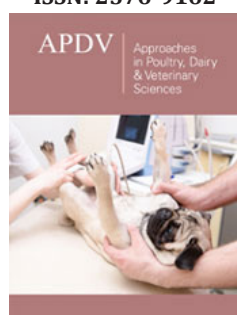


Review of Life Cycle Assessment in Environmental Performances of the House-Feed Sheep

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Abstract

Life cycle assessment is widely used to assess the environmental impact of the sheep industry. This paper sorts out some common methods of LCA application in the sheep industry and summarizes the environmental performance and hot spots of house-feed sheep. Literature review shows that most scholars use the systematic boundary of “from cradle to farm gate”, and the selection of functional units and distribution methods is similar. Most studies focus on carbon footprint, and its sources are mainly enteric fermentation, manure management and feed production. The GHG emissions range from 10.0 to 20.0kg CO₂-eq per kg live weight for meat sheep, and 2.0 to 3.0kg CO₂-eq per kg FPCM for dairy sheep. Other environmental categories have also been evaluated such as acidification, eutrophication and terrestrial ecotoxicity. The release of ammonia from fertilizer and manure and the loss of nitrate and phosphorus caused by fertilization are the main sources of acidification and eutrophication, respectively. Compared with grazing, the carbon footprint of the house-feed sheep system is lower, but it has a great impact on acidification and eutrophication. More research needs to be conducted to put forward potential mitigation schemes, such as the benefits of carbon sequestration and improvement of production efficiency

Keywords: House-feed sheep; Life cycle assessment; Environmental performance; Carbon footprint

Introduction

Sheep play an important social and economic role in developing countries. Thanks to sheep's breeding advantages, they can easily adapt to various production conditions, whether it is an extensive production system or an intensive production system. In the past few decades, the market trade of sheep products such as meat, wool, sheep's milk and sheep's cheese has been continuously expanded, which has brought sustained economic benefits to farmers [1,2]. Besides, a wide range of sheep breeding pattern can also have a positive impact on the ecosystem and cultural landscape [3]. While sheep breeding is accompanied by various environmental impacts, the first of which is climate change. As stated by FAO, the current gas emissions from animal husbandry are an important source of global non-carbon dioxide greenhouse gas emissions, among which sheep account for nearly half of the greenhouse gas emissions from small ruminant products [4].

Life Cycle Assessment (LCA), particularly as governed by ISO standards 14040 and 14044, is a method used to evaluate the environmental impact of products or services in the whole life process from cradle to grave. With the continuous development and improvement of the methodology system, LCA has also been widely used in the animal husbandry industry in the agricultural field, to assess greenhouse gas emissions and other potential environmental impacts related to animal husbandry products, and to reveal environmental hot spots. It has become a tool to support the continuous improvement of farm environmental management. Many studies have shown that intensification and improvement of production efficiency can reduce greenhouse gas emissions per functional unit product [5-8]. Bhatt & Abbassi

[9] reviewed environmental performance of sheep farming using life cycle assessment found that the impact results are difficult to generalize due to wide discrepancies in farming practices, production efficiencies, product allocation and emission modeling methods.

In this paper, the application of LCA in the production of house-fed sheep was reviewed, and different works of literature about the environmental performance of house-fed sheep breeding were sorted out, including not only the emission of greenhouse gases but also the impacts of other environmental categories, so as to provide some reference for improving the environmental performance of intensive sheep production system.

Purpose

First of all, from the goal of LCA, the research of LCA can be roughly divided into two categories. One is to evaluate the environmental burden of the selected sheep production system. Mondello et al. [10] used LCA to evaluate the environmental performance of “Pecorino” sheep cheese produced by intensive sheep. The second kind is to compare the emission intensity of sheep products in different regions [11,12] and the environmental burden of sheep production systems with different management modes. Ripoll-Bosch et al. [8] used LCA to compare the greenhouse gas emissions of three sheep production systems with different intensification degrees in Spain;

Batalla et al. [13] compared the differences in the carbon footprint of three different sheep milk production systems before and after incorporating soil carbon sequestration into carbon footprint; O'Brien et al. [7] compared various farm system types, so as to evaluate the impact of intensification on various environmental impacts and resource utilization of sheep breeding.

System Boundary

Ideally, the system boundary of LCA is “from cradle to grave”. However, for most agricultural and livestock products, the system boundary setting is basically “from cradle to farm gate”, that is, from the acquisition of raw materials to the sale of livestock products from the farm. Impacts associated with the production of farm inputs (e.g. feed, fertilizer, fuel, electricity, etc), management of inputs (e.g. emissions from storing manure) and direct emissions from livestock are included in cradle-to-farmgate system boundaries. As is typical in LCA studies, the production of machinery and building was not included in the analysis. Some studies in this review expanded the boundary beyond the farmgate. Mondello et al. [10] considered the transportation outside the farm gate and the impact of material input needed to process sheep's milk into cheese. Geß et al. [14] expanded the system boundaries to slaughterhouse to include the transport and processing of lamb meat. While, we computed the environmental impacts based on “from cradle to farm gate” in those two studies (Table 1).

Table 1: Summaries of studies on life cycle assessment in environmental performance of house-feed sheep

Studies	Country ^a	Purpose	Number of Farms [#]	Products (Functional Unit)	GHG Emission Model	Main Environmental Performance, per FU
Mondello et al. [10]*	IT	To evaluate “Pecorino” sheep milk and cheese environmental burden	1(modeled)	Milk (1kg fresh milk)	IPCC Tier 1	Climate change: 3.35kg CO ₂ -eq Marine eutrophication: 21.1g N eq Terrestrial ecotoxicity: 5.3g 1,4-DB eq
Batalla et al. [13]	ES	To estimate the carbon footprint of sheep milk from different farming system with carbon sequestration	2	Milk (1kg FPCM)	IPCC Tier 2	Climate change: Before C sequestration: 2.29kg CO ₂ -eq After C sequestration: 2.43kg CO ₂ -eq
Ripoll-Bosch et al. [8]	ES	To compare three sheep farming systems environmental burden	1(modeled)	Meat (1kg LW)	GLEAM (IPCC Tier 2)	Climate change : 19.5 kg CO ₂ -eq
O'Brien et al. [7]	IE	To assess the effect of intensification on environmental burden	167(modeled)	Meat (1kg LW)	IPCC Tier 2	Climate change: 10.2kg CO ₂ -eq Terrestrial eutrophication: 46.3g PO ₄ -eq Fresh water acidification: : 92.4g SO ₂ -eq
Geß et al. [14]\$	ES	LCA and land use analysis combined to evaluate different farming system environmental burden	1	Meat (1kg LW)	IPCC Tier 2	Climate change : 22.3kg CO ₂ -eq Terrestrial eutrophication: 0.72kg PO ₄ -eq Fresh water acidification: 65.0g SO ₂ -eq

Note: ^athe housing farm country in the study; [#]the number of housing farms or intensive farms in the study;

*The products and main environmental performance were calculated based on the study data; \$the products and main environmental performance were calculated based on the study data and literature data [8].

Function Unit

The purpose of selecting the functional unit is to link the main function of LCA in evaluating the sheep production system with the environmental impact produced by the system, so the functional unit of LCA evaluation is to allocate the environmental impact to each unit of sheep products for measurement. In the sheep production system, sheep milk products often use fat and protein-corrected milk per kilogram (FPCM) as functional units, and some use energy-corrected milk per kilogram (ECM) as functional units. Meat products usually use live weight as the functional unit. While Geß et al. [14] set 1kg producing lamb meat and Mondello et al. [10] set 1kg Pecorino cheese as the function unit. We used 1kg live weight and 1kg fresh milk as the function units for those two studies based on “from cradle to farm gate” system boundary in this review. Besides using sheep products as functional units, some scholars also use the land area occupied by sheep production as the second functional unit. O’Brien et al. [7] not only used the weight of the sold sheep as the functional unit but also linked the local environmental impact (such as eutrophication) with the occupied

farmland area, and used the land-occupied area of the farm as the functional unit. McAuliffe et al. [15] used the nutrient content of meat to replace the mass of meat as the functional unit, with cattle systems outperforming pig and poultry systems in some cases.

Because the sheep production system will produce a variety of co-products, it is necessary to use some method to distribute the environmental impact caused by the whole sheep production system to different products. Economic value and biophysical allocation are the most commonly used methods of agricultural LCA. The most popular form is to distribute a larger share of environmental impact to co-products that generate higher income according to economic value distribution [16]. Biophysical allocation refers to the distribution of co-products according to biological criteria such as protein content or product quality, energy content and product protein quality [17]. As sheep products are made of protein, and their quality can be measured by their protein content to some extent, the environmental impact can be distributed by the proportion of absorbed protein required by each co-product (Figure 1).

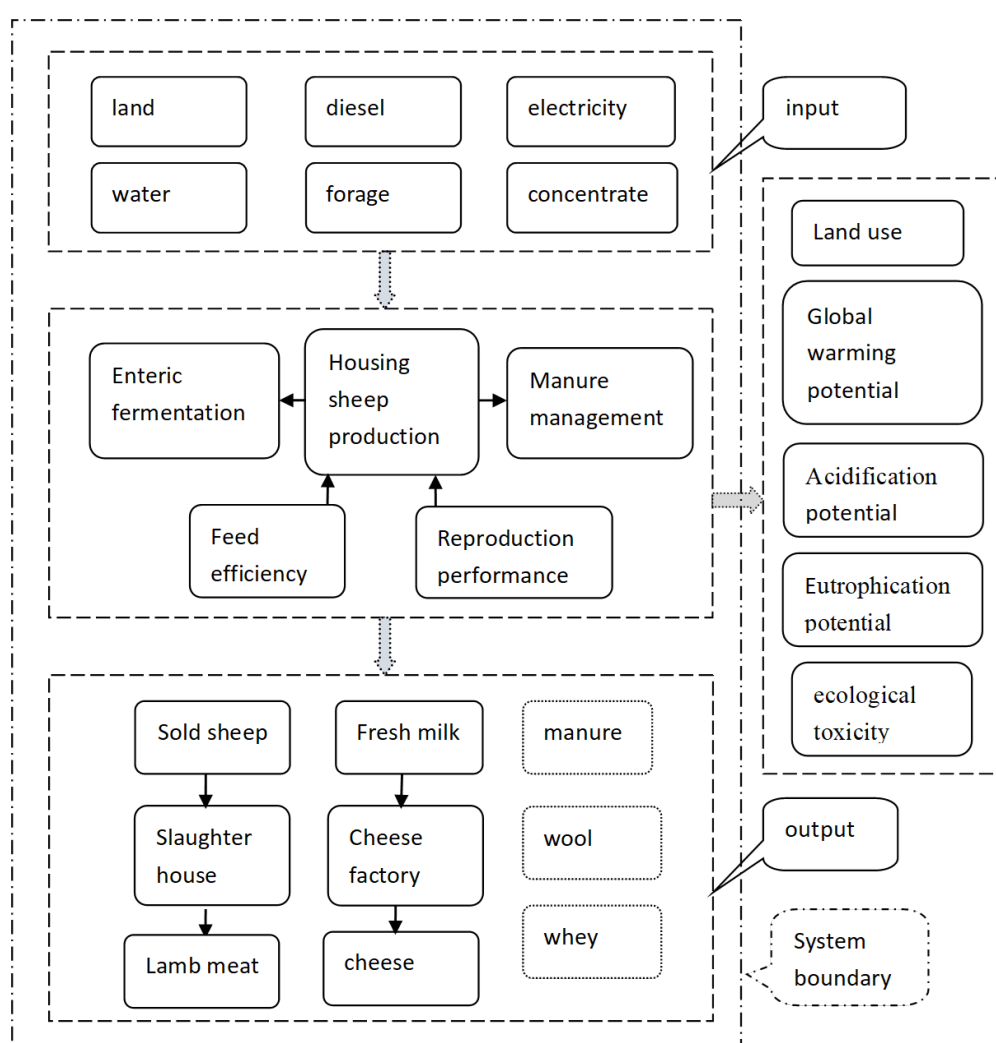


Figure 1: The system boundary of LCA in the environmental performance of house feed sheep.

Inventory Analysis

Inventory analysis is a basic data arrangement within the boundary of the LCA system. Firstly, according to the determined research purpose and scope, the inventory data of resource and energy consumption and waste discharge of each link of the studied system are listed, so as to quantify the relevant input and output in the product system. In the next data collection, the data to be collected can be divided into two categories, namely foreground data and background data. Generally speaking, the foreground data are usually collected from farmers on the farm through field research [18], and can also be obtained through online published literature; background data is usually obtained based on LCA-related database. At present, the commonly used LCA databases mainly include Ecoinvent in Switzerland, ELCD in the European Union and Gabi in Germany. Most studies utilized GHG emission model created by the Intergovernmental Panel on Climate Change (IPCC), and the methodology used to estimate them is defined in detail in IPCC [19]. Tier 1 method involves using pre-defined emissions factors listed (in units of kg CH₄/head/y) based on livestock species, region and productivity system. Tier 2 method involves using country-specific climatic data and animal feed intake amounts to determine more accurate, regional emission factors. After data collection, based on the production of each functional unit product, different types of data obtained are characterized, standardized and weighted normalized, to eventually obtain input and output list of each functional unit product.

Environmental Impact Assessment

The most common environmental impact category considered in each study is climate change or carbon footprint. Almost all scholars will quantitatively measure the environmental performance of sheep breeding by greenhouse gas emissions. The GHG emissions range from 10.0 to 20.0kg CO₂-eq per kg live weight for meat sheep, and 2.0 to 3.0kg CO₂-eq per kg FPCM for dairy sheep. The emission intensity varied because of difference in climate, specialization in production, the emission model, selection of function unit and allocation method. In addition, some life cycle assessments discussed various environmental impacts of sheep breeding. For example, O'Brien et al. [7] evaluated the acidification and eutrophication on sheep farms in the Irish sheep production system. Mondello et al. [10] studied the environmental burden of "Pecorino" sheep cheese production, by assessing the climate change, and, marine eutrophication and terrestrial ecotoxicity. Geß et al. [14] evaluated the environmental impacts of different lamb meat production systems, including intensive production systems, and evaluated the Global Warming Potential (GWP), Eutrophication Potential (EP) and Acidification Potential (AP).

Hot Spot Analysis

As far as environmental hotspots are concerned, the biggest contributor to greenhouse gas emissions is the CH₄ emissions produced by sheep enteric fermentation and manure management. Most studies found that the emissions of CH₄ and N₂O decrease with the production system increase in intensity. O'Brien et al. [7] found

that the carbon footprint was mainly methane emission from sheep intestines, CH₄ and N₂O emission from manure, and N₂O emission from artificial fertilizer. Ripoll-Bosch et al. [8] showed that when only meat production is considered in greenhouse gas emission, the greenhouse gas value of pasture system is the highest, and that of the zero-grazing system is the lowest. Geß et al. [14] and Ma et al. [20] also showed similar results that compared with extensive farms, intensive farms have lower greenhouse gas emissions, but they have a greater impact on eutrophication and acidification. The release of ammonia from fertilizer and manure and the loss of nitrate and phosphorus caused by fertilization were the main sources of acidification and eutrophication, respectively. When marine eutrophication and terrestrial ecological toxicity were assessed, the environmental hot spots were only related to feed production in sheep breeding. Batalla et al. [13] showed that for intensive farms with indoor farming and no pasture management when soil carbon sequestration is not considered, the carbon footprint of intensive farms is significantly lower than that of other sheep production systems with different grazing degrees, and the purchased feed is the biggest contributor to the total greenhouse gas emissions.

Future Perspective

It is well known that GHG emission intensity for sheep products tend to be higher in developing regions such as East & Southeast Asia, and Northwest Africa. This difference is due to variations in reproductive efficiency, feed quality, and management practices that are generally poorer in developing regions [12]. Methanic emissions from manure are also slightly higher in Asia and Africa due to higher average temperatures. The more complex emission models, such as GLEAM have recognized the role that climatic zones of different regions can play in parameters such as manure methane conversion factor and feed digestibility which can drastically change the overall GHG emissions [10]. It is important to establish regional emission factor system or model based on different sheep production system. This emission system or model could also benefit for mitigation strategy or policy making.

The ultimate goal of sheep production system is to offset its own carbon dioxide or greenhouse gas emissions through afforestation, energy conservation and emission reduction and other forms and achieve relative "Zero Emissions". As well as enhancing soil quality and food security, estimates of the total potential of C sequestration in world soils vary widely from a low of 0.4 to 0.6Gt C/year to a high of 0.6 to 1.2Gt C/year [21-23], with cropland contributing the most. The achievable SOC sequestration potential in global grasslands is 0.6 to 2.0Gt C/year for biodiversity restoration, 40 to 190Mt C/year for improved grazing management, and 40Mt C/year for sown legumes in pasturelands. In addition to C sequestration, animal based agrivoltaics, which is the co-development of land for both Solar Photovoltaic (PV) electrical production and animal product is a rapidly growing field throughout the world [24-26]. Andrew et al. [27] investigated the environmental performance of sheep-based agrivoltaic systems through life cycle analysis, found that agrivoltaic systems are superior to conventional ground-mounted PV systems

because they have dual purposes and reduce the environmental impacts associated with producing food and electricity. At both the regional and global scales, large uncertainties exist regarding the projected soil carbon sequestration or agrivoltaic systems potential and rate of accrual. Scientific research and management innovations are required in the future to maximize the C neutrality [28-30].

Conclusion

This review focuses on the main steps of LCA, and sorts out some common methods and conclusions of LCA application in the housing sheep industry. Each sheep product is similar in the setting of system boundaries, the selection of functional units and distribution methods. Most greenhouse gas emissions mainly come from enteric fermentation, manure management and feed production. The emissions of CH₄ and N₂O decrease with the increase of intensive degree. In addition to carbon footprint, this review also summarizes some other environmental impact assessment studies, covering acidification, eutrophication, terrestrial ecological toxicity and other impact categories. Contrary to the carbon footprint, intensive farms have a greater impact on the environment of acidification and eutrophication. More research needs to be conducted, such as the benefits of carbon sequestration and establishment of regional emission factor system, to put forward potential improvement schemes that may reduce the environmental impact of house-feed sheep.

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