorsement for food quality/local food production (including awards but excluding certifications)? None, local, regional, national	Qualit.		2

		How many environmental management options do you undertake on your farm?	Qualit.		3
	Feedback mechanism	Do you have any evidence of consumer satisfaction?	Qualit.		4
		Do you sell produce directly to customers on-farm?	Qualit.		5
		How many of these routes are local markets (e.g. farm shop, local delivery, local market, local shops)	Qualit.	N/A	
	Transparency	What level of food quality certification do you have? E.g. Basic farm assured, Global GAP/ Europe GAP, full organic certification	Qualit.		1

Conclusions

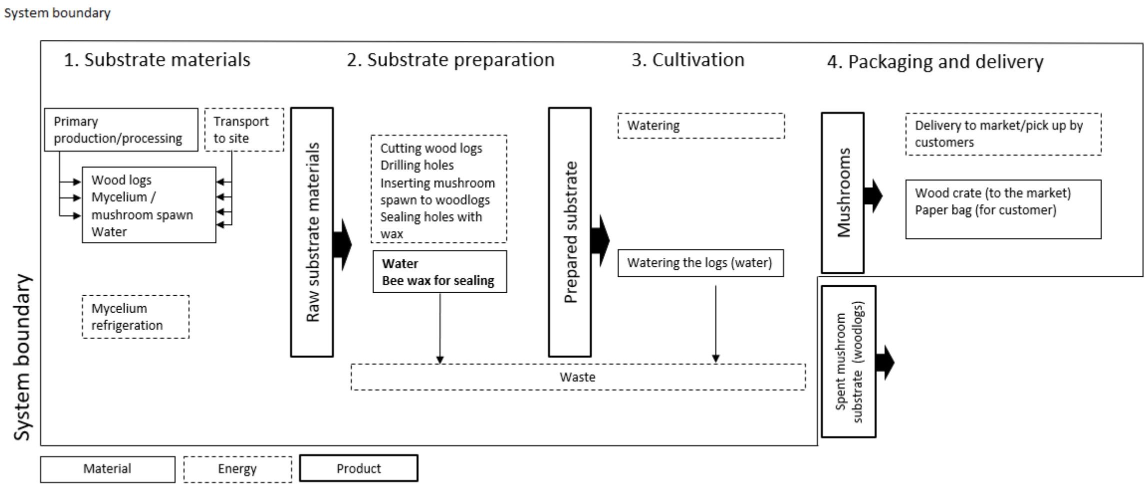
- No significant differences were found between the case study and assumed mainstream milk system in Romania.
- The farm phase has the greatest impact on climate change, acidification and eutrophication
- The carbon footprint of 1 kg of milk at the farm gate is approximately 1 kgCO_2eq. kg^{-1} in both compared systems and the whole life cycle CF is 1.28 and 1.30 kg CO_2eq kg^{-1}, respectively for case study and mainstream system.
- Main source of GHG emission is CH4, its share in total emission is 81% and 67% on farm gate respectively for case study and mainstream milk system;
- Due to extensive production system total share of CO2 emission on farm is very low while onfarm operations are responsible for 22% of emission in comparative system
- The shorter supply chain in the case study did not have a significant impact on the environmental impact of milk.
- In the SLCA consumer category, the farm was rated below the acceptable level due to the fact that has not renewed its organic certificate

Finland, organic shiitake cultivation

Overview

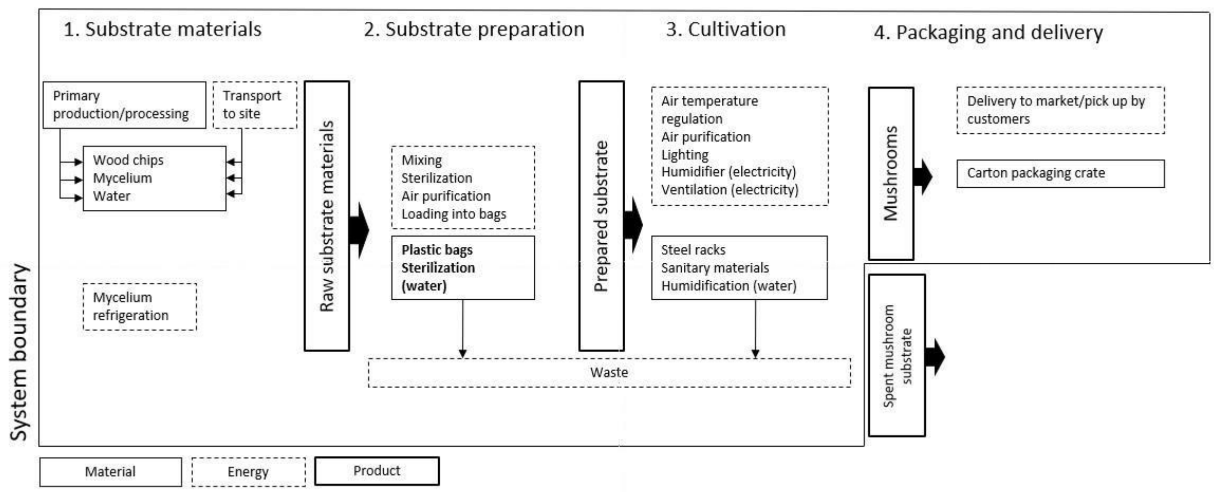
The outdoor case study is situated at Iso-orvokkiniitty farm located in Karjalohja in southern Finland. Here shiitake mushroom cultivation on logs has been practiced since 2017. In Finland, shiitake can be cultivated on oak, birch, alder and aspen. As a cultivation substrate, tree logs with a diameter of 10-15 cm are bought from a nearby farm (2 km distance) and cut to a length of about 1m. Tree logs can produce mushrooms for about 4-6 years after which they need to be replaced. The farmer has about 1800 tree logs for shiitake cultivation, and he replaces about 300 logs (= 2.5 m3 or 1600 kg dry-fresh weight) per year. The dowels containing the mushroom mycelium are bought from the same farm (2 km distance) as where the logs are bought. The annual production between 2018-2021 was about 78,75 kg of shiitake per year on an area of about 0.12 ha. During the summer season the logs have to be kept moist otherwise the mushroom mycelium might degenerate or die. The logs need to be watered if there hasn't been rain for a period of about two weeks. To water the logs, the farmer uses water from his own well. The mushrooms are mostly sold on the nearby market in Karjalohja (distance 2.5 km) and a smaller proportion of the harvest is sold on the farm directly to the customers. After about 4-6 years the logs need to be replaced. The waste mushroom substrate is used in the own vegetable garden as a soil amendment. Production system is shown in Figure 14.

Figure 14. Outdoor shiitake mushroom cultivation (case study) production system, Finland.



The reference farm is located in the Helsinki metropolitan area and produces indoors. The biggest difference between growing indoors and growing in a forest is the need to control the environment, i.e. use electricity to maintain the appropriate temperature, humidity and lighting.
Cultivation phase: the bags are incubated for approximately 2 weeks at 70% RH and 17 C and then for 7 weeks at 93% RH and 16.5 C. During this phase, almost 25% of the bags of substrate prepared can be lost due to contamination by competing fungi and bacteria. Harvesting is done manually during these 7 weeks and is done several times during these weeks before the substrate is considered spent. The mushrooms are packed in wooden crates (3 kg per crate) and delivered to restaurants in the Helsinki Metropolitan Area (average distance about 10 km). The spent mushroom substrate is sold to private customers who use it as a soil improver in private gardens (See Figure 15).

Figure 15. Indoor cultivation system (mainstream). Shiitake mushrooms cultivation, Finland.



Main LCI data

Due to clarity of the data inventory description of main cultivation phases and processes is shown below in Table 13. Detailed data inventory for both systems as well as for mycelim production stage can be found in Annex , Tables A9-A11.

Table 13. The comparative inventory of main data, shiitake mushrooms cultivation, Finland.

Item	Unit	Case study	Mainstream*	Source/Comments
Functional unit		1 kg of fresh shiitake mushroom purchased by customer	1 kg of fresh shiitake mushroom purchased by customer	Consumer phrase also included
System boundary		cradle to grave	cradle to grave	
Time coverage		2018-2021	2018-2021	
Localisation		Karjalohja, FI	Helsinki, metropolitan area, FI	
Source of data		farm survey + publications	farm survey + publications	Mycelium production inventory based on Leiva et al.,2015
Main similarities and differences		shiitake cultivation in forest	indoor mushrooms farm	
Cultivation		**per 1 kg**	**per 1kg**	
Mycelim production	kg	0.358	0.358	See Table A9, same assumption for both systems

Substrate materials	description	wood chips, transport, electricity, water	wood chips, transport, electricity, water	See Table A10, A11, minor differences between systems
Substrate transformation	description	wooden logs, petrol, electricity for cutting and drilling the holes to insert mycelium	electricity, natural gas	See Table A10, A11, major differences between systems
Cultivation	description	watering only	water, electricity, infrastructure	See Table A10, A11, major differences between systems
Packaging and delivery				
Carton box	kg	0.168	0.168	
Delivery - passenger car, small size electirc	km		10	delivery to restaurants mainly
Transport, passenger car, compact size, petrol (EURO 5)	km	2.5		customer pick up
Paper bag/paper	kg	0.0186		
Consumer cooking				
Electricity	kWh	0.0339	0.0339	Same assumption for both systems
Natural gas	MJ	0.18306	0.18306	

Results

Table 14. Detailed results of impact assessment , 1kg of shiitake mushrooms, Finland, ReCiPe Midpoint (H) V1.13 / World Recipe H

		forest cultivation				indoor cultivation			
Impact category	Unit	Total	cultivation	packaging and delivery	consumer	Total	cultivation	packaging and delivery	consumer
Climate change	kg CO2 eq	3.000343	2.868257	0.10439	0.027696	5.700574	5.432271	0.240607	0.027696
Ozone depletion	kg CFC-11 eq	1.01E-07	9.74E-08	3.08E-09	4.35E-10	7.82E-08	7.3E-08	4.76E-09	4.35E-10
Terrestrial acidification	kg SO2 eq	0.009161	0.008866	0.000245	4.95E-05	0.110932	0.109783	0.0011	4.95E-05
Freshwater eutrophication	kg P eq	0.000513	0.000491	1.68E-05	5.56E-06	0.001388	0.00126	0.000122	5.56E-06
Marine eutrophication	kg N eq	0.000627	0.000604	2E-05	3.2E-06	0.001086	0.001005	7.82E-05	3.2E-06
Human toxicity	kg 1,4-DB eq	0.562627	0.532184	0.024319	0.006124	1.154138	1.014941	0.133073	0.006124
Photochemical oxidant formation	kg NMVOC	0.016649	0.01623	0.000357	6.16E-05	0.026828	0.025432	0.001334	6.16E-05
Particulate matter formation	kg PM10 eq	0.003848	0.003693	0.000135	2.01E-05	0.025436	0.02475	0.000666	2.01E-05

Terrestrial ecotoxicity	kg 1,4-DB eq	0.001169	0.001127	4.15E-05	9.62E-07	0.001336	0.001279	5.65E-05	9.62E-07
Freshwater ecotoxicity	kg 1,4-DB eq	0.069803	0.064259	0.004671	0.000872	0.076663	0.056553	0.019237	0.000872
Marine ecotoxicity	kg 1,4-DB eq	0.062232	0.057371	0.00409	0.000772	0.069362	0.051575	0.017015	0.000772
Ionising radiation	kBq U235 eq	0.538568	0.518239	0.003223	0.017106	3.988189	3.94261	0.028473	0.017106
Agricultural land occupation	m2a	28.96931	28.96582	0.002132	0.001362	22.58287	22.57356	0.007951	0.001362
Urban land occupation	m2a	0.176419	0.173783	0.002501	0.000134	0.243004	0.235843	0.007027	0.000134
Natural land transformation	m2	0.002336	0.002285	4.2E-05	8.9E-06	0.001096	0.001031	5.65E-05	8.9E-06
Water depletion	m3	0.025763	0.021211	0.000752	0.0038	0.090469	0.08147	0.0052	0.0038
Metal depletion	kg Fe eq	0.201714	0.189904	0.01054	0.001271	0.230874	0.155459	0.074145	0.001271
Fossil depletion	kg oil eq	1.880088	1.83988	0.031504	0.008705	1.896148	1.820713	0.06673	0.008705

Figure 16. Contribution, %, of the mains stages for each impact category of 1kg shiitake mushrooms purchased by consumer (case study = forest cultivation). Impact assessment method used: ReCiPe 2016 Midpoint (H) V1.13 / World (2016) H.V1.13.

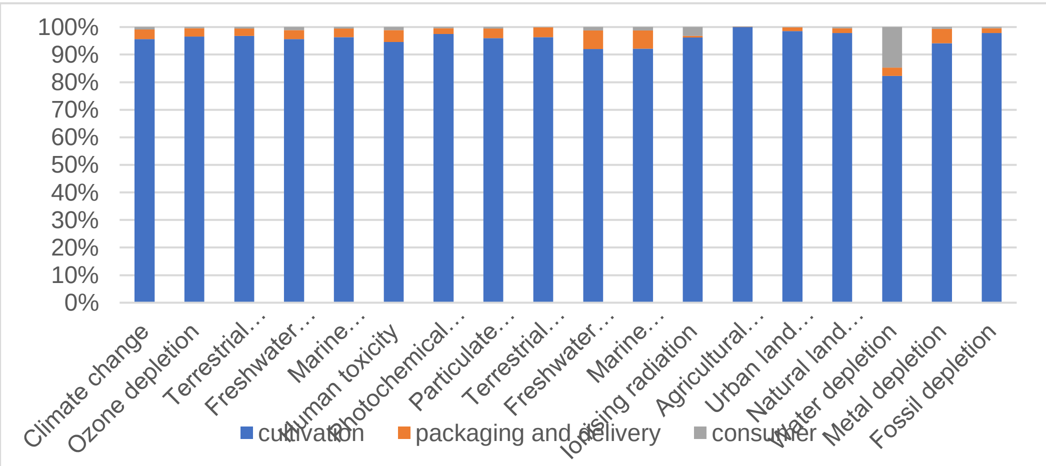


Figure 17. Contribution, %, of the mains stages for each impact category of 1kg shiitake mushrooms purchased by consumer (mainstream = indoor cultivation). Impact assessment method used: ReCiPe 2016 Midpoint (H) V1.13 / World (2016) H.V1.13.

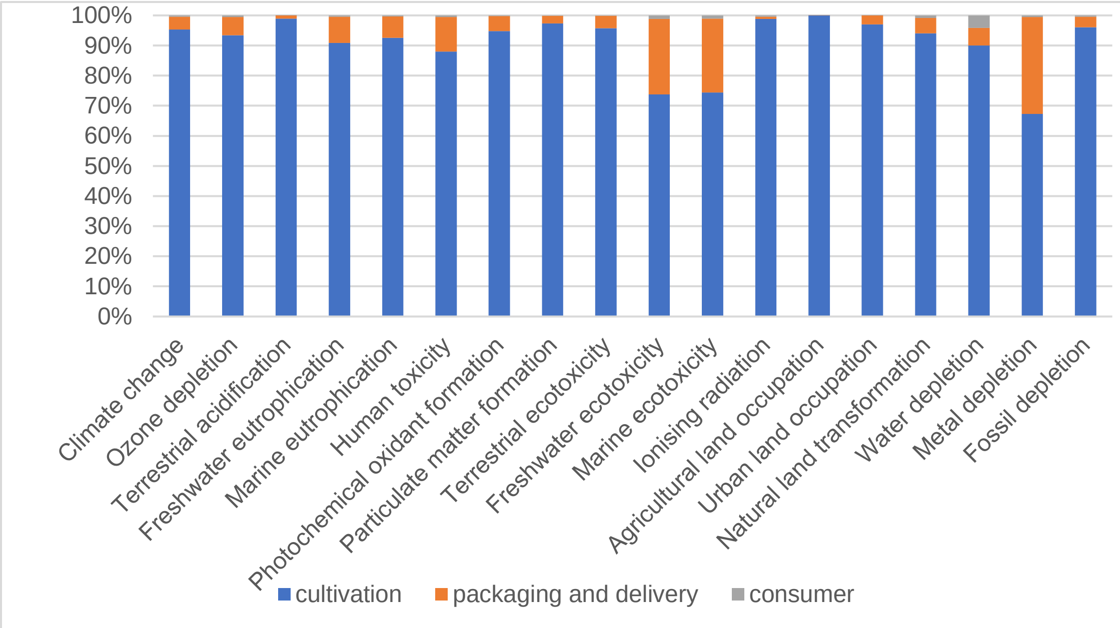
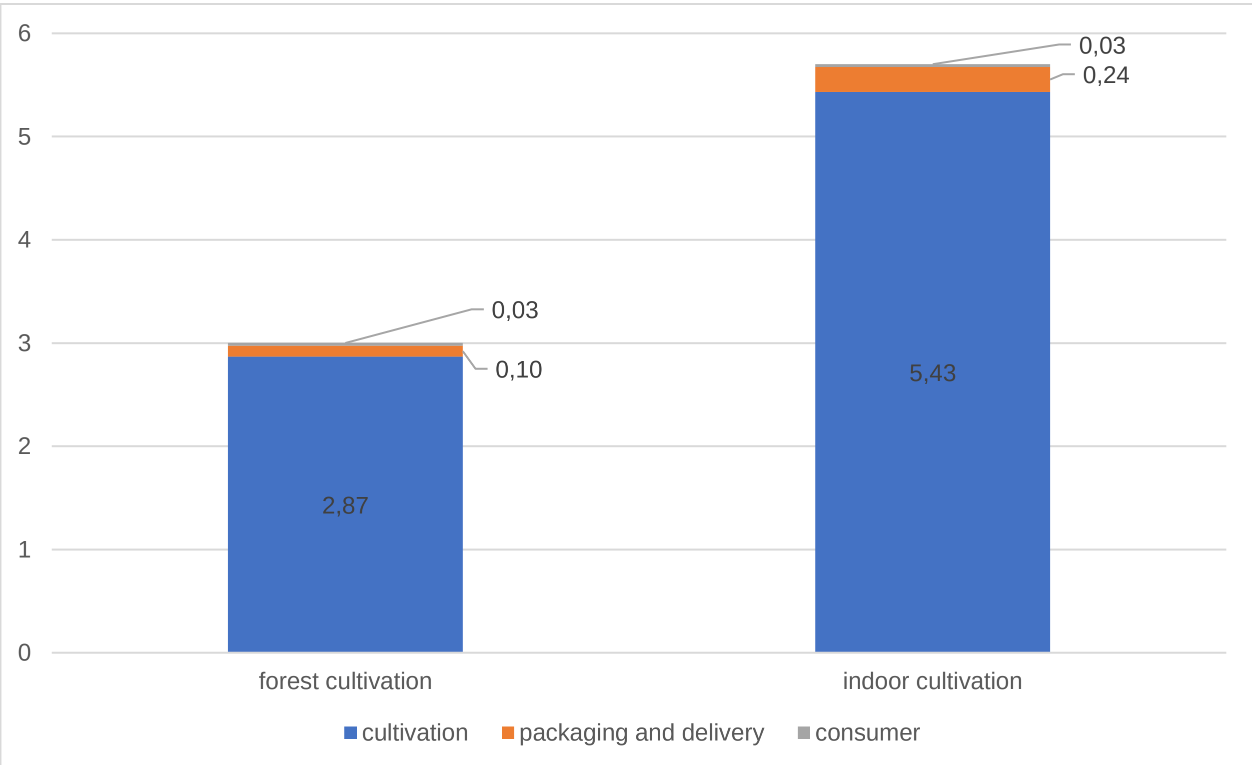


Figure 18. GWP through all life cycle stages: cultivation, post farm activities (including transport and packaging) and home cooking, shiitake mushrooms, Finland.



The results of the SLCA analyzes are presented in Figure 18 and Table 15. The employee's results in individual categories indicate a level above acceptable in terms of occupational health and safety and life balance. The impact on the local community was rated as above the median. In the consumer category, the farm was rated high, mainly due to having an organic certificate.

Figure 19. Results of SLCA analysis for each subcategory, shiitake mushrooms, case study farm, Finland.

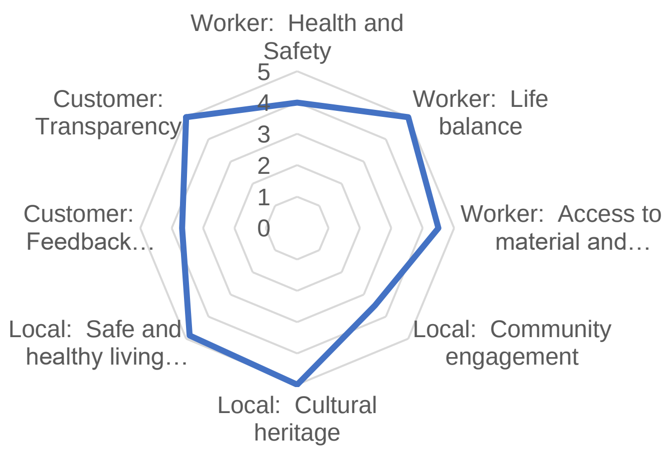


Table 15. Detailed results for SLCA analysis, shiitake mushrooms, case study, Finland.

	Category	Question	unit	FARM SCORE
Worker	Health and Safety	How many training days have staff (including the farmer) had per year in total - number of days per person	Qualit. : # transformed	5
		Have you carried out a COSHH assessment?	Qualit.	N/A
		How rigorously is health and safety enforced on the farm?	Qualit.	5
		Are staff who handle potentially hazardous substances/machinery (e.g pesticides, heavy plant machinery) given training?	Qualit.	N/A
		How would you describe the working environment at your farm in terms of health and safety?	Qualit.	5
	Working hours	Number of working hours per week per emploee	Quant. : # transformed	5
		How onerous (tough) is the workload on your farm?	Qualit.	3
		Are you happy with the amount of holiday period you can take over a year?	Qualit.	5

	Access to material and immaterial resources	How many environmental management options do you undertake on your farm?	Qualit.		3
		Habitat and conservation planning	Qualit.		3
		Richness of landscape	Qualit.		5
	Community engagement	Do you promote public access?	Qualit. :1,5		5
		How many community events do you attend/ host as a farm per year (this excludes events just for sales, like many farmers markets)?	Qualit.		5
		Any awards for staff welfare/community enagagement?	Qualit.		2
		Approximately what percentage of your produce (by weight) is sold to the local sales (<16km)	Qualit.		5
Local community	Cultural heritage	How much maintenance/care do you give to historic features present on the farm?	Qualit.	N/A	
		Do you farm any Rare Breeds Survival Trust watchlist breeds? https://www.rbst.org.uk/Our-Work/Watchlist/Watchlist2	Qualit.		3
		Does the farm produce Produce of Designated Origin (PDO), Protected Geographic Status (PGS) or Traditional Specialities Guaranteed (TSG)?	Qualit.		1
		Do you farm using heritage varieties of crops?	Qualit.		5
	Safe and healthy living conditons	How many of these routes are local markets (e.g. farm shop, local delivery, local market, local shops)	Qualit.	N/A	
		Do you sell produce direct to customers on-farm?	Qualit.		5
		Herbicide and other pesticide use	Qualit.		5
		Water management score	Qualit.		2.6
		Nitrogen surplus score	Qualit.		3
		Phosphorus and Potassim surplus score	Qualit.		5
		Are animals correctly identified and is product traceability ensured through animal identification tags (e.g. eat tags, ID tatoo)?	Qualit.		5

Consumer	Health and safety	Have you received any 3rd party endorsement for food quality/local food production (including awards but excluding certifications)? None, local, regional, national	Qualit.		2
		How many environmental management options do you undertake on your farm?	Qualit.		3
	Feedback mechanism	Do you have any evidence of consumer satisfaction?	Qualit.		4
		Do you sell produce directly to customers on-farm?	Qualit.		5
		How many of these routes are local markets (e.g. farm shop, local delivery, local market, local shops)	Qualit.	N/A	
	Transparency	What level of food quality certification do you have? E.g. Basic farm assured, Global GAP/ Europe GAP, full organic certification	Qualit.		1

Conclusions

- Growing shiitake mushrooms indoors has significantly higher impact on the environment in all impact categories considered, especially in climate change, acidification and eutrophication
- Energy carries (petrol fuel, electricity, natural gas) have a predominant impact on environmental footprint in both systems (usually 70 - 90%)
- The carbon footprint of forest cultivation is almost 2 times smaller than that of traditional cultivation (2.87 vs 5.43) mainly due to lower energy consumption
- The forest cultivation of 1 kg of mushrooms demand 4 times less water than indoors cultivation (21 vs. 81 l per 1 kg)
- The short sales chain also means that the packaging and delivery of mushrooms to the consumer has less impact on the environment.

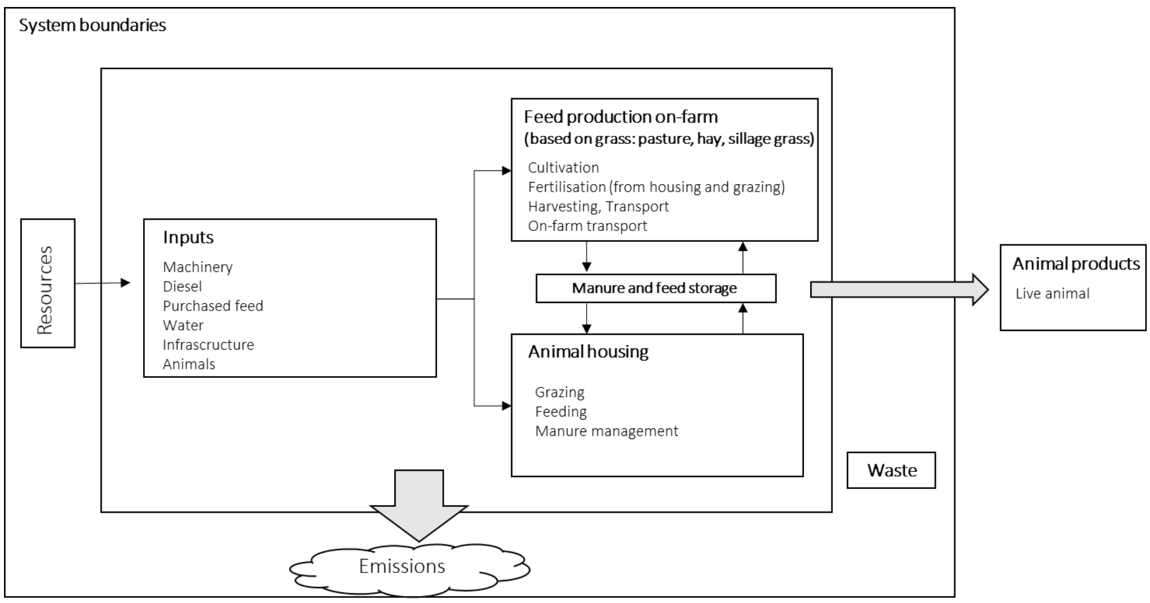
Poland,organic beef production

Overview

OIKOS farm (owned by Mr. Marcin Wójcik) is located in the Low Beskids. It is an ecological farm that breeds limousine beef cattle. Currently, he keeps about 120 suckler cows in the basic herd. The area of farms is approx. 280 ha, of which 205 ha are grasslands, and the rest are forests and woodlots. Production is carried out on the basis of own fodder, natural grasslands characterized by very high biodiversity. There are many protected plants, numerous species of wild birds and deer. Meat from the farm is sold at Targ Pietruszkowy in Krakow and Bio Bazaar in Warsaw. The inventory data are from 2022, but it should be noted that according to the owner's declaration there are no large fluctuations between years in terms of herd size and feeding, so they can be considered as data describing a certain period. Visualisation of production system is presented on Figure 20.

Mainstream organic system description is based on polish FADN document "Wyniki Standardowe 2021 uzyskane przez ekologiczne gospodarstwa rolne uczestniczące w Polskim FADN Część I. Wyniki Standardowe";(https://fadn.pl/publikacje/wyniki-standardowe-2/wyniki-standardowe/).
The average farm area is approximately 31.3 ha, of which meadows and pastures constitute approximately 27 ha. The feeding system is based on grazing with the addition of farm-produced feed and approximately 5 tons per year of purchased feed. The herd size is 23.5 LU (livestock unit). Other parameters such as fuel and energy consumption were determined using average prices published by the Central Statistical Office.

Figure 20. Organic beef production system, OIKOS farm, PL.



Main LCI data

Table 16. Main data of LCI for live weight beef production on farm in Poland. Comarision beetwen innovative farm (case study) and mainstream organic system.

Item	Unit	Case study	Mainstream
Functional unit	#	1 kg of live weight animal on farm gate	1 kg of live weight animal on farm gate
Time coverage	#	2022	2021
Localisation		OIKOS farm, Poland	average beef farm
Data source		farm survey	polish FADN statistics
Farm area	ha	280	31.3
Main similarities and differences	The case study farm is an extensive beef farm and the feeding system is based on grass (grazing, hay, silage). The mainstream system corresponds to a typical livestock farm, with grazing		

	supplemented by home-grown fodder and a small amount of bought-in feed.				
Output to technosphere					
Animal, live weight	kg	23060		5569.22	
Inputs from nature		**per farm**	**per 1kg**	**per farm**	**per 1kg**
Land occupation, pernament pasture, PL	ha	205	0.008889853	26.83	0.00481755
Land occupation, forest, PL	ha	75	0.003252385	1.69	0.00030345
Land occupation, annual crop, PL	ha			4.4	0.00079006
Water for animal drinking (calculated)	m3	2821.72	0.122364267	295.65	0.05308643
Transport of inputs					
Lorry transport (<10t)	tkm	650	0.028187337	536.29	0.09629535
Transport of inputs by couriers or own transport (van, <3.5t)	km	2500	0.108412836		
Grassland and pasture cultivation					
Diesel fuel	l	8000	0.346921075	696	0.12497262
Machinery time	h	1879	0.081483088		
Feeding					
1/2 of year (summer)		100% grazing		100% grazing	
1/2 of year (winter)		produced on-farm		produced on-farm	
Compounded feed, purchased	kg			5362.92	0.96295711
Inputs from technosphere: electricity/heat					
Electricity, low voltage {PL}| market for electricity, low voltage | Cut-off, U	kWh	1500	0.065047702	1486	0.26682372
Emissions to air					
Methane (enteric fermentation+manure management)	kg CH4	14221.51	0.616717693	1956.97	0.35139032
Dinitrogen monoxide - direct (manure management)	kg N2O	43.92	0.001904597	4.12	0.00073978
Dinitrogen monoxide -indirect (manure management)	kg N2O	36.89	0.00159974	3.46	0.00062127
Ammonia (manure management: housing)	kg NH3	1606.73	0.069676062	152.70	0.02741856
Nitrogen oxides (manure management: housing)	kg NO2	624.69	0.027089766	61.08	0.01096742
Dinitrogen monoxide (soil cultivation, direct)	kg N2O	52.65	0.002283174	14.93	0.00268081
Dinitrogen monoxide (soil cultivation, indirect)	kg N2O	34.01	0.001474848	9.07	0.00162859
Ammonia (grazing + manure application)	kg NH3	937.26	0.040644406	89.08	0.01599506
Nitrogen oxides (grazing + manure application)	kg NO2	127.07	0.005510408	36.63	0.00657722
Emissions to water					
Nitrate leaching and run-off	kg NO3	0	0	0.00	0
Phosphorus leaching and run-off	kg P2O5	760	0.032957502	35.00	0.00628454
Source of data: Case study - See Report M2.2 Mainstream system: based on polish FADN document "Wyniki Standardowe 2021 uzyskane przez ekologiczne gospodarstwa rolne uczestniczące w Polskim FADN Część I. Wyniki Standardowe", https://fadn.pl/publikacje/wyniki-standardowe-2/wyniki-standardowe/ Transport of input assumptions: Agri-footprint: Beef cattle, at farm , Economic, U					

Table 17. Post farm inventory data for 1 kg of beef purchased by consumers. There was no reason to assume differences at the slaughterhouse stage.

Post farm activity: transport, slaughtering, transport to consumer	Unit	Case study	Mainstream system
Transport to slaughterhouse (>7.5t)	tkm	0.00624458	1
Meat and edible offal rate	#	0.49	
Economic allocation of beef	%	92.9	
Electricity, low voltage {PL}| market for electricity, low voltage | Cut-off, U	MJ	0.391	
Heat, district or industrial, natural gas {Europe without Switzerland}| market for heat, district or industrial, natural gas | Cut-off, U	MJ	0.15	
Transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO3, carbon dioxide, liquid refrigerant, cooling {GLO}| market for transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO3, carbon dioxide, liquid refri(...)_1 | Cut-off, S	km	0.6938421	1
Source of data: slaughtering: PEFCR Guidance 6.3 case study: Report M2.2 mainstream system: Agri-footprint 5.0 Report (transport from farm and to consumer)			

Results

Table 18. Detailed results of impact assessment: case study, 1kg of beef, Poland, ReCiPe Midpoint (H) V1.13 / World Recipe H

Impact category	Unit	Total	farm	slaughtering	transport	consumer
Climate change	kg CO2 eq	32.4595	31.24628	0.738612	0.474608	1.110373
Ozone depletion	kg CFC-11 eq	6.07E-08	4.74E-08	3.81E-09	9.55E-09	3.33E-08
Terrestrial acidification	kg SO2 eq	0.557264	0.551853	0.00412	0.001292	0.005876
Freshwater eutrophication	kg P eq	0.060561	0.059609	0.000889	6.35E-05	0.001227
Marine eutrophication	kg N eq	0.022348	0.021957	0.000308	8.34E-05	0.000352
Human toxicity	kg 1,4-DB eq	1.166912	0.478075	0.577153	0.111684	0.798884
Photochemical oxidant formation	kg NMVOC	0.085771	0.081773	0.001959	0.002039	0.003463
Particulate matter formation	kg PM10 eq	0.084635	0.082735	0.001233	0.000667	0.001791
Terrestrial ecotoxicity	kg 1,4-DB eq	0.000215	0.000119	2.99E-05	6.66E-05	3.6E-05
Freshwater ecotoxicity	kg 1,4-DB eq	0.09997	0.048038	0.029064	0.022868	0.040109
Marine ecotoxicity	kg 1,4-DB eq	0.089655	0.043468	0.026226	0.019961	0.036492
Ionising radiation	kBq U235 eq	0.079234	0.044708	0.024396	0.01013	0.034563
Agricultural land occupation	m2a	0.068152	0.027847	0.035541	0.004764	0.049459
Urban land occupation	m2a	0.033463	0.015709	0.005261	0.012493	0.00767
Natural land transformation	m2	0.001439	0.001201	5.36E-05	0.000184	0.000251
Water depletion	m3	0.405638	0.222702	0.012316	0.002653	0.167967
Metal depletion	kg Fe eq	0.319755	0.245496	0.022027	0.052232	0.038248
Fossil depletion	kg oil eq	1.246002	0.902644	0.195467	0.147892	0.41384

Table 19. Detailed results of impact assessment: mainstream, 1kg of beef, Poland, ReCiPe Midpoint (H) V1.13 / World Recipe H

Impact category	Unit	Total	farm	slaughtering	transport	consumer
Climate change	kg CO2 eq	26.31889	23.02011	0.738612	2.560167	1.110373
Ozone depletion	kg CFC-11 eq	2.15E-07	7.4E-08	3.81E-09	1.38E-07	3.33E-08
Terrestrial acidification	kg SO2 eq	0.248903	0.233608	0.00412	0.011175	0.005876
Freshwater eutrophication	kg P eq	0.013879	0.012773	0.000889	0.000217	0.001227
Marine eutrophication	kg N eq	0.010737	0.00968	0.000308	0.000749	0.000352
Human toxicity	kg 1,4-DB eq	1.961008	0.899886	0.577153	0.48397	0.798884
Photochemical oxidant formation	kg NMVOC	0.078895	0.05801	0.001959	0.018926	0.003463
Particulate matter formation	kg PM10 eq	0.046804	0.040165	0.001233	0.005407	0.001791
Terrestrial ecotoxicity	kg 1,4-DB eq	0.019254	0.018738	2.99E-05	0.000487	3.6E-05
Freshwater ecotoxicity	kg 1,4-DB eq	0.162989	0.06711	0.029064	0.066815	0.040109
Marine ecotoxicity	kg 1,4-DB eq	0.143899	0.057226	0.026226	0.060447	0.036492
Ionising radiation	kBq U235 eq	0.166755	0.072138	0.024396	0.070222	0.034563
Agricultural land occupation	m2a	0.344865	0.290958	0.035541	0.018366	0.049459
Urban land occupation	m2a	0.122695	0.062844	0.005261	0.05459	0.00767
Natural land transformation	m2	0.001664	0.000626	5.36E-05	0.000985	0.000251
Water depletion	m3	0.313963	0.124404	0.012316	0.009277	0.167967
Metal depletion	kg Fe eq	0.364664	0.192245	0.022027	0.150392	0.038248
Fossil depletion	kg oil eq	1.719396	0.692226	0.195467	0.831704	0.41384

Figure 21. Contribution to Climate Change of all product stages, 1 kg of beef, Poland.

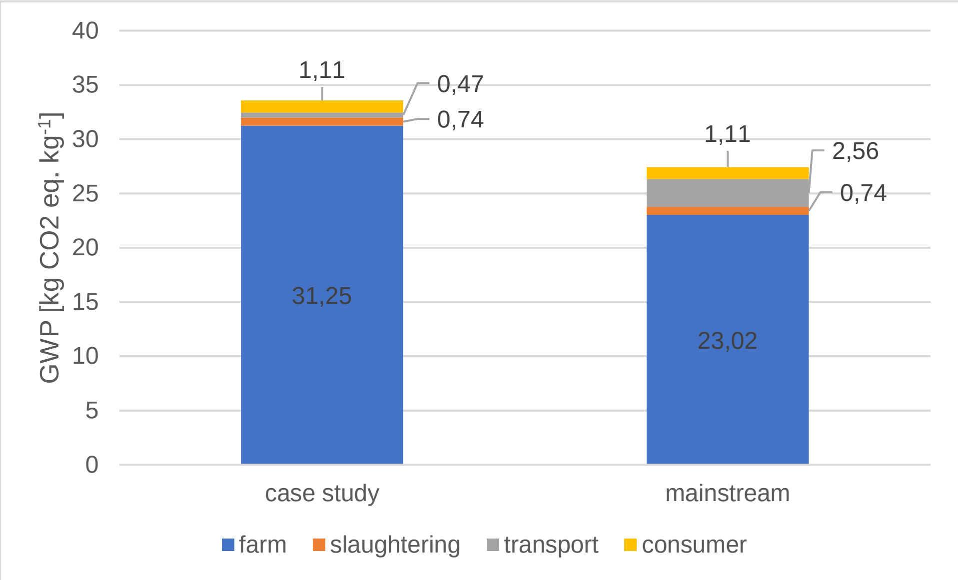


Figure 22. Contribution, %, of the mains stages for each impact category of 1kg Brussels sprout purchased by consumer (case study). Impact assessment method used: ReCiPe 2016 Midpoint (H) V1.13 / World (2016)

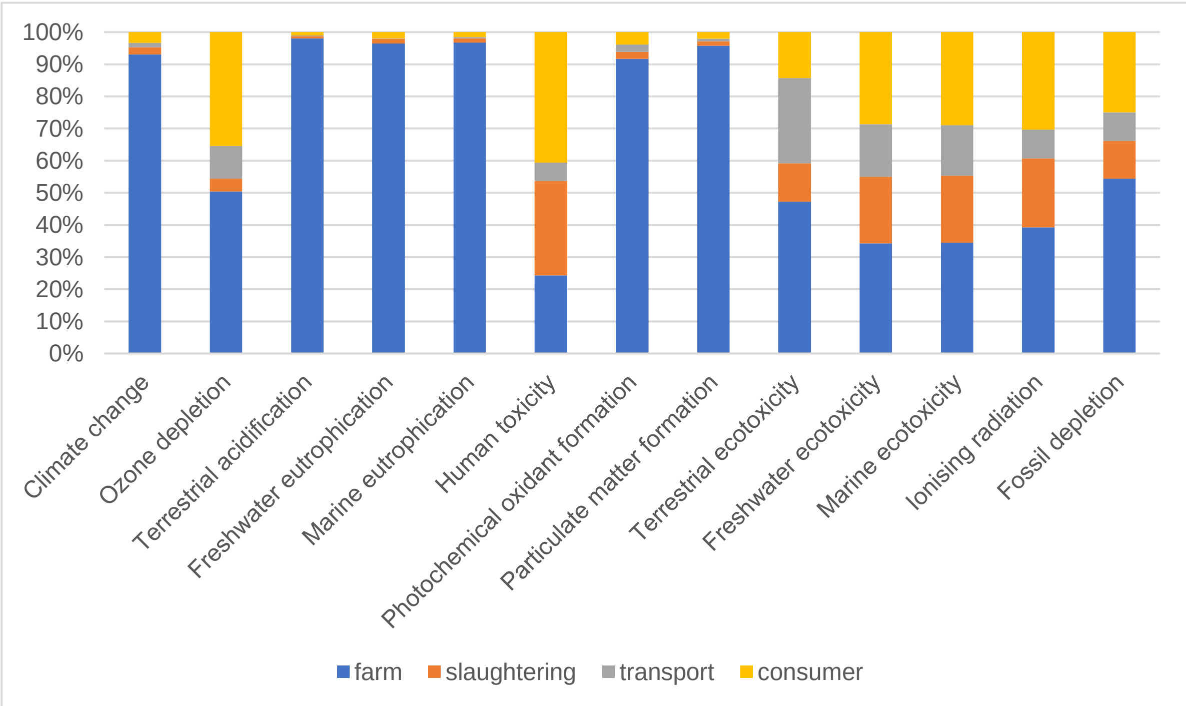


Figure 23. Contribution, %, of the mains stages for each impact category of 1kg beef purchased by consumer (mainstream organic). Impact assessment method used: ReCiPe 2016 Midpoint (H) V1.13 / World (2016)

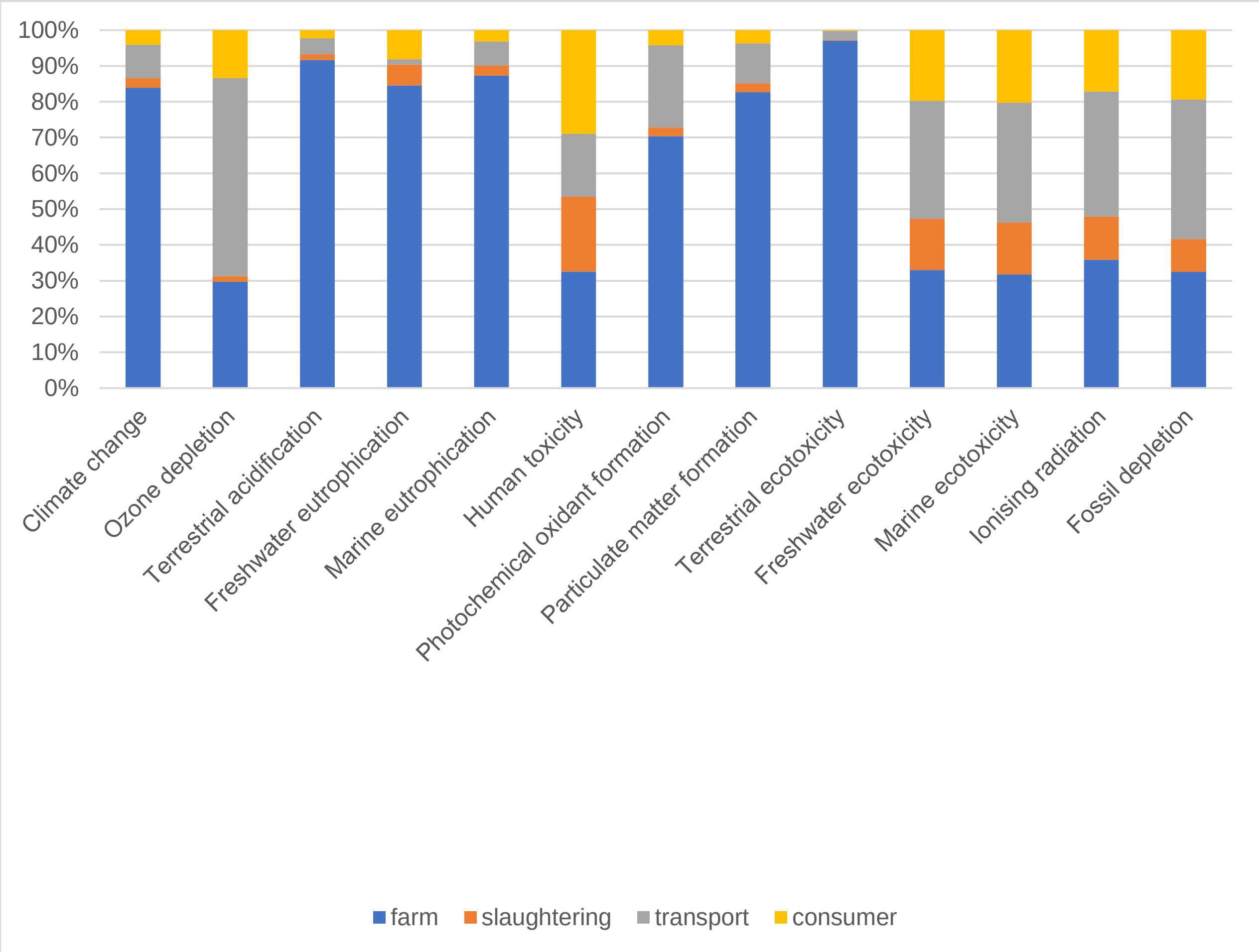


Figure 24. Greenhouse gas emissions at the farm stage divided into main sources: CH4 means emissions from enteric fermentation and animal excrements, N2O - soil emissions mainly from grazing, additionally showing the share of agrotechnical operations (expressed in CO2) and additional sources such as electricity and purchased feed. Figure a) shows the absolute share and figure b) shows the percentage share.

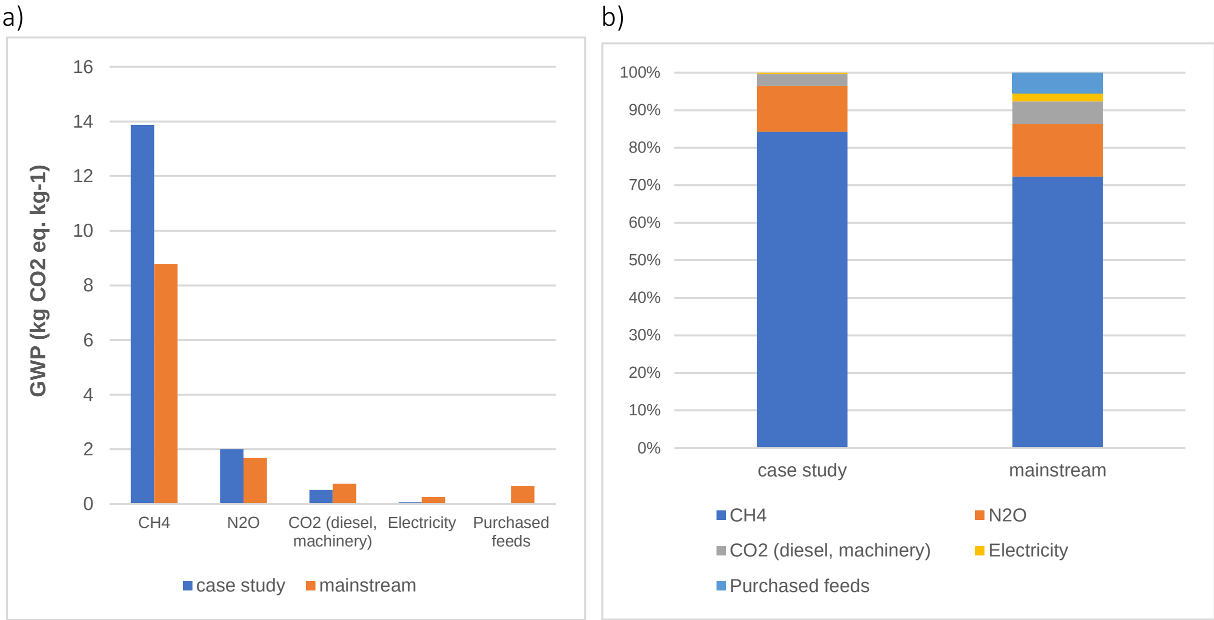


Figure 25. Results of SLCA analysis for each subcategory, beef, case study farm, Poland.

Table 20. Detailed results for SLCA analysis, beef, case study, Poland.

	Category	Question	FARM SCORE
Worker	Health and Safety	Skills and knowledge	4
		Have you carried out a COSHH assessment?	N/A
		How rigorously is health and safety enforced on the farm?	5
		Are staff who handle potentially hazardous substances/machinery (e.g pesticides, heavy plant machinery) given training?	5
		How would you describe the working environment at your farm in terms of health and safety?	5

	Working hours	Number of working hours per week per employee	5
		How onerous (tough) is the workload on your farm?	3
		Are you happy with the amount of holiday period you can take over a year?	5
Local community	Access to material and immaterial resources	How many environmental management options do you undertake on your farm?	5
		Habitat and conservation planning	5
		Richness of landscape	5
	Community engagement	Do you promote public access?	5
		How many community events do you attend/ host as a farm per year (this excludes events just for sales, like many farmers markets)?	5
		Any awards for staff welfare/community enagagement?	4
		Approximately what percentage of your produce (by weight) is sold to the local sales (<16km)	3
	Cultural heritage	How much maintenance/care do you give to historic features present on the farm?	3
		Do you farm any Rare Breeds Survival Trust watchlist breeds? https://www.rbst.org.uk/Our-Work/Watchlist/Watchlist2	5
		Does the farm produce Produce of Designated Origin (PDO), Protected Geographic Status (PGS) or Traditional Specialities Guaranteed (TSG)?	1
		Do you farm using heritage varieties of crops?	5
	Safe and healthy living conditions	How many of these routes are local markets (e.g. farm shop, local delivery, local market, local shops)	5
		Do you sell produce direct to customers on-farm?	5
		Herbicide and other pesticide use	5
		Water management score	4
		Nitrogen surplus score	4
		Phosphorus and Potassim surplus score	5
		Are animals correctly identified and is product traceability ensured through animal identification tags (e.g. eat tags, ID tatoo)?	5
Consumer	Health and safety	Have you received any 3rd party endorsement for food quality/local food production (including awards but excluding certifications)? None, local, regional, national	5
		How many environmental management options do you undertake on your farm?	5
	Feedback mechanism	Do you have any evidence of consumer satisfaction?	4
		Do you sell produce direct to customers on-farm?	5
		How many of these routes are local markets (e.g. farm shop, local delivery, local market, local shops)	5

	Transparency	What level of food quality certification do you have? E.g. Basic farm assured, Global GAP/ Europe GAP, full organic certification	5

Conclusions

- The farm phase has the greatest impact on climate change, acidification and eutrophication in both cases.
- The GWP of 1 kg of living animal on farm gate is 16.48 and 12.14 for case study and mainstream organic beef system, respectively; while CH4 emission from enteric fermentation and manure management account for over 80% or total GHG on farm emissions.
- The carbon footprint of 1 kg of beef throughout its life cycle is 23% higher for case study farms than for mainstream organic beef; this difference is caused by the lower efficiency of grass-based cattle feeding (grazing, hay, silage grass). Additionally, on an innovative farm, animals of lower weight are sold for meat than in the mainstream system.
- The results of the SLCA analysis indicate that the case study farm is above the median for all examined impact subcategories

UK, SCA farm, organic beef system

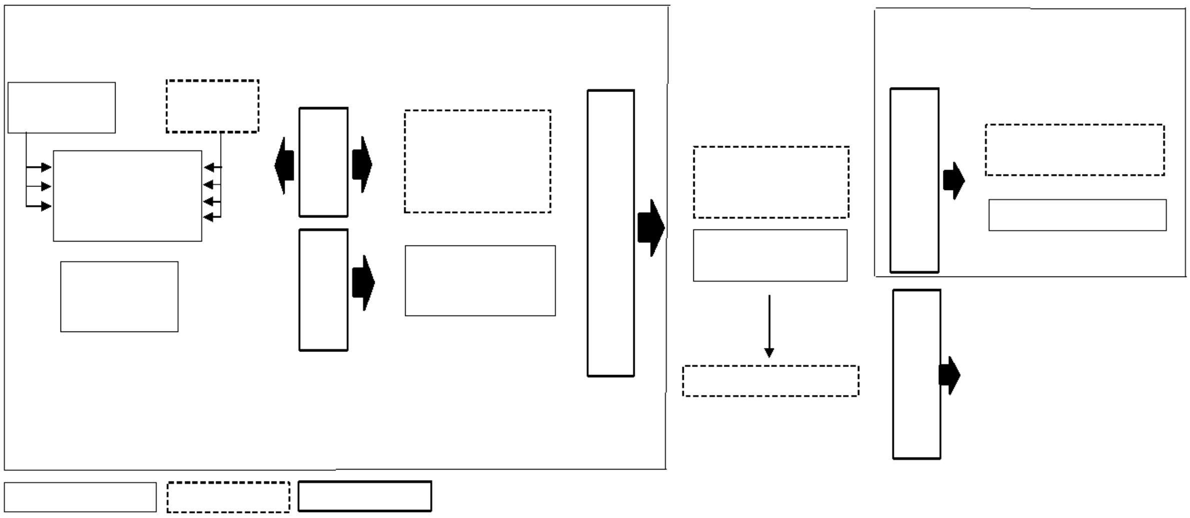
Systems overview

Stroud Community Agriculture (SCA) is a biodynamic organic mixed farm in South West England. It is one of the original Community Supported Agriculture projects in the UK. The Scheme has over 350 members providing an innovative governance structure for restructuring local distribution channels. The diversity of products from the farm include vegetables, beef, pork, poultry meat, eggs and dairy products. The farm is 21 ha in total: 3 ha of cropping land including temporary leys, 18 ha permanent pasture and 2.3 km of mixed species field boundary hedges. The farm is mostly heavy clay soils with the polytunnels on light sandy soil. SCA has been fully certified organic for over 20 years. The vegetable production is managed on a nine year rotation with three years of fertility building ley that is used for grazing 2 of these years and, 60+ vegetable varieties grown as part of the rotation. Minimal external inputs (straw, plug plants and concentrate for pigs). SCA is mostly self-sufficient in livestock feed with home grown forage beet along with silage and hay production from the grassland. SCSA has a fully integrated mixed breed lowland suckler beef herd (breeds include Hereford, short horn and Jersey cross) with spring calving and low/ no mortality. Cattle are housed for 5 months in an unheated barn over winter. Manure is collected and composted in open windows before spreading on the fields. SCA mainly sells farm produce directly from site with 100% of sales occurring less than 16 km from site. High annual visitor numbers (400 plus), regular volunteers, events and a high level of community engagement. The flow diagram is presented in Figure 26.

The functional unit used in the LCA calculations is 1 kg of beef at farm gate and is based on the number finished cows sold per year and the average liveweight. Values from Stroud are averaged

over a three year period. By-products are allocated at the slaughterhouse stage based on Killing Out Percentages plus economic allocation of by-products using the Agri-footprint approach.
Mainstream organic system describes 'standard' UK organic lowland suckler herd. Most post-farm gate processes e.g. slaughter, processing were assumed to be similar, exception was post farm transportation which was modelled due to the highly localised distribution systems at the innovative case study farm.

Figure 26. Organic beef production system, SCA farm, UK.



Main LCI data

A brief inventory of inputs and outputs is presented in Tables 21.

Table 21. Overview of input and output data modelled and differences between Stroud Community Agriculture and the comparative system (Mainstream)

Data		case study	mainsteram
Functional unit		1 kg of beef on farm gate	1 kg of beef on farm gate
Time coverage		2017-2019	2017-2019
Localisation		Stroud Community Agriculture farm, South West England	'standard' UK organic lowland suckler herd
Data source		farm survey	literature +experts opinions
Farm size (ha)		21.0	118.1 [a]
Farm type		mixed farm	organic lowland beef farm
Main similarities and differences		The SCA farm rears beef cattle on a small scale and relies 100% on forages produced on the farm, while the reference farm breeds cattle on a larger scale and purchases 15% of its feed.	
Description of the farm			
Area of land for beef cattle (ha)	Permanent pasture	13.5	56.19 [a]
	Temporary grass/ ley	0.3	22.04 [a]
	Cropped land	0.09	5.55 [a]
Herd size and composition	Beef cows lactating	11	34.3 [a]
	Calves (0-12 months)	22	42.3 [a]
	Stores (12-24 months)	5	19.8 [a]
	Beef finishers (>24 months)	1	20.8 [a]
	Bulls	1	1.7 [a]
Herd diet and fodder production		100% forage	15% non-forage (concentrates and compound feeds) [a,b,c.e]
Housing period (days)		153	200 [b]
Manure management system (AWMS)		40% composted using passive windrow 60% deposited on pasture	As SCSA
FYM application rates	Pasture ($t\ ha^{-1}$)	10	10 [b]
	Fodder beet ($t\ ha^{-1}$)	25	25 [b]
Bedding requirements ($t\ yr^{-1}$)		13.50	53.69 [c]
Average no. cows sold per year		6	29 [a]
Average live weight ($kg\ head^{-1}$)		447	560 [b]
After farm stages			
Killing out (%)		53	54 [b]
Average distance from farm to slaughterhouse/ butcher to market (km)		36.04	389.31 [d]
Average distance travelled by from market to consumer table (km)		0.73	0.59 [f]
Spend on beef per customer (%)		2.25	3.30 [g]
a. Farm Business Survey (2009-2011)			

b. Organic Farm Management Handbook (2017) c. Nix pocketbook (2022) d. Schroeder et al. (2012) e. SimaPro LCA databases (Agribalyse/ Ecoinvent 3.0/ Agri-footprint 5.0) f. Piecyk et al. (2021), ONS (2022) g. ONS Family spending in the UK: April 2020 to March 2021.

Results

Table 22. Detailed results of impact assessment of , 1kg of living animal on farm gate, UK, ReCiPe Midpoint (H) V1.13 / World Recipe H

Impact category	Unit	Live weight animal at farm gate, case study, UK	Live weight animal at farm gate, mainstream, UK
Climate change	kg CO2 eq	20.25672804	14.99683923
Ozone depletion	kg CFC-11 eq	8.32066E-09	2.99587E-08
Terrestrial acidification	kg SO2 eq	0.003782778	0.00539045
Freshwater eutrophication	kg P eq	9.12594E-05	0.000129481
Marine eutrophication	kg N eq	0.000242208	0.000338979
Human toxicity	kg 1,4-DB eq	0.145773869	0.239200703
Photochemical oxidant formation	kg NMVOC	0.012204461	0.01223969
Particulate matter formation	kg PM10 eq	0.0021661	0.00294936
Terrestrial ecotoxicity	kg 1,4-DB eq	9.23656E-05	0.01197324
Freshwater ecotoxicity	kg 1,4-DB eq	0.013945386	0.024123166
Marine ecotoxicity	kg 1,4-DB eq	0.012548021	0.019437346
Ionising radiation	kBq U235 eq	0.010629562	0.037835993
Agricultural land occupation	m2a	0.116965041	0.147870837
Urban land occupation	m2a	0.025873191	0.032116168
Natural land transformation	m2	0.000212452	0.00030059
Water depletion	m3	0.027646323	0.068762354
Metal depletion	kg Fe eq	0.06865556	0.091720377
Fossil depletion	kg oil eq	0.187107398	0.281463518

Table 23. Detailed results of impact assessment , 1kg of beef purchased by consumer, UK; ReCiPe Midpoint (H) V1.13 / World Recipe H

	case study	mainstream

Impact category	Unit	Total	live weight animal, farm gate	slaughtering	transport	consumer	Total	live weight animal, farm gate	slaughtering	transport	consumer
Climate change	kg CO_2 eq	36.44566	35.50660443	0.0723804	0.497965	0.368708	27.15952	26.28691	0.07238	0.800224	0.368708
Ozone depletion	kg CFC-11 eq	5.86E-08	1.45847E-08	2.945E-09	9.79E-09	3.13E-08	6.87E-08	5.25E-08	2.94E-09	1.32E-08	3.13E-08
Terrestrial acidification	kg SO_2 eq	0.009123	0.006630568	0.0001277	0.001409	0.000956	0.012442	0.009449	0.000128	0.002865	0.000956
Freshwater eutrophication	kg P eq	0.000309	0.000159962	1.826E-05	7.1E-05	5.97E-05	0.00034	0.000227	1.83E-05	9.44E-05	5.97E-05
Marine eutrophication	kg N eq	0.000745	0.000424549	0.0001198	0.000148	5.25E-05	0.000971	0.000594	0.00012	0.000257	5.25E-05
Human toxicity	kg 1,4-DB eq	0.503031	0.255516838	0.0143059	0.119404	0.113805	0.618085	0.419278	0.014306	0.184501	0.113805
Photochemical oxidant formation	kg NMVOC	0.024958	0.021392348	0.000168	0.002247	0.001151	0.026477	0.021454	0.000168	0.004854	0.001151
Particulate matter formation	kg PM10 eq	0.004933	0.003796805	4.924E-05	0.000723	0.000363	0.006641	0.00517	4.92E-05	0.001422	0.000363
Terrestrial ecotoxicity	kg 1,4-DB eq	0.000297	0.000161901	1.985E-05	8.19E-05	3.31E-05	0.021171	0.020987	1.98E-05	0.000165	3.31E-05
Freshwater ecotoxicity	kg 1,4-DB eq	0.074971	0.024443894	0.0014863	0.023451	0.02559	0.072403	0.042284	0.001486	0.028633	0.02559
Marine ecotoxicity	kg 1,4-DB eq	0.065836	0.021994549	0.0009578	0.020338	0.022546	0.060461	0.03407	0.000958	0.025433	0.022546
Ionising radiation	kBq U235 eq	0.348821	0.018631817	0.0506378	0.010565	0.268987	0.131064	0.06632	0.050638	0.014106	0.268987
Agricultural land occupation	m2a	0.327363	0.205019856	0.0184378	0.004968	0.098938	0.284927	0.259192	0.018438	0.007296	0.098938
Urban land occupation	m2a	0.063827	0.045351311	0.0004277	0.013155	0.004893	0.078498	0.056294	0.000428	0.021776	0.004893
Natural land transformation	m2	0.001125	0.000372392	4.437E-05	0.000193	0.000515	0.000884	0.000527	4.44E-05	0.000312	0.000515
Water depletion	m3	0.088173	0.04845931	0.0325087	0.00691	0.000295	0.16182	0.120529	0.032509	0.008083	0.0007
Metal depletion	kg Fe eq	0.211427	0.120341537	0.0025717	0.052975	0.035539	0.774568	0.493358	0.024397	0.256814	0.035539

Fossil depletion	kg oil eq	0.751801	0.327967494	0.0243967	0.155622	0.243814	0.226897	0.16077	0.002572	0.063555	0.243814

Figure 27. GWP through all life cycle stages: farm, slaughtering, transport, and home cooking.

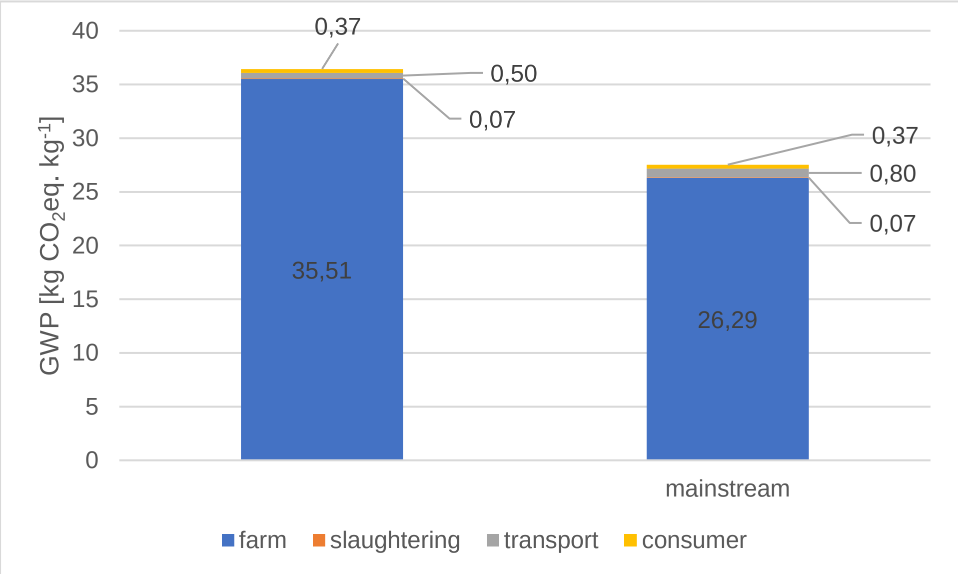


Figure 28. Contribution, %, of the mains stages for each impact category of 1kg beef purchased by consumer (case study).

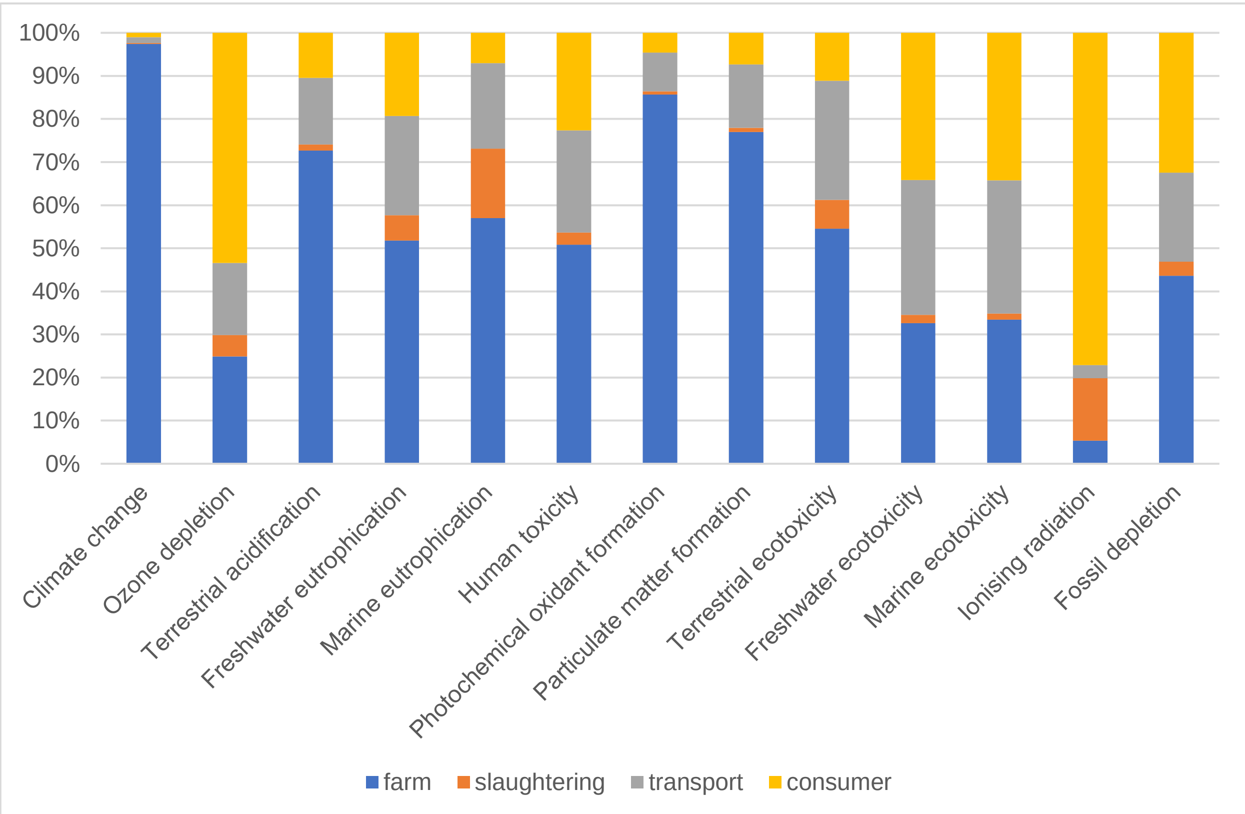


Figure 29. Contribution, %, of the mains stages for each impact category of 1kg beef purchased by consumer (mainstream).

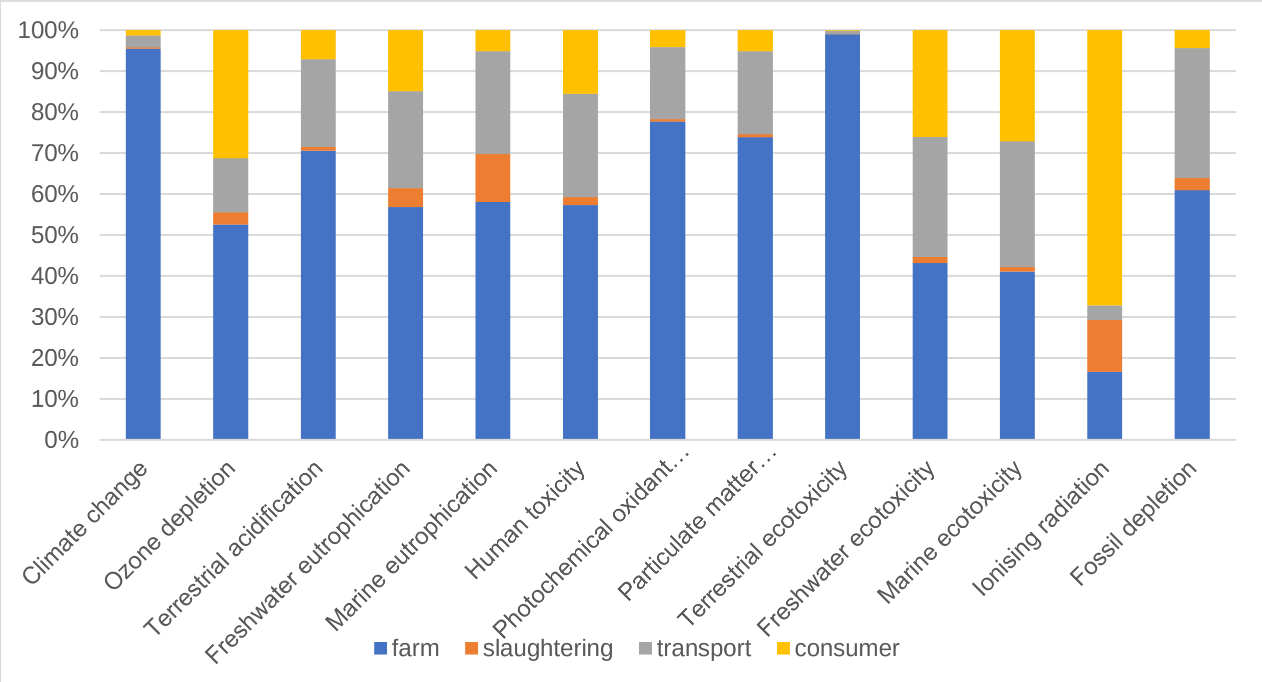


Figure 30. Greenhouse gas emissions at the farm stage are divided into main sources: CH4 means emissions from enteric fermentation and animal excrements, N2O - soil emissions mainly from grazing, additionally showing the share of agrotechnical operations (expressed in CO2) and additional sources such as purchased feed. Figure a) shows the absolute share and figure b) shows the percentage share.

a) b)

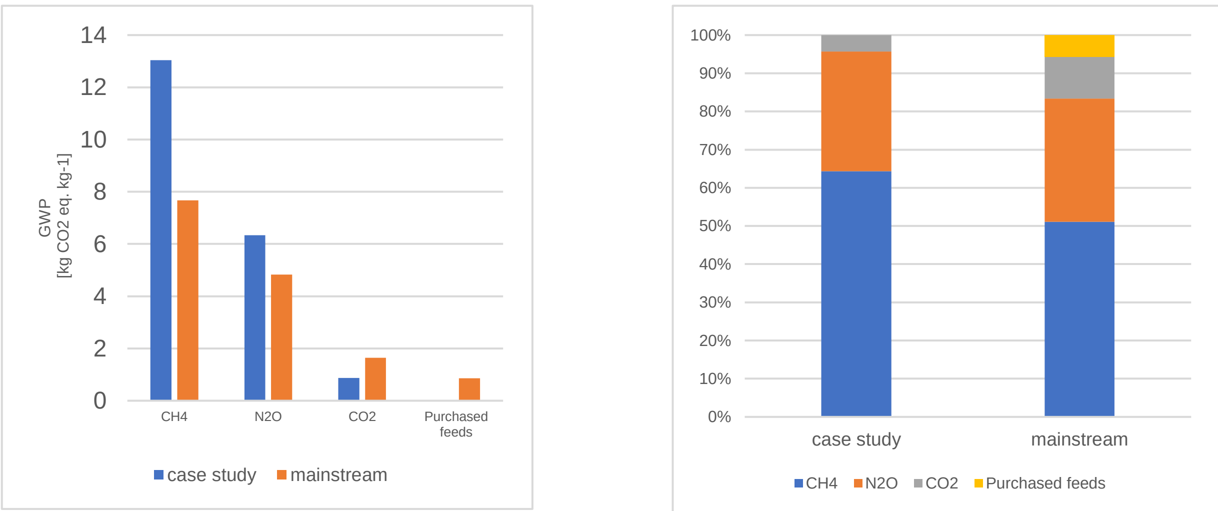


Table 24. Results of SLCA analysis for each subcategory, beef, case study farm, UK.

Actor	Category	Score	Scale	Actor scale
Worker	Health and Safety	3.50	0	0.5
	Work life balance	3.67	1	
Local community	Access to material and immaterial resources	4.33	1	1
	Community engagement	3.00	0	
	Cultural heritage	3.67	1	
	Safe and healthy living conditions	4.66	2	
Consumer	Health and safety	3.00	0	1.33
	Feedback mechanism	4.67	2	
	Transparency	5.00	2	

Conclusions

- Raising cattle on a farm has the most significant influence on overall impacts
- Beef produced in a more intensive 'standard' system had a lower climate impact than meat from the more extensive innovative case-study system (27.2 vs. 36.4 kg CO_2eq. kg^{-1}) and that managing enteric methane emissions is the most important factor in reducing the climate impact of beef production systems
- Results also suggest that reducing the use of bought in feed would contribute most to reducing the water consumption impact, but potentially with a trade off in terms of methane emissions
- In order to achieve more accurate estimations of the impact of extensive innovative beef production systems, further research and improved methods are needed, taking into account factors such as the different characteristics of the breeds used in these systems and the farm's contribution to overall ecosystem service provision
- The case study farm scored above median (in SLCA analysis) for all actors considered, but in particular for the local community and consumers, reflecting the social objectives of the farm

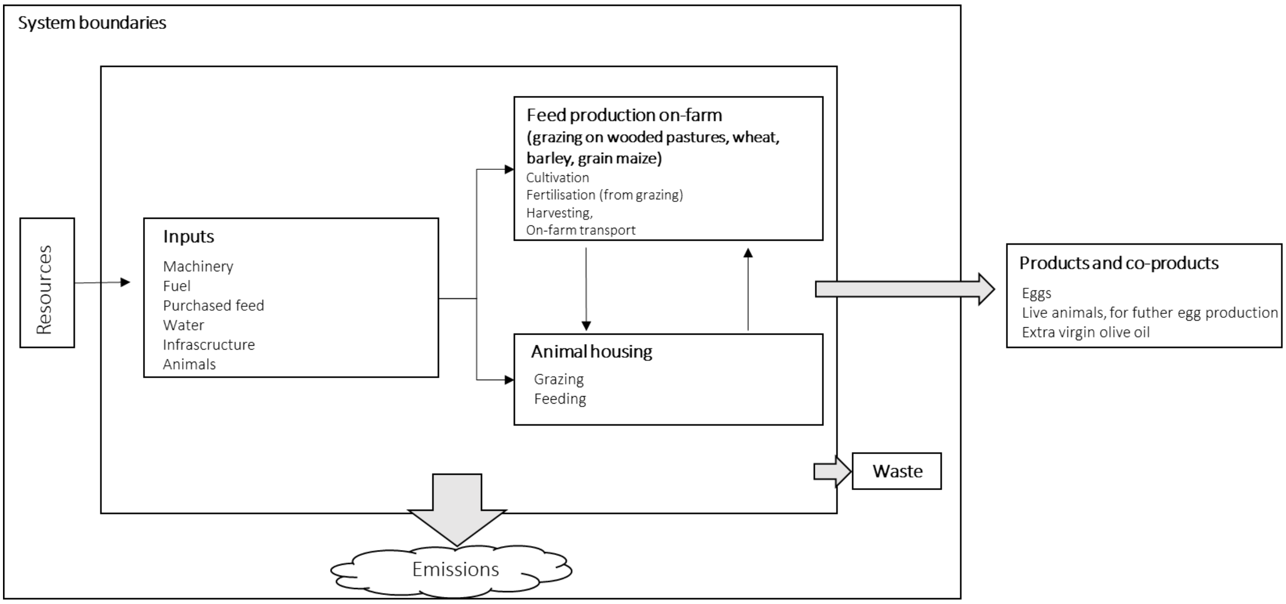
Italy, Fattoria Cupidi farm, Organic eggs production

Overview

The investigated farm has an area of 24.2 ha, of which 22 ha is agricultural land with a stocking rate of approx. 300 trees per hectare. The main product of the farm is organic eggs. The hens' feeding system is based on grazing; in addition wheat (13ha), barley (2ha) and maize for grain (7ha) are grown on farm. Additional feeds such as peas, fodder beet and soya bean are purchased. The herd comprises 9,000 laying hens replaced on a bi-annual cycle. While grazing, the hens fertilise the olive and walnut trees. The oil and the laying hens sold are co-products. As the walnuts grown on the farm have a long growth and shearing cycle (about 50 years) and have no economic value and this is not expected in the coming years, they have been omitted as a co-product. Background data relating to purchased feeds and production of pullets were obtained from Agrifootprint 6.0. Production system is presented in Figure 31.

The inventory data describing the mainstream system is based on Costantini et al (2020). The surveyed farm purchased 3,000 pullets at 16 weeks of age, ready for egg production, and kept them for up to 72 weeks. The feeding system is based on purchased feed from nearby organic farms. Additionally, there is a 1.25 ha free-range sown with alfalfa every three years. Detailed herd and feeding information are included in the Appendix, Tables A2-A4.

Figure 31. Organic egg production sytem boundary (cradle to farm gate).



Main LCI data

Inventory data for both compared farms are provided in Table 25.

Table 25. Productive parameters of the analysed farm, Fattoria Cupidi, Italy.

Item	Unit	case study	mainstream	Source/Comments
Functional unit		1 kg of eggs	1 kg of eggs	
Time coverage		2020-2021	2018-2020	
Localisation		Fattoria Cupini farm, IT	North-Eastern, IT	
Source of data		farm survey	Constantini et al. (2020)	
Main similarities and differences	The mainstream feeding system on the farm is based on purchased organic feed, and the animals also use a 1.25ha paddock sown with alfalfa every 3 years. On the case study farm, in addition to eggs, olive oil is produced and animals graze and fertilize the arable area. Wheat, barley and corn are cultivated on-farm; soybeans and peas are purchased.			
Productive parameters				

Purchased pullets	# per cycle	9000	3000	
Laying cycle duration weeks	#	42	72	
Egg weitht	g	60	58	
Mortality rate	%	0.8	4	
Broken eggs	%	6	1.5	
Allocation: economic				
Eggs	%	97.2*	100	*800 thous. Euro per year
Live weight animals	%	1.7*	0	*2 Euro per hen * 9000/ 2
Olive oil	%	1.1*	0	*14 thous. Euro per year
Land occupation				
Arable land	ha	22	1.25	
Woodland	ha	1		
Built-up land	ha	0.5	no data	
Other	ha	0.8		
Electricity	kWh	55000	7200	
Water for animal	m3	720	255.5	
Feeding		**per 1kg eggs**	**per 1kg eggs**	
Grazing	p	see text	see text	
Maize grain	kg	0.549*	1.095	* cultivated on-farm
Wheat grain, bran	kg	0.459*	0.438	* cultivated on-farm
Barley grain	kg	0.071*		* cultivated on-farm
Sunflower meal	kg		0.1752	
Linseed meal	kg		0.0219	
Maize germ	kg		0.0438	
Peas, dry	kg	0.133		
Field beans	kg	0.141		
Soya bean meal	kg	0.11	0.3285	
Packaging and transport				
Transport to retail centre	kgkm		100	PEF transport matrix IT-IT
Farm to consumer/ pick-up by consumer	km	0.15	0.15	farm survey; assumed 15 km average distanse for both systems (retail to conumer)
Egg tray	km	0.08	0.08	0.08 kg of carton box per 1kg of eggs
Consumer				
Electricity	kWh	0.0756	0.0756	Same assumption for both systems
Natural gas	m3	0.0113	0.0113	
Water	l	0.7	0.7	

Results

Table 26. Detailed results of impact assessment , 1kg of eggs, Italy, ReCiPe Midpoint (H) V1.13 / World Recipe H

		case study				mainstream			
Impact category	Unit	Total	farm	transport, retail	consumer	Total	farm	transport, retail	consumer
Climate change	kg CO2 eq	1.410302	1.261191259	0.112085	0.037025	1.768875	1.561819	0.170031	0.037025
Human toxicity, cancer effects	CTUh	7.78E-08	6.49843E-08	1.05E-08	2.28E-09	5.31E-07	5.13E-07	1.54E-08	2.28E-09
Human toxicity, non-cancer effects	CTUh	2.2E-06	2.16348E-06	2.79E-08	8.19E-09	8.95E-08	4.02E-08	4.11E-08	8.19E-09
Photochemical ozone formation	kg NMVOC eq	0.004848	0.004281568	0.000411	0.000156	0.008615	0.007625	0.000834	0.000156
Acidification	molc H+ eq	0.004335	0.003727724	0.000465	0.000142	0.168792	0.16786	0.000789	0.000142
Terrestrial eutrophication	molc N eq	0.014221	0.012883001	0.001063	0.000275	0.748242	0.745549	0.002418	0.000275
Freshwater eutrophication	kg P eq	0.000347	0.00031243	2.83E-05	6.74E-06	0.000589	0.000548	3.39E-05	6.74E-06
Marine eutrophication	kg N eq	0.009486	0.009343861	0.000117	2.43E-05	0.018027	0.01776	0.000243	2.43E-05
Freshwater ecotoxicity	CTUe	29.94187	26.54222274	2.42764	0.972009	7.069453	3.173034	2.92441	0.972009
Mineral, fossil & ren resource depletion	kg Sb eq	2.18E-05	1.67023E-05	3.85E-06	1.3E-06	3.34E-05	2.70E-05	5.12E-06	1.3E-06

Figure 32. GWP through all life cycle stages of eggs: farm, post farm activities (including transport and packaging) and home cooking.

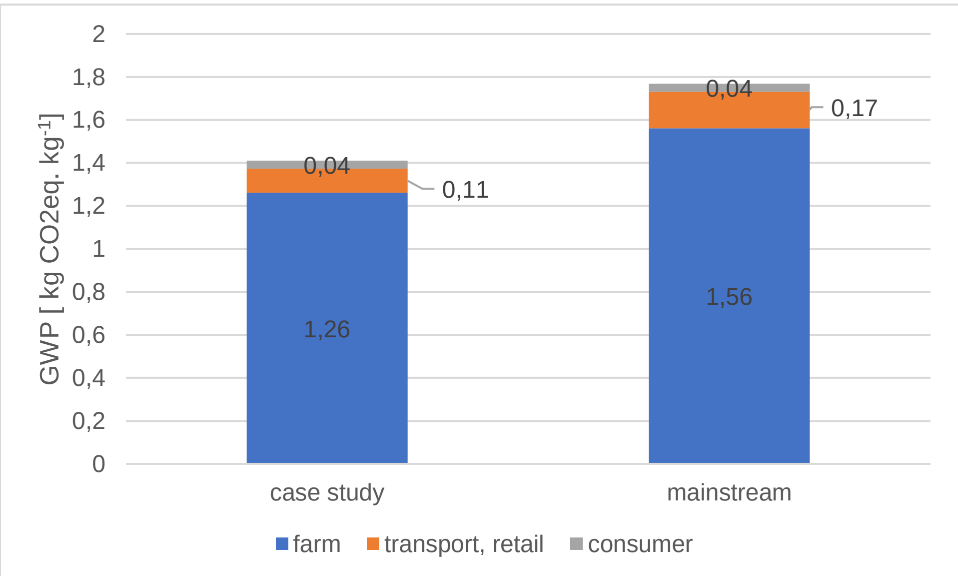


Figure 33. Contribution, %, of the mains stages for each impact category of 1kg eggs purchased by consumer (case study). Impact assessment method used: ReCiPe 2016 Midpoint (H) V1.13 / World (2016) H.V1.13

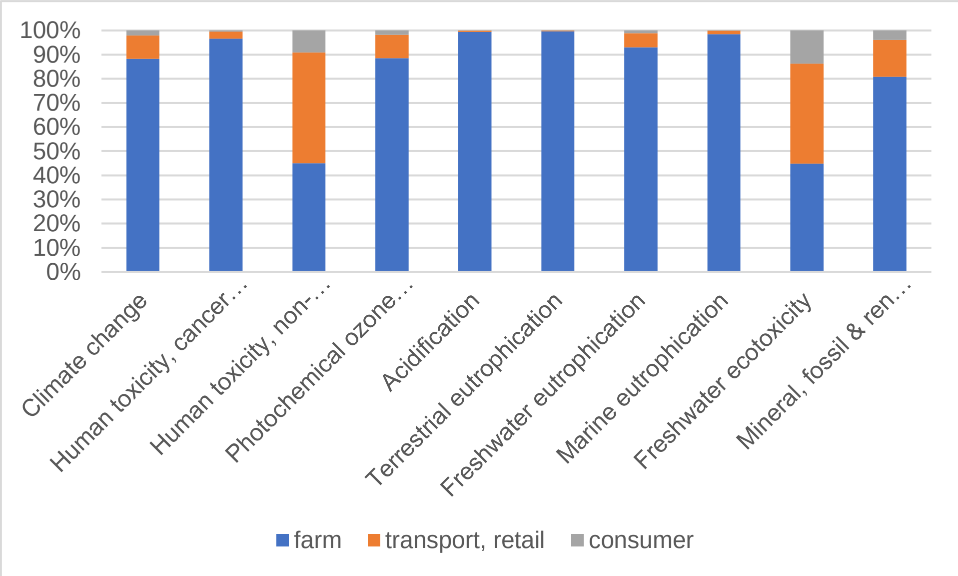


Figure 34. Contribution, %, of the mains stages for each impact category of 1kg eggs purchased by consumer (mainstream). Impact assessment method used: ReCiPe 2016 Midpoint (H) V1.13 / World (2016) H.V1.13

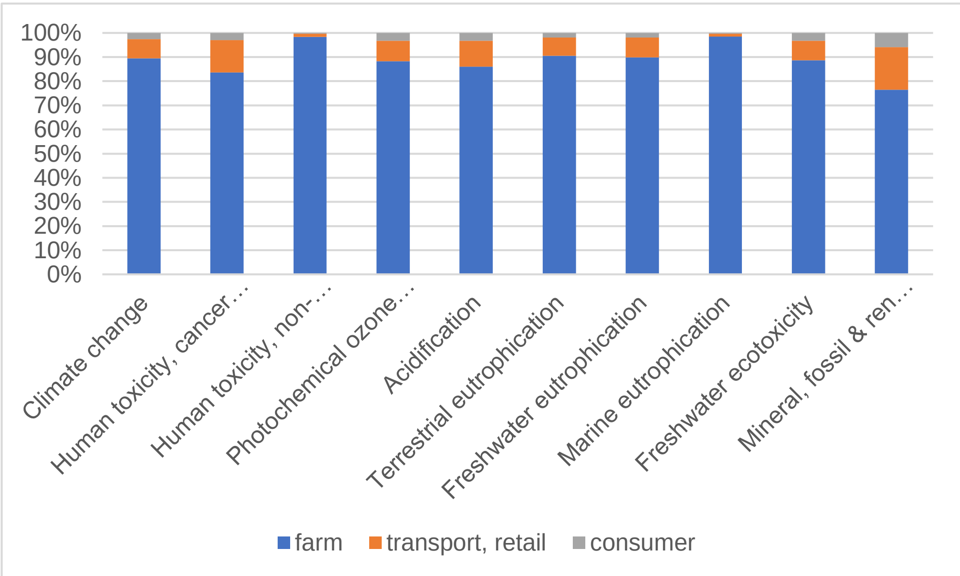


Figure 35. Share, %, of individual emission sources on farm eggs production (case study), Italy.

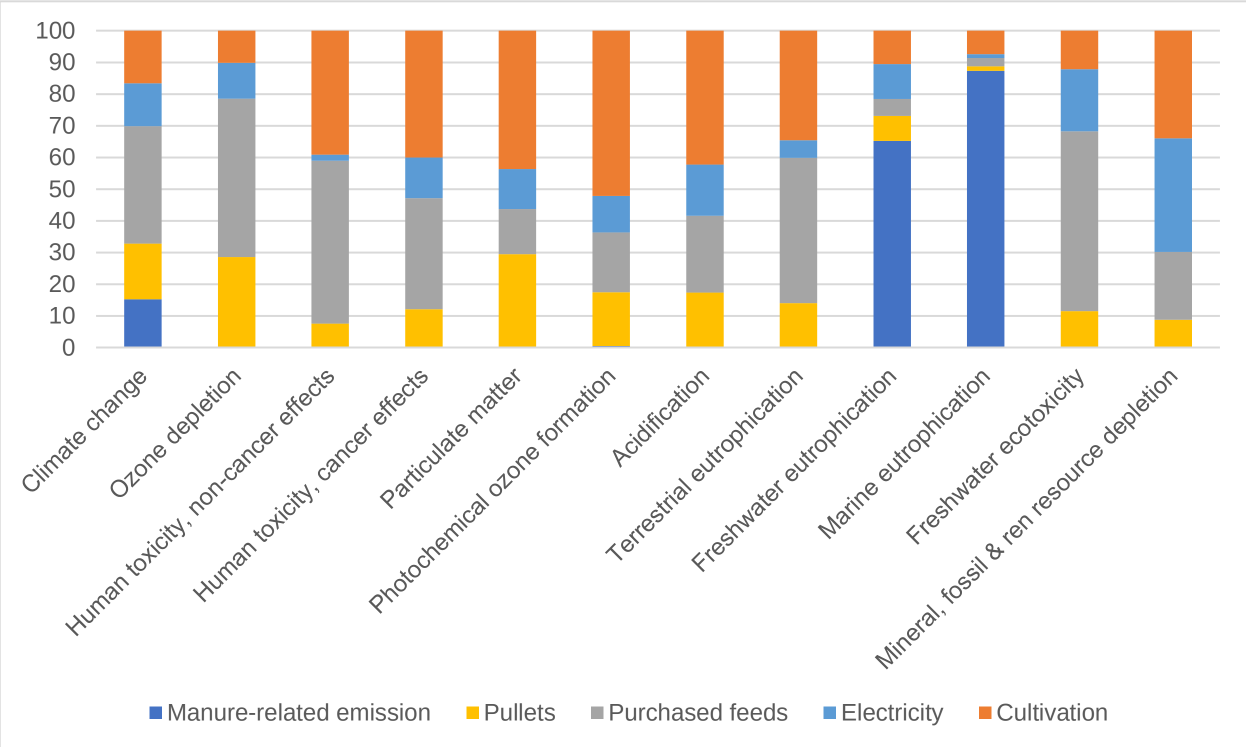


Figure 36. Share, %, of individual emission sources on farm eggs production (mainstream), Italy.

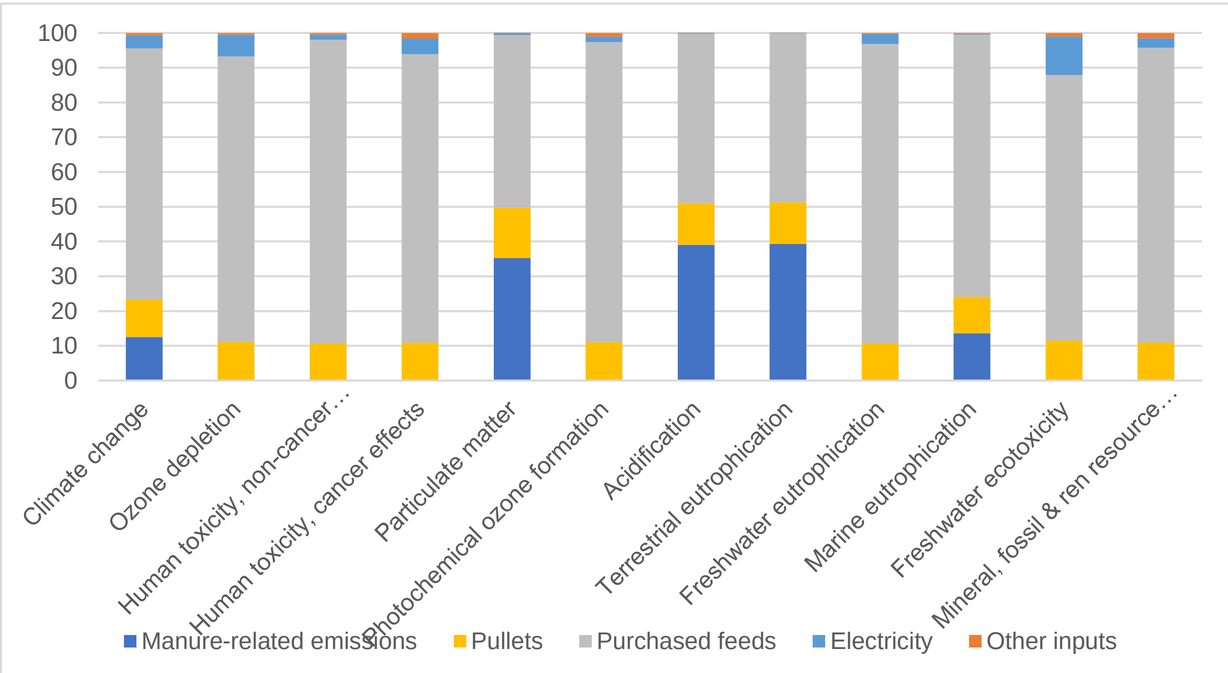


Figure 37. Results of SLCA analysis for each subcategory, eggs, case study farm, Italy.

Table 27. Detailed results for SLCA analysis, eggs, case study, Italy.

	Category	Question	FARM SCORE
Worker	Health and Safety	Skills and knowledge	1
		Have you carried out a COSHH assessment?	5
		How rigorously is health and safety enforced on the farm?	5
		Are staff who handle potentially hazardous substances/machinery (e.g pesticides, heavy plant machinery) given training?	5
		How would you describe the working environment at your farm in terms of health and safety?	5
	Working hours	Number of working hours per week per emploee	5
		How onerous (tough) is the workload on your farm?	3
		Are you happy with the amount of holiday period you can take over a year?	3
Local community	Access to material and immaterial resources	How many environmental management options do you undertake on your farm?	4
		Habitat and conservation planning	3
		Richness of landscape	3.3
	Community engagement	Do you promote public access?	5
		How many community events do you attend/ host as a farm per year (this excludes events just for sales, like many farmers markets)?	1
		Any awards for staff welfare/community enagagement?	N/A

		Approximately what percentage of your produce (by weight) is sold to the local sales (<16km)	4
	Cultural heritage	How much maintenance/care do you give to historic features present on the farm?	N/A
		Do you farm any Rare Breeds Survival Trust watchlist breeds? https://www.rbst.org.uk/Our-Work/Watchlist/Watchlist2	1
		Does the farm produce Produce of Designated Origin (PDO), Protected Geographic Status (PGS) or Traditional Specialities Guaranteed (TSG)?	N/A
		Do you farm using heritage varieties of crops?	3
	Safe and healthy living conditons	How many of these routes are local markets (e.g. farm shop, local delivery, local market, local shops)	2
		Do you sell produce direct to customers on-farm?	5
		Herbicide and other pesticide use	4
		Water management score	4.2
		Nitrogen surplus score	5
		Phosphorus and Potassim surplus score	1
		Are animals correctly identified and is product traceability ensured through animal identification tags (e.g. eat tags, ID tatoo)?	5
Consumer	Health and safety	Have you received any 3rd party endorsement for food quality/local food production (including awards but excluding certifications)? None, local, regional, national	5
		How many environmental management options do you undertake on your farm?	5
	Feedback mechanism	Do you have any evidence of consumer satisfaction?	1
		Do you sell produce direct to customers on-farm?	5
		How many of these routes are local markets (e.g. farm shop, local delivery, local market, local shops)	2
	Transparency	What level of food quality certification do you have? E.g. Basic farm assured, Global GAP/ Europe GAP, full organic certification	5

Conclussions

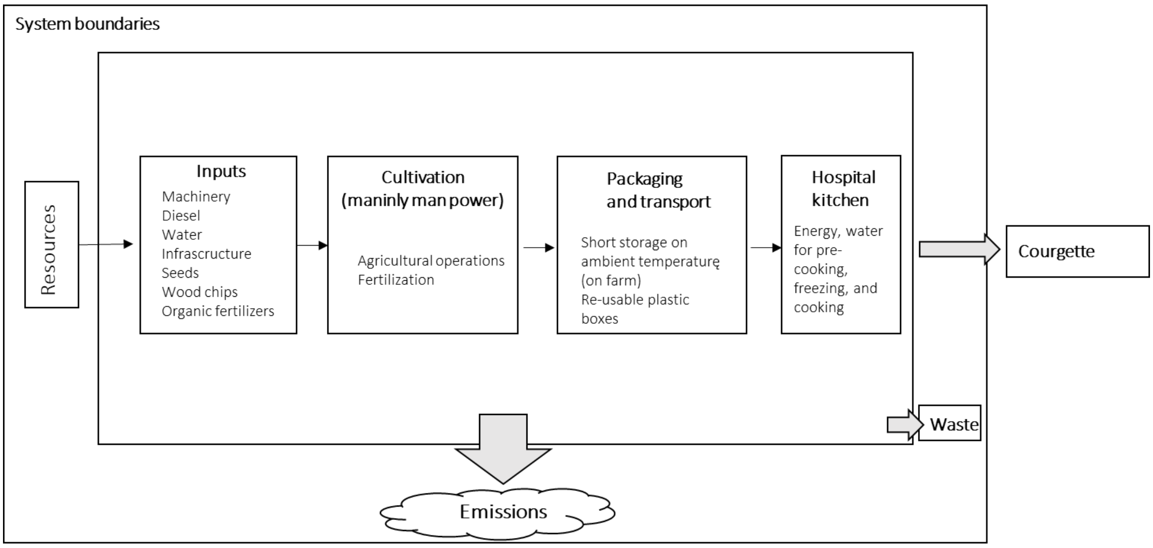
- Case study farm (with grazing) has a significantly less impact on the environment (except freshwater exotoxicity category) then mainstream system (limited grazing)
- Feed provision plays the main role in all impact categories for both systems
- The carbon footprint of 1 kg of eggs at the farm gate is 24% lower for case study farm than that of eggs from a farm based on purchased feed (1.26 vs 1.56 $kgCO_2kg^{-1}$, respectively).
- Purchased feed (mainly cereal grains, peas and soybeans) has the greatest impact on GWP in the case of the innovative farm, their impact is approximately 37%, in the reference farm it is over 70%. This is related to the daily dose of purchased feed, which is 57 and 130 grams per animal, respectively
- The case study farm scored mostly above median for all subcategories considered in SLCA analysis, but in particular categories received a lower score. The lack of customer satisfaction records may be due to lack of interest in social media, while the weaker result in the cultural heritage category may be due to natural conditions and fewer cultivated plants.

Belgium, Het Polderveld farm, Organic courgette (zucchini) production

Overview

The organic farm Het Polderveld is located in Westkapelle (51.321226; 3.282769), Belgium, and is based on principles of Community-Shared-Agriculture (CSA). The farm area is 7.2 ha. Het Polderveld Community-Shared-Agriculture is providing organic meals for a local hospital (main consumer) as well as by private customers self-picking vegetables. The agroforestry plot within the farm also serves as a 'healing garden' for patients. At the beginning of the season, the cultivation plan is made in consultation with the hospital. The hospital kitchen prepares about 1200 meals a day. With a total number of around 80 vegetables and herbs being grown, Het Polderveld farm can almost meet the annual needs of the hospital. The polder soil is improved by the use of wood chips. Poultry and sheep manure and mushroom substrate compost are used for fertilization. The inventory data are from 2022 and were collected directly at the farm by a questionnaire. Organic courgette production system is shown in Figure 38. Primary data from farm inventory for courgette cultivation

Figure 38. Courgette production system. The diagram shows the main phases of cultivating organic Brussels sprouts from seedlings production to consumer use.



Main LCI data

Table 28. Life cycle Inventory of inputs and outputs , organic courgette production, Belgium.

Item	Unit	case study	mainstream	Source/Comments
Functional unit		1 kg of zucchini	1 kg of zucchini	purchased by consumer
Time coverage		2022	2022	
Localisation		Het Polderveld CSA farm	typical organic vegetable farm*	*based on experts opinions and results from zucchini variety trials at two Belgian practice research centres: Inago and PSKW (Research Station for vegetable production in Sint-Katelijne-Waver)
Source of data		farm survey	expert opinion	

Main similarities and differences	The differences in cultivation are due to the addition of wood chips and fertilisation with mushroom compost and purchased organic fertiliser on the case study farm, while manure is used on the mainstream farm. However, the main differences occur in the off-farm activities. Courgettes from the case study farm go to a nearby hospital, where they are frozen and used to prepare meals, while the mainstream system distributes through a 'normal' supply chain.			
General information				
Area of cultivation	ha	0.0465	1*	* reference area
Total yield	t	87.25*	76.7*	* composted on-farm
Marketable yield	t	85.51	63.2	
Pland residues		incorporated	incorporated	
Main inputs		per 1 ha	per 1 ha	
Transport of inputs		2150tkm (lorry<10t)	24 km van, 192 km tractor + manure spreader	
Total manpower hours	h	1533.33	1256	
Seeds	kg	5	5	Carrot seed, Carrot seed, for sowing {CH}| carrot seed production, for sowing | Cut-off, U, ecoinvent 3.9 as a proxy
Wood chips	t	83.66		
Mushroom cultivation waste (substrate)	t	63.44		
Farmyard manure	t		50	
Diesel	l	108.17	90.6	
Organic Plant Feed, OPF 11-0-5 granulate	kg	507.53		
Ferric phosphate (iron (III) orthophosphate)	kg	0.124	0.168	molluscide
Potasium bicarbonate	kg		2.55	
Sulfur	kg		8	
Polypropylene anti-root mat	kg	96.77	4.5	
Electricity	kWh		13.2	
Water	m3	6.19	121.5	
Farm storage				
Duration (room temperature)	day	1	no data*	* no infrasturcture and energy taken account
Packaging and transport		per 1kg	per 1kg	
Transport to nearby hospital	km	0.0611(van)		total 273 km by van (<3.5t)
Transport to retailer	kgkm		0.389 (lorry 7.5t)*	*720 km (farm to vegetable auction, lorry<10t), 640 km vegetable auction to distribution centre); 587 km distribution centre to retailer)
Transport by consumer from retailer	km		1*	*assumed 10 km radius (customer car)
Consumer		per 1kg	per 1kg	
Electricity	kWh	2.25*	0.2156	* assumed: blanching, frozing, defrozing and cooking ; frozen time 24 weeks
Natural gas	m3	0.0763*	0.03504	
R404a	kg	0.0002677*		

Water	l	0.7	0.7

The courgettes are pre-treated (blanched) in the hospital kitchen and then frozen and added to dishes. The energy and water required to blanch and cook after defroze 1kg of zucchini was were adopted from Frankowska et al. (2020) (share of cooking method sum up to 200% then). Assumptions for freezing phase were taken from Agribalyse database, taking 24 weeks frozen storage period and appriobiate amount of cooling substance R404a. The assumption for the cooking and frozing/defrozing phase can be found in M2.2 Report (See Table 66).

The reference system's data inventory is mainly based on results and setup from zucchini variety trials at two Belgian practice research centres (Inago and PSKW(Research Station for vegetable production in Sint-Katelijne-Waver)). A typical farm specializing in vegetable cultivation does not engage in animal production and uses manure obtained from nearby farms, mainly from dairy cows. Additionally, they rely on nitrogen stock provided by grass-clover in the previous years. Summary of all inputs and outputs is provided in Table xxx (See Annex).

Results

Table 29. Detailed results of impact assessment , 1 kg of zucchini, Belgium, ReCiPe Midpoint (H) V1.13 / World Recipe H

		case study				mainstream			
Impact category	Unit	Total	farm	transport and packaging	hospital kitchen	Total	farm	transport and retail	consumer
Climate change	kg CO2 eq	0.281834	0.101558	0.037734	0.142542	0.573409	0.104036	0.354906	0.114467
Ozone depletion	kg CFC-11 eq	1.02E-08	1.27E-09	7.63E-10	8.17E-09	1.17E-08	2.28E-10	7.18E-09	4.25E-09
Terrestrial acidification	kg SO2 eq	0.0024	0.002026	0.000102	0.000272	0.001719	0.000528	0.000957	0.000233
Freshwater eutrophication	kg P eq	0.000513	0.000364	5.07E-06	0.000144	0.000246	6.16E-05	4.77E-05	0.000137
Marine eutrophication	kg N eq	0.000528	0.000482	6.54E-06	3.92E-05	0.000647	0.000549	6.16E-05	3.59E-05
Human toxicity	kg 1,4-DB eq	0.123552	0.01666	0.008889	0.098003	0.180324	0.004066	0.083603	0.092655
Photochemical oxidant formation	kg NMVOC	0.001493	0.000883	0.00016	0.00045	0.001977	0.000183	0.001506	0.000287
Particulate matter formation	kg PM10 eq	0.000567	0.000408	5.26E-05	0.000106	0.000693	0.000111	0.000495	8.66E-05
Terrestrial ecotoxicity	kg 1,4-DB eq	5.57E-05	3.83E-05	5.24E-06	1.21E-05	6.2E-05	2.76E-06	4.93E-05	9.94E-06
Freshwater ecotoxicity	kg 1,4-DB eq	0.01156	0.001645	0.001833	0.008083	0.025175	0.000314	0.017227	0.007634
Marine ecotoxicity	kg 1,4-DB eq	0.010345	0.001508	0.001599	0.007238	0.022143	0.000283	0.015029	0.006831
Ionising radiation	kBq U235 eq	0.028816	0.004941	0.00081	0.023066	0.030549	0.000975	0.007616	0.021958

Agricultural land occupation	m2a	0.1220697	0.1169517	0.00038	0.004738	0.1658502	0.00222	0.003572	0.004435
Urban land occupation	m2a	0.019881	0.017623	0.000992	0.001266	0.010826	0.000389	0.009334	0.001103
Natural land transformation	m2	0.000146	3.1E-05	1.47E-05	0.000101	0.000194	3.9E-06	0.000138	5.19E-05
Water depletion	m3	0.00037	0.0009	0.00021	0.000744	0.000443	0.001688	0.00199	0.000746
Metal depletion	kg Fe eq	0.020701	0.005939	0.004188	0.010574	0.048958	0.001141	0.039375	0.008443
Fossil depletion	kg oil eq	0.132928	0.024304	0.011747	0.096877	0.176799	0.009309	0.110494	0.056995

Figure 39. GWP through all life cycle stages of zucchini cultivation in Belgium: on-farm cultivation, post farm activities (including transport and packaging) and cooking.

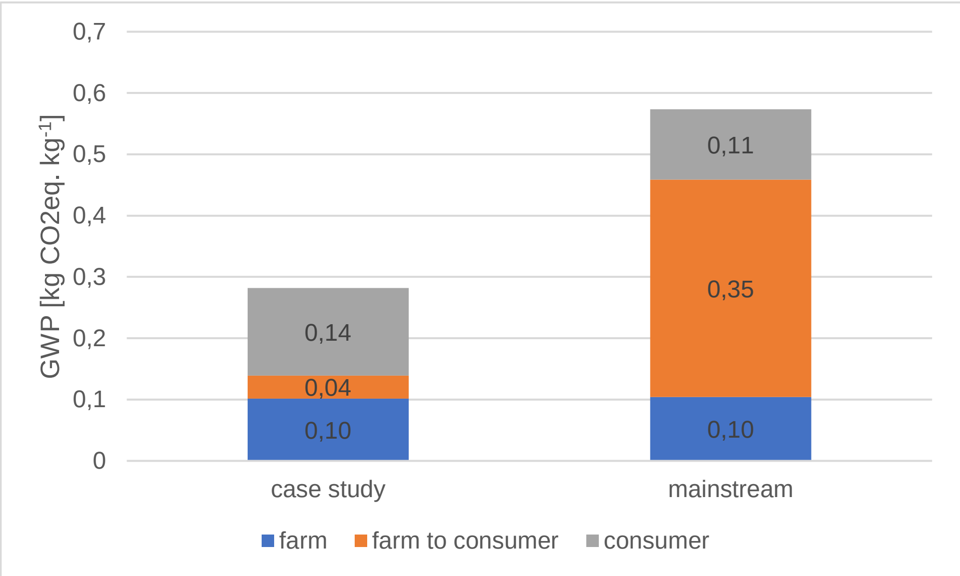


Figure 40. Contribution, %, of the mains stages for each impact category of 1kg zucchini purchased by consumer (case study). Impact assessment method used: ReCiPe 2016 Midpoint (H) V1.13 / World (2016) H.V1.13

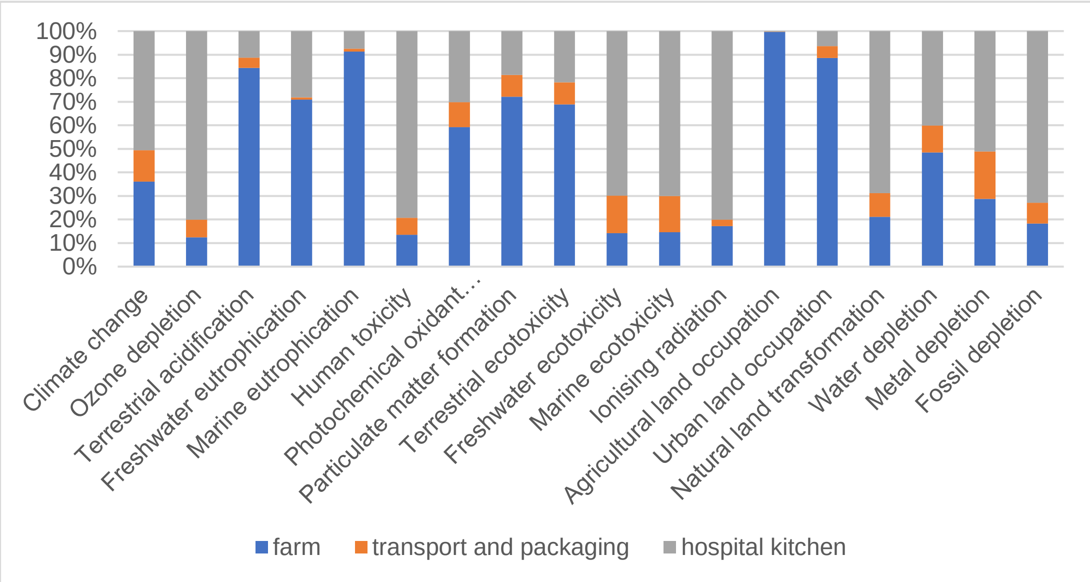


Figure 41. Contribution, %, of the mains stages for each impact category of 1kg zucchini purchased by consumer (mainstream organic). Impact assessment method used: ReCiPe 2016 Midpoint (H) V1.13 / World (2016) H.V1.13

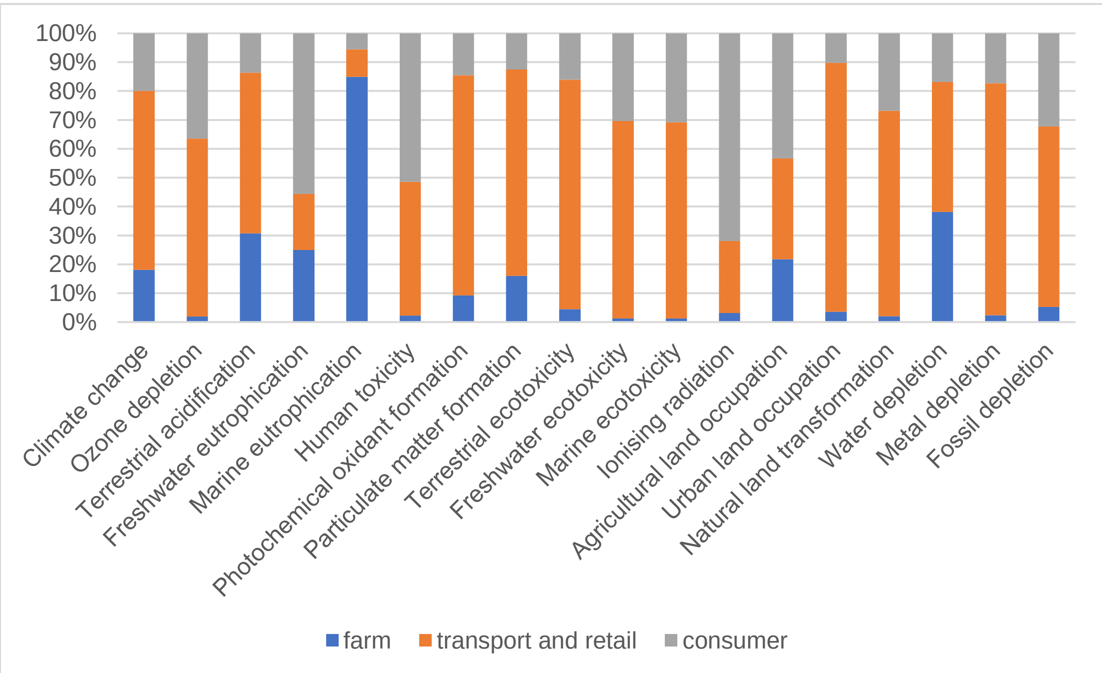


Figure 42. Results of SLCA analysis for each subcategory, zucchini, case study farm, Belgium.

Table 30. Detailed results for SLCA analysis, zucchini, case study, Belgium.

	Category	Question	FARM SCORE
Worker	Health and Safety	How many training days have staff (including the farmer) had per year in total - number of days per person	3
		Have you carried out a COSHH assessment?	N/A
		How rigorously is health and safety enforced on the farm?	5
		Are staff who handle potentially hazardous substances/machinery (e.g pesticides, heavy plant machinery) given training?	5
		How would you describe the working environment at your farm in terms of health and safety?	5
	Working hours	Number of working hours per week per employee	5
		How onerous (tough) is the workload on your farm?	3
		Are you happy with the amount of holiday period you can take over a year?	5
Local community	Access to material and immaterial resources	How many environmental management options do you undertake on your farm?	5
		Habitat and conservation planning	3
		Richness of landscape	5
	Community engagement	Do you promote public access?	1
		How many community events do you attend/ host as a farm per year (this excludes events just for sales, like many farmers markets)?	5
		Any awards for staff welfare/community enagagement?	1
		Approximately what percentage of your produce (by weight) is sold to the local sales (<16km)	5

	Cultural heritage	How much maintenance/care do you give to historic features present on the farm?	N/A
		Do you farm any Rare Breeds Survival Trust watchlist breeds? See list below or access https://www.rbst.org.uk/Our-Work/Watchlist/Watchlist2	4
		Does the farm produce Produce of Designated Origin (PDO), Protected Geographic Status (PGS) or Traditional Specialities Guaranteed (TSG)?	1
		Do you farm using heritage varieties of crops?	5
	Safe and healthy living conditons	How many of these routes are local markets (e.g. farm shop, local delivery, local market, local shops)	5
		Do you sell produce direct to customers on-farm?	5
		Herbicide and other pesticide use	5
		Water management score	3.4
		Nitrogen surplus score	1
		Phosphorus and Potassim surplus score	1
		Are animals correctly identified and is product traceability ensured through animal identification tags (e.g. eat tags, ID tatoo)?	5
Consumer	Health and safety	Have you received any 3rd party endorsement for food quality/local food production (including awards but excluding certifications)? None, local, regional, national	1
		How many environmental management options do you undertake on your farm?	5
	Feedback mechanism	Do you have any evidence of consumer satisfaction?	4
		Do you sell produce direct to customers on-farm?	5
		How many of these routes are local markets (e.g. farm shop, local delivery, local market, local shops)	5
	Transparency	What level of food quality certification do you have? E.g. Basic farm assured, Global GAP/ Europe GAP, full organic certification	5

Conclusions

- Due to the high yield (approx. 60 tons per hectare), zucchini cultivation has a smaller impact on the environment than the other phases of the life cycle (transport and sale, consumer).
- The comparison between the innovative farm and the mainstream system shows a similar impact on climate change at the farm gate of 0.1 kg CO_2eq. kg^{-1}; while the entire life cycle is 0.28 and 0.57 kgCO_2eq, respectively. kg^{-1}.
- Zucchini from the innovative farm is transported to a nearby hospital, blanched, frozen and later used to prepare meals. However, zucchini from the reference farm is sold 'traditionally'. In the case study, the greatest impact on the environment is caused by cultivation and preparation in the hospital kitchen; and in the case of zucchini from the reference farm, transport and sale.
- The farm achieved results of SLCA above the median for the worker and customer categories and results close to the median for the category 'local'. Due to the location of the farm (there are many farms around), the local community may not feel the need to visit the farm.

Additional analysis and indicators

Climate Change metric assessement

The Global Warming Potential (GWP) is a commonly used metric to aggregate the climate impacts from different gases into CO_2 equivalent over a given period of time. The most commonly used time period is 100 years, but it is an arbitrary choice that has great influence on the results. For example, the GWP factor over 100 years (GWP100) for biogenic methane is 28 compared to 84 for GWP over 20 years (GWP20) [21].Methane differs from other gases because is a short-lived GHG, it is removed in the atmosphere after approximately 10 years. Due to the limitations with GWP other metrics were proposed, for instance Caine et al. (2019) [22], propose the use of GWP* mainly for assessing animal production (because of methane emission from enteric fermentation and manure management). However this metric is less applicable for calculating specific and localized product carbon footprint (GWP* consider the change in the emissions rate over two points in time). In addition, we believe that due to the cultivation of feed crops on the farm and the purchase of feed from outside the farm, the focus should not be on reducing methane emissions but on all greenhouse gases (CO2, N2O, CH4). Therefore, below we present the results of a comparative analysis of the choice of GWP on the carbon footprint results of the animal products analysed: beef, milk and eggs (see Table 31).

Table 31. The effect of the choice of climate change impact assessment method and time horizon (characterization factors for N2O and CH4) on the results of the carbon footprint of animal products.

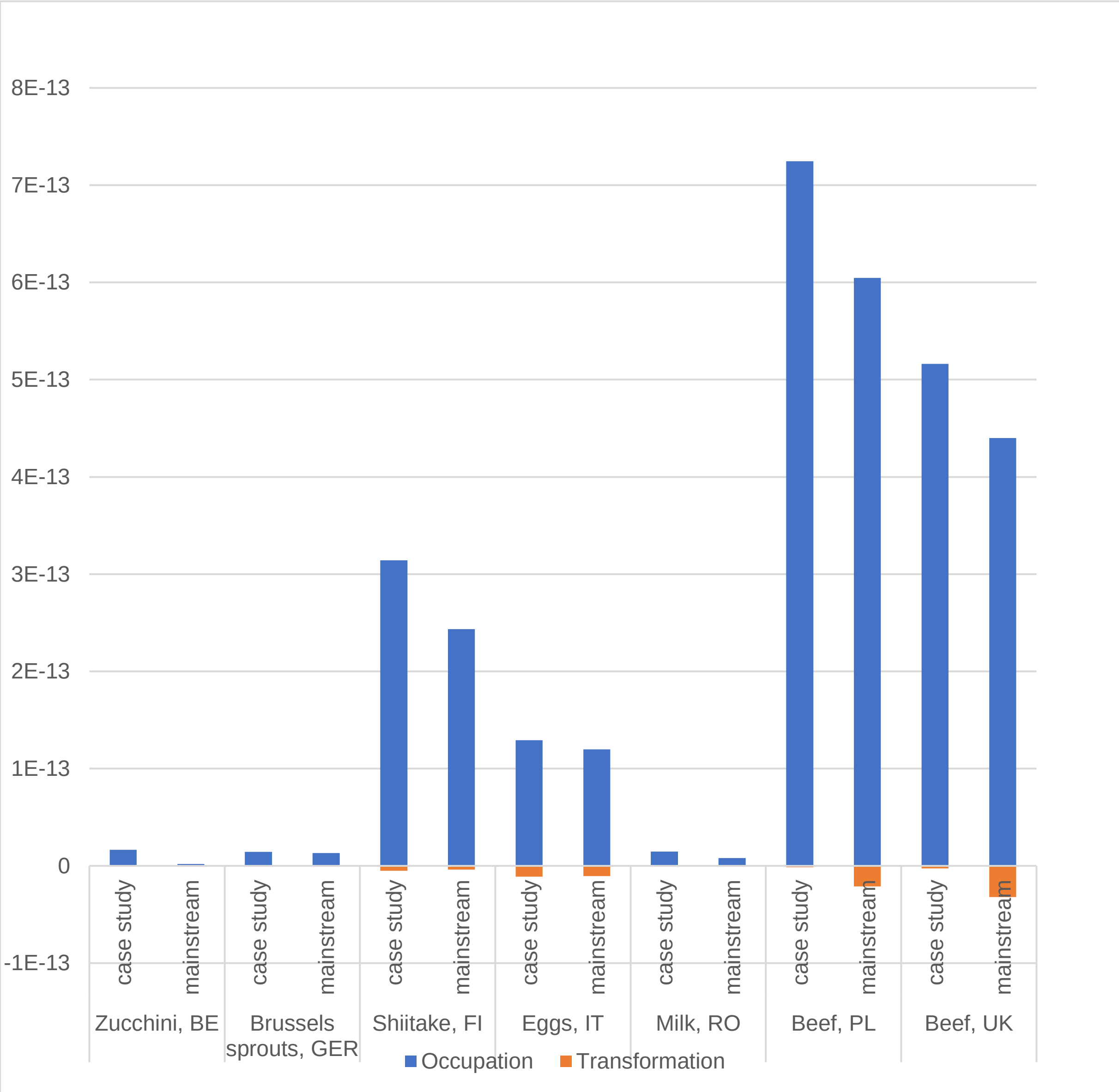
Impact Assessment Method (SimaPro name)	Timeline (years)	CH4	N2O	Beef, PL	Beef,UK	Milk, RO	Eggs, IT
ReCiPe Midpoint, H	100	25	298	32.5	36.4	1.28	1.41
ILCD Midpoint	100	25	298	33.6	36.4	1.28	1.41
IPCC 2013 GWP 20	20	72	289	89.1	84.1	2.95	1.61
IPCC 2013 GWP 100	100	25	298	33.5	36.4	1.28	1.41
IPCC 2021 GWP20	20	85.4	264	105	96.9	3.41	1.65
IPCC 2021 GWP100	100	30.5	265	39.6	40.8	1.46	1.41

Taking into account GWP20 for methane increases the carbon footprint of products from ruminants: meat (up to 3 times), milk (2.5 times) due to the change in the methane coefficient from 25 to even 85 and the large share of enteric fermentation in the carbon footprint. In the case of eggs, the changes were minor (17%) due to the fact that the IPCC methodology does not take into account enteric fermentation for poultry.

Biodiversity Index analysis

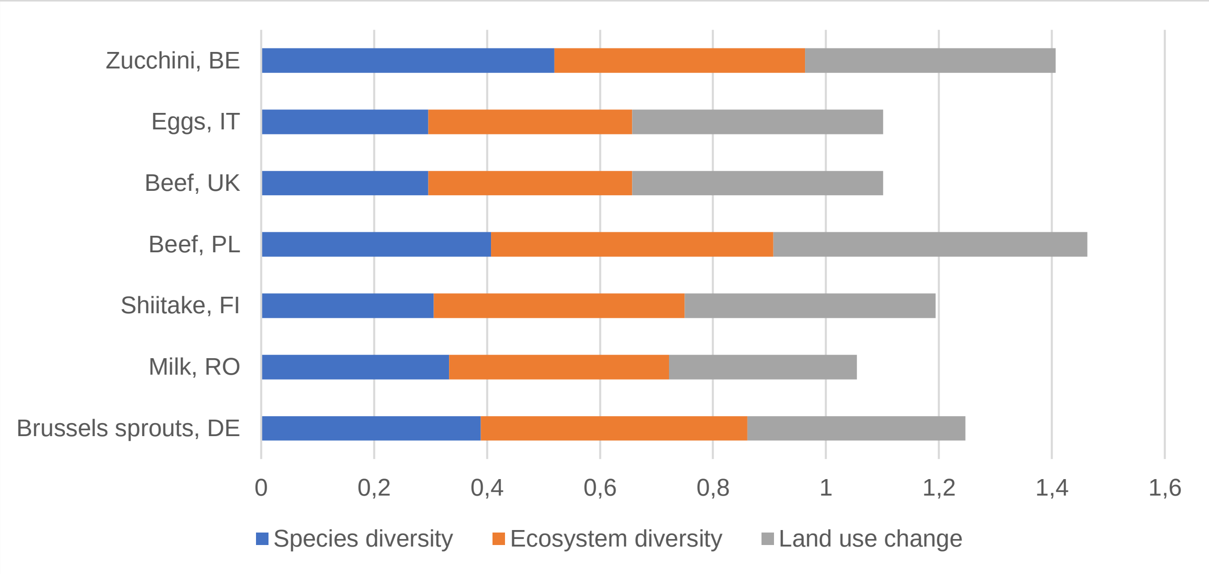
The results of the comparative analysis of the case study products with the mainstream products using Biodiversity Damage Potential (Chaudhary et al., 2015) are shown in Figure 43. The blue (positive) bars show the impact of land occupation, while the red (negative) bars show the impact of land transformation on species loss. The results obtained indicate that mainstream farms generally have a lower impact on BPD. The differences between the products compared are 7.9% (milk, Romania), 9.54% (Brussels sprouts, Germany), 17.2% (beef, UK), 19.8% (beef, PL), 29% (shiitake mushrooms, Finland) and 735% (courgettes, Belgium). The very high difference in the BPD coefficient in Belgium is caused by the use of wood chips on case farms as a way to enrich the soil with carbon and protect against weeds and water losses. It should be noted that the BDP metric is difficult to interpret and it was used for testing purpose.

Figure 43. Land use biodiversity (Chaudhary et al., 2015) results. Impact of 1kg of product on BDP.



Results of on-farm biodiversity analysis examined using the developed index is show in Figure 44. In all considered categories: species diversity, ecosystem diversity and land use change, the farm received scores above the unity, what means that they perform generally well preserving and enriching biodiversity.

Figure 44. Biodiversity Index analysis results for all case study farms.



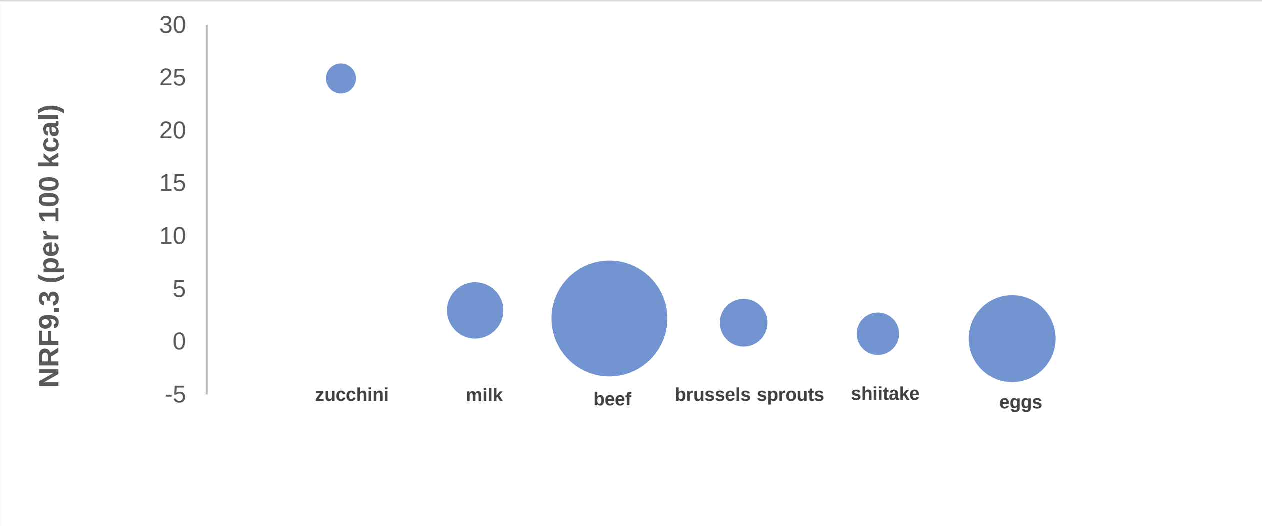
Human nutrition index

The nutritional index NFR9.3 was related to 100 kcal of products and presented in a Table 32 and a Figure 45. Due to the lack of evidence of differences in the nutritional content (tests on chemical properties) of products from innovative farms, it was not possible to compare them with mainstream products. At the same time, the results rank the nutritional value of the tested products in non-increasing order using the NFR9.3 index as follows: zucchini, milk, beef, Brussels sprouts, mushrooms, eggs.

Table 32. NRF9.3 results for all products.

Product	NRF9.3 per 100kcal	kcal per 1kg
zucchini	24.93	170
milk	2.96	600
beef	2.19	2540
brussels sprouts	1.80	430
shiitake	0.75	340
eggs	0.29	1430

Figure 45. NRF9.3 results per 100 kcal of chosen products. The size of dots means a caloric value per 1 kg of product.



Animal welfare index

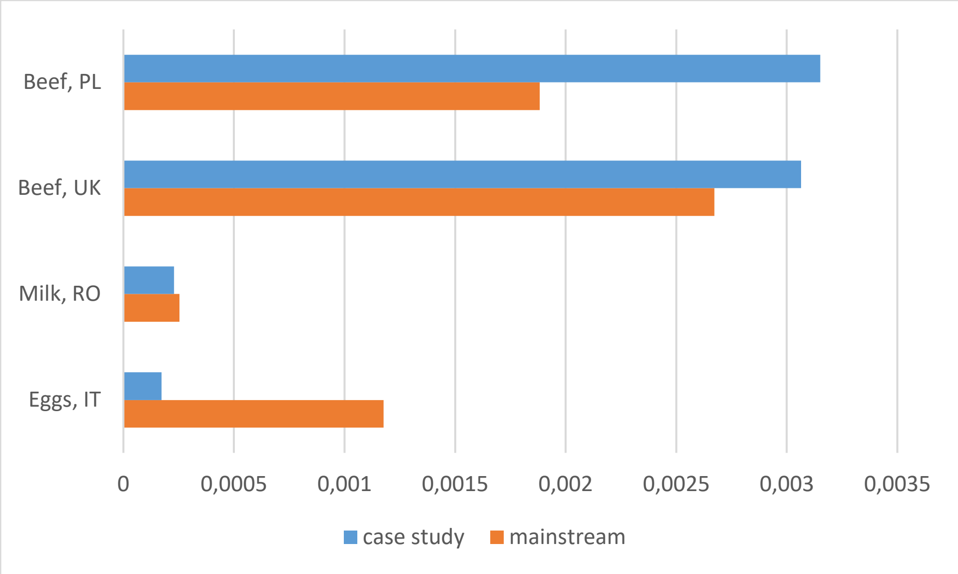
The animal welfare index adopted for the assessment (specifically: animal welfare loss index) after Scherer et al. (2018) can be incorporated directly into Life Cycle Assessment. The index allows to compare different groups of food on different scales. It takes into account the quality of life (mainly grazing share over a year and space available for animals), the slaughter age as well as life expectancy and moral value depending on the animal species. The analytical results for all animal products are shown in Figure 46.

The results indicate that the greatest welfare losses occur in cattle raised for meat, followed by milk production and laying hens. In the case of beef cattle, the value of the indicator depends, among other things, on the proportion of grazing and the weight of the animal at slaughter and was lower on the reference systems; in the case of Poland, share of grazing was similar but the weight of the animals at slaughter was lower on case study farm; in the case of the United Kingdom, the grazing share was bigger on the reference farm and the weight of the animals at slaughter was lower on the case study farm.

In the case of dairy cows, the indicator was at a similar level due to the similar milk yield of the cows and the similar proportion of grazing.

Differences in the performance of laying hens showed a large difference in the magnitude of the index in favour of the case study farm. This is related to the stocking density used to calculate the index. A lower stocking density on a case study farm results in lower welfare losses.

Figure 46. Animal welfare loss index (Scherer et al. 2018) calculated for all case studies with livestock.



Limitations of the study

The present report contains a wide range of results and informations, however it is appropriate to mention here some limitations:

- The compared systems, i.e. innovative farms and mainstream systems/farms, in some cases present non-homogeneous data quality levels, which might affect the uncertainty value of the final results. This is due to the fact that (in most cases) virtual farms were used as a reference system, which are a certain representation of the production system based on real data, expert opinions and literature.
- The main critical aspects related to the LCI of organic products include the lack of data collection on inputs used in organic production systems, such as plant protection products and organic fertilisers and other products used. Therefore, the production of similar chemicals was used as a proxy in the analyses. However, emissions related to the use of organic fertilisers have been calculated according to the nitrogen (and phosphorus) content.
- Due to the impossibility of comparisons with mainstream systems (representation of virtual systems), additional analyses on aspects such as SLCA and biodiversity took the medians of possible results as reference values. There was no evidence of differences between products in terms of nutritional quality due to a lack of chemical analysis.
- The use of BPD index (Chaudhary et al, 2015) has been tested, but it is not fully suitable for biodiversity comparisons at farm level and the interpretation of its results is unclear.

Summary

The report presents the results of a comparative life cycle analysis of selected products from innovative organic farms with products from mainstream organic farms. The selection of innovative farms for the project was arbitrary (Task 1.2) due to the diversity of organic farms. There were difficulties in collecting data from the farms, which led to some delays in the analyses.

Depending on the country, the inventory data for mainstream systems are based on: direct farm data, farm data complemented by expert opinion, statistical and literature data and expert opinion.

A summary of the LCA analyses is presented in Tables 33 and 34. The key focus is on the differences between the innovative farms (case study) and the mainstream.

Climate change

The impact of the analysed plant products on climate change was lower than from reference farms. The cultivation of Brussels sprouts had a comparable carbon footprint on both farms; the differences concerned the phase from farm to customer. The situation was similar for courgettes, where post-farm activities (mainly transport and retail) accounted for 200 or even 400% of the initial carbon footprint (at the farm gate). Cultivation of shiitake mushrooms in the forest had almost twice the carbon footprint, mainly due to lower electricity consumption (needed only for mycelium production).

Animal products (milk, eggs) also had similar or lower carbon footprints.

Beef had a higher life cycle carbon footprint in both Poland and the UK. An extensive feeding system based on grazing (in the case of Poland, only grass-based) does not allow for similar growth as additional feed.

Acidification and Eutrophication

The comparative results show a more differentiated picture regarding acidification and eutrophication than climate change. Acidifying emissions are commonly caused by sulfur oxides (SOx), nitrogen oxides (NOx), ammonia (NH3), and carbon dioxide (CO2) while eutrophication potential is mainly due to nitrogen and phosphorus leaching. On farms growing zucchini, dairy cows and beef cows, nitrogen and phosphorus emissions per functional unit were higher, and therefore in both of these categories the products had a greater impact on the environment than the reference farms.

Land occupation

The main factors influencing the results in this category are the yield per hectare. In the case of most products, innovative farms performed better or similarly then reference systems. The result indicating worser results of shiitake mushroom cultivation in this category is debatable. It is caused by the use of log woods and related land use in the forest category.

Water depletion

Most products from innovative farms require less water to produce than products from reference farms. Throughout the life cycle of the products, from 0.4 (courgettes, Belgium) to 405 (beef, Poland) litres of water were used per 1 kg. More water in innovative farms was required for milk (Romania) and beef (Poland), but it should be noted that in both systems the amount of water drunk by the cattle was calculated rather than measured and therefore the results are subject to a high degree of uncertainty.

Energy use

This category takes into account the upstream energy in the form of fuel, chemicals, heat, feeds, and electricity used for cultivation or animal growing. The results indicate that all products from innovative farms in their life cycle have a lower or similar demand for energy from fossil fuels than from reference farms.

Table 33. Comparison of the results for the LCA of the tested products (all phases) in the main impact categories. A threshold of 10% has been used as no difference. Green colours indicate a lower impact in each category (better performance), red colours indicate a higher impact (worse performance) than the corresponding products from the reference systems.

		Climate change	Acidification	Eutrophi-cation	Land occupation	Water depletion	Energy use
Plants	Brussels sprouts, Germany						
	Zucchini, Belgium						
	Shiitake mushrooms, Finland						
Animal origin	Milk, Romania						
	Eggs, Italy						
Meat	Beef, Poland						
	Beef, UK						

Where:

	significantly more impact (>50%)
	more impact (20% to 50%)
	slightly more impact (10% to 20%)
	no difference (less then 10 %)
	slightly less impact (10% to 20%)
	less impact (20% to 50%)

	significantly less impact (>50%)

Table 34. Main conclusions from the impact analysis for the products under study.

Product	Product, country	Main results of impact assessment	Reference
Plants	Brussel sprouts, Germany	• no significant diffenences at the farm level • relatively large impact of purchased seedlings (14% share in the GWP) • main differences are due to post farm activities (distribution, retail), for GWP over all stages is 10% difference (0.77 vs. 0.86 kg CO_2eq. kg^{-1})	Table 8, Figures 2-6
	Zucchini, Belgium	• Due to the high yield per hectare (70-80 tonnes), cultivation doesn't has dominant role on the overall environmental impact. • The carbon footprint of the zucchini on farm gate is similar (~0.1 kg CO_2eq kg^{-1}) • The consumer phase (freezing, storage, thawing) has the largest share of all impact categories in the case study; in the mainstream system, the transport and sales phase has the largest share.	Table 28, Figures 39-41
	Shiitake mushrooms, Finland	• Growing shiitake mushrooms indoors has significantly higher impact • Energy carries (petrol fuel, electricity, natural gas) have a predominant impact on environmental footprint in both systems (usually 70 - 90%) • The carbon footprint of forest cultivation is almost 2 times smaller than that of traditional cultivation (2.87 vs 5.43 $kgCO_2$eq. kg^{-1}) mainly due to lower energy consumption	Table 14, Figures 15-17
Animal origin	Milk, Romania	• no significant differences at the farm level • The shorter supply chain in the case study did not have a significant impact on the environmental impact of milk • Main source of GHG emission is CH_4, its share in total emission is 81% and 67% on farm gate respectively for case study and mainstream milk system	Table 11, Figures 9-12
	Eggs, Italy	• Case study farm (with grazing) has a significantly less impact on the environment (except freshwater exotoxicity category) then mainstream system (limited grazing) • Feed provision plays the main role in all impact categories for both systems • The carbon footprint of 1 kg of eggs at the farm gate is 24% lower for case study farm than that of eggs from a farm based on purchased feed (1.26 vs 1.56 kgCO2eq.kg^{-1}, respectively). • Purchased feed (mainly cereal grains, peas and soybeans) has the greatest impact on GWP in the case of the innovative farm, their impact is approximately 37%, in the reference farm it is over 70%.	Table 26, Figures 32-36

Meat	Beef, Poland	• The carbon footprint of 1 kg of beef throughout its life cycle is 23% higher for case study farms than for mainstream organic beef; this difference is caused by the lower efficiency of grass-based cattle feeding (grazing, hay, silage grass) • Emissions of CH_4 are the largest contributor to greenhouse gas emissions, and are about 30% higher per 1 kg of beef in the case study than in the mainstream system.	Table 18, Figures 21-24
	Beef, UK	• Beef produced in a more intensive 'standard' system had a lower climate impact than meat from the more extensive innovative case-study system (27.2 vs. 36.4 kg CO2eq. kg-1) and that managing enteric methane emissions is the most important factor in reducing the climate impact of beef production systems	Table 22,23; Figures 27-30

Emergy assessment

The following table summarizes the found values for the Solar equivalent Joules of emergy.

Product	Country	Scenario	Emergy (in Solar Equivalent Joules)
Beef	Poland	Case study	2.0485151E+15
Beef	United Kingdom	Case study	2.0485142E+15
Brussels sprouts	Germany	Case study	2.0485142E+15
Eggs	Italy	Case study	2.0471328E+15
Milk	Romania	Case study	2.0485160E+15
Shiitake mushrooms	Finland	Case study	2.0487730E+15
Zucchini	Belgium	Case study	2.0485198E+15
Beef	Poland	Mainstream	2.0487803E+15
Beef	United Kingdom	Mainstream	2.0487852E+15
Brussels sprouts	Germany	Mainstream	2.0485142E+15
Eggs	Italy	Mainstream	2.0471328E+15
Milk	Romania	Mainstream	2.0485142E+15
Shiitake mushrooms	Finland	Mainstream	2.0487729E+15
Zucchini	Belgium	Mainstream	2.0485198E+15

The results found must be considered as the minimum value found using huge background databases.

The ecoinvent 3.9.1 background database itself contains about 20000 different datasets. Life-cycle inventories built for this project contained in average 15000 datasets in the full graph made out of the technosphere matrix. This leads to taking into account the different emergy flows from a system made of at least so many inputs, in contrast to regular emergy models that usually only include hundreds of entries.

Results may then seem too similar, but one must consider that a very big part of the ecoinvent and other databases are included in every functional unit.

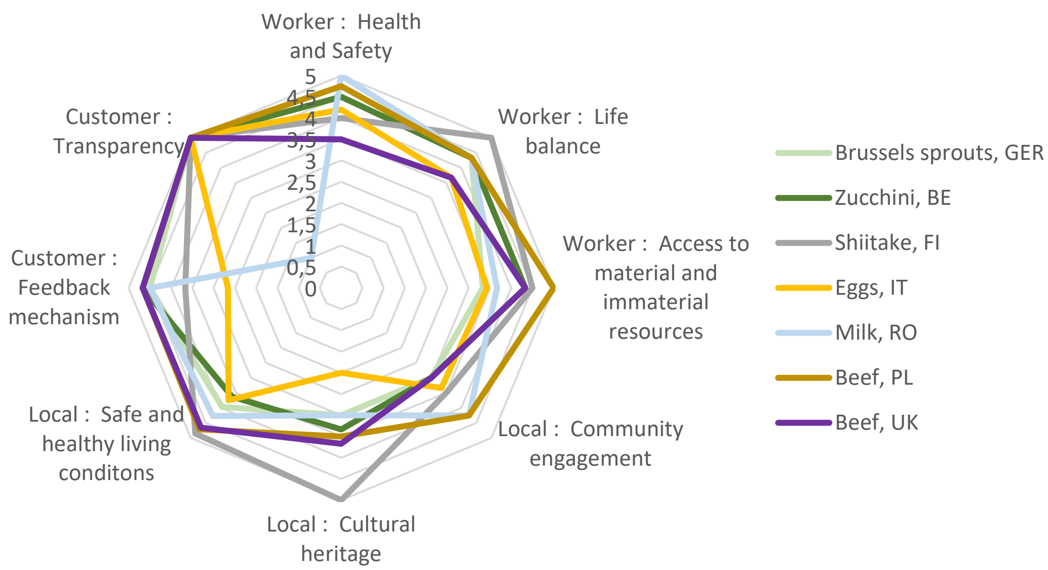
The emergypy software is built internally at LIST and has the vocation of becoming a generally available tool, as was SCALEM. The exact distribution model to be used will be only defined in the future.

Emergypy only contains a few of the features of SCALEM, but they are being backported to it, and should be available when emergypy is fully distributed. One key feature that should be developed in the future, is the ability to do a contribution analysis of the values found during the graph analysis.

Social aspects analysis

The summary result of the social analyses for all products is presented in Figure 47. The data source for the analyses was the data collected as part of task T1.2. In the methodology used, the median (in this case 3) represents the acceptable level of the factor. In general, all products tested achieved values equal to or higher than acceptable levels. The worst results were achieved by farms producing milk and eggs at the consumer stage. In the case of Romania, the farm did not renew its organic certificate, which means that it formally ceased to be an organic farm (which was the case during the project), but maintained its present organic production methods. In the case of organic egg production, the owners have no official feedback from customers, which of course does not mean that customers are not satisfied.

Figure 47. The SLCA results for all analysed products.



Additional indices

The additional tools proposed in the proposal to compare farms were found to be inadequate or difficult to use due to lack of data. The biodiversity assessment shows that all case study farms achieve a satisfactory level of performance. Innovative farms are also characterized by better animal welfare for laying hens, similar for dairy cattle and worse for beef cattle than the reference farms.

Appendix

Table A1. Germany mainstream organic brussels sprouts production, LCI primary data and sources.

Item	Unit	Value	Source, Comments
INPUTS			
Residue incorporated into soil	%	100	(3)
Total LGV (<3.5tonne) distance sum	km	30	(3) seedlings
Total LGV (<3.5tonne) distance sum	km	3	(3) hairflour pellets
Seedlings	#/ha	33000	(1)
Machinery			
Diesel use	l/ha	174.44	(1)
Machine hours	h/ha	40.76	(1)
Water for irrigation	m3/ha	4000	(3); vs. (1) 950m3/ha
Water for plant protection	m3/ha	1.8	(1)
Electricity	kwh/ha	177.14	(1)
Fertilizers			
Hairflour pellets (14% N)	kg	1200	(1) hairflour pellets (14% N); vs. (3) insufficient -> 1500kg/ha in trials
Kali-Magnesia (30% K20, 10% MgO)	kg	680	(1)
Farm-grown mulch (mainly clover grass)	kg	35000	(3) Fresh material, approx. 20000 kgDM
Micro-organisms (bacteria, viruses and fungi)	kg	1.8	(1) Bacillus Thuringiensis
Crop protection nets	m2/ha	10000	(1); (3) Crop protection net: cabbage fly protection net, life span approx. 10 years, 8x8mm mesh size
Processing (on-farm)			
Cut, sort, weigh and pack Brussels sprouts (1,2 t/h; 7 workers)	h/ha	58.38	(1)
OUTPUT			
Brussel sprouts total yield	kg/ha	10000	Total yield, approx. 20% returned into ground as a organic residues
Brussel sprouts marketable yield	kg/ha	8000	
Sources: (1) Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL): https://daten.ktbl.de/dslkrpflanze/postHv.html#anleitung (2) Interview with two consultants in organic horticulture from Bioland e.V. (3) Interview with Expert in (organic) horticulture, Teaching and experimental operations, Department of Horticulture, SERVICE CENTRE FOR RURAL AREAS RHINELAND-PALATINATE			

Table A2. Detailed information about eggs production , case study farm, Italy; Source: farm survey

Item	Unit	Value	Comments
Purchased pullets	# per cycle	9000	biennial cycle
Eggs soldable production	# per year	2124000	
Laying cycle duration	# of weeks	42	per cycle
Live weight, at pullets purchase	kg per head	1.5	

Live weight, end of the cycle	kg per head	2.2	sold after 2 years for further egg production 2 Euro/hen
Feed intake, as feed excluding grazing	g per day per head	57	see M2.2, Table 54
Egg weight	g	60	
Mortality	% per cycle	0.8	
Broken eggs	%	6	
Indoor stocking density	# hens / m2	5	
Outdoor stocking density	# hens / m2	0.5	
Electricity consumption	kWh /year	55000	

Source: farm survey

Table A3. Detailed information about eggs production, mainstream organic system, Italy

Item	Unit	Value
Purchased pullets	# per cycle	3000
Eggs soldable production	# per year	2124000
Laying cycle duration	# of weeks	56
Live weight, at pullets purchase	kg per head	1.55
Live weight, end of the cycle	kg per head	1.95
Feed intake, as feed excluding grazing	g per day per head	130
Egg weight	g	58
Mortality	% per cycle	4
Broken eggs	%	1.5
Indoor stocking density	# hens / m2	6
Outdoor stocking density	# hens / m2	4.17
Electricity consumption	kWh /year	7200
Water consumption	l/ day	700

Source: Constantini et al. (2020)

Table A4. Feed ingredients composition [dag kg^{-1}, as fed (88% of dry matter on fresh mass)], mainstream organic eggs production system, Italy

Feed component	Feed 1st phase	Feed 2nd phase
Maize grain	50	56
Soybean meal, extracted	15	12
Wheat bran	10	8

Wheat grain	10	8
Sunflower meal	8	8
Calcium carbonate	4	5
Maize germ	2	2
Linseed meal	1	1

Source: Constantini et al. (2020)

Table A5. Detailed description of case study farm, eggs production, Italy.

Eggs production system	Unit	Value	Source/Comments
Eggs,	kg	127440	calculated
Exported animals for raising, live weight	kg	9900	calculated
Olive oil	kg	1000	calculated
Economic allocation			calculated
Eggs	%	97.2	800 thous. Euro per year
Live weight animals	%	1.7	2 Euro per hen * 9000/ 2
Olive oil	%	1.1	14 thous. Euro per year
Material for treatment			
N deposited during grazing	kg N	6287.49	calculated, farm survey
Animals for treatment (dead)	kg	79,2	mortality rate: 0.8% per cycle
Land occupation			farm survey
Arable land	ha	22	farm survey
Woodland	ha	1	farm survey
Built-up land	ha	0.5	farm survey
Other	ha	0.8	farm survey
Feeding			
Grazing	p	see text	on-farm
Maize grain	t	70	on-farm
Wheat grain	t	58.5	on-farm
Barley grain	t	9	on-farm
Peas, dry	t	17	purchased
Field beans	t	18	purchased
Soya bean meal	t	14	purchased
Wheat grain	t	0.25	purchased
Transport of eggs			
Farm to consumer	km	xxx	farm survey
Consumer to farm	km	xxx	farm survey
Electricity (purchased)	kWh	55000	farm survey
Water	m3	720	calculated : assumption 80l/ laying hen/year (Agri-footprint 5.0)
Packaging			
Paper box	$kg\ kg^{-1}$	0.1	farm survey
Farm storage			
Duration (room temperaturę)	day	1	farm survey

Source: farm survey

Table A6. Romanian mainstream milk system , cradle to milk plant unit.

Milk production system	Unit	Value	Source/Comments
Output			
Milk production	kg	279130	Allocation to milk = 0.782
Exported animals for raising, live weight	kg	7670	
Herd description			
Dairy cows	#	22	
Dairy heifer	#	10	
Dairy calf (0-6 months)	#	30	
Feeding			
Permanent grassland	ha	72	
Annual crops (cereals, maize)	ha	17.5	
Inputs from technosphere			
Diesel use	l	16380	
Electricity	kWh	16260	
Emissions to air			
Methane	kg	10012	
Dinitorgen monoxide	kg	100	
Ammonia	kg	397	
Nitrogen oxides	kg	197.67	
Emission to water			
Phosphorus	kg	54	
Nitrates	kg	0	Negative N balance
Transport of raw milk to dairy plant	km	22	
Packaging	kg of glass	0,0221	20 reuse of 442g bottle, PEF
Transport to retailer	kgkm	56	lorry with refregeration, PEF transport matrix
	kgkm	34	rail
	kgkm	11	barge
Transport to consumer/by consumer	km	20/100=0.2	assumed 20km with 1/100 trunk share

Source: Harmonised Environmental Sustainability in the European food and drink chain, Life cycle assessment of Romanian beef and dairy products, 2013

Table A7. Inventory data from cradle to farm gate per plot (0.0465ha) of cultivation of courgette for hospital.

Variable	Value	Unit	Comments
Yield	4.057	t	CC non fossil = 0.0311446 kg C kg DM; DM=0,06 FM
Marketable yield	3.976	t	
Tillage system	no-till		
Plants residues	left on the field		
Transport of inputs	16.2	km	Lorry <10t
Diesel use tractor (55hp)	5.03	l	

Total manpower hours	71.3	h	
Water for irrigation	0.288	m3	open air plants watered once at season
Mushroom substrate waste	2.95	t	N content =0.63% ; P content = 0.4% FM (Source: PGTool)
Wood chips	3.89	t	CC= 0.494 kg C/kg DM; WM = 2.1 kg kg DM^{-1}; HV = 10.81 MJ; market for wood chips, wet, measured as dry mass Europe without Switzerland, Ecoinvent 3, N content =1.04%, P content 0.041% FM (PGTool)
Composted or fermented mixture of vegetable matter (purchased)	0.0236	t	Organic Plant Feed, OPF 11-0-5 Granulate, https://www.phc.eu/product/opf-granulaat-11-0-5/ N content- 11%
Ferric phosphate (iron (III) orthophosphate)	0.0058	kg	Molluscicide: kg active ingredient used
polypropylene anti-root mat (kg)	4.5	kg	https://royalbrinkman.be/content/files/productdocuments/PhormiSol%20137%20R-TDS-English_BD102951.pdf
Total transport to nearby hospital	243	km	van <3,5t

Source: farm survey

Table A8. Life cycle Inventory of inputs and outputs , mainstream organic courgette production outdoor, Belgium. All values referes to 1ha of cultivation

Variable	Value	Unit	Comments
Yield	76.66	t	CC non fossil = 0.0311446 kg C kg DM; DM=0,06 FM
Marketable yield	63.35	t	
Tillage system	full tillage		
Plants residues	left on the field		
Transport of inputs	24 192	km	van Farmyard manure transport by contractor (heavy tractor + manure spreader)
Diesel use tractor (55hp)	18 72.6	l	own use by contractors
Total manpower hours	1256	h	
Water for irrigation	121.5	m3	open air plants watered once at season
Electricity	13.2	kWh	

Farmyard manure	50	t	
Ferric phosphate (iron (III) orthophosphate)	0.168	kg	Molluscicide: kg active ingredient used Phosphoric acid, industrial grade, without water, in 85% solution state {GLO}| market for phosphoric acid, industrial grade, without water, in 85% solution state | Cut-off, U used as a proxy
Sulfur	8	kg	Sulfur {GLO}| market for sulfur | Cut-off, U
Potassium bicarbonate	2.550	kg	Hydrogen, liquid {RoW}| potassium hydroxide production | Cut-off, U
polypropylene anti-root mat (kg)	4.5	kg	Polypropylene, granulate used as a proxy, https://royalbrinkman.be/content/files/productdocuments/PhormiSol%20137%20R-TDS-English_BD102951.pdf
Total transport after farm	720 640 587	km (lorry)	farm to vegetable auction vetatable auction to distribution centre distriubution centre to retail

Source: Results from zucchini variety trials at two Belgian practice research centres (Inago and PSKW(Research Station for vegetable production in Sint-Katelijne-Waver)) + experts opinions

Table A9. Mycelium production, inventory for a 3 kg package A. bisporus seeds

Life cycle stage	Input	Material	Ecoinvent code	Value per FU (3 kg package)	Unit
Rye preparation stage	Rye	Rye grain	Rye grain, Swiss integrated production {GLO}| market for | Alloc Rec, U	1.9	kg
	$CaCO_3$	Lime	Lime, packed {GLO}| market for lime, packed | Alloc Rec, U	0.3102	kg
	Diesel	Diesel	Diesel, burned in agricultural machinery {GLO}| market for diesel, burned in agricultural machinery | Alloc Rec, U	0.1632	kwh
	Bags	Polyethylene, low density	Polyethylene, linear low density, granulate {GLO}| market for | Alloc Rec, U	1.29	Units
	Electricity usage	Electricity, Finnish grid	Electricity, medium voltage {FI}| market for | Alloc Rec, U	0.311	kwh
	Water consumption	Tap water	Tap water {Europe without Switzerland}| market for | Alloc Rec, U	5.97	kg
Inoculum creation stage					
	Electricity usage	Electricity, Finnish grid	Electricity, medium voltage {FI}| market for | Alloc Rec, U	0.3075	kWh
	Water	Tap Water	Tap water {Europe without Switzerland}| market for | Alloc Rec, U	0.213	kg
Mycelium preparation stage	Electricity usage	Electricity, Finnish grid	Electricity, medium voltage {FI}| market for | Alloc Rec, U	0.407	kWh
	Water	Tap water	Tap water {Europe without Switzerland}| market for | Alloc Rec, U	0.213	kg

Source: Leiva et al., 2015

Table A10. Data inventory per 1kg (fresh weight) shiitake mushroom produced between 2018-2021. Annual average yield for forest cultivation is 78.75kg.
Source: farm survey

Life cycle stage	Input	Material	Comments/Process name	Value per FU	Value per year	Unit
Substrate materials	Wood chips	Wood chips, as a byproduct	Wood chips, wet, measured as dry mass {RER}| market for | Alloc Rec, U	1.500		Kg
		Transport, 3.7-7.5 ton lorry (EURO 5)	Transport, freight, lorry 3.5-7.5 metric ton, EURO5 {GLO}| market for | Alloc Rec, U	145.2		kgkm
	$CaCO_3$	Lime	Lime {GLO}| market for | Alloc Rec, U	0.063		kg
		Transport, 3.7-7.5 ton lorry (EURO 5)	Transport, freight, lorry 3.5-7.5 metric ton, EURO5 {GLO}| market for | Alloc Rec, U	0.535		kgkm
	Mycelium	Mycelium inoculated rye seeds	Inventory taken from [23]	0.358		kg
		Transport, 3.7-7.5 ton lorry (EURO 5)	Transport, freight, lorry 3.5-7.5 metric ton, EURO5 {GLO}| market for | Alloc Rec, U	708.8		kgkm
		Electricity, French grid	Electricity, medium voltage {FI}| market for | Alloc Rec, U	0.012		kWh
	Water	Tap water	Tap water {Europe without Switzerland}| market for | Alloc Rec, U	1.137		kg
	Wood logs	Wood logs: birch, aspen, alder, oak	Wood logs from nearby farm (2.5 m3/yr)	20.3	1600	kg
Substrate transformation	Log cutting with chainsaw	Petrol	Cutting logs with a chainsaw	0.0136	1.07	l
	Electric drill for drilling holes in the logs for inserting mycelium	Electricity, Finnish grid	Drilling holes in the logs for inserting mushroom spawn/dowels	0.0101	0.8	KWh
	Bee wax	Natural bee wax for sealing	Sealing the holes with beewax	0.0101	0.8	kg
	Water	Water from own well	Watering the logs	3.67	289	l
Cultivation	Water	Water from own well	Watering the logs	3.81	300	l
Packaging and delivery	Wood crates	Carton board box	Carton board box production, with gravure printing {GLO}| market for | Alloc Rec, U	0.186		Kg
	Delivery	Transport, passenger car, compact size, petrol (EURO 5)	Transport, passenger car, compact size, petrol, EURO 5, delivery at the local market		2.5	km
	Pick up by customer	Paper bag/paper	A small amount is sold on the farm directly to the customers. A paper bag can hold about 0.5 kg of mushrooms	2 pieces	20	pcs

Table A11. Indoor shiitake mushrooms cultivation. Data inventory per 1kg (fresh weight) shiitake mushroom produced between 2018-2021

Life cycle stage	Input	Material	Ecoinvent code	Value for 100 kgs fresh shiitake	Unit

	Wood chips	Wood chips, as a byproduct	Wood chips, wet, measured as dry mass {RER}| market for | Alloc Rec, U	850 (Helsieni data)	Kg
		Transport, 3.7-7.5 ton lorry (EURO 5)	Transport, freight, lorry 3.5-7.5 metric ton, EURO5 {GLO}| market for | Alloc Rec, U	145.2 (tbc)	kgkm
	Mycelium	Mycelium inoculated rye seeds	Inventory taken from [23]	0.358 for 1 kg; 35.8 kg for 100 kg	kg
		Transport, 3.7-7.5 ton lorry (EURO 5)	Transport, freight, lorry 3.5-7.5 metric ton, EURO5 {GLO}| market for | Alloc Rec, U	708.8	kgkm
		Electricity, French grid	Electricity, medium voltage {FR}| market for | Alloc Rec, U	0.012 for 1 kg; 1.2 for 100 kg	kWh
	Water	Tap water	Tap water {Europe without Switzerland}| market for | Alloc Rec, U	1.137 for 1 kg;114 for 100 kg;	kg
Substrate transformation	Air purification	Electricity, Finnish grid	Electricity, medium voltage {FI}| market for | Alloc Rec, U	0.132 for 1 kg; 13.2 for 100 kg	KWh
	Conveyor belt	Electricity, Finnish grid	Electricity, medium voltage {FI}| market for | Alloc Rec, U	0.079 for 1 kg; 7.9 for 100 kg	KWh
	Substrate mixing	Electricity, Finnish grid	Electricity, medium voltage {FI}| market for | Alloc Rec, U	0.552 for 1 kg; 55.2 for 100 kg	KWh
	Substrate cooling	Electricity, Finnish grid	Electricity, medium voltage {FI}| market for | Alloc Rec, U	0.110 for 1 kg; 11 for 100 kg	KWh
	Sterilization: Gas	Sour gas, global average	Sour gas, burned in gas turbine {GLO}| market for | Alloc Rec, U	5.534 for 1 kg; 550 for 100 kg	KWh
	Total electricity			Sum form above: 638	KWh
	Sterilization: Water	Tap water	Tap water {Europe without Switzerland}| market for | Alloc Rec, U	5.765 for 1 kg; 280 for 100 kg;	kg
	Plastic bags	Polyethylene, low density	Polyethylene, linear low density, granulate {GLO}| market for | Alloc Rec, U	0.032 for 1 kg; 3.2 for 100 kg	KWh
	Air purification	Electricity, Finnish grid	Electricity, medium voltage {FI}| market for | Alloc Rec, U	0.188 for 1 kg; 18.8 for 100 kg	KWh
Cultivation	Air temperature regulation	Electricity, Finnish grid	Electricity, medium voltage {FI}| market for | Alloc Rec, U	4.403 for 1 kg; 440.3 for 100 kg	KWh
	Humidifier	Electricity, Finnish grid	Electricity, medium voltage {FI}| market for | Alloc Rec, U	0.117 for 1 kg; 11.7 for 100 kg	KWh
	LED lighting	Electricity, Finnish grid	Electricity, medium voltage {FI}| market for | Alloc Rec, U	1.539 for 1 kg; 154 for 100 kg	KWh
	Ventilation	Electricity, Finnish grid	Electricity, medium voltage {FI}| market for | Alloc Rec, U	0.478 for 1 kg; 47.8 for 100 kg	KWh
	Water	Tap water	Tap water {Europe without Switzerland}| market for | Alloc Rec, U	19.461 for 1 kg; 1946 for 100 kg	kg
	Steel racks	Steel, low-alloyed	Steel, low-alloyed {GLO}| market for | Alloc Rec, U	0.0082 for 1 kg; 0.82 for 100 kg	kg
	Sanitary materials	Polypropylene	Polypropylene, granulate {GLO}| market for | Alloc Rec, U	0.0007 for 1 kg; 0.07 for 100 kg	kg
		Polyethylene, low density	Polyethylene, low density, granulate {GLO}| market for | Alloc Rec, U	0.00012 for 1 kg; 0.012 for 100 kg	kg
		Polyethylene, high density	Polyethylene, high density, granulate {GLO}| market for | Alloc Rec, U	0.0016 for 1 kg; 0.16 for 100 kg	kg
		Synthetic rubber	Synthetic rubber {GLO}| market for | Alloc Rec, U	0.0019 for 1 kg; 0.19 for 100 kg	kg

Packaging and delivery	Carton box	Carton board box	Carton board box production, with gravure printing {GLO}| market for | Alloc Rec, U	0.186 for 1 kg; 1,86 for 100 kg	Kg
	Delivery	Transport, passenger car, small size electric	Transport, passenger car, small size electric	10 km	km

Source: farm survey and Leiva et al., 2015

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