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A life cycle perspective of lamb meat production systems from Turkey and the EU

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ABSTRACT

This study assesses the environmental impacts and the life cycle costs (LCC) of various European lamb meat production systems. Primary data was collected on sheep farms in six countries: Germany, Italy, Portugal, Slovenia, Spain and Turkey. The main goal of the study was to indicate the most sustainable management form of sheep farming which is not only ecologically viable, but also economically profitable for the farmer. To that end, a life cycle analysis (LCA) and a land use analysis (LANCA®) were combined with a LCC assessment to evaluate eleven case study farms in various ecoregions with extensive, semi-extensive, semi-intensive and intensive management. The intention of the results is not only be used for the sake of scientific progress, but shall also give farm consultants, farmers and policy officials recommendations to re-design consulting approaches and plan new initiatives to make all aspects of the European sheep industry more sustainable.

The LCA analysis produced varying results for global and local impact categories: Due to lower efficiencies, the global warming potential (GWP) results showed higher emissions of extensive production systems. However, local impact categories like eutrophication potential (EP) and acidification potential (AP) as well as land use impacts indicated more positive effects of extensive sheep flocks on the surrounding flora and fauna. The LANCA® analysis revealed significantly lower influences on land use change of rather extensively practiced sheep farming in comparison to the very intensively managed ones. The LCC analysis determined a high dependency on subsidies for extensive farming. Beyond that, the local consumption preferences play an important role for the profitability, especially for traditionally managed farms.

The most significant result of this study is the development of generic LCA models on lamb meet production. Furthermore, this study puts the environmental assessment by single indicator methods (like GWP or LCA) of food production systems in general and sheep farming in particular up for discussion and promotes multidisciplinary approaches combining various aspects of sustainable farming.

1. Introduction

According to Eurostat (2019), there are 62 million sheep in Europe. Consequently, around 14 % of Europe's livestock farms work with sheep (Rossi, 2018). Most of these farms are small businesses, working in a rather traditional manner and in remote areas (Scortichini et al., 2016). Even though, lamb meat only accounts for around 1.5 % of the total meat production in Europe, the fact that most of the farming is conducted in a relatively extensive fashion has a positive effect on ecosystems and the cultural landscape in Europe (Rancourt et al., 2006). Sheep farming is sometimes practiced as part of subsistence farming, as sheep provide various types of food and wool for manufacturing cloth and carpets. Additionally, sheep tend to natural vegetation or improve soil fertility and hereby not only produce but also indirectly provide profits to their surroundings. As a result, they play an important role in the social, cultural and religious aspects of everyday life (Pollott and Wilson, 2009). These generalities about the benefits of sheep farming require further evaluation and quantification of the sustainability of sheep farming to underline the potential of sheep farming from an environmental perspective. Furthermore, sheep and lamb meat has not yet been as comprehensively assessed as other livestock farming and it is predicted that sheep farming will increase by 60 % until 2050 (Jones et al., 2014).

A suitable method for the quantification of environmental effects of

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production processes is the life cycle assessment (LCA). LCA systems were initially developed for industrial processes and not particularly for livestock farming. This circumstance and the relation of the environmental impacts to a certain amount of product, result in the conclusion that intensification and productivity enhancement decrease the environmental impacts per kg of product. (Foley et al., 2011; McClelland et al., 2018; O'Brien et al., 2016; Ripoll-Bosch et al., 2013) Since factors like animal well-being or influences on biodiversity, soil and the local surroundings are generally not considered in LCA analysis (Guinee, 2002), a point of this study is to emphasize that especially agricultural production shows impacts on various environmental categories - not only global warming - and to promote an interdisciplinary approach for more holistic sustainability assessments of livestock farming for future assessments.

As the FAO (2019) stated, 17 % of the global greenhouse gas emissions in 2018 derived from the agricultural sector. Within that, 39 % are cause by ruminants and their enteric fermentation. Furthermore, livestock manure and manure management cause 26 % of the emissions, aggregating up to 65 % of the total agricultural or 9 % of the global greenhouse gas emissions from animal farming. (FAO, 2019)

The following literature data are presented in substance equivalent per product as it is common practice in LCA and instructed in various characterization methods e.g. CML 2001 (Guinee, 2002).

The metastudy of Clune et al., 2017 on fresh food shows that the results of existing LCA studies on the global impact of greenhouse gases measured as Global Warming Potential (GWP) of lamb meat production in the EU vary considerably. A world average of 25.6 kg CO2 eq/kg meat was calculated. The EU median appears to have higher emissions per kg of meat than the world average with 32.7 kg CO_2eq/kg meat due to European farms being managed - in comparison - rather extensively. Since the allocation of secondary products and potential credits of GWP for e.g. landscape management and ecosystem services varies in the analysed studies, a large range from around 15 kg CO_2eq/kg meat up to ca. 57 kg CO_2eq/kg meat was determined. Similar ranges and tendencies have also been identified by other studies and metastudies. Nijdam et al. (2012) found an even broader range of GWP results of lamb meat production in Europe. Here the results range from 10 to 150 kg CO_2-eq/kg meat, due to an economic allocation of secondary products. A study by (Jones et al., 2014), showed a range of ca. 11–18 kg CO_2 eq/kg liveweight. Converted into kg CO_2 eq/kg meat according to Nijdam et al., 2012, this equals a range of ca. 24–39 kg CO_2 eq/kg meat.

Further, the before mentioned study by (Jones et al., 2014), stated that less CO_2 was emitted by intensively managed farms. While the possibility of lowering the GWP of animal production through intensifying the farming system are proven by several assessments (Cottle et al., 2016; Ma et al., 2018; O'Brien et al., 2016), the impact of intensification of lamb meat production on the local surroundings have not yet been quantified in a standardized manner. Grazing flocks were a decisive factor in the shaping of today's European cultural landscape. With this, species have developed that rely on these grazing flocks. Transforming this way of farming can therefore have consequences for certain species and moreover for the cultural landscape (Geß, 2021). Many existing studies address positive effects like ecosystem services, improvement of soil structure or increasing the input of organic matter into the ground (Głowacz and Niżnikowski, 2018; Khan et al., 2015; Ripoll-Bosch et al., 2013; Rodríguez-Ortega et al., 2014).

Since cost recovery is a primary goal of production, various analyses of sheep husbandry can be found. The prerequisite for efficient lamb breeding is the number of lambs born and the related productivity of the ewes. This is also the reason why the basic unit of cost accounting is €/ewe. The results for e.g. southern Germany show that 59 % of the income is generated from support payments, 34 % from the sale of lambs. The remaining 7 % are generated from the proceeds of breeding animals or other sheep products (Schmid-Boy and Scharnhölz, 2015). The amount of incurred costs and generated revenues depend on the location as insurance and medical coverage requirements, breed, size of farm and other factors influence the efficiency of a business. This study shall provide a comparison of cost and revenues of differently managed sheep farms.

Table 1
Case study farms and their management farms.

ID	Location	Grazing area [ha]	No. of ewes [-]	No. of lambs [-]	Management form
ESP1	Salamanca, Spain	0	1150	2200	Intensive
ESP3	Zamora, Spain	0	0	200	Intensive
ITA1	Grugliasco, Italy	4	45	50	Semi-Extensive
GER2	Rhön Mountains, Germany	460	800	1200	Semi-Intensive
ITA2	Piedmont, Italy	120	230 – 305	180 - 70	Semi-Intensive
ESP2	Valladolid, Spain	1150	1350	2100	Semi-Extensive
POR	Bragança, Portugal	13	99	117	Semi-Extensive
GER1	Swabian Alb, Germany	180	524	536	Extensive
SLO	Southern Slovenian Alps	221.5	31	58	Extensive
TUR1	Aksaray, Turkey	5	210	193	Extensive
TUR2	Balikesir, Turkey	2.5	30	37	Extensive
TUR3	Aydin, Turkey	5.6	150	218	Extensive

2. Case study characteristics

In the following, the outline of this study and structure of the modelling is explained. Further the applied, practical examples of actual lamb meat farms including their flock size, location and management form are presented.

2.1. Case study farms

All case study farms are categorized according to their management form: from intensive farms, that are working with larger flocks in a profit-minded manner up to extensive ones, meaning traditional ways of working and large areas for rather small flocks. The case study farms were chosen to represent various farming methods in various European eco-regions. They are listed in Table 1. It may be noted that the farm ITA2 worked with different flock sizes during summer and winter and, on the farm ESP3, only lambs were bought, raised and sold for slaughtering.

Due to a lack of data, ESP3 was not used in the LCA analysis and ESP1-3 and POR were not included in the LCC analysis.

The primary data was collected via questionnaires and interviews between 2017 and 2019.

2.2. System boundaries in the LCA analysis

Fig. 1 illustrates the system boundaries applied in this study for the LCA analysis.

The assessment comprises the production and transport of fodder (grazing, silage, concentrated feed and mineral feed) bedding material, water and fertilizer for the pastures as well as electricity and diesel, the emissions of rumination and the transport and processing of the lamb meat. The data of the life cycle inventory analysis (LCIA) was predominantly provided as primary data from the farmers. Additional data input was acquired from literature sources: the fodder demand by grazing was calculated as the basal metabolic rate of sheep in different life stages minus the nutrition input through bought fodder (Landwirtschaftskammer Nordrhein-Westfalen, 2005). Further, literature based amounts were utilized for the evaluation of manure and urine

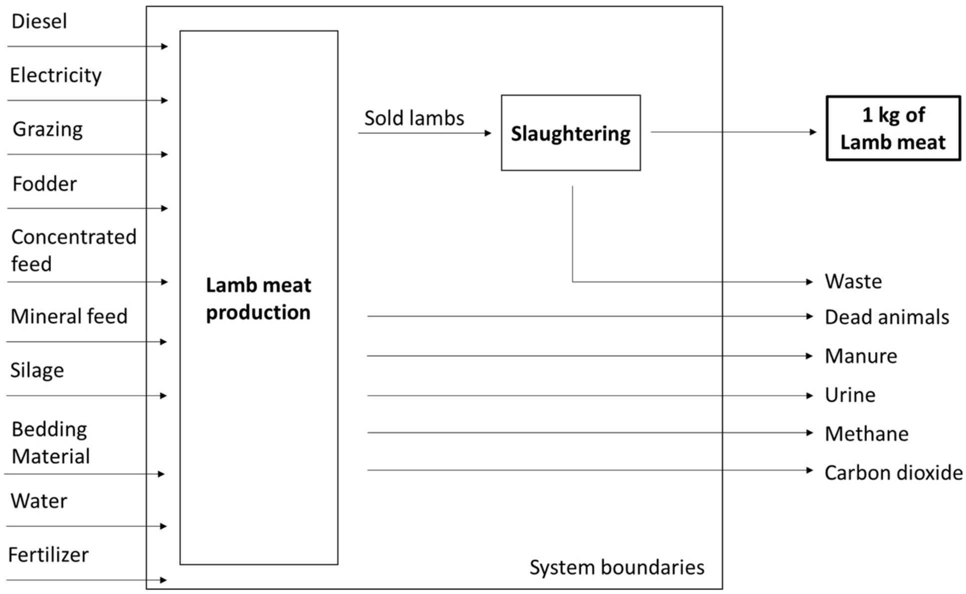

Fig. 1. System boundaries for the lamb meat production model.

emission, water demand as well as CO2 and CH4 emissions through rumination and respiration as well as the calorific value and the carbon contents of the fodder (Bollen, 1953; ECN.TNO Biomass and Energy Efficiency, 2020; Frohnmayer, 2015; Rahmann, 2013; Graves, 2022; Landwirtschaftskammer Nordrhein-Westfalen, 2005; Le Point Vétérinaire, 2012).

Since the study was aimed to assess lamb meat production systems, the functional unit of the LCA was set to 1 kg of produced lamb meat. In the LCA analysis, no secondary products like dairy products or wool were accredited. Within the model, all material outputs and production residues were put in a hypothetical waste incineration to accredit the end-of-life and account its heating value as a gain in electrical and thermal energy. Further credits were given for carbon sequestration through plant growth.

All impacts are assessed for each production process. To provide clarity and comprehensibility, the processes are clustered in the following stages of production:

1 Feed and water (concentrated feed, mineral feed, grazing, hay, silage, water)
2 Bedding material
3 Respiration and rumination (sheep husbandry, lamb husbandry, carbon balance correction)
4 Pasture maintenance (manure storage, fertilizer, machinery usage, spreading of manure through machinery, spreading of manure trough sheep, emission of urine)
5 Transports (transport to slaughterhouse, transport of fertilizer, transport of hay, transport of concentrated feed, transport of bedding material, transport of mineral feed, transport of silage, transport of dead animals)
6 Fuel demand, waste incineration (waste incineration of dead animals, waste incineration of by-products)
7 Electricity (electricity (used), electricity (generated), credit of electricity)
8 Thermal energy (credit thermal energy, thermal energy)

Further processes that were required to provide modelling continuity but didn't contain background data were summed up as auxiliary processes. Consequently, none of these cause any emissions.

3. Methodology

In this section, the applied methodologies are described. For the evaluation of environmental impacts and emission the life cycle assessment (LCA) is an established and standardized method, recommended by authorities like the EU's Joint Research Centre (JRC) and was found most fitting for product based environmental impact assessment (O'Brien et al., 2012). LANCA® was chosen since it is the method for land use assessment recommend by the product environmental footprint (PEF) guidelines (European Commission, 2018) and LCC as the cost calculation method as it also uses the life cycle thinking and therefore a similar data inventory (European Commission, 2020).

3.1. LCA

The LCA assessment is based on the approach laid out in the DIN EN ISO 14,040 and 14044. Herein, four steps are proposed for a comprehensive evaluation. First of all, goal and scope of the study are defined. Based on the goal and scope, the LCIA is conducted, in which all process stages of the production system are identified and the necessary and collectable data is gathered. Later on, the compiled primary data is completed with literature data and further information from LCA databases. In the third step, the impact assessment is carried out for the relevant impact categories. As the characterization methodology CML 2001 provides numerous impact categories (Guinee, 2002), the most relevant were chosen. In case of this study global warming potential (GWP), eutrophication potential (EP) and acidification potential (AP) are chosen, as they reflect the environmental impacts usually associated with agricultural systems (O'Brien et al., 2016). For this purpose, a LCA model of the production system including all material and energy flows is created. Lastly, the results of the impact assessment are interpreted (Deutsches Institut für Normung, 2018, 2009).

For modelling the environmental effects of the various lamb meat production systems, the GaBi Software and databases V8.7 SP40 (Sphera Solutions GmbH, 1992-2020) and herein the CML 2001 methodology including the update in 2016 developed at the Leiden University were applied. CML2001 is an impact assessment method that limits uncertainties by restricting quantitative modelling to early steps of the production process. Results are grouped in midpoint categories (Guinee, 2002).

All result are presented in relation to the same amount of product to ensure comparability, the so-called functional unit (FU), in case of this

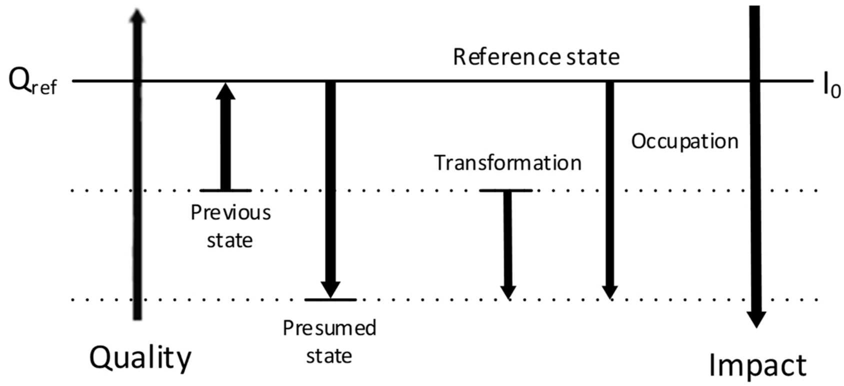

Fig. 2. Schematic illustration of transformation and occupation calculation of the LANCA® indicators (freely adapted from (Bos et al., 2016)).

study per kg of produced lamb meat.

Since it's a challenge to quantify ecosystem services, the LCA of this study also includes the impact categories eutrophication potential (EP) and acidification potential (AP). In contrast to the global impact of greenhouse gases in GWP, these two factors indicate the degree of impact of a production process or system on the direct vicinities of the production area. To give a more holistic overview on the effects of sheep farming and to add another dimension of environmental impacts, a land use analysis (LANCA®) was included. This combination of land use, local factors and GWP within a LCA of sheep farming has not been conducted in literature yet.

3.2. LANCA®

For the land use assessment the LANCA® method (Land Use Indicator Value Calculation) was applied. Herein, the effects of land use on various ecosystem services and soil quality are described. The calculations are based on geo-ecological classification systems and use site-specific input data. The method was integrated in the Product Environmental Footprint (PEF) evaluation standards (European Commission, 2018). These PEF guidelines for LANCA® (Beck, 2010; Bos et al., 2016) were applied for this study.

The methodology compares the current state of land use of the respective area with a fictitious state of the same area without human interference, since land use is locally dependent and influences vary with differing surrounding conditions (Beck, 2010). The changes in land use impact are distinguished in transformation and occupation. Transformation impacts address permanent effects caused by the respective land use, which occur after the considered land use. Occupational effects, by contrast, transpire during the time of the considered land use. The impacts are then calculate and set in to a reference quality of the assessed area (Q_{ref}) without impacts from land use (I_0). This approach is graphically shown in Fig. 2.

For modelling the reference states of each case studies, data from various soil maps and literature was used (Climate Data, 2020; Oberto et al., 2007; HLNUG, 2020; Instituto Tecnológico Agrario de Castilla y León, 2020; Ramos et al., 2017). The collected input data from the case study farms was completed with database information of the LANCA® tool (Beck, 2010; Bos et al., 2016).

The considered impact categories comprise erosion effects, here erosion resistance, filtration capacities of the soil, here mechanical and physicochemical filtration, and water permeability of the soil, here groundwater replenishment.

3.3. LCC

The costs of lamb breeding were assessed by carrying out a Life Cycle Costing (LCC) analysis. The objective of a LCC is to compare cost-effectiveness of alternative investments or businesses in a product based manner (European Commission, 2020). Here, the focus is on the production phase, meaning the growing of the lambs, and a depreciation period of equipment used for the production of lamb meat, not on the use phase of a product since the use phase would simply be the consumption of the meat and emission would vary strongly depending on preparation methods. Therefore the direct influencing factors like costs and benefits during and following the investment are decisive for the results of this LCC. For lamb meat production indirect cost as defined in LCCs (European Commission, 2015) were not accounted for, since costs to ecosystems, human health or climate change are generally not included in lamb meat pricing. Both internal and external cost factors are included. (Norris, 2001) The latter has not been considered in this analysis. Subsidies and premiums have also been left out. Only internal cost factors in the form of variable and fixed costs were considered. In addition, all costs were set in proportion to the number of ewes on each site so the unit € per ewe [€/ewe] is used. The costs and revenues considered in this study are summarized in Table 2. Investment cost are accounted for with an annual depreciation. Market and levy costs are comprised under "Others" and abattoir cost are included in "Contract work" as the slaughtering has been conducted externally on all case study farms

Table 2
Cost and Revenue assets of lamb meat production.

Revenue	Variable Costs	Fixed Costs
Sales of lambs	Fertilisers	Investment costs
Sales of ewes	Pesticides	Insurances
Sales of rams	Animal purchase	Employee wages
	Supplementary feed	Leases
	Medical care	
	Electricity	
	Water supply	
	Machine costs	
	Contract work	
	Machine rental	
	Variable wages	
	Others	

4. Results and discussion

4.1. LCA

In the following, the results of the LCA analysis are presented for the impact categories global warming potential (GWP), eutrophication potential (EP) and acidification potential (AP).

Fig. 3 and Table 3 show that the lowest GWP results are found on the extensive case study in Slovenia. In general however, the more intensively a farm is managed, the less CO2 equivalents are emitted per kg product. The low values of the case study in Slovenia derive from the

GLOBAL WARMING POTENTIAL

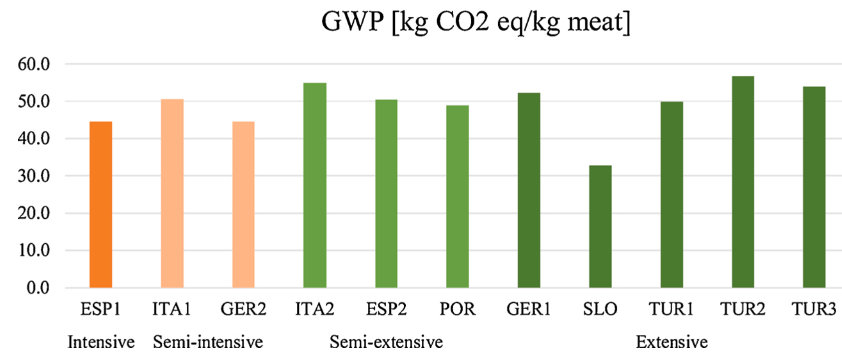

Fig. 3. Overall results of GWP assessment for the case studies categorized in the respective farm management form (orange = intensive, green = extensive).

Table 3
Results of GWP in [kg CO_2 eq/kg lamb meat] per production processes (F&W = Feed and Water, BM = Bedding Material, R&R = Respiration and Rumination, PM = Pasture maintenance, TP = Transport,FD = Fuel demand, WI = Waste Incineration, E = Electricity, TE = Thermal Energy and Aux = Auxiliary processes) and in total. All results are rounded for visual purposes.

	Inten-sive	Semi-intensive		Semi-Extensive			Extensive				
	ESP1	ITA1	GER2	ITA2	ESP2	POR	GER1	SLO	TUR1	TUR2	TUR3
F&W	−58.3	−30.7	−35.7	−25.8	−42.1	−67.3	−73.2	−67.3	−45.9	−72.2	−43.1
BM	−6.9	−0.1	−9.1	−27.0	−4.7	−7.0	−0.2	−0.3	0.0	0.0	0.0
R&R	106.3	78.2	84.5	106.1	96.5	120.7	123.8	98.1	94.5	127.9	95.6
PM	1.6	0.0	2.2	0.3	0.1	0.2	0.0	0.2	0.1	0.0	0.3
TP	0.5	0.1	0.2	0.0	0.1	0.3	0.1	0.0	0.0	0.0	0.0
FD	0.2	0.5	0.3	0.3	0.1	1.2	0.2	0.1	0.0	0.0	0.1
WI	1.6	2.0	2.1	1.0	1.1	1.5	1.8	2.2	1.1	1.4	1.0
E	−0.2	1.0	0.0	0.1	−0.5	−0.7	0.0	0.0	0.0	−0.1	0.2
TE	−0.2	−0.3	−0.1	−0.1	−0.1	−0.1	−0.3	−0.3	−0.1	−0.2	−0.1
Aux	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**44.6**	**50.6**	**44.5**	**55.0**	**50.5**	**48.8**	**52.2**	**32.8**	**49.8**	**56.8**	**53.9**

EUTROPHICATION POTENTIAL

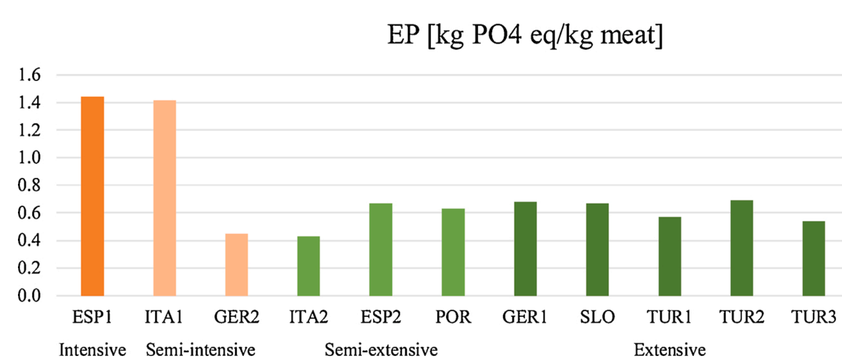

Fig. 4. Overall results of EP assessment for the case studies categorized in the respective farm management form (orange = intensive, green = extensive).

double lambing per year of the respective sheep breed and the resulting higher output of product per ewe on farm. The highest GWP results are reached in Turkey 2 and Italy 2, the two farms with the lowest lambing rates per year. This shows that the lambing rate is the most crucial factor for GWP.

In comparison to the range from literature data shown in chapter 1, the result for GWP lies in the upper spectrum of the range.

As seen in Table 3, sheep respiration and rumination are the most significant processes within lamb meat production. Since the lambs only ruminate after weaning, they emit only a fraction of the methane compared to adult sheep (Landwirtschaftskammer Nordrhein-Westfalen, 2005). As a result, the more lambs are born per ewe per year, the more lamb meat is produced per ewe and the lower the corresponding GWP is. The local differences derive from the respective fodder characteristic. Other production processes that have an influence on the result are fodder and bedding material. Since almost all of it is plant based, carbon is bound within this production step which results in negative GWP values (Sphera Solutions GmbH, 1992-2020).

EP shows a different trend than the GWP: the most intensively managed farms had the highest impacts on eutrophication. The lowest impacts on EP are found on farms like GER2 and ITA2 where an effective lambing rate is combined with sufficient grazing land, see Fig. 4. Nonetheless, extensive farms also show low impacts on eutrophication in relation to their intensive counterparts.

Table 4
Results of EP in [kg PO_4 eq/kg lamb meat] per production processes (F&W = Feed and Water, BM = Bedding Material, R&R = Respiration and Rumination, PM = Pasture maintenance, TP = Transport, FD = Fuel demand, WI = Waste Incineration, E = Electricity, TE = Thermal Energy and Aux = Auxiliary processes) and in total. All results are rounded for visual purposes.

	Inten-sive	Semi-intensive		Semi-Extensive			Extensive				
	ESP1	ITA1	GER2	ITA2	ESP2	POR	GER1	SLO	TUR1	TUR2	TUR3
F&W	4E-02	5E-02	2E-02	3E-03	2E-02	6E-02	−3E-04	1E-02	4E-02	3E-02	3E-02
BM	8E-05	8E-05	7E-03	2E-02	4E-03	6E-03	2E-04	2E-04	0E+00	0E+00	0E+00
R&R	4E-04	5E-02	4E-02	4E-02	5E-02	3E-02	3E-02	2E-02	3E-02	4E-02	3E-02
PM	1E+00	1E+00	4E-01	4E-01	7E-01	5E-01	6E-01	6E-01	5E-01	6E-01	5E-01
TP	2E-05	8E-05	2E-04	2E-05	7E-05	2E-04	5E-05	1E-05	3E-05	2E-05	2E-05
FD	7E-05	2E-04	7E-05	1E-04	4E-05	4E-04	3E-05	3E-05	6E-06	9E-07	1E-05
WI	4E-04	4E-04	4E-04	2E-04	2E-04	3E-04	4E-04	4E-04	2E-04	3E-04	2E-04
E	1E-02	3E-04	5E-06	1E-05	−9E-04	−1E-03	−2E-05	−2E-05	1E-05	−4E-05	6E-05
TE	−2E-05	−2E-05	−1E-05	−1E-05	−6E-06	−9E-06	−2E-05	−3E-05	−6E-06	−2E-05	−1E-05
Aux	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00
Total	1,44	1,42	0,45	0,43	0,76	0,63	0,68	0,67	0,57	0,69	0,54

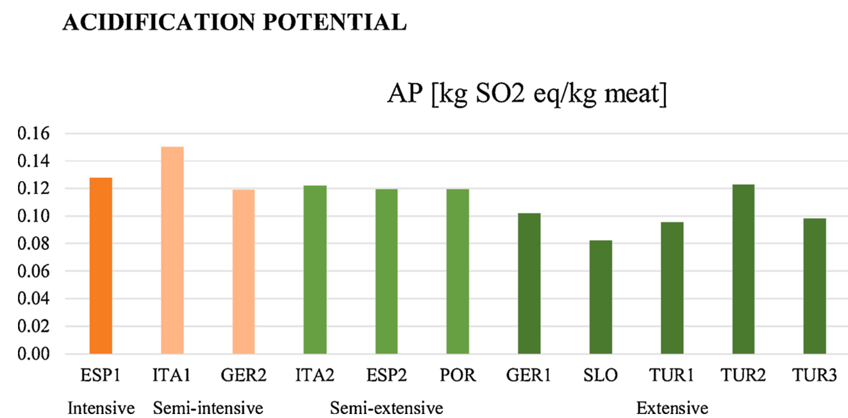

Fig. 5. Overall results of AP assessment for the case studies categorized in the respective farm management form (orange = intensive, green = extensive).

Table 5
Results of AP in [kg SO_2 eq/kg lamb meat] per production processes (F&W = Feed and Water, BM = Bedding Material, R&R = Respiration and Rumination, PM = Pasture maintenance, TP = Transport, FD = Fuel demand, WI = Waste Incineration, E = Electricity, TE = Thermal Energy and Aux = Auxiliary processes) and in total. All results are rounded for visual purposes.

	Inten-sive	Semi-intensive		Semi-Extensive			Extensive				
	ESP1	ITA1	GER2	ITA2	ESP2	POR	GER1	SLO	TUR1	TUR2	TUR3
F&W	3E-02	3E-02	2E-02	9E-03	2E-02	4E-02	2E-02	2E-02	3E-02	3E-02	2E-02
BM	5E-03	7E-05	7E-03	2E-02	3E-03	5E-03	2E-04	2E-04	0E+00	0E+00	0E+00
R&R	7E-02	1E-01	8E-02	9E-02	1E-01	7E-02	7E-02	5E-02	6E-02	9E-02	7E-02
PM	1E-02	1E-05	1E-02	3E-03	5E-04	2E-03	2E-05	1E-03	5E-04	3E-04	2E-03
TP	1E-03	3E-04	7E-04	6E-05	2E-04	8E-04	2E-04	5E-05	1E-04	6E-05	7E-05
FD	8E-04	2E-03	9E-04	1E-03	5E-04	5E-03	4E-04	4E-04	8E-05	1E-05	2E-04
WI	6E-03	7E-03	7E-03	4E-03	4E-03	5E-03	6E-03	8E-03	4E-03	5E-03	3E-03
E	−5E-04	3E-03	3E-05	2E-04	−3E-03	−5E-03	−1E-04	−1E-04	1E-04	−4E-04	6E-04
TE	−1E-04	−1E-04	−6E-05	−6E-05	−4E-05	−5E-05	−1E-04	−2E-04	−4E-05	−1E-04	−7E-05
Aux	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00
Total	0,13	0,15	0,12	0,12	0,12	0,12	0,10	0,08	0,10	0,12	0,10

The main influencing factor is the size of the grazing area per sheep. ESP1 showed the highest EP having 0 ha of grazing area per sheep, farms with larger grazing areas like GER2 or ITA2 show the lowest EP (see also Table 1). The greatest impact on eutrophication was observed in the process of pasture maintenance, see Table 4. Here, the emission of urine and manure are included, which are a natural source of nutrients. A larger area per sheep can take up more nutrients and therefore reduces the EP. In contrast to rumination, young lambs also emit urine and manure. Therefore, the rate of lambs per ewe per year has less impact on EP than on GWP.

This gives an explanation of the higher EP of the intensively managed farms.

The analysis shows that AP – just like EP a local impact factor – also has a similar profile as EP, but with smaller differences between the management forms, see Fig. 5 and Table 5. The more intensively managed farms reach a higher impact potential than the extensive farms. The Slovenian case study achieved the lowest impact on acidification per kg of meat produced, hence it can be concluded that the proportion of lambs per ewe per year also has an impact on the AP, although less than on the GWP.

Other extensive farms showed low APs, which leads to the conclusion that a smaller grazing area per sheep results in higher APs, which is true for rather intensively managed farms. The combination of these two effects explains the smaller differences per management form compared

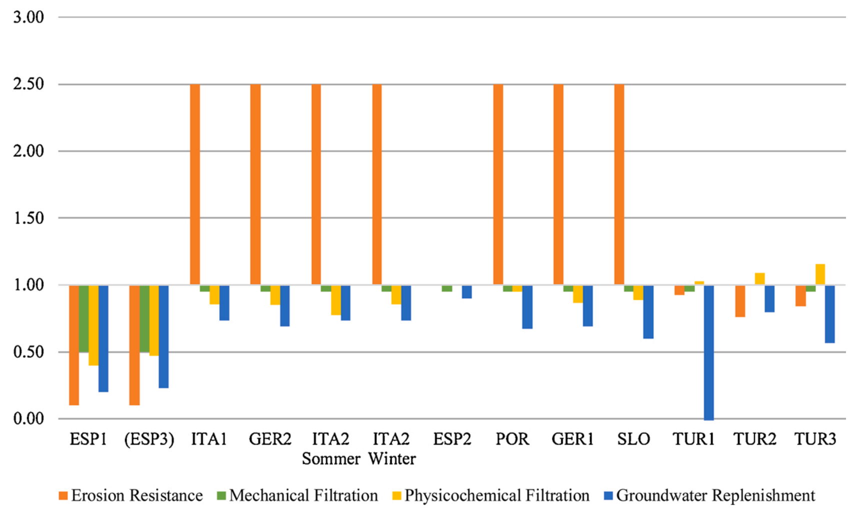

Fig. 6. Factors of land use change in the various impact categories of the LANCA® analysis.

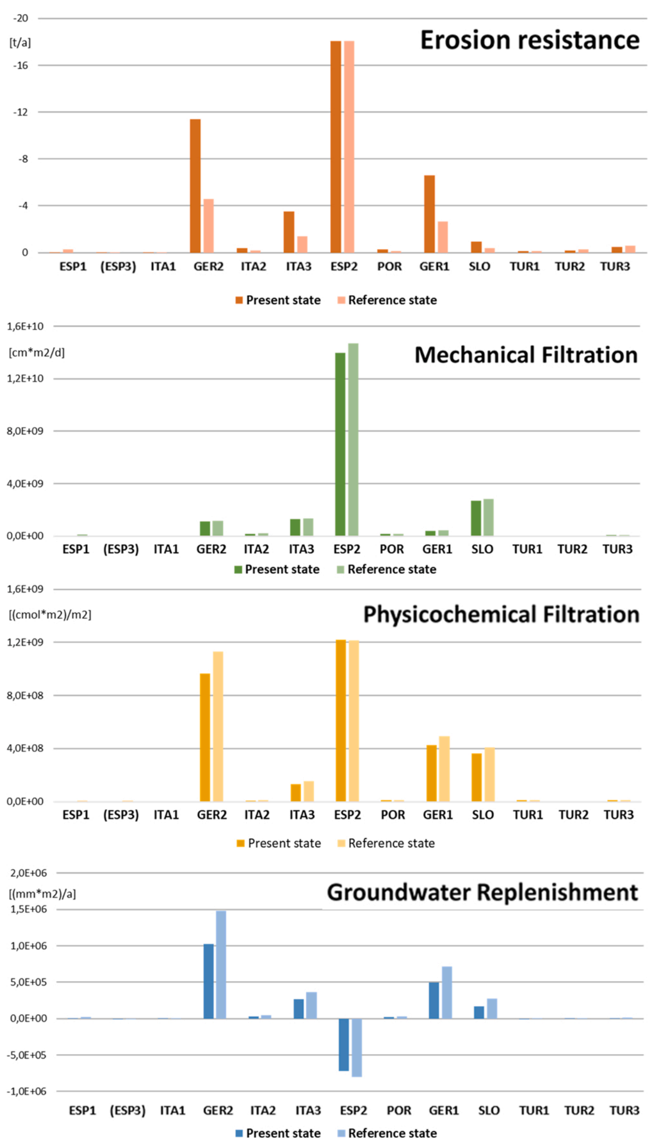

Fig. 7. Results for the LANCA® impact categories Erosion Resistance, Mechanical Filtration, Phisicochemical Filtration and Groundwater Replenishment.

to the differences found in GWP and EP.

In all case studies, respiration and rumination are responsible for about three quarters of the total impact values, see Table 5. Feed and water has the second biggest share. The rest of the production process have negligible influences on AP. It may be noted, that the Portuguese case study received AP credit for energy provision and therefore reached a negative AP in this step of the production.

4.2. LANCA®

Fig. 6 gives an overview of the change in each impact category that is caused by the land use of sheep farming. In this diagram, a value of 1 resembles no change, a value > 1 indicates increase and a factor < 1 decrease. The exception is the impact category “Erosion Resistance”, which is, by its nature, given in negative values. Here, the diagram is to be read the other way around: a value > 1 indicates decrease and a factor < 1 increase, while a value of 1 resembles no change.

The strong decrease in erosion resistance at most western European case studies is explained by the respective reference state: a broad-leafed forest, which has a higher resistance against erosion than plain pasture. The more intensive forms of lamb meat production, however, show an increase in Erosion Resistance. Here, due to the construction of stables, the soil is sealed and natural erosion is inhibited. For the arid sites, meaning the three farms in Turkey and ESP2, the reference state is already grassland, so the change here is negligible.

Both mechanical and physicochemical filtration appear to be little affected by extensive sheep farming. For the two intensive farms, however a decrease of around 50 % can be observed. This again is due to soil sealing and the subsequent hindrance of run-off and filtration.

Considering Groundwater Replenishment, intensive farms have a higher impact than the non-intensive ones. Nevertheless, the highest change in Groundwater Replenishment was measured at TUR1, where more water is drawn from the ground than is replenished. Since the other two Turkish case study farms work at similar conditions and with similar management forms and do not show this tendency, this can be lead back to a local occurrence.

The results in numbers for all case study farms are presented in Fig. 7. All results of the present state with the respective sheep farming form on site are to be seen in relation to the hypothetical reference state of the same site without any land use.

4.3. LCC

The LCC results are illustrated in Fig. 8. Exact figures can be taken from Table 6. It should be noted that there was insufficient data for ESP1

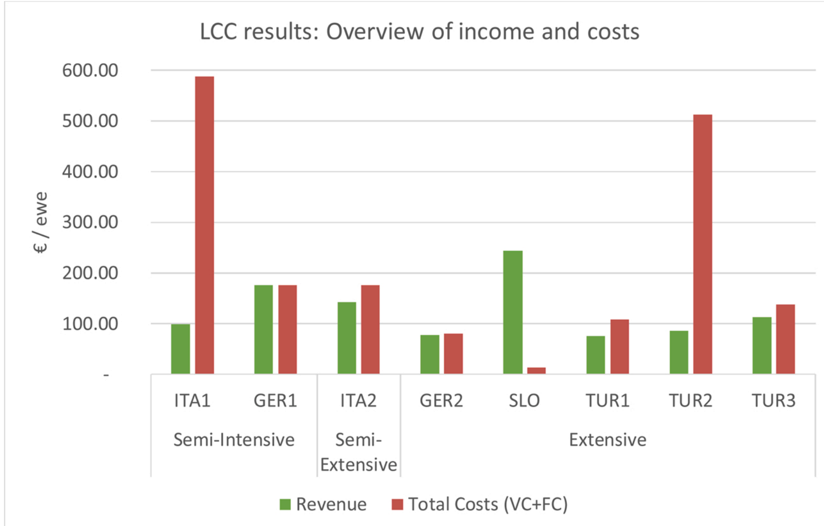

Fig. 8. LCC results for Revenue, Total Costs and Total Value in [€/ewe] (VC = Variable Costs, FC = Fixed Costs, FV = Flock Value).

Table 6
LCC results of all case study farms.

	Unit	Semi-intensive		Semi- Extensive	Extensive				
Location		ITA1	GER2	ITA2	GER1	SLO	TUR1	TUR2	TUR3
Revenue	€/ewe	98.3	175.6	142.4	77.3	243.7	75.5	85.7	112.4
VC[1]	€/ewe	262.8	49.7	74.8	39.1	12.8	87.6	148.2	91.9
FC[2]	€/ewe	324.8	125.8	100.7	41.1	0.0	21.0	364.7	46.4
Earnings	€/ewe	−489.3	0.1	−33.1	−2.9	230.9	−33.1	−427.1	−25.9

[1]Variable Costs.
[2]Fixed Costs.

and ESP3 which is why they were excluded from the results. Therefore, no results could be generated for intensively operated farms. As can be seen, the Slovenian site generated the highest revenue of all (243.2 €/ewe). This is due to two factors. Firstly, the ewes have a high lambing efficiency, giving birth twice a year. Secondly, the lamb meat price was the highest compared to the other countries (5.5 €/kg). The lowest income was found for TUR1 with 75.5 €/ewe. Both locations run an extensive business. The median revenue across all locations analysed was 105.4 €/ewe. It can be stated that the sole consideration of the revenue figures does not allow a clear evaluation of the different production processes. The cost factors must be considered in addition.

For the variable costs (VC) the semi-intensive farm ITA1 showed a significant higher amount than all other sites (262.8 €/ewe). This results from the fact that the farm is mainly used for research and therefore has higher additional feed costs, as well as a higher demand for medical care and water consumption. TUR2 also showed a high level of variable costs (148.7 €/ewe). The decisive factors were the same as for ITA1. However, the median with 81.2 €/ewe was clearly below these cost levels. The lowest variable costs were found in the Slovenian case study with only 12.8 €/ewe. Here, external medical treatment and the purchase of supplementary food was avoided to save money.

The fixed costs (FC) result show that TUR2 and ITA1 had the highest costs. Here, the wages for the employed shepherds were crucial. At the Slovenian farm, on the other hand, there were no fixed costs at all, as neither insurance nor lease had to be paid. Furthermore, according to the data collection, no stable investment costs incur in this case study farm.

Overall, the results lead to the conclusion that only SLO and GER2 can cover their costs. All other locations generate losses.

5. Conclusion and outlook

In this study, a new LCA model for the evaluation of various lamb meat production systems was developed, which now can be adapted and applied on sheep farms in Europe and Turkey.

In comparison to literature results, the analysis found relatively high values for GWP with a tendency of intensive farms having a lower impact than extensive ones. For EP and AP intensive farms showed the highest impacts. Semi-extensive and semi-intensive farms with a well-managed pasture system or extensive systems with a high breeding rate appear to be the most reasonable form of farming. The case study farm with the lowest GWP, SLO, is considered an exception, due to the high lambing rates of its sheep breed despite being extensively managed. For the LANCA® assessment, it can be stated that results and the conducted recommendations strongly depend on the reference system. Generally, the results of the land use analysis shows the lowest impacts for extensive farming systems.

To improve the validity of the sustainability analysis of livestock farming, the fundamental importance to the health of the surrounding ecosystems should be accounted for in the analysis. Extensive grazing and the emitted animal excreta are a major source of nutrients for the soil, contribute to the improvement of the soil structure by increasing its organic matter content, and hereby maintaining an adequate plant cover. Further, animal welfare and the meat quality are missing in the evaluation. However, an overview on land use change through sheep farming is given in this first evaluation.

The analysis of internal cost factors has shown that conclusions about profitability cannot necessarily be drawn on the basis of production conditions. However, the LCC indicated that lamb meat production itself is hardly profitable. Other sources of income are therefore crucial for the farmers. This might be the production of secondary products like wool or dairy or, for rather extensively managed farms, subsidies for landscape management services. These revenues are not accounted for in this study. Furthermore, other external factors could change the outcome. The ewes' and rams' life expectancy was not considered, which varies between the different ways of production. Ewes on extensive farms live twice as long at 10–12 years as on intensive producing farms (Aaron and Ely, 2014). Similar rules seem to apply for the ram's life expectancy. They reach a lifespan of 4–6 years in extensive and semi-extensive farms (Yalçın, 1986). As it is recommended to make use of breeding rams between 2.5–7 years of age, lower life spans can be assumed for intensive, respectively semi-intensive conditions. This leads to the conclusion that the investment costs for the flock under extensive production conditions are lower in the long term.

To improve the assessment, the analysis of more farms from different ecoregions is recommended as well the collection of primary data on soil, meteorological characteristics and emissions from respiration, rumination and nutrition.

To conclude, LCA, LANCA® and LCC are only parts of a holistic assessment of the sustainability of sheep farming. The now popular CO_2 emission analysis paints a contrary picture of the public opinion and the results of the other assessment methods of extensive farming being the most eco-friendly way of working. It is therefore recommended to combine these three approaches with a biodiversity impact analysis, an animal welfare assessment and a meat quality analysis.

Authors statement

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

Declaration of Competing Interest

The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript.

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References

Aaron, D.K., Ely, D.G., 2014. An Introduction to Sheep. Agriculture and Natural Resources Publications.

Beck, T., 2010. LANCA: Land Use Indicator Value Calculation in Life Cycle Assessment. Fraunhofer-Verl., Stuttgart, p. 71.

Bollen, W.B., 1953. Mulches and soil conditioners, carbon and nitrogen in farm and forest products. J. Agric. Food Chem. 1, 379–381. https://doi.org/10.1021/jf60005a004.

Bos, U., Horn, R., Beck, T., Lindner, J.P., Fischer, M., 2016. LANCA - Characterization Factors for Life Cycle Impact Assessment: Version 2.0. Fraunhofer Verlag, Stuttgart, p. 164.

Climate Data, 2020. Klimadaten für Städte weltweit (Accessed 7 December 2020). https://de.climate-data.org/.

Clune, S., Crossin, E., Verghese, K., 2017. Systematic review of greenhouse gas emissions for different fresh food categories. J. Clean. Prod. 140, 766–783. https://doi.org/10.1016/j.jclepro.2016.04.082.

Cottle, D.J., Harrison, M.T., Ghahramani, A., 2016. Sheep greenhouse gas emission intensities under different management practices, climate zones and enterprise types. Anim. Prod. Sci. 56, 507. https://doi.org/10.1071/AN15327.

Deutsches Institut für Normung, 2009. DIN EN ISO 14040:2009-11, Umweltmanagement_- Ökobilanz_- Grundsätze und Rahmenbedingungen (ISO_14040:2006); Deutsche und Englische Fassung EN_ISO_14040:2006. https://doi.org/10.31030/1555059.

Deutsches Institut für Normung, 2018. DIN EN ISO 14044:2018-05, Umweltmanagement_- Ökobilanz_- Anforderungen und Anleitungen (ISO_14044:2006_+ Amd_1:2017); Deutsche Fassung EN_ISO_14044:2006_+ A1:2018. https://doi.org/10.31030/2761237.

ECN.TNO Biomass & Energy Efficiency, 2020. Phyllis2 - Database for the Physico-Chemical Composition of (treated) Lignocellulosic Biomass, Micro- and Macroalgae, Various Feedstocks for Biogas Production and Biochar. https://phyllis.nl/.

European Commission, 2015. Life Cycle Cost (LCC) Calculation Tool (Accessed 10 September 2021).

European Commission, 2018. Product Environmental Footprint Category Rules Guidance.

European Commission, 2020. Life Cycle Costing - GPP - Environment - European Commission. https://ec.europa.eu/environment/gpp/lcc.htm.

Eurostat, 2019. Agricultural Production - Livestock and Meat - Statistics Explained. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agricultural_production_-_livestock_and_meat&oldid=470510#Meat_production.

FAO, 2019. Emissions Due to Agriculture: Global, Regional and Country Trends, 2000–2018.

Foley, P.A., Crosson, P., Lovett, D.K., Boland, T.M., O'Mara, F.P., Kenny, D.A., 2011. Whole-farm systems modelling of greenhouse gas emissions from pastoral suckler beef cow production systems. Agric. Ecosyst. Environ. 142, 222–230. https://doi.org/10.1016/j.agee.2011.05.010.

Frohnmayer, S.C., 2015. Betriebsanalyse zu Produktionskennzahlen und Lämmerverlusten in baden-württembergischen Schäfereien.

Geß, A., 2021. Biodiversity impact assessment of grazing sheep. In: Albrecht, S., Fischer, M., Leistner, P., Schebek, L. (Eds.), Progress in Life Cycle Assessment 2019, 1st ed. Springer International Publishing, Cham, pp. 227–239.

Głowacz, K., Niżnikowski, R., 2018. The effect of animal grazing on vegetation and soil and element cycling in nature. Environ. Sci. Pollut. Res. Int. 25, 3565–3570. https://doi.org/10.1007/s11356-017-0740-5.

Graves, R.E. Waste Management: Managing Sheep and Goat Manure. Pennsylvania State University. http://goatconnection.com/articles/publish/article_85.shtml (Accessed 11 December 2020).

Guinee, J.B., 2002. Handbook on life cycle assessment operational guide to the ISO standards. Int. J. Life Cycle Assess. 7 https://doi.org/10.1007/BF02978897.

HLNUG, 2020. Fachinformationssystem Boden (FISBO): Bodenarten des Feinbodens in Form eines hierarchischen Schlüssels (Accessed 7 December 2020). https://www.hlnug.de/static/medien/boden/fisbo/bodenviewer/hilfe/30427_FEINBOD.html.

Instituto Tecnológico Agrario de Castilla y León, 2020. Visor de datos - Portal de Suelos - ITACyL Portal Web (Accessed 7 December 2020). http://suelos.itacyl.es/visor_datos.

Jones, A.K., Jones, D.L., Cross, P., 2014. The carbon footprint of lamb: sources of variation and opportunities for mitigation. Agric. Syst. 123, 97–107. https://doi.org/10.1016/j.agsy.2013.09.006.

Khan, Z.I., Ahmad, K., Ashraf, M., Naqvi, S.A.H., Seidavi, A., Akram, N.A., Laudadio, V., Tufarelli, V., 2015. Evaluating pasture and soil allowance of manganese for Kajli rams grazing in semi-arid environment. Trop. Anim. Health Prod. 47, 563–566. https://doi.org/10.1007/s11250-015-0763-1.

Landwirtschaftskammer Nordrhein-Westfalen, 2005. Futterwerttabellen für Schafe (Accessed 2019). https://www.landwirtschaftskammer.de/.

Le Point Vétérinaire, 2012. Mouton. Fiches pense-bête poules étudiants, p. 2 (Accessed 7 December 2020). https://www.lepointveterinaire.fr/upload/media/fiches_pense_bete/Mouton.pdf.

Ma, L., Zhong, M., Zhu, Y., Yang, H., Johnson, D.A., Rong, Y., 2018. Annual methane budgets of sheep grazing systems were regulated by grazing intensities in the temperate continental steppe: a two-year case study. Atmos. Environ. 174, 66–75. https://doi.org/10.1016/j.atmosenv.2017.11.024.

McClelland, S.C., Arndt, C., Gordon, D.R., Thoma, G., 2018. Type and number of environmental impact categories used in livestock life cycle assessment: a systematic review. Livest. Sci. 209, 39–45. https://doi.org/10.1016/j.livsci.2018.01.008.

Nijdam, D., Rood, T., Westhoek, H., 2012. The price of protein: review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy 37, 760–770. https://doi.org/10.1016/j.foodpol.2012.08.002.

Norris, G.A., 2001. Integrating life cycle cost analysis and LCA. Int. J. Life Cycle Assess. 6, 118–120. https://doi.org/10.1007/BF02977849.

O'Brien, D., Shalloo, L., Patton, J., Buckley, F., Grainger, C., Wallace, M., 2012. Evaluation of the effect of accounting method, IPCC v. LCA, on grass-based and confinement dairy systems' greenhouse gas emissions. Animal 6, 1512–1527. https://doi.org/10.1017/S1751731112000316.

O'Brien, D., Bohan, A., McHugh, N., Shalloo, L., 2016. A life cycle assessment of the effect of intensification on the environmental impacts and resource use of grass-based sheep farming. Agric. Syst. 148, 95–104. https://doi.org/10.1016/j.agsy.2016.07.004.

Oberto, E., Canzano, A., Falcone, G., Bonifacio, E., 2007. Charatteristiche del suolo.

Pollott, G., Wilson, R.T., 2009. Sheep and Goats for Diverse Products and Profits, p. 42.

Rahmann, Gerold, 2013. Ökologische Schaf- und Ziegenhaltung, p. 265.

Ramos, T.B., Horta, A., Gonçalves, M.C., Pires, F.P., Duffy, D., Martins, J.C., 2017. The INFOSOLO Database as a First Step Towards the Development of a Soil Information System in Portugal.

Rancourt, Mde, Fois, N., Lavín, M.P., Tchakérian, E., Vallerand, F., 2006. Mediterranean sheep and goats production: an uncertain future. Small Rumin. Res. 62, 167–179. https://doi.org/10.1016/j.smallrumres.2005.08.012.
Ripoll-Bosch, R., de Boer, I., Bernués, A., Vellinga, T.V., 2013. Accounting for multi-functionality of sheep farming in the carbon footprint of lamb: a comparison of three contrasting Mediterranean systems. Agric. Syst. 116, 60–68. https://doi.org/10.1016/j.agsy.2012.11.002.
Rodríguez-Ortega, T., Oteros-Rozas, E., Ripoll-Bosch, R., Tichit, M., Martín-López, B., Bernués, A., 2014. Applying the ecosystem services framework to pasture-based livestock farming systems in Europe. Animal 8, 1361–1372. https://doi.org/10.1017/S1751731114000421.
Rossi, R., 2018. The Future of the EU's Sheep and Goat Sector: Main Features, Challenges and Prospects.
Schmid-Boy, S., Scharnhölz, A., 2015. Schafreport Baden-Württemberg 2015 (Accessed 11 December 2020). https://docplayer.org/67808527-Schafreport-baden-wuerttemberg-2015.htm.
Scortichini, G., Amorena, M., Brambilla, G., Ceci, R., Chessa, G., Diletti, G., Esposito, M., Esposito, V., Nardelli, V., 2016. Sheep farming and the impact of environment on food safety. Small Rumin. Res. 135, 66–74. https://doi.org/10.1016/j.smallrumres.2015.12.013.
Sphera Solutions GmbH, 2020. GaBi Software-System and Database for the Life Cycle Engineering. Leinfelden-Echterdingen (DE), Leinfelden-Echterdingen (DE).
Yalçın, B.C., 1986. Sheep and Goats in Turkey. Food and Agriculture Organization of the United Nations, Rome, p. 168 xiii.