SUSTINERE

Life cycle assessment of sheep and beef meat

Report

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ESTONIAN FUND FOR NATURE

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Content

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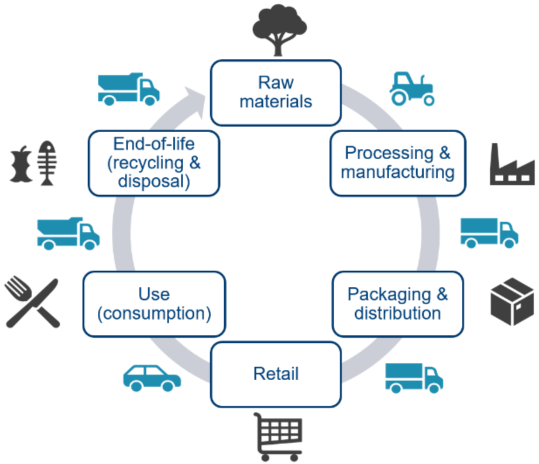
This study contributes to the objective of Eat4Change, a European project aiming at the transition towards more sustainable consumption and production in Estonia and Europe, with a special focus on the livestock sector. The results will be used for creating consumer tool.

Background and aim of the study

The aim of the study was to perform a life cycle assessment of Estonian sheep and beef production to gain increased knowledge on the environmental impacts of meat from different local production systems.

Life Cycle Assessment (LCA) is the most widely accepted international methods of quantifying the environmental impacts of products and services. LCA allows for the identification of the environmental consequences of the life cycle of a product/service by evaluating potential environmental impacts over its entire life cycle production chain (ISO 14040, 2006).

LCA consists **four standard phases**: (1) goal and scope definition, (2) life cycle inventory, (3) life cycle impact assessment, and (4) interpretation. All environmental impacts are related to the function that is delivered by the system under assessment. The so-called **"functional unit"** is a quantitative description of that function. As the primary function of food is to satisfy the need of the human body to be nourished, typical functional units are based on a quantity of food (e.g., 1 kg of eggs at farm gate, delivery of 1 litre of drinking milk to consumer) (Cucurachi et al. 2019).



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Methodology

Goal and scope

The goal of this study was to perform a life cycle assessment (LCA) of sheep and beef meat production in Estonia. The functional unit of the study was 1 kg of meat (carcass weight) from cradle to farm gate.

The assessment is based on real farm data collected from organic and conventional farms. Farm data included all inputs, outputs and processes linked to meat production at farm: purchased feeds, used energy, feed production, manure management, production amounts etc. Data was collected about 2 operational years for sheep farms (2018 – 2019) and 3 operational years for beef farms (2017 – 2019). All beef farms were specialised on beef breed production, no milk production farms were included.

The assessment includes all inputs, outputs and processes, including all animal classes and ages present over the 24 or 36-month period required to produce the given mass of product. Description of the main parameters of farms is given in p 13–14.

Impact categories assessed were global warming potential (GWP100, kg CO2eq) and pesticide use (kg active ingredient).

Economic allocation for purchased feeds was preferred when possible (resulting from processes yielding several co-products). Climate change impact due to land use change was included to carbon footprint of purchased feeds for all plant and animal based feeds and feed components (as included in Agri-footprint 5 database) except grass and silage. All environmental life cycle impacts quantified for the animal producion were allocated to meat.

Methodological specifications

- Life Cycle Assessment software Simapro v9.2. was used for the assessment. Global warming potential factors were based on the IPCC Fifth Assessment Report (AR5).

GHG*	GWP100**
CO2	1
CH4	28
N2O	265

- Professional databases (Ecoinvent v3, World Food LCA Database, Agri-Footprint 5, etc.), reports and scientific literature were used to identify the impacts of inputs used for production (foreground data).
- Both meat and live animals sold out from farm were quantified to kg of carcass weight based on average LW/CW factors 0.47 for sheep and 0.55 for beef.
- Additionally it was tested how the inclusion of soil organic carbon sequestration affects the results. Actual long term carbon sequestration to soil (i.e. change in soil organic carbon stock) is influenced by several aspects: soil type, soil clay content, water regime, temperature, current soil carbon content, carbon input to soil (including from roots and residues). There is a lack of data about long term sequestration potential of permanent grasslands in Estonia. It has been estimated that the conversion into (permanent) grassland in Europe results in sequestration rate between 0.4 and 0.8 t C/ha/year (Lugato et al. 2015). Widely used French CAP2ER assessment model uses carbon sequestration value 0.57 t C/ha/year for permanent grasslands. Based on that a rough estimation on carbon sequestration of 0.5 tonne C/ha/year was made only for the permanent and semi-natural grasslands. Permanent grasslands were defined as areas where grass has been grown at least 5 years (following the definition of The Agricultural Registers and Information Board). Renewal frequency of permanent grasslands in studied farms varied from 4, mostly from 5-7 or even 10+ years, some farms do not renew permanent grasslands at all. Carbon sequestraton potential was considered the same for all permanent grasslands due to lack of data regarding the impact of renewal frequency.
- Results including soil carbon sequestration are presented starting from page 19.

Methane enteric fermentation

Methane emissions were found based on IPCC 2016 (Tier 2):

$$EF = \frac{GE \bullet \left(\frac{Y_m}{100}\right) \bullet 365}{55.65}$$

GE – gross energy intake, MJ/animal/day

Ym – <methane formation factor, percentage of energy in feed converted into methane (4.5 – 5.5 for sheep , 6.5 for cattle)

365 – number of days per year

55.65 – energy content of methane (MJ/kg of CH_4)

Gross energy was calculated for sheep and beef based on metabolizable energy intake (Oll, 1995; Piirsalu 2019), 63% of energy was assumed to metabolise.

Sheep	ME (MJ)*	GEI (MJ)	CH4 conversion rate	CH4, kg/head
Ewe (60 kg), yearly amount	5650	8968	5,5	8,9
Adult male sheep (80 kg), yearly amount	4722	7496	5,5	7,4
Lamb (up to 30 kg), total amount	1175	1865	4,5	1,5
Lamb (up to 40 kg), total amount	1937	3075	4,5	2,5
Beef		**GEI (MJ) per day****	**CH4 conversion rate**	**CH4, kg/head/year**
Cows and other adults		178	6,5	75,9
Heifer		146	6,5	62,3
Calf		82	6,5	35

* based on Oll 1995

** Based on Piirsalu et al. 2019, GEI is calculated based on dry matter consumption and dry matter ME content. 63% of energy was assumed to metabolise.

Methane from manure management

Methane emissions from manure management were calculated based on IPCC 2006 (Tier 2):

$$EF_{(T)} = (VS_T \cdot 365)\left[B_{0(T)} \bullet 0.67 \bullet \sum_{S,k} \frac{MCF_{S,k}}{100} \bullet AWMS_{(T,S,k)}\right]$$

where:

- VS – daily volatile solids excreted (kg DM/animal/day)
- 365 – number of days per year
- B0 – potential of methane production (m^3 CH_4/kg VS)
- 0.67 – methane conversion factor to m^3 kg
- MCF – methane formation factor (%, depending on the manure management system and climatic location)
- AWMS – proportion of the respective manure management system

kg volatile solids = [kg DMI / animal x (1.04 – DMD)] x 0.92

- VS excretion per animal was calculated on the basis of total energy consumption for each animal class (MJ) (equation based on FAO 2016). MJ were converted to DMI (dry matter intake) based on assumption 1 kg DM = 9 MJ ME on average. In this equation it is assumed that 4% of energy is attributed to urinary energy excretion, dry matter digestibility (DMD) is 63% and factor 0,92 is based on a default of 8 percent ash content of manure.
- B_o shows the maximum methane producing capacity (m^3 CH4/kg VS) and is considered 0.19 for sheep and 0.17 for beef cattle (based on IPCC 2006 default factors).
- MCF was considered 2% for solid manure (IPCC 2019).

Sheep cattle	Volatile solids (VS)/day	kg CH4/head/year
Ewe with lamb	0,72	0,67
Adult male sheep	0,54	0,50
Beef cattle	**Volatile solids (VS)/day**	**kg CH4/head/year**
Cows and other adults	4,9	4,0
Heifer	3,5	2,9
Calf	2,0	1,7

N_2O from manure management and fields

Manure

- The N_2O emissions of manure were calculated on the basis of the quantity of N emitted as the annual manure of an animal group. This was based on the „Maaeluministri 30.09.2019 määrus nr 73".
- 1% of N (solid manure) were calculated as direct N_2O emissions (based on IPCC 2016).
- Indirect N_2O accounts for 1% of NH_3-N emissions. 7.5% was calculated as the NH_3-N emissions from barns (the case of solid manure). The NH_3-N emissions of storage facilities were 20-40% from solid manure nitrogen and NH_3-N emissions from grazing were 21% from nitrogen.
- The NH_3-N emission of manure spreading was calculated as 50% of the ammoniacal nitrogen (14% for solid manure, provided that the manure is ploughed into the soil in 24 hours).

Fields

- Direct N_2O emissions account for 1% of the entire N input on fields (fertilisers used, manure, aboveground and belowground biomass remaining in soil as residue).
- Indirect N_2O accounts for 1% of NH_3-N and NOx-N emissions.
- 5% of the N of mineral fertilisers is emitted as NH_3-N and 1.2% of manure and mineral fertilisers are emitted as NOx-N.
- In order to calculate N-content in aboveground and underground biomass, the values of the Baltic Deal nutrition calculator and the IPCC 2006 guidelines were combined.

Main emission factors of inputs used in this study

Input	Emission factor	Unit	Reference
Electricity	0.98	kg CO2eq/kWh	Ecoinvent v3: Electricity, low voltage {EE}| market for | Cut-off, U
Petrol	2.76	kg CO2eq/litre	UK Government GHG Conversion Factors for Company Reporting 2020, WTT + direct emissions
Diesel	3.16	kg CO2eq/litre	UK Government GHG Conversion Factors for Company Reporting 2020, WTT + direst emissions
Concentrate feed without soy	1.75	kg CO2eq/kg	Based on composition formula of Shannak et al. 2000; emissions are calculated for each component using data from Ecoinvent, Agri-Footprint 5, World Food LCA Database and scientific papers
Concentrate feed with soy	2.58	kg CO2eq/kg	Based on composition formula of Shannak et al. 2000; emissions are calculated for each component using data from Ecoinvent, Agri-Footprint 5, World Food LCA Database and scientific papers
Cereals	0.58	kg CO2eq/kg	Agri-footprint 5: Oat grain, dried, at farm/EE Economic
Milk replacer	3.20	kg CO2eq/kg	Based on composition formula of Lee et al. 2008; emissions are calculated for each component using data from Agri-Footprint 5, World Food LCA Database and scientific papers
Mineral nitrogen	4.23	kg CO2eq/kg	EF for NPK fertilizers in Europe, World Food LCA Database
Mineral phosphorus	0.49	kg CO2eq/kg	EF for NPK fertilizers in Europe, World Food LCA Database
Mineral potassium	0.54	kg CO2eq/kg	EF for NPK fertilizers in Europe, World Food LCA Database

Results

Main characteristics of sheep farms*

Parameter	Farm 1	Farm 2	Farm 3	Farm 1	Farm 2
Farm management type	Organic	Organic	Organic	Conventional	Conventional
Total on-farm land use, hectars	34	50	73	30	32
Cropland (including temporary grasslands), ha	7.2	0	17	8	21.6
Permanent grassland, ha	27	50	42	12	7.7
Semi-natural grassland, ha	0	0	15	10	3
Average number of main herd, heads	62	59	128	75	165
Lambs per ewe	1.4	1.4	1.6	1.6	1.5
Output meat, kg CW	1150	694	3719	2476	4371

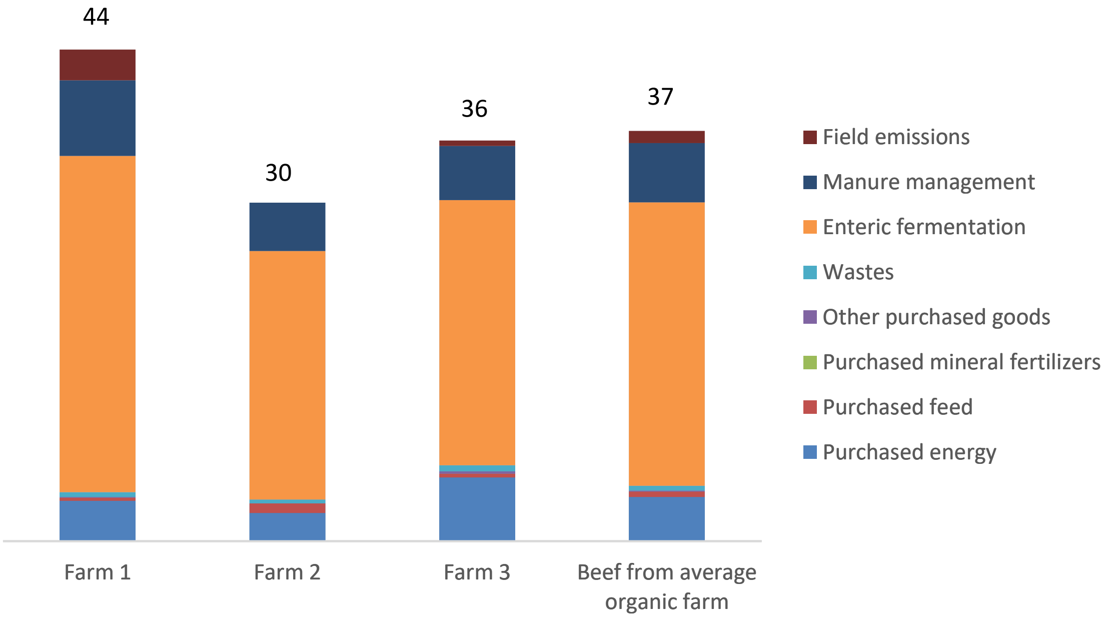
* Yearly average values

Main characteristics of beef farms*

Parameter	Farm 1	Farm 2	Farm 3	Farm 1	Farm 2	Farm 3
Farm management type	Organic	Organic	Organic	Conventional	Conventional	Conventional
Total on-farm land use, hectars	239	284	175	599	72	108
Cropland (including temporary grasslands), ha	0	0	31	293	27	56
Permanent grassland, ha	239	115	144	305	45	0
Semi-natural grassland, ha	0	169	0	0	0	51
Number of suckler cows and other adults	92	29	40	71	40	34
Output meat, kg CW	9331	7904	6923	16047	7563	4053

* Yearly average values

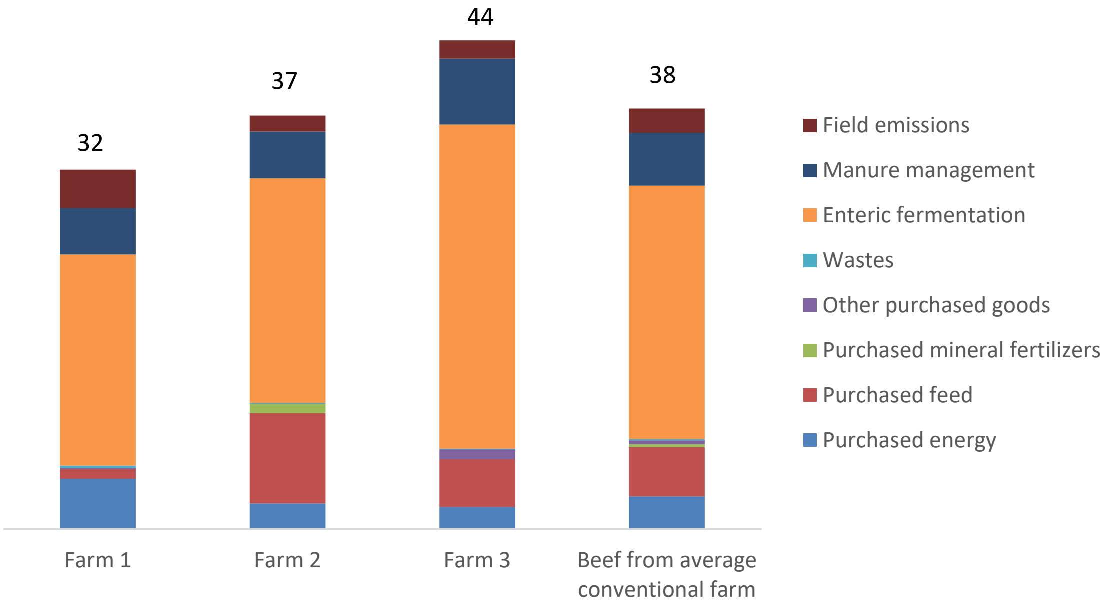
Carbon footprint of 1 kg (CW) of organic beef meat



413	**241**	**250**	**Tonne CO2eq/farm/y**

The average carbon footprint of 3 studied organic farms was 37 kg CO2eq/kg beef CW.

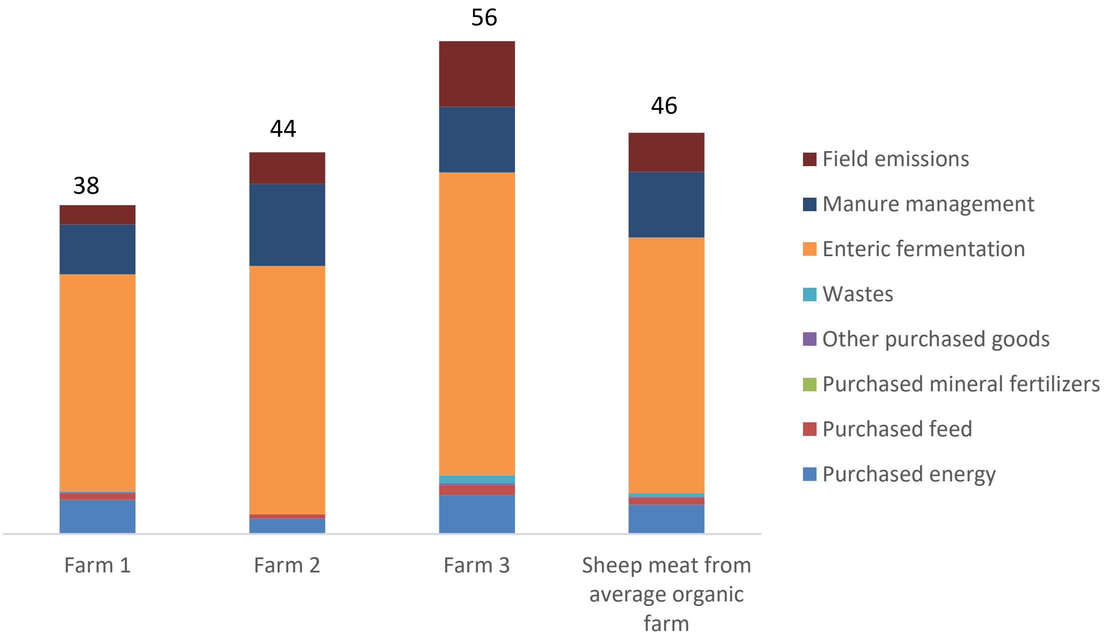
Carbon footprint of 1 kg (CW) of conventional beef meat



520	**282**	**179**	**Tonne CO_2eq/farm/y**

The average carbon footprint of 3 studied conventional farms was 38 kg CO_2eq/kg beef CW.

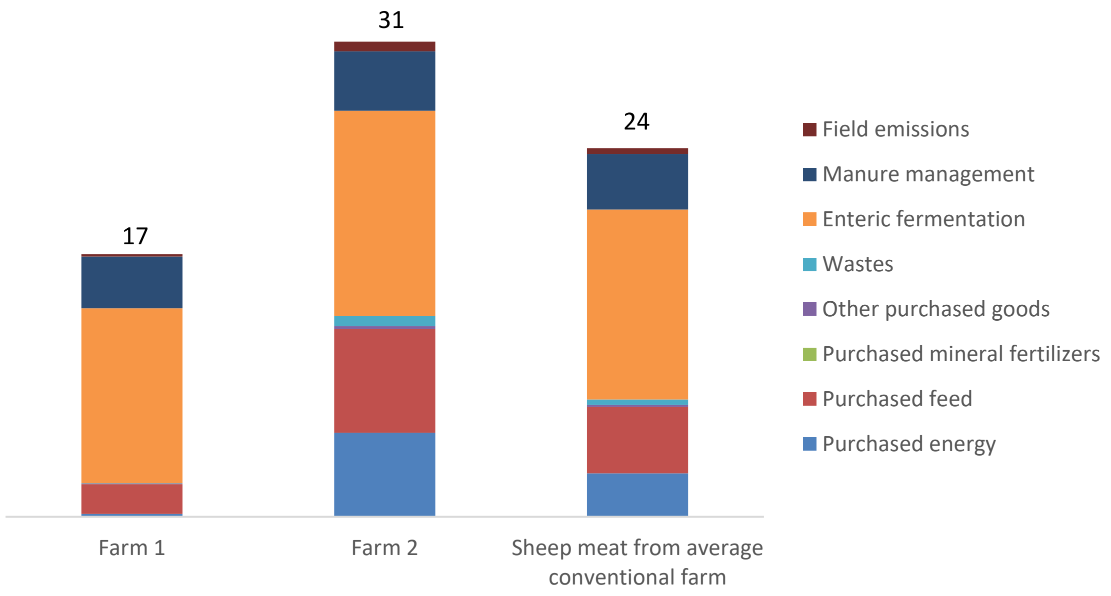
Carbon footprint of 1 kg (CW) of organic sheep meat



43	**30**	**105**	**Tonne CO_2eq/farm/y**

The average carbon footprint of 3 studied organic farms was 46 kg CO_2eq/kg sheep meat CW.

Carbon footprint of 1 kg (CW) of conventional sheep meat

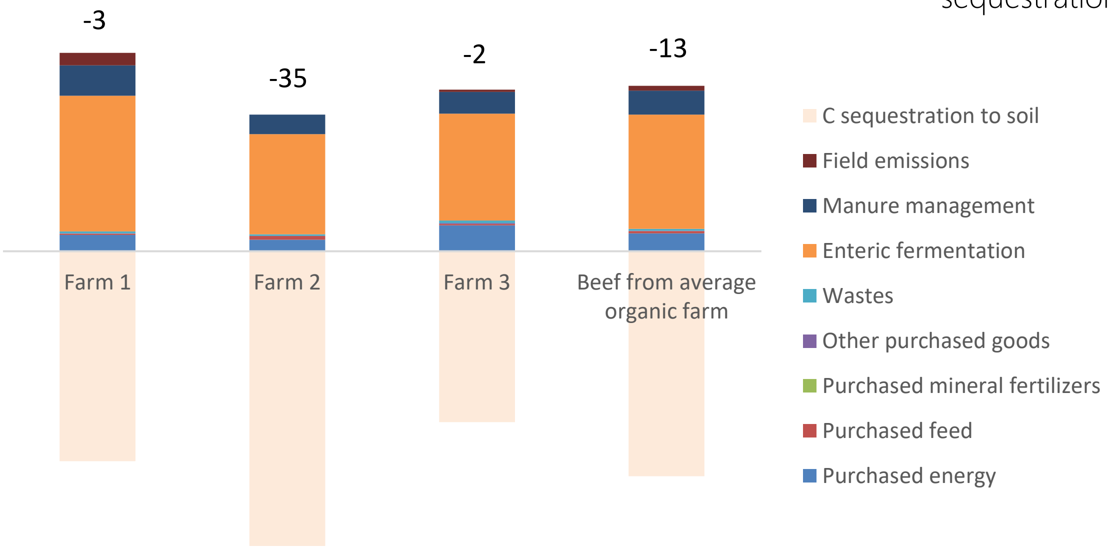


43	**136**	**Tonne CO2eq/farm/y**

The average carbon footprint of 2 studied conventional sheep farms was 24 kg CO2eq/kg CW meat. These two farms showed the biggets variation in results.

Carbon footprint of 1 kg (CW) of organic beef meat, soil carbon sequestration included

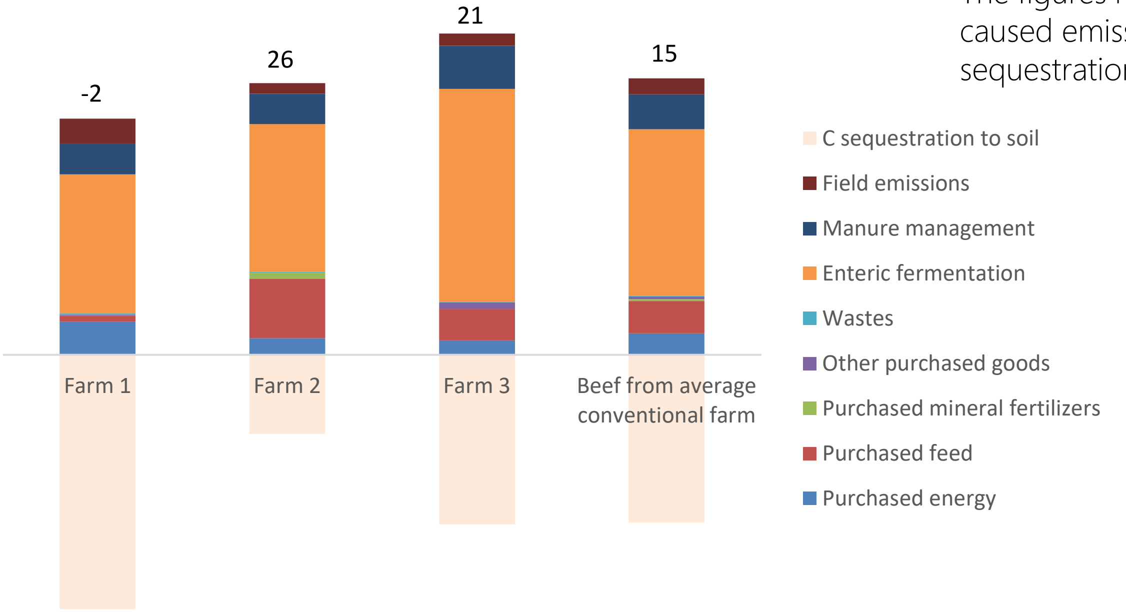
The figures represent the net result, i.e. caused emissions minus soil carbon sequestration per functional unit.



Including soil carbon sequestration, organic beef shows negative footprint, i.e. the production sequesters more carbon than emits per 1 kg of meat CW. The variations between farms are large, this is affected by the differencies in land use (the area of permanent or natural grasslands they manage).

Carbon footprint of 1 kg (CW) of conventional beef meat, soil carbon sequestration included

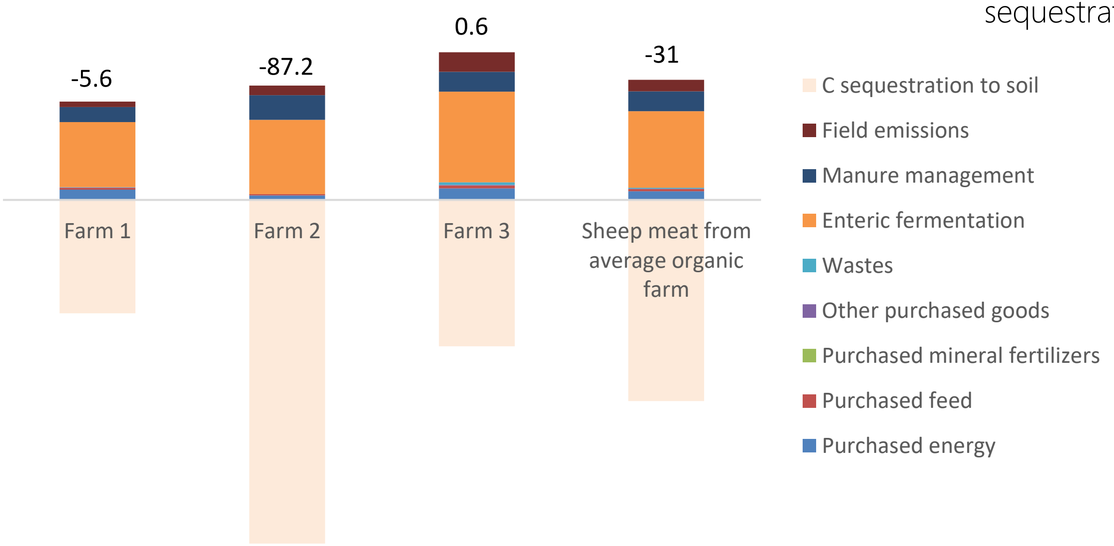
The figures represent the net result, i.e. caused emissions minus soil carbon sequestration per functional unit.



Including soil carbon sequestration, reduces the footprint of conventional beef. It may result negative footprint as well (Farm 1), i.e. the production sequesters more carbon than emits per 1 kg of meat CW. The variations between farms are large as it is affected by the differencies in land use (the area of permanent or natural grasslands they manage).

Carbon footprint of 1 kg (CW) of organic sheep meat, soil carbon sequestration included

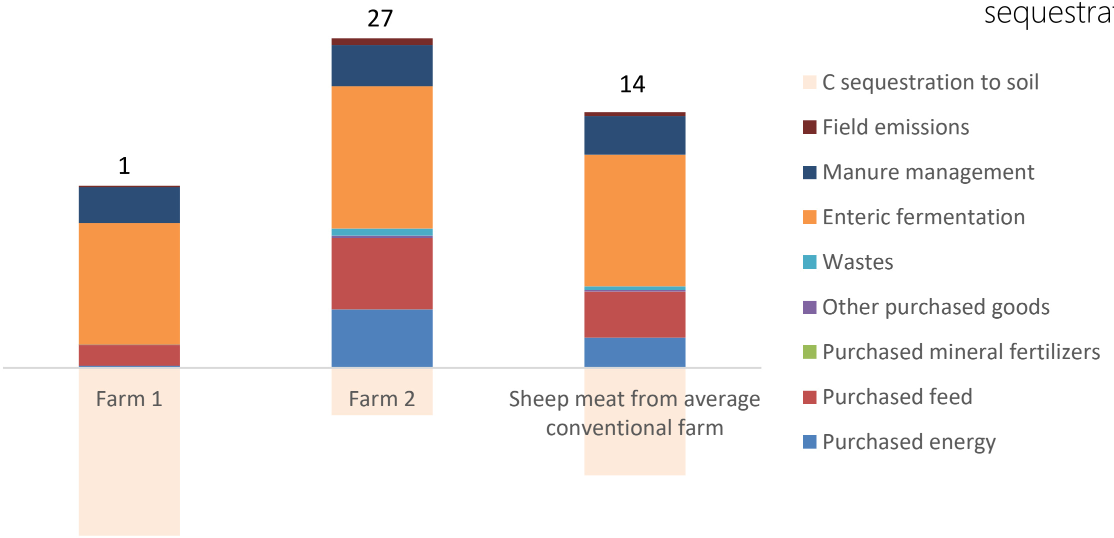
The figures represent the net result, i.e. caused emissions minus soil carbon sequestration per functional unit.



Including soil carbon sequestration reduces significantly the footprint of organic sheep meat. The variations between farms are large as it is affected by the differencies in land use (the area of permanent or natural grasslands they manage).

Carbon footprint of 1 kg (CW) of conventional sheep meat, soil carbon sequestration included

The figures represent the net result, i.e. caused emissions minus soil carbon sequestration per functional unit.



Including soil carbon sequestration reduces the footprint of conventional sheep meat. The variations between farms are large as it is affected by the differencies in land use (the area of permanent or natural grasslands they manage).

Pesticide use per kg of meat

In organic farms synthetic pesticide use is forbidden. Synthetic pesticide use was considered zero for purchased feed in organic farms as well. Conventional farms in this study were also not using pesticides on their fields and grasslands. For purchased feed in conventional farms pesticide use was quantified based on different data sources:

- Purchased mineral feeds (with soy component): 0.0008 active ingredients (ai)/kg of feed (more details available in Annex 1).
- Purchased mineral feeds (no soy included): 0.0011 kg active ingredients (ai)/kg of feed (more details available in Annex 1). Higher active ingredient amount compared to mineral feed with soy was caused by the rapeseed component.
- Purchased cereals (barley, oat): 0.0006 kg ai/kg of feed (conventional cereal production scenario based on expert assumptions (Põllumajandusuuringute keskus, 2020)).
- Purchased silage: 0.00006 kg ai/kg of silage (silage production scenario based on expert assumptions (Põllumajandusuuringute keskus, 2020)).
- Purchased hay: 0.0002 kg ai/kg of hay (hay production scenario based on expert assumptions (Põllumajandusuuringute keskus, 2020)).

In reality pesticide use at farms vary a lot. It is difficult to find average pesticide use values per crop for different production intensity levels.

Conventional sheep farms:	Conventional beef farms:
Farm 1: 0.0015 kg ai/kg of meat CW	Farm 1: 0.0003 kg ai/kg of meat CW
Farm 2: 0.0040 kg ai/kg of meat CW	Farm 2: 0.0031 kg ai/kg of meat CW
	Farm 3: 0.0033 kg ai/kg of meat CW

Main outcomes

Main outcomes

- Organic and conventional beef meat resulted in similar average carbon footprint, 37 and 38 kg CO2eq per 1 kg of meat CW respectively.
- Some examples of other studies (no carbon sequestration included): 32-34 kg CO2eq/kg beef CW in Finland (Hietala et al. 2021), 45 kg CO2eq/kg beef CW in Brazil (extensive production, Dick et al. 2014), 32 kg CO2eq/kf beef CW in UK (live weight gain is calculated to CW using factor 0.55, McAuliffe et al. 2018).
- Conventional sheep meat shows lower impact than organic (24 vs 46 kg CO2eq on average) but this is based only two farms analysed and is affected by significantly lower result of one farm.
- Some examples of other studies (no carbon sequestration included): 39 to 57 kg CO2eq/kg sheep CW in Spain (Ripoll-Bosch et al. 2011), 49 kg CO2eq/kg sheep CW as an average value for Italy, Portugal, Slovenia, Spain, Germany and Turkey (Ecolamb).
- Previous studies have mostly used lower GWP for methane (25), compared to this study which is based on current GWP for methane (28; IPCC 2013).
- Methane from enteric fermentation is the main GWP impact hotspot, contributing on average 55-64% of the total emissions for sheep meat and 60-69% of the total emissions for beef meat.
- Purchased feeds give higher contribution in conventional farms compared to organic farms.
- Pesticide use was 0.0003 – 0.0033 kg active ingredient/kg of conventional beef and 0.0015 – 0.0040 kg active ingredient/kg of conventional sheep meat. Farms in this study were not using pesticides in their fields and grasslands.
- Some studied farms have lower production output (CW meat) even compared to others with similar main herd size. This results in higher absolute impact value (as it is quantified per output unit) together with all the contributing process impacts (i.e. showing higher enteric fermentation as well).
- Including soil carbon sequestration to assessment, both organic and conventional animal farms have a potential to reduce their carbon footprint to negative value, i.e. to sequester more carbon than emit per 1 kg of meat. The sequestration varies significantly between farms, caused by the differences in land use - more hectares of permanent or natural grasslands results in higher carbon sequestration potential.

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Annex 1. Pesticide active ingredient calculation for mineral feeds

Mineral feed Components	Option 1: without soy, composition % of mineral feed	Pesticide active ingredient, kg per kg of component	Pesticide active ingredient, kg in mineral feed (without soy)	Option 2: with soy, composition % of mineral feed	Pesticide active ingredient, kg per kg of component	Pesticide active ingredient, kg in mineral feed (with soy)	Reference
Cereals	31	0,0006	0,00018	20	0,0006	0,00012	Pesticide use based on barley and oat production data (Põllumajandusuuringute keskus, 2020). This is a conventional cereal production scenario based on expert assumptions (2,63 kg/ai/ha). The amount is similar to averages in other countries, e.g. for France and Belgium the average amount assumed in LCA databases is 2 kg/ai/ha (Marinussen et al. 2012).
Molasses	3,1	-	-	3	-	-	Not available
Dried beet pulp	31	-	-	25	-	-	By-product from sugar-beet processing
Maize	0	-	-	17	0,00006	0,0000103	Pesticide use assumed based on Baltic Agro production scheme for maize: https://www.balticagro.ee/skeem; maize yield based on EU 5 year average: 7800 kg
Rapeseed	34	0,0028	0,00095	10	0,0028	0,00028	Pesticide use assumed based on Baltic Agro production scheme for rapeseed: https://www.balticagro.ee/skeem; maize yield based on EU 5 year average: 7800 kg
Soybean	0	-	-	23,4	0,0017	0,00040	1,73 kg/tonne of soybean (Pollak 2020).
Plant oil	0,5	-	-	0	-	-	Not available
Mineral-vitamin mix	0,9	-	-	1,6	-	-	Not available
TOTAL kg/ai mineral feed	100		0,0011	100		0,0008	

ai= active ingredient

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Being climate neutral is the new minimum standard for Corporate Responsibility.

SUSTINERE

Sirli Pehme