Ontario Sheep Industry
Desired Outcomes &
Potential Areas for Investigation

Spring 2019

Ontario Sheep Farmers (OSF)
Desired Research Outcomes
&
Potential Areas for Investigation

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Background

On June 14th, 2018 Ontario Sheep Farmers (OSF) together with The Livestock Research Innovation Corporation (LRIC) held a sheep industry research priorities elicitation day. (See appendix 1 for report)

Participants were invited to discuss what they felt are important issues in the sheep industry that could be addressed through research investment by OSF. Participants were asked to make their research priorities as specific as possible.

Ranking	Research Area
1	*Benchmarking/Cost of Production/C3omposite industry data*
2	**Parasites**
3	**Lamb mortality**
4	*Market traits – carcass quality characteristics*
5	*KTT/communications*
6	**Environmental impact/sustainability**
7	**Efficacy trials and diagnostic tests**
7	**Feed efficiency**
7	**Grazing – agronomic factors**
7	*High health status programs*
8	**AMR/AMU, alternatives, gut health**

Ranking 1, 4, 5 and 7 (*italicized and not highlighted*) were considered important but post-meeting discussions revealed there is considerable information already available on these topics which is not currently being used or taken advantage of by producers and/or the topics did not have an applicable novel research question. It is recommended that the industry review the current KTT/extension efforts to identify how they can more effectively meet producer interest in these topics.

The remaining priorities were separated into three overarching areas of interest; Environment, Nutrition and Health. Teleconferences were held with small groups of producers, researchers, Ontario Ministry of Agriculture Food and Rural Affairs (OMAFRA) personnel and members of the sheep industry to further understand and develop research outcomes and directions in each of the areas. The outcomes below combine the information from the meetings and can be used to inform OSF and OMAFRA investment in sheep research.

Research Outcomes

1 - Environment

Outcome:

Ontario sheep production positively impacts the natural environment

Background:

OSF has completed a life cycle analysis (Appendix 2) of sheep production in Ontario.

The value of wool production research.

Wool contains more than 50% pure atmospheric derived organic carbon. One kilogram of wool can be converted to 1.8kg of CO^2 (IWTO 2014) making wool a more environmentally sustainable clothing option than synthetics and a method of carbon sequestration directly derived from carbon in pastures, not from fossil fuels.

Concern over microplastics in the environment is increasing due to the negative impact of marine wildlife ingesting them and their persistence and tendency to aggregate in our environment. One of the largest and most relevant sources of microplastics are synthetic textiles such as nylon, acrylic and polyester which are widely used in clothing.

The manufacturing of clothing is becoming a more important concern as alothing made from synthetic textiles is produced using chemicals and synthetic polymers, and the processes involved in its manufacture are not environmentally friendly.

Wool is a natural substitute for synthetics and as it relates to Corporate Social Responsibility a highly palatable regarded alternative.

Value of sheep to the ecosystem

The ecosystem benefits of livestock grazing include maintaining species rich habitats through limiting aggressive species and removing grass and plants gradually and giving more mobile species a chance to spread. The effect of trampling and grazing can also allow for the creation of niche areas in which new species have the chance to compete with the more aggressive ones. Maintaining sustainable grazing with a suitable stocking density is ideal for the maintenance of wildlife habitats.

When sheep ingest plant based carbon and convert it to meat, leather and wool, that carbon particularly in the case of leather and wool is potentially stored for long periods of time. These are all positive research findings.

There is of course, research that contests the assertion that sheep are beneficial for the environment in which they graze.

If we are to grow the Ontario sheep industry, research is needed under typical Ontario conditions to validate that the findings from other studies as per the examples above, can be repeated here in

Ontario. The aim is to demonstrate that the immediate environmental impact of managed grazing of sheep, particularly on marginal land, is insignificant and when the potential to replace synthetic fibres with wool is taken into account, actually leads to positive environmental outcomes.

Potential area(s) for investigation:

- A literature review of existing data to determine its applicability to sheep production, the landscapes and climatic conditions in Ontario
- Identifying methods for improving whole farm water use efficiency
- Determine the cost and environmental benefits of wool as a replacement for synthetic fibers.

2 - Nutrition

Outcome:

The economics of various feeding strategies for sheep and lambs in Ontario are available to and useful for producers

Background:

In Ontario, a wide variety of feeding methods are employed when raising sheep. These vary from seasonal rotational grazing to complete TMR systems. Research is required to give producers the tools/knowledge to improve their cost efficiency, through understanding the advantages and drawbacks of non-traditional feed sources used within a grazing rotation and/or a TMR regime. Considerations should include the identification and availability of alternative feed sources, feeding methods and options which could include the length of grazing period. All research should also determine the economics and cost efficiency of the systems.

Potential area(s) for investigation:

- Could winter wheat or rye be grazed with a minimal impact and/or improvement to the crop yield?
- The impact of dietary ingredients on meat quality
- Options and methods for forage and grass grazing during drought conditions
- Assessment of feed sources and their impact on the gut microbiome

3 - Nutrition & Health

Outcome:
A measurable decline in on-farm lamb mortality and morbidity compared with that which was reported in the OMAFRA (Appendix 3) report of 2010.

Background:
The determinants of maternal and lamb immunity are multi-factorial with many inter-related components and factors that impact offspring mortality and morbidity.

Potential area(s) for investigation:

- Maternal Nutrition: Identify nutritional strategies that will reduce variations and optimize ewe body condition score in accelerated rearing systems
- Vaccinating ewes to reduce mortality and morbidity of lambs
- Assessment of passive immunity and the factors that determine its efficacy
- The development of water-based delivery options for nutraceuticals and alternatives to antimicrobials within the various production systems (This work could be linked to identifying methods for improving whole farm water use efficiency)
- Nutritional/gut health management to help guide antimicrobial use (AMU) decisions
- Efficacy of immunobiotics including immune stimulants and/or probiotics
- The relationship between genetics and lamb mortality and morbidity

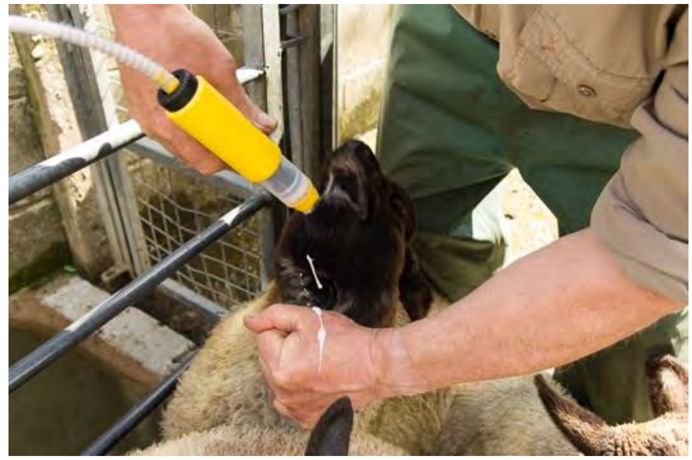
4 - Health Management

Outcome:
Producers have access to the information they need to make appropriate management decisions that will positively impact flock health within their individual farm system context.

Background:
With the huge diversity in Ontario production systems, an understanding of the various methods, impacts and costs, will provide information to determine the management systems most appropriate for the conditions and context in which sheep are being produced.
The implementation of contextualized management systems will result in an overall improvement in animal health and welfare.

Potential area(s) for investigation:

- Cost effective tests for identification of parasite loads
- Methods including grazing systems to improve control of parasites
- Management and nutritional methods to manage gastrointestinal parasitism
- Selecting sheep that are better able to manage parasite infections
- Investigate ability to have the CARLA saliva test administered in Ontario without needing to ship samples to New Zealand
- Housing system design to help control of bacterial infections
- Air quality/ventilation systems for improved manure management in housed flocks



Secondary issues for the industry to consider

Non-Research:

- OMAFRA should support an Ontario wide survey to record the different pasture management systems and other feeding options being practiced for sheep production in the Province. Industry and researchers need to be included in the survey design to optimize the questions in order to obtain relevant, useful data.
- All groups identified management as the critical component of rearing sheep and that the need for education and teaching is critical. It was noted that research into the best way to accelerate behavioural change would be beneficial.

Research:

- GenOvis incorporates phenotype data but needs to go further. Research (not just in Ontario) is needed to validate phenotype and genotype data relationships for incorporation into the GenOvis database.
- There is a lack of registered pharma products that are available to sheep farmers. Rated highly, is the need for continuing access to research resources to prescribe off-label products for sheep and to be able to determine withdrawal times. CgFARAD research was considered to be of vital importance to the industry.

Appendix 1 Sheep Research Day Summary Report

Sheep Industry Research Day

Guelph

Monday, June 4, 2018

MEETING SUMMARY

Sheep Industry Research Day
Meeting Summary

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Sheep Industry Research Day Meeting Summary

1. Meeting Discussion Summary

The Livestock Research Innovation Corporation (LRIC) in conjunction with Ontario Sheep Farmers organized a meeting to discuss sheep research in Ontario on June 4, 2018 in Guelph. Invitations were extended to a broad cross-section of sheep industry stakeholders including producers, veterinarians, research and academia, government staff and OSF representatives. The objectives of the meeting were:

- to discuss issues and challenges relating to the provision of sheep research in Ontario, and
- to identify the top research priorities with a focus on a five to 10-year objective.

There were 37 meeting attendees including the facilitator and meeting organizers divided into groups of six to eight for the discussion segments. The list of participants is included in section 9 of this report.

Tim Nelson, CEO of LRIC, opened the meeting with an overview of research priority setting followed by Jennifer MacTavish who provided highlights of Ontario sheep research. A copy of Jennifer's presentation is included in section 10. This report focuses on the content of the facilitated discussions.

Meeting attendees were provided with a worksheet and asked to record their personal thoughts for each topic in addition to the open group discussion comments. While verbally submitted comments were recorded on a flip chart and also on sticky notes posted on the walls during the meeting, it is recognized that not all comments and ideas end up being shared in open discussions. Twenty-seven completed worksheets were received at the end of the meeting. A compilation of the feedback is included in section 7.

There were four segments to the facilitated portion of the meeting:

- Part 1 – Identifying Top Barriers for the Ontario Sheep Industry
- Part 2 – Strengths and Weaknesses Related to Sheep Research in Ontario
- Part 3 – Priorities for Research
- Part 4 – Ranking Research Priorities

Top Barriers for the Ontario Sheep Industry

The attendees were asked to consider what is limiting or restricting the Ontario sheep sector from reaching its potential. This did not have to be related to research per se. They spent a few minutes recording their opinions on their personal recording sheets followed by 10 minutes sharing within their table group. Based on the contributions during the open discussion (section 2) and the personal worksheets summary (section 6), the most significant barriers, in no particular order, are:

- **Education/Knowledge and Retaining Producers** – There is a high turnover rate of new entrants which may be due to a lack of easily accessible production and management information. The same is true for producers who want to optimize their production and/or expand; there is insufficient knowledge transfer whether from more knowledgeable producers or industry experts.

- **Cost of Production** – The cost of production in Ontario is high: land costs, feed costs, labour shortage and labour per unit produced.

- **Access to Quality Animals and Low Number of Sheep Overall** – There is not enough sheep to meet Ontario market demand for lamb and a lack of quality breeding stock to support expansion
- **Market/Price Uncertainty -** The market price is unpredictable and inconsistent.
- **Inconsistent Product and Lamb Availability** – There is an inconsistent supply of lamb (seasonal lambing cycles and not enough producers) and also inconsistent carcass quality. The latter is exacerbated by the disconnect between price and quality, i.e. good quality lamb does not necessarily bring a premium price and lower quality carcasses still find a market.
- **Benchmarking and Record Keeping** - Lack of benchmark data and good record keeping to improve genetics and overall business viability
- **Limited Access to Registered Medications and Vaccines**
- **Animal Health Challenges –** Examples include lamb mortality, parasites, pneumonia

Strengths and Weaknesses Related to Sheep Research in Ontario

Meeting participants were asked to spend five minutes considering what is limiting or restricting sheep research in Ontario and jot down their thoughts on their personal recording sheet. Another five minutes were spent sharing within groups and then the facilitator went around the room, taking one item from each table and recording on the flip chart until submissions were exhausted. Section 3 of this report provides the complete list of items recorded during the full group discussion and section 6 documents the feedback received from the personal recording sheets. The comments can be summarized into four basic issues:

1. **Funding** – Limited financial resources was seen as a definite weakness for sheep research in Ontario. The topic was linked to multiple contributions from the open discussion and was the most cited item on the personal recording sheets for this question. The sheep sector is a small industry with limited funds however it is also a very diverse sector with many breeds and production systems. It is challenging to determine how best to allocate available funds whether a few, larger projects or more but smaller, short-term projects. In addition, government research programs and funding windows are sometimes quite narrow.
2. **Knowledge Transfer** – It was felt that uptake by producers of research results has not been as great as desired. This could be due to researchers not adequately communicating the direct applicability of the results or producers not having the correct tools to utilize the research, e.g. time, equipment, dedicated staff or money.
3. **Collaboration** – There were multiple contributions from the group relating to collaboration whether between producers and researchers or amongst researchers from different disciplines (goats, dairy, wool, environment, etc.). The goals would be to better leverage funds, potentially

access new sources of funding, and increase awareness and understanding amongst groups of research objectives.

4. **Research Vision and Goals** – The benefit, and perceived lack, of a common research vision and goals was more heavily noted on the personal recording sheets than during the open discussion.

Priorities for Research

The groups were then asked to discuss amongst themselves what they felt are the more important issues in the sheep industry that could benefit from research. The facilitator emphasized that the key point was the issues identified had to be able to be connected to a research question.

Participants were urged to make their research priority as specific as possible and to write down one topic per sticky note. These notes were collected and grouped under the following 10 categories:

- **Animal Health** – e.g. lamb mortality, pneumonia
- **Animal Welfare** – e.g. ventilation, docking
- **Nutrition** – e.g. alternative feeds, feed efficiency, grazing
- **Reproduction and Production** – e.g. predation control, reproductive technologies
- **Genetics** – e.g. resistance markers
- **Marketing and Product Quality** – e.g. carcass traits
- **Food Safety** – e.g. depletion studies
- **Economics** – e.g. benchmarking, business viability
- **Environment** – e.g. impact of sheep
- **Other** – e.g. KTT, labour

The full list of suggested research topics is shown in section 4 and the feedback on this question from the individual worksheets is listed in section 6. By far the greatest number of research topics suggested during the facilitated session fell under the animal health category followed by genetics and economics. The personal recording sheet summary shows animal health as the category with the most entries followed by economics and then reproduction and production.

Ranking Research Priorities

Over the lunch break, the full list of research items from the morning session were sorted and condensed into 19 generalized topic areas. Each person was given a paper ballot and told they had 100 points which could be allocated in blocks of 20 points. They were to list their top research priorities on the ballot and assign how many points they wanted to give to each priority.

Note: The limitation of such broad categorization is some topics may end up being ranked higher when bundled with another, more highly prioritized topic than on its own merit. Conversely, specific research topics which may be considered a priority could score lower when matched with all topics within a generalized theme. In addition, some ranked items were very broad (e.g. benchmarking/CoP/ composite industry data) whereas others were very specific (e.g. pneumonia).

The ranking and total votes are shown on the following page.

Ranking	Total Points	Research Area
1	385	Benchmarking/CoP/composite industry data
2	250	Parasites
3	240	Lamb mortality
4	205	Market traits – carcass quality characteristics
5	200	KTT/communications
6	190	Environmental impact/sustainability
7	180	Efficacy trials and diagnostic tests
7	180	Feed efficiency
7	180	Grazing – agronomic factors
7	180	High health status programs
8	120	AMR/AMU, alternatives, gut health
9	100	Housing – space requirements, ventilation, air quality
9	100	Pneumonia
10	50	Pain mgt. for lambs (including tail docking)
10	50	Social science/decision-making
11	40	Coccidiosis
12	30	Fertility/reproduction traits
13	15	Consumer perceptions/preferences
	0	Tail docking

The research topics were connected to either the Canadian Agricultural Partnership Program priority areas (those highlighted in red above) or OMAFRA's seven research themes. It was emphasized that it is important to have a commitment from industry for cash and in-kind contributions to support research and demonstrate industry support to the funding agency. Identified industry research priorities help form the research themes and priority areas within the OMAFRA/University of Guelph agreement.

The next steps outlined were to have a summary meeting report prepared and circulated to attendees for feedback.

2. Top Barriers for the Ontario Sheep Industry

Attendees were asked to consider what is limiting or restricting the Ontario sheep sector from reaching its potential. This did not have to be related to research per se. They were instructed to take five minutes and jot down their thoughts on their recording sheet and then spend another five minutes discussing within their groups. The facilitator then went around the room, taking one item from each table and recording on the flip chart. The complete list of items proposed is listed below.

- Lack of knowledge transfer
  - Generational
  - Extension/research
- Lack of benchmark data – production and financial
  - Weaknesses/strengths
  - Also comparison of Ontario to other jurisdictions
- Lamb mortality
  - Define it, measuring consistency
  - Optimum number of lambs
  - Why? What management changes may impact?
- Barriers to using grazing
  - Cost of land
  - Predation
  - Parasites
- Carcass quality – inconsistency
- Disconnect between quality and price received
- Decrease in volume = increased costs
- Market driven by live sales
- Mixed signaling – good quality lambs discounted when lots of volume
- Lack of value chain feedback – definition
- What does market want
- Recognize there are different market segments – different needs or requirements
- What market are you producing for?
- Cost of production high in Ontario
- Land costs, feed, labour, economy of scale
- Lack of skilled and reliable labour
- Age of sheep farmers and engaging young/new farmers
- Retention of new entrants
- Access to high health genetics
- Lack of numbers and appreciation of importance
- Get good information (and credible) to new entrants
- Lack business education/focus – viable business
- Decisions need data
- Growth can look differently – not just increased ewe numbers, more important to look at productivity

- Master Shepherds' course targets existing producers
- Animals must be genetically suitable for the target market
- What is the main aim?
- Increasing imports – lower ON production for domestic market
- Room for improved efficiency (e.g. feed)
- Realistic expectation – all agriculture faces cycles
- Getting producers to share data to get composite summaries
- Pick right measures, provide immediate feedback, constant contact to encourage measuring, show how it benefits them plus industry
- Establish trust for sharing
- Keep it manageable – focus on KPIs rather than a broad range
- Practical
- Need human resources to gather data, summarize, circulate, discuss/analyze
- Farmers influenced by farmers
- Easy templates
- Funded programs to aid measurement and tied to usage for two years to generate information
- Promote importance of industry having data – how it can support OSF in its advocacy efforts
- Market fluctuations and cycles
- Lack of registered pharmaceuticals
  - Impacts cost of production
  - Increased animal health
  - Decreased vet costs, health costs
- Tools and programs to ensure optimum sheep health, e.g. disease status programs, diagnostic testing
- Regulatory burden, red tape, impacts on ag
- Climate change – link to parasites, feed, grazing
- Managing feed costs
- Challenge in measuring/benchmarking with different production systems i.e. annual, accelerated

3. Strengths and Weaknesses Related to Sheep Research in Ontario

Meeting participants were asked to spend five minutes considering what is limiting or restricting sheep research in Ontario and jot down their thoughts on their personal recording sheet. Another five minutes was spent sharing within groups and then the facilitator went around the room, taking one item from each table and recording on the flip chart until submissions were exhausted. Below is a list of the items recorded.

- Ontario focused, should we look at national focus? – difference geographically within Canada
- Not all provinces have sufficient funding
- Lack of funds – ongoing funding for projects – focus on a few large, long-term projects or more but smaller, short-term projects?
- On-going funding would help retain researcher interest – some stability is required to get commitment to building capacity for the particular focus area
- Lack of research on what makes a business viable

- Don't underestimate producer priorities and decision making - impacts types of research and sharing
- Wide variety of breeds so a challenge to focus genetics funding
- Is there a common goal? Should there be one?
- Should research money focus on majority of commercial breeds? Many are cross-breeds
- Diversity in market segments pose variety of target markets
- Limited number of researchers e.g. forage and grazing pasture
- Need multiple funders to make a project viable, increased paperwork, challenge to find industry partners
- A positive is that the market is growing – potential for improvement
- Seed money from industry is critical
- Sheep is a minor species in Ontario
- But, strong support via University of Guelph/OMAFRA agreement
- Being industry driven sometimes limits research, i.e. difficult to garner money for new, innovation, something that doesn't have a clear, direct, applicability to industry right now
- How to connect to industry needs – build partnerships with researchers not conducting sheep production research currently
- Link with other commodities to leverage funding, e.g. goats, dairy
- As resources become limited, narrower parameters for funding, not always addressing priorities, i.e. make research fit funding
- Some projects do not fit into short-term funding windows
- KTT – getting research out to producers – adoption, adaption
- Is it a research need or uptake need?
- Some older research still relevant – perhaps not remembered or known

4. Priorities for Research

Within their groups, participants were instructed to discuss what they felt are the more important issues in the sheep industry that could benefit from research. The key point they were asked to remember is the issue had to be able to be connected to a research question. They were asked to make their research priorities as specific as possible and write one topic per sticky note. The notes were collected and posted on the wall under one of 10 categories: animal health, animal welfare, nutrition, reproduction and production, genetics, marketing and product quality, food safety, economics, environment, and an "other" category. The complete list of submissions is reproduced below.

Animal Health

- Colostrum quality in lambs to decrease mortality – refractometer and colostrum testing
- Improving milk quality in Ontario dairy sheep – mastitis prevention
- Lamb mortality is probably a result of many factors – need research in all factors (genetics, health, nutrition, and environment)
- Study causes of lamb mortality
- Efficacy trials, e.g. vaccines
- Pneumonia research on housing, environment, vaccination, etc.

- Control of ovine paratuberculosis
- Pneumonia in growing lambs – causes and effect on productivity, control measures
- Control of coccidiosis in lambs – diagnosis, epidemiology
- Research on withdrawal times for commonly prescribed off-label drugs
- Control of zoonotic diseases of sheep – infectious abortion, toxoplasma, orf (scabby mouth or contagious ecthyma)
- What is the cost-benefit of improving macro and micro air quality in growing lambs
- Alternatives to AMU – gut health, probiotics
- Researching bioactive forages to combat antimicrobial resistance
- Economics of high health status programs
- Use of CARHA testing in control of parasites in Canadian lambs
- GI parasites – are we delaying immune response development by focusing on "clean grazing" for lambs? Delayed exposure = better growth BUT also delayed immune response. Very NB for replacement ewes

Animal Welfare

- Space requirements
- Do market lambs need to be tail-docked. Welfare and public health issues associated with docking
- Ventilation
- Practical, low-cost, easily applied pain control method for tail docking and castration where lambs are processed in groups at older ages, i.e. pasture, lambing lambs – 3d to 4wks old

Nutrition

- Nutrition project on alternative feed usage to lower cost of production
- Nutritional research on alternative feeds to extend grazing season, i.e. grazing corn to lower COP
- What are the different pasture management systems (and forage crops) that are prevalent on sheep farms?
- What average daily gains are achievable on grass for sheep/lambs
- Optimizing BCS at weaning for re-breeding success (accelerated system)

Reproduction and Production

- What farm-level factors are associated with efficiency of gain
- Production-limiting disease. Cost-benefit of control/eradication of Maedi visna
- Raven predation prevalence and prevention on-farm
- Improving feed efficiency
- Feed efficiency – management systems, genetics-marker, breed specific?
- Where are the knowledge gaps between known risk factors for productivity losses, such as coccidiosis and pneumonia in lambs, and actual implemented management practices on Ontario farms

Genetics

- Mycotoxin tolerance – markers
- Very different environment, needs emphasis on different traits

- With only three breeds representing the majority of Genovis data, how do we make improvements on traits important for both production systems? Pasture lambing, accelerated lambing
- Strength of breeds – immunity to diseases
- Parasite resistant breeding – determine markers to support genetic selection for parasite resistant animals
- Genetic research - Parasite resistance (haemonchus worms)
- Determine major ON markets and set breeding objectives for each
- Identify genetic traits that could most impact production. Which are most important? Last segment of supply chain to participate (closer to consumer needs)
- Supply chain genetics
- Marker enhanced genetic selection for complex traits, such as fertility/reproduction – use of omics technologies to define/find out such markers.
- Identify research goals for Genovis and clarify its misconceptions – can't have genetic improvement without an up-to-date "GE system" that farmers are aware of, know how to use, and understand its basis.
- Work on genetics so more breeders aware and improve data

Marketing, Product Quality
- Defining better phenotypes – carcass length, bone:meat
- What is ideal meat? Age, consistency, fat content – lean, extra lean, high fat?
- Analysis on product movement within Canada
- Identifying the various markets for lambs in Ontario and volume of lamb through each. Once you determine the target market you can set research goals for that market
- What is purchaser's desired lamb – whole, ground, chops? – all determines quality of meat
- Survey: consumer perceptions and preferences related to sheep/lamb industry – help identify markets and measures within a verification program to meet consumer needs
- Human nutritional profile of lamb – portion size, taste, omegas
- Halal market breeds? What has the biggest market potential? A lot of different niche markets – is there anything in common we can focus on
- Market and market viability – market cyclicality, market strength, market quality (quality and price relationship), marketing Canadian lamb, where should we make our target market (what has most potential, what is presently strongest, what are the requirements for said market).

Food Safety
- Depletion trials

Economics
- Creating benchmarking systems and implementing the system
- Research driven from producer data to set benchmarks
- How do we design record keeping systems that facilitate use and provide good quality data
- Minimum data points that should be collected on farm to increase profitability?
- Knowledge and communication – do we need more or better data? Need better courses. Better access to databases

- Price determining mechanism outside the live sales auction market – dust off what we have started
- Grazing cover crops on another person's land: develop sample business models that provide value to both sheep producers and cash crop producers, considering: short duration grazing, fencing/water, value of manure, value of cover crop, responsibilities of each party
- COP case studies on management practices – e.g pasture/confinement/stored feed
- Farm diversification options and business case for wool production and dual use breeds – management systems
- Meeting the demand – what market to focus on: high end, local, international, under-cutting imports, etc.
- Business education – finance, health, production, source funding

Environment

- Research on sheep, role on the carbon cycle and soil health
- Research on environmental sustainability and climate change – value-added product to compete with other sectors and imports. Includes: data on land use, feed efficiency, CO_2 emissions sink/source, disease diagnosis, wool quality, animal resilience, welfare and genetic selection and mutation

Other

- Labour training and allocation on farms
- Adoption of practices to control GI parasites – efficacy of control program
- Interdisciplinary research to bring together "teams" with complimentary research or who could collaborate on a particular theme
- Measure efficacy of KTT plans
- What do producers want from KTT? Do different generations and management systems need different strategies
- What makes producers want to adopt new research? – social science study

5. Ranking Research Priorities

The meeting participants were asked to rank the research priorities. Their basis for considering a research area a priority could include a challenge that: is the most debilitating; has the most significant economic impact (negative or positive); is new or emerging; has the potential to benefit the sheep sector as a whole; is an area of lack of current knowledge, etc.

Each person was given a paper ballot and told they had 100 points which could be allocated in blocks of 20 points. They were to list their top research priorities on the ballot and assign how many points they wanted to give to each priority. The maximum number of priorities they could list would be five priorities at 20 points each. The minimum would be one priority with all 100 points.

To assist in the "voting", the full list of research items, as shown in section 4, were condensed into 19 generalized topic areas. The limitation of such broad categorization is some topics may end up being ranked higher when bundled with another, more highly prioritized topic than on its own merit. Conversely, specific research topics which may be considered a priority could score lower when matched with all topics within a generalized theme. In addition, some items were very broad (e.g. benchmarking/CoP/composite industry data) whereas others were very specific (e.g. pneumonia).

The ranking and total votes were as follows:

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10	50	Social science/decision-making
11	40	Coccidiosis
12	30	Fertility/reproduction traits
13	15	Consumer perceptions/preferences
	0	Tail docking

6. Summary of Worksheet Comments

Meeting attendees were provided with a worksheet for the facilitated discussions and asked to jot down their personal thoughts in addition to suggesting items during the open group discussions. While verbally submitted comments were recorded on the flip chart and on sticky notes posted on the walls, it is recognized that not all comments and ideas end up being shared during the meeting.

Twenty-eight completed worksheets were collected at the end of the day which represented 85% of those in attendance excluding the meeting facilitator and event organizers. A compilation of the feedback from all submitted worksheets is presented below. Every statement has been reproduced with similar comments listed under a general, common theme.

Part 1 – Top Barriers for the Ontario Sheep Industry
What is limiting or restricting the Ontario sheep sector from reaching its potential?

Education/Knowledge and Retaining Producers

- Low uptake of programs
- Extension – new producers with lack of easily accessible information
- Hobby mentality/serious business
- Not enough work can be done on farms
- Number of producers (knowledgeable)
- Sheep is a very small industry
- Competitive – size – capacity
- Need for more good production of lamb, new generation and expansion
- Smaller number of commercial size operations
- Producer entry and exit – retainment of producers
- High turnover rate of sheep farms
- Retaining new producers
- Why is there such a turn-over of producers – many stop within first five years
- Stigma – perception of sheep industry
- KTT on environmental sustainability
- KTT – new producers, all producers
- KTT
- Lack of knowledge transfer
- Knowledge transfer and accessibility

Cost of Production

- Investment (startup) costs
- Price of land
- Price of land
- Cost of feeds
- Cost of land in Ontario, how to cash flow
- Land price/grazing

- Price of land/lack of pasture
- Land costs, feed costs, labour shortage
- High labour per unit output
- Labour (grazing management)
- Feed management – grazing, alternative feedstuffs, COP, stored feeds, etc.
- Barriers to using grazing – predators, cost of land, parasites, consistent quality
- Amount of work
- Dedicated trades (?) to industry/labour
- Cost of production – feed, winter feeding, facilities
- Cost of production (feed, vet/drugs, labour)
- Cost of production
- Cost of production
- Business environment
- Business environment
- Barriers to slaughter – marketing systems, abattoirs, cost of stored feed, buildings, equipment
- Lack of financial/human resources
- Scaling to match income to workload
- Opportunities to invest in facilities

Access to Quality Animals and Low Number of Sheep Overall

- Lack of animals
- Number of sheep
- Number of sheep
- Short supply – not enough sheep – wait time for breeding stock
- Lack of breeding stock
- Starting with quality sheep
- Access to high health genetics/replacement stock
- Use of genetic programs
- Use of genetic evaluation (lack of)
- Genetic improvement – record keeping and analysis, replacements, meds and vaccines, labour, hobby mentality
- Genovis misconceptions – how does data get in, what does Genovis mean? CEPOQ vs. Ag Sights
- Finding type of sheep needed in Ontario

Market/Price Uncertainty

- Consistency in price of lamb
- Unpredictable price
- Unstable market – cycle and fluctuation
- Payment system (carcass and meat quality)
- Wool price and quality
- Low $ / lamb impacts cash flow
- Market (size, strength, exports, etc.)
- Profitability

- Price volatility and risk
- Price of imports
- Market consistency

Inconsistent Product and Lamb Availability

- Consistent supply
- Inconsistent supply – seasonal – lack of supply for the market, i.e. not enough producers
- Lack of marketing signals to producers on traits
- Inconsistent carcass quality and disconnect between price and quality
- Inconsistent carcass quality
- Seasonal production

Benchmarking and Record Keeping

- Benchmarking – data
- Lack of benchmarks
- Record keeping/benchmarking
- Record keeping facilitation/benchmarking
- Lack of benchmark data
- Lack of good record keeping to improve genetics (data)
- Lack of data
- Lack of value-chain feedback – no incentive
- Most sheep farmers are not interested in data

Access to Medicines and Cost

- Medication and costs
- Antimicrobial
- AMR
- Lack of labelled/approved vaccines and antibiotics
- Meds/vaccines
- Medicine and vaccine use in other countries but not available in Canada
- Limited access to medications/vaccines
- Lack available vaccines/drugs approved
- Health: approved vx/abx, parasites

Animal Health - General

- Health/production issues
- Health (need to get more out of investment)
- Maedi visna and other production-limiting diseases
- Lamb mortality
- Lamb mortality (health and management)
- Mortality
- Neo natal pneumonia – mortality
- Winter housing – risk of confinement diseases (pneumonia, cocci, etc.)
- Disease

Parasites

- Parasites – animal health
- Parasites (grazing management)
- Parasites and measuring economic loss
- Parasite resistance and management
- Parasite control
- Parasites
- Parasites

Predation

- Predators – need better sheep protection
- Predation (grazing management)
- Predation and government regulations around controlling predators, cost of control measures
- Predators
- Predation
- Predation
- Predation

Consumers and Consumption

- Increase consumption; public
- Lower consumption
- Higher price point compared to competing proteins
- Profile among men – urban markets
- If you want to compete with beef sector and sheep imports, assessment of environmental sustainability would be useful for value-added markets

Processing

- Non-profitable processing
- Slaughter capacity

Different Production Systems

- Challenges of three production systems
- Lack of standard system
- Multi-breed (too many)

- Research structure
- Regulatory burden
- Traceability for production – full circle
- Climate change

Part 2 – Strengths and Weaknesses Related to Sheep Research in Ontario

Funding

- Funding – most is provincial
- Funding long-term projects
- Funding – producer/researchers connections
- Funding
- Funding
- Funding
- Funding
- Funding
- Funding
- Small funding

- Research funding (amount of)
- Difficult to obtain funding for what is quite basic work in other industries
- Need funding for long-term projects – stable funding 2-3 years, 10 years for some types (e.g. breeds)
- Money, small industry and few research dollars – FUNDING
- Money, administration of money
- Money (parasite impacts)
- Money
- Money
- Dollars!
- Lack of research money
- Limited money
- Weakness – not enough money, a lot of work to do
- Research money – leverage to extend
- Leveraging dollars – comparing against dairy, swine, poultry
- Where to get matching dollars from
- Having enough money to get the "big research" done
- Matching industry partners? They don't see market value in doing sheep research

Knowledge Transfer

- Knowledge transfer
- Knowledge transfer of research conducted – needs to be practical, written for producers, how it will apply on farm
- Transferring knowledge – getting research out
- Applications/results of research projects
- History of leaving research results on the shelf
- Distribution of research – sitting on shelf
- Producer utilization of research – education
- Extension
- Producers not having tools to utilize research – money, equipment, time
- We post results but don't effect change
- KTT
- KTT
- Lack of tech transfer
- Communications, focus on good breeds; Rideau Dorset Suffolk

Researchers and Infrastructure

- We have lots of knowledgeable researchers who are keen to do work
- Lack of foraging/grazing researchers
- Research infrastructure – maintain it
- Limited number of researchers – forage and grazing researchers, health, nutrition, meat quality, etc.
- Lack of commercial research facilities – have Ponsonby but need commercial scale research facilities like USA
- We have infrastructure – need to maintain

- Strength – good collaboration
- Expertise may be tied to other commodities in competition
- Time

Collaboration

- Collaboration between funding programs and academic
- Research is now industry driven and with limited funding things that are newer/more complicated, that may be bigger picture, helping industry - difficult to get this funded in our current model.
- Cooperation with pharmaceutical industry and other funding sources
- Incentive to get producers on board with researchers
- Lack of connectedness
- Farmers not willing to work on ridding diseases – Maedi visna
- Great potential for growth, research amplification

Data

- Small data pools (size of farms)
- Weakness – getting good data
- Data
- Record keeping
- Widespread lack of overall industry data collection
- Having the data to ID the research needs (smaller picture)
- Standardization of management

Types of Research

- Research that deals with the business environment – focused on business viability
- Operationalize research to producers
- Practical research for producers
- Field trials – lack of
- Balance basic science with farm level science
- Business models for sharing land between sheep farmers and cash crop farmers (grazing cover crops)
- Not an excellent test for Johnes disease
- Integrative systems approaches
- Sheep as a ruminant model

Vision and Goals

- Having a solid industry "vision" to research towards
- No coherence around goals, target carcasses
- Diversity of industry – focus and scope large?
- Lack of common goal (selection, production, etc. – breeds/genetic material)
- Segmented market/different needs
- National vs. provincial
- A lot of "low hanging fruit" – don't waste resources on minutia
- Set breeding objectives – too many niche markets within

- The need (determining which direction) – lobby
- Industry needs don't always match livestock priorities

Size and Viability of Sector

- Lack of scale of size
- Size of the industry
- Industry size – small ruminant cluster?
- Not focused on commercial viability
- Size of sector limits industry cash need to leverage money
- Business viability
- Business viability
- Have to compete with larger industries
- Competing against large livestock sectors i.e. dairy cattle, swine, poultry
- Volume of lambs
- Commercial

Regulation and Policy

- Red tape (predation/pasture use)
- Policy/red tape around medications

Part 3 – Priorities for Research

Animal Health

- Lamb mortality
- Lamb mortality – what are main causes, role of FPT
- Lamb mortality – all factors
- Lamb health
- Colostrum quality to reduce lamb mortality – refractometer and colostrum testing
- Pneumonia
- Pneumonia research on housing/environment/vaccination
- Lamb pneumonia vaccines – to replace or reduce need for antibiotics
- Animal health – work on Johnes – long time
- Health data research
- Health programs
- Alternatives to vaccines/treatments – AMR
- Bioactive forages to combat antimicrobial resistance
- Efficacy trials and diagnostic tests

Animal Welfare

- Ventilation
- Facility design/ventilation, retro fits and cost/benefit
- Do market lambs need to be tail docked?

Nutrition

- Nutrition project on alternative feeds
- Feed efficiency and alternative feeds
- Nutritional research on alternative feeds to extend grazing season i.e. grazing corn to lower COP
- What average daily gains are achievable on grass for sheep - feed efficiency – genetics – marker or mycotoxin tolerance

Reproduction and Production

- Alternative feeds
- Feed efficiency
- Alternative (low cost) feed and feed management
- Efficient grazing
- Co-grazing (with cattle or fit in to cropping systems)
- Co-grazing with livestock, with cropping systems, with other (viticulture solar farm)
- Standard operating procedures for confinement/pasture systems
- Grain processing
- Develop more efficient and economic predation control
- Raven predation prevalence and prevention on-farm
- Cost of predation tools
- Reproductive technologies

Genetics

- Animal health genetics – resistance markers (parasites, disease, haemonchus worms)
- Parasite resistant breeding – determine markers to support genetic selection for resistant animals
- Genetics/genomics – relation to health and selecting maternal traits
- Genetics – feed conversion
- Genetics – somehow more breeders in this
- Courses on genetics for people
- Expand genetic improvement
- Gene markers

Marketing, Product Quality

- Market traits
- Survey – consumer preferences and perceptions of lamb/sheep industry – help determine markets and requirements for verification program
- Key Ontario markets and set breeding objectives for each
- Increased production, quality product – how to develop research when we have 3000 different production systems?
- Novel phenotypes – carcass traits, disease resistance
- Identifying phenotypes before looking into genotypes

Economics

- Business viability
- Business models for sharing cover crop land as above
- Decision making
- Communications and databases
- Consumer perceptions/preferences

- Benchmarking systems
- Benchmark
- Benchmarking
- Record keeping facilitation/benchmarking/individual for analysis (how to design, how to get max value out of)
- Business education on entire finance, health, production etc.
- COP case studies on management practices – i.e. pasture vs. confinement/stored feed
- Key data points that drive profitability and their value to the producer (i.e. ROI for collecting data)
- Sustainability and management (business)
- Develop price determination mechanism
- Research on identifying templates for production systems. Return on investment, management systems, cost of production

Environment

- Sheep's role in carbon cycle
- Environmental impact of grazing – sheep are good for soil quality
- Data on environmental sustainability and climate change – taps into value-added products, land use, feed efficiency, CO_2 emissions, disease (diagnostics), wool quality, welfare, genetics, resilience (could also go under marketing)

Other

- KTT for managing risk factors for cocci and pneumonia in lambs
- KTT

7. Feedback Sheet Summary

Sheep Industry Research Day
June 4, 2018

Feedback Sheet Summary

Below is a summary of the feedback from the June 4, 2018 Sheep Industry Research Day. There were 27 feedback sheets returned from a possible 33. That equates to a 82% response rate.

1. How useful did you find the meeting in refining Ontario Sheep's research strategy and setting a path forward?

Poor – 1 (3%) Fair – 2 (7%) Good – 5 (19%) Very Good – 14 (52%) Excellent – 5 (19%)

Comments:

- Well facilitated, excellent. One of the best I've attended
- Sound system wasn't good. Really enjoyed interactions with producers at our table
- What is the main goal of the ON sheep industry?
- It felt like we got off topic a lot
- (very good) but many varied views
- Well run, good process – difficult topic because the industry needs are very high
- Turned very specific (good) research ideas into overly broad goals – too much generalization may cause initial barriers we identified to be missed by our generalization

2. The time given to each agenda item was enough time for thorough discussion.

St. Agree – 5 (19%) Agree – 18 (67%) Ambivalent – 3 (11%) Disagree – 1 (3%) St. Disagree – 0

Comments:

- More time would allow for more fruitful conversation – brain storming
- Sometimes tables didn't contribute because discussion went off topic
- Would have been nice to have a bit more time in part 3
- More time on themes to develop more solidly
- Problems should have been given more time to complete
- Too much time identifying barriers left too little time for the rest of the day

3. There was an opportunity for all participants to state their views and have their perspectives heard.

St. Agree – 11 (42%) Agree – 14 (52%) Ambivalent – 1 (3%) Disagree – 1 (3%) St. Disagree – 0

Comments:

- (agree) but time at each table to introduce to each other
- I probably talked too much – most people said nothing
- Summary of points to vote on was poorly done – split some (animal health) points into too many and over simplified several others. Recommend using a defined methodology to build consensus. This seemed haphazard when arriving at the list to vote on

4. Were there other areas that should have been included in the presentations and discussion that were not included?

Yes – 4 (15%)   No – 22 (85%)

If yes, please specify:

- Thought it was an excellent time
- Topic was well covered
- Local available researcher strengths
- I would break past funding out to see where money has been invested in the past. May help identify gaps i.e. health 30%, genetics 20%, welfare 5%, nutrition 10%, etc.
- Research needed/research to be furthered
- Structure of how research objectives are determined

5. Did you learn something about the Ontario sheep industry at the meeting either from the presentations or in discussion with other meeting participants?

Yes – 21 (88%)   No – 3 (12%)

If yes, please describe:

- Research flock and what is happening in Quebec
- How the change of research is decided. I also believe that in relation to animal welfare we need to focus on food safety i.e. we tail dock so that lambs do not get fly strike or carcass contamination.
- Orbiviruses in Ontario
- Good format, lots of communication
- My table had Phil Smith and Heather. They discussed their different farming systems and why they chose them which was very informative
- From research perspectives
- Different views of the industry
- How prioritization is determined
- Creative ways research used to be able to do sheep related research
- Not really
- Good to hear current concerns and perspectives
- More of the stuff I know
- This was my first time, so it was very informative
- Complexity of grazing systems in Ontario. OBS: the list of priorities did not reflect well (i.e. topics raised) during the morning

8. Workshop Agenda

Sheep Industry Research Day

June 4th, 2018, 9:30 AM - 2:00 PM Conference Room 1, OMAFRA

1 Stone Rd, Guelph

9:15	**Registration**
9:30	**Welcome – Overview of the Day** **Tim Nelson** *CEO, Livestock Research Innovation Corporation*
9:45	**Sheep Research Overview/Success Stories** **Jenn MacTavish,** *General Manager, Ontario Sheep Farmers* *Chair – Ontario Sheep Value Roundtable Research Working Group*
10:15	**Collective Industry Priority Setting Facilitated Discussions** **Susan Fitzgerald** *Fitzgerald & Co*
12:15	**Lunch**
1:00	**Review and Verification of Priorities** **Susan Fitzgerald**
1:30	**Funding Opportunities** **Wrap up and Next Steps** **Tim Nelson**

9. List of Attendees

The 39 meeting participants and their affiliation are noted in the chart below.

1.	Cathy	Bauman	University of Guelph
2.	Steve	Beadle	OMAFRA
3.	Sandi	Brock	Producer
4.	Allison	Brown	OMAFRA
5.	Jillian	Craig	OMAFRA

6.	Rex	Crawford	Veterinarian
7.	Samantha	Dixon	OSF Staff
8.	Bill	Duffield	Producer
9.	Jason	Emke	Producer
10.	Susan	Fitzgerald	Facilitator
11.	Greg	Folinazzo	AAFC
12.	Anna	Formusiak	OMAFRA
13.	John	Hemsted	Producer
14.	Jean	Howden	LRIC
15.	Jocelyn	Jansen	OMAFRA
16.	Sally	Jorgensen	Producer
17.	Niel	Karrow	University of Guelph
18.	Delma	Kennedy	OMAFRA
19.	Nicole	Klenk	University of Toronto
20.	Heather	Little	Producer
21.	Paul	Luimes	University of Guelph
22.	Jennifer	MacTavish	OSF Staff
23.	Paula	Menzies	University of Guelph
24.	Tim	Metzger	OMAFRA
25.	Jasper	Munro	Industry
26.	Tim	Nelson	LRIC
27.	Anita	O'Brien	Producer
28.	Santiago	Palacio	OMAFRA
29.	Julie	Poirier Mensinga	OMAFRA
30.	Flavio	Schenkel	University of Guelph
31.	Rob	Scott	Producer
32.	Phil	Smith	Producer
33.	Liz	Smith	Producer
34.	Nicholas	Watson	CFIA
35.	Charlotte	Winder	University of Guelph
36.	Larry	Witzel	OLEX
37.	Katie	Wood	University of Guelph
Joined via teleconference			
38.	Hélène	Mèthot	CEPOQ
39.	Virginie	Rochet	AAFC

GROUPE AGĒCO

LIFE CYCLE ASSESSMENT OF SHEEP PRODUCTION IN ONTARIO

PRESENTED TO

ONTARIO Sheep MARKETING AGENCY

FINAL REPORT

OCTOBER 2017

This project was funded in part through *Growing Forward 2 (GF2),* a federal-provincial-territorial initiative. The Agricultural Adaptation Council assists in the delivery of *GF2* in Ontario.

Growing Forward 2 AAC agricultural adaptation council Ontario Canada

Groupe AGÉCO 2014, Cyrille-Duquet St., office 307, Québec (Quebec) G1N 4N6 Canada 418 527-4681

REPORT PRESENTED TO

Jennifer MacTavish, General Manager, Ontario Sheep Marketing Agency

PROJECT TEAM – GROUPE AGÉCO

Édouard Clément, Eng., M.Sc.A.	Projet Manager
Antoine Léger Dionne, Jr. Eng.	Analyst
François Charron-Doucet, Eng., M.Sc.A.	Quality Assurance/Quality Control

ABBREVIATIONS AND ACRONYMS

CO_2 eq.	Carbon dioxide equivalent
GHG	Greenhouse gas
GWP	Global warming potential
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life cycle assessment
LCI	Life cycle inventory
LW	Live weight
MJ	Megajoule
NMP	Nutrient management plan

SUMMARY

CONTEXT AND OBJECTIVES

In order to provide a better understanding of the environmental profile of sheep production in Ontario, the Ontario Sheep Marketing Agency (OSMA) has commissioned an environmental life cycle assessment of sheep production in Ontario. Through this project OSMA aims at demonstrating responsible stewardship of the environment as well as its proactive approach toward continuous improvement. It should be noted that this initiative is in line with the Agricultural Adaptation Council's priority area of focus on Environment and Climate Change Adaptation.

The approach proposed for measuring the environmental performance of sheep production is the Life Cycle Assessment (LCA), an internationally recognized analytical tool that is compliant with the ISO 14040 series. In addition, the study will follow the methodological guidelines for the environmental assessment of small ruminants supply chain as proposed by the FAO (2013). Study results will be used to identify priority areas for footprint reduction and mitigation, using a set of four environmental indicators: energy use, greenhouses gas (GHG) emissions, water consumption and land use. It is important to note that the impacts described by the LCA are estimates of potential impacts and not direct measurements of actual impacts, with its limitations described in the ISO 14040 standard series.

The specific goals of this study are to:

1. Conduct a streamlined life cycle assessment (LCA) of sheep production in Ontario to quantify its environmental impact.
2. Identify priority areas for footprint reduction.
3. Assess potential footprint reduction or increase of different scenarios (e.g. production intensification, indoor housing trend, etc.).
4. Determine a baseline against which the sector will be able to benchmark its performance over time.

The report is intended to provide results in a clear and useful manner so that accessible environmental information may be communicated to internal and external stakeholders (e.g. partners, suppliers, customers, and the public).

METHODOLOGY

This study assesses the life cycle of sheep production for which the system boundaries consider a cradle-to-farm gate approach.

The functional unit for this study is
the production of one (1) kg of live weight Ontario-produced sheep at the farm gate.

The life cycle model system and results were calculated and are presented in terms of kg live weight sheep.

The system is divided into the following life cycle stages:

1. Feed production: extraction and processing of raw materials used to produce pesticide and synthetic fertilizers as well as their application on crops, manure spreading, direct emissions from agricultural soils, energy required for field operations and irrigation.
2. Farm operations: sheep and lamb rearing, energy consumption (electricity, heating and diesel fuel), buildings and water consumption.
3. Enteric emissions: methane emissions from the digestion process of adult sheep and lambs.
4. Manure and waste management: methane and nitrogen dioxide emissions produced during manure storage and treatment.

Secondary data adapted from the literature was used for on-farm and off-farm processes (chemical manufacturing, infrastructure, electricity production, natural gas extraction, fuel refining and transportation processes). These datasets were adapted from the internationally recognized life cycle inventory database ecoinvent database v3, taking the Ontarian context into account.

The impact assessment phase of the study evaluates the impact on climate change with the amount of greenhouse gases emitted into the environment, expressed in kilograms of carbon dioxide equivalent (kg CO_2 eq.). The conversion of the quantity of different GHG in kg CO_2 eq. is based on the global warming potentials (GWPs) published in the 5th Assessment Report by the Intergovernmental Panel on Climate Change (IPCC, 2013). In addition, the results of three inventory indicators were calculated, including energy use (expressed in megajoules (MJ) of non-renewable primary energy extracted from the earth), water consumption (expressed in m^3 of the total water volumes consumed in the life cycle) and a land-use indicator (expressed in $m^2 \cdot y$, i.e. area of land used during one year). The last indicator is a measure of the amount of land occupied by the activities related to the life cycle of sheep production.

RESULTS

The results of the average environmental profile of one kilogram of live weight Ontario-produced sheep are summarized in Figure 1.1. The production of one (1) kilogram live weight sheep leads to an emission of 10.6 kg CO_2 eq.—this value defines the baseline scenario.

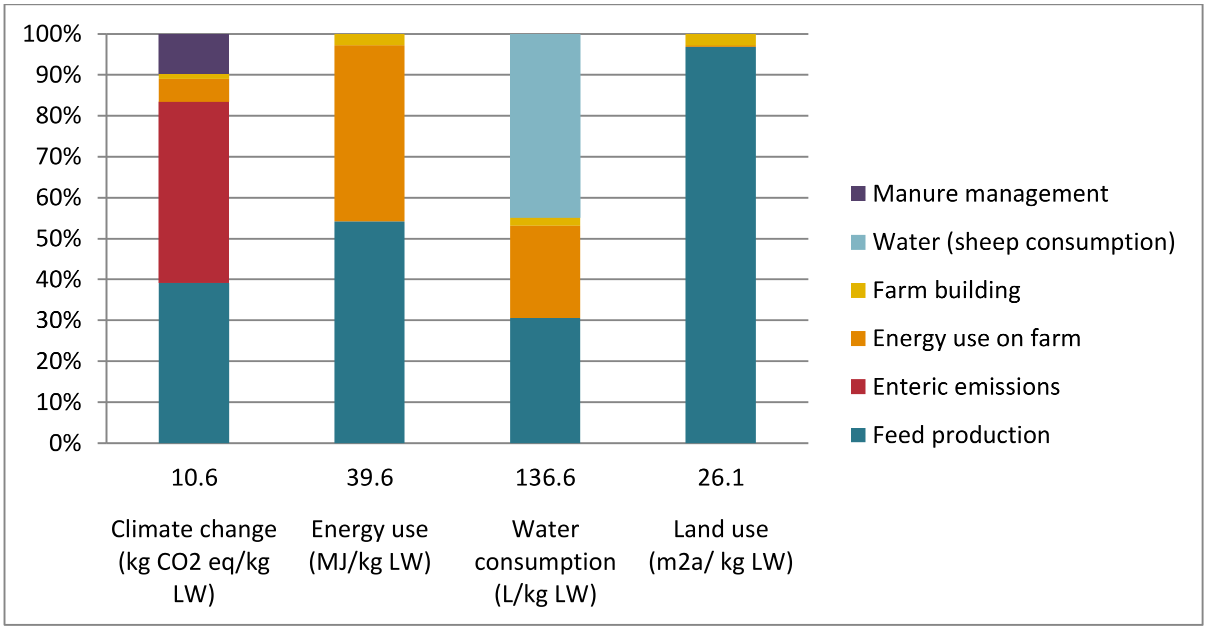

Figure 1.1 Relative contribution of life cycle stage of the average environmental profile of one kilogram of live weight Ontario-produced sheep

Among the life cycle stages, enteric emissions and feed production contribute to the majority of the potential impacts to climate change, representing respectively 44% and 39% of impacts for the climate change indicator. Enteric fermentation is the main GHG emissions contributor, attributable to the gross energy requirements of sheep and lambs, and will vary according to animal weights and the type of diet fed to the animals. Productivity is the key parameter explaining variations in emission intensities. High-productivity systems are characterized by high fertility and growth rates, low mortality rates and high feed digestibility. Producers who wish to reduce their carbon footprint need to maintain or increase the level of productivity.

The land use indicator is dominated by the use of agricultural land for feed production. Non-renewable resource consumption is explained by the use of fossil fuels in synthetic fertilizer production and the energy consumption related to farm operations. The feed production stage also contributes to 54% of the energy use impacts. The main contributor to the water consumption indicator is the water consumed by the animals. Irrigation is also a significant contributor to this indicator, even though the use of irrigation is low in Ontario.

Figure 1.2 shows the comparison of life cycle impact results between farms using an annual lambing system with those using an accelerated lambing system.

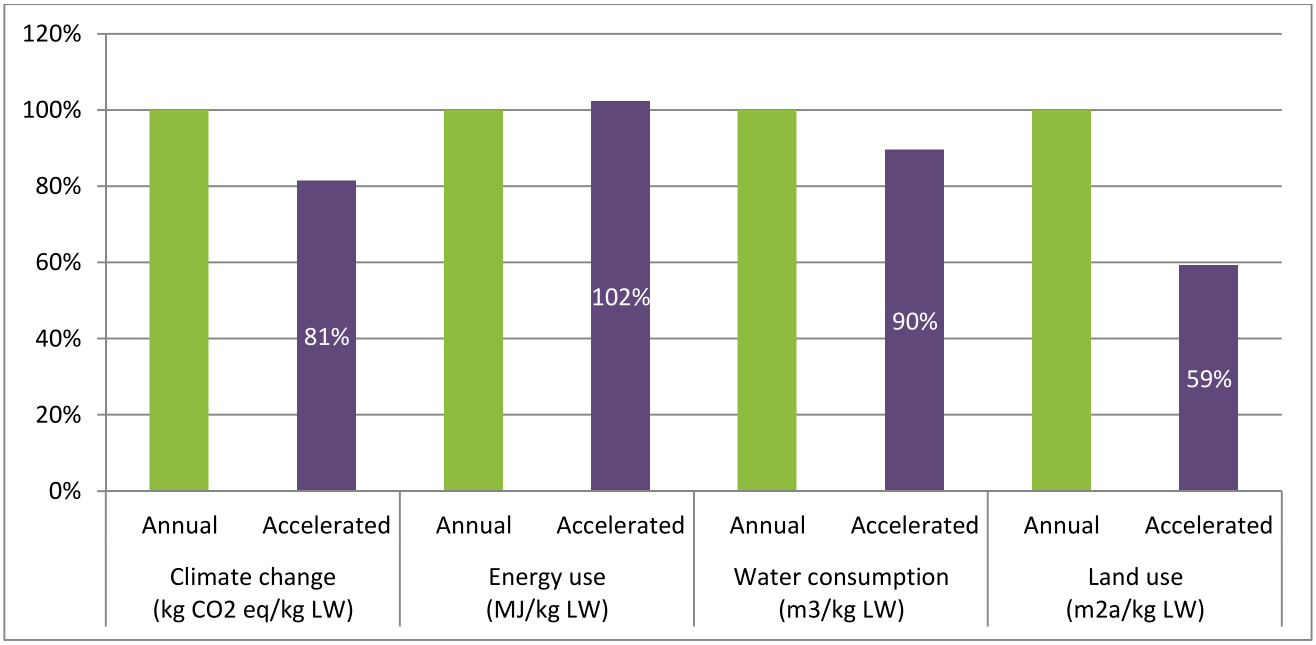

Figure 1.2 Relative comparison of life cycle impacts for annual and accelerated lambing systems

Results indicate that farms using an accelerated lambing system have potentially lower climate change impacts by approximately 19% in comparison to the annual lambing system. While energy use impacts are fairly similar between lambing systems, the water consumption and land use results are respectively 10% and 41% higher for the annual lambing system.

Here is the summary of the study's main findings regarding the comparison between both systems:

- Although the accelerated lambing system will produce more enteric emissions as a whole, the number of enteric emissions produced per kg of live weight produced is smaller than for the annual lambing system. This can be explained by the higher number of lambs per ewe in the accelerated system, which translates into a higher productivity since more lamb meat can be sent for processing.
- Forage-based diets, mostly associated to annual lambing systems, reduce feed digestibility, hence increasing the amount of enteric methane emissions produced. However, grain production has a greater impact than forage production due to the higher fertilizer application rates associated with grain production, which generates GHG emissions during the production phase of fertilizers and emissions when they are applied on crops.
- Based on a sensitivity analysis, increasing the proportion of forages in the diet of sheep improves the carbon footprint of sheep production when using an annual lambing system. The positive impact of grain feed on reducing enteric emissions is counterbalanced by the increase in environmental impacts related to grain production.
- Annual lambing systems, associated with a higher proportion of pastures and forages in the sheep diet further benefit from the positive contribution of forages to

carbon sequestration. On the other hand, the conventional tillage practises used in the cultivation of annual crops reduce carbon sequestration.

In addition, a series of sensitivity analyses were performed to better understand the influence of the feed composition and the number of lambs per ewe, which varied between farmers.

When compared to other studies, Ontario sheep generates between 135 kg CO_2 eq./kg protein (accelerated lambing) and 166 kg CO_2 eq./kg protein (annual lambing), which is in the lower range of world average carbon intensity calculated for small ruminants by the FAO's GLEAM initiative (varying between 100 and 300 kg CO_2 eq./kg protein).

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1. INTRODUCTION

The increasing awareness of the importance of environmental consequences associated with agricultural products and services has sparked the innovation of methods to better understand and proactively manage the potential impacts. A leading tool in the field – the only tool that can fully evaluate all the sources and types of impacts—is the life cycle assessment (LCA), a framework defined by the International Organization for Standardization (ISO) 14040-14044 standards (ISO 2006a; ISO 2006b).

LCA is an internationally recognized method that assesses potential environmental and human health impacts associated with products and services throughout their life cycles from raw materials extraction and including transportation, production, use and end-of-life management. This type of comprehensive analysis requires a substantial amount of high-quality, detailed information.

Depending on the objective of the project, a study may only focus on a certain part of the life cycle. For example, major commodity producers (e.g. agri-food producers) may want to adopt a cradle-to-farm gate approach to determine the impacts of producing a commodity, and not its subsequent transformation and use. This may be the case for producers (or producer associations) responding to agri-food producer or retailer requests when asked by consumers or stakeholders to communicate their environmental footprints. This type of assessment will help producers better understand the environmental impacts. The information can be shared with stakeholders, including those who aim to conduct LCAs using the commodity.

LCA is the only tool to assess the environmental impacts of products and services from a holistic point of view. LCA can determine the relative contributions of life cycle stages, providing opportunities to improve the environmental performances of products at various points in the life cycles, inform decision-making and support marketing and communication efforts. It is important to note that the impacts described by LCA are estimates of potential impacts and not direct measurements of actual impacts, with the limitations described in the ISO 14040 standard series.

The Ontario Sheep Marketing Agency (OSMA) is a producer operated organization which represents all aspects of the sheep, lamb and wool industry in Ontario. It was established to encourage, promote and represent the industry. The OSMA works to improve the marketing of sheep, lamb and wool through producer education, promotional campaigns, consumer education and public awareness.

OSMA is seeking to conduct an environmental assessment of the sheep production in Ontario that could be used to establish a baseline against which the sector will benchmark its performance over time and to identify priority areas for footprint reduction and mitigation in the context of an anticipated increase in production.

Through this project, OSMA aims at demonstrating responsible stewardship of the environment as well as its proactive approach toward continuous improvement. It should be noted that this initiative is in line with the Agricultural Adaptation Council's priority area of focus on Environment and Climate Change Adaptation.

Several studies on livestock LCA were conducted at the international level. For instance, the FAO's Global Livestock Environmental Assessment Model (GLEAM) provides an overview of the GHG emissions for different livestock value chains (FAO, 2013). The results of such a model are global averages, but are still of interest as they provide perspective on the relative positioning of the sheep sector:

- At a sectorial level, the small ruminants sector is among the lowest contributors to global GHG emission (after poultry)
- Yet, expressed per protein basis, the small ruminants sector has a relatively high emission intensity (after beef, significantly over milk and pork)
- This intensity varies significantly – from 100 to 300 kg CO_2 eq./kg protein – depending on the regions of production and production systems
- The report also highlights that there is a significant mitigation potential (30% reduction) assuming that producers would adopt best management practices (BMPs)

In Ontario, where the sheep production is anticipated to increase in the coming years, there is definitely a necessity and a rationale to establish a contextualized baseline to understand where the sector stands, how it can be improved and what the opportunities for improvement are.

The approach proposed for measuring the environmental performance is the Life Cycle Assessment (LCA), an internationally recognized analytical tool that is compliant with the ISO 14040 series. In this project, Groupe AGÉCO is proposing to conduct the LCA, an internationally recognized analytical tool that follows ISO 14040 series that will follow the methodological guidelines for the environmental assessment of the small ruminants supply chain as proposed by the FAO (FAO, 2016). Four environmental indicators will be considered in this study: energy use, greenhouses gas (GHG) emissions, water consumption and land use.

2. Goal and Scope of the Study

This section describes the goal and scope of the study and the methodological framework of the LCA. It includes the objectives of the study, a general description of sheep production activities, the functional unit, the system boundaries, the data sources and the data quality requirements.

This study aims to characterize current practices in Ontario sheep production from an environmental perspective. More specifically, the objectives of the study are as follows:

- Conduct a streamlined life cycle assessment (LCA) of sheep production in Ontario to quantify its environmental impact;
- Identify priority areas for footprint reduction;
- Assess potential footprint reduction or increase of different scenarios (e.g. production intensification, indoor housing trend, etc.) and;
- Determine a baseline against which the sector will be able to benchmark its performance over time.

Target audiences include the Ontario Sheep Marketing Agency (OSMA) and its members. The interpretation of the results will allow to define broad recommendations regarding opportunities about footprint reduction. However, the definition and assessment of specific recommendations (e.g. which best management practices should be implemented) require the input of experts and stakeholders, which is beyond of the project’s scope. Groupe AGECO has developed a robust expertise in organizing and managing such consultation and we could support OSMA in a subsequent project for this task.

This study is considered a streamlined LCA because it relies mainly on readily available information on the production of sheep in Ontario and expert estimates. No specific survey on sheep producer activities and practices was conducted for this study. Also, no independent external review of the report has been carried out. However, the study was conducted in a way to ensure compliance with the main requirements of the ISO 14040 series of standards.

3. GENERAL DESCRIPTION OF THE STUDIED SYSTEM

The Ontario sheep industry is comprised of approximately 3800 farms, accounting for 30% of the total sheep population in Canada (OSMA, 2008). Sheep production at the farm consists of managing a population of adult ewes that will reproduce and ensure regeneration of the sheep flock.

In annual lambing systems, sheep farmers in Ontario typically breed ewes during the fall (late October to November). Most sheep-producing farms in Ontario using an annual lambing system are farm flocks which combine pasture grazing for warmer months and indoor housing during the winter months (OSMA, 2008). Adult ewes will typically be housed in the weeks preceding lambing and will be fed forages and supplementary grains and concentrates. After five months of pregnancy, lambing occurs in spring and this enables lamb growth to be synchronized with grass growth in pastures. Once lambing is finished, ewes and lambs are sent out to graze on pasture. Between the first week and weaning, which occurs after 70 to 95 days, lambs are generally fed with a creep feed mostly composed of grains in order to provide extra nutrition to the lambs. It will usually take five months for lambs to reach a marketable weight of 40.1 to 45.4 kg. During the last two months before slaughter, some lambs will be fed high-energy diets at feedlots in order to maximize weight gain. A portion of the ewe lamb flock will be used to replace the dead or unproductive adult ewes that were culled.

In the case of accelerated lambing where lambing occurs three times in two years, sheep producers aim to market lambs on a year-round basis to take advantage of higher market prices throughout the year. As such, lambs will be weaned in less than two months and will be marketed at 3 to 4 months of age. Sheep and lambs will often be confined year-round in pens instead of pastures and sheep will typically be fed with higher levels of concentrates and grains.

3.1 FUNCTIONAL UNIT

Life cycle assessment relies on a functional unit as a reference to evaluate the components within a single system or among multiple systems on a common basis. It is critical for the parameter to be clearly defined and measurable. In this case, the function is to produce sheep for human consumption.

The functional unit is the production of one (1) kg of live weight Ontario-produced sheep meat at the farm gate

3.2 BOUNDARIES AND ASSUMPTIONS

The system boundaries determine the life cycle stages, processes and flows considered in the LCA and should include all activities relevant to attaining the study objectives. They are therefore necessary to provide the specified function. The following paragraphs present a general description of the system, the temporal and geographical boundaries of the study and the exclusions.

The study assesses the life cycle of Ontario sheep production from the extraction and processing of raw materials and energy carrier for all farm inputs to the use of these inputs and other types of activity on the farm. Within each of these stages, the LCA considers all identifiable upstream inputs to provide a comprehensive view of the production system.

Various practices are implemented to produce Ontario sheep. More specifically, feeding and lambing strategies, as well as manure management, can vary between producers. In that sense, the analysis will focus on two separate production models, one using an annual lambing system and the other using an accelerated lambing system (three lamb crops per ewe every two years).

The project team worked in collaboration with industry experts to better understand common farm practises and conventional Ontario sheep production. Once the information was reviewed, appropriate scenarios were established for evaluation.

For the purpose of this analysis, the system was grouped into the following main life cycle stages, presented in Figure 3.1.

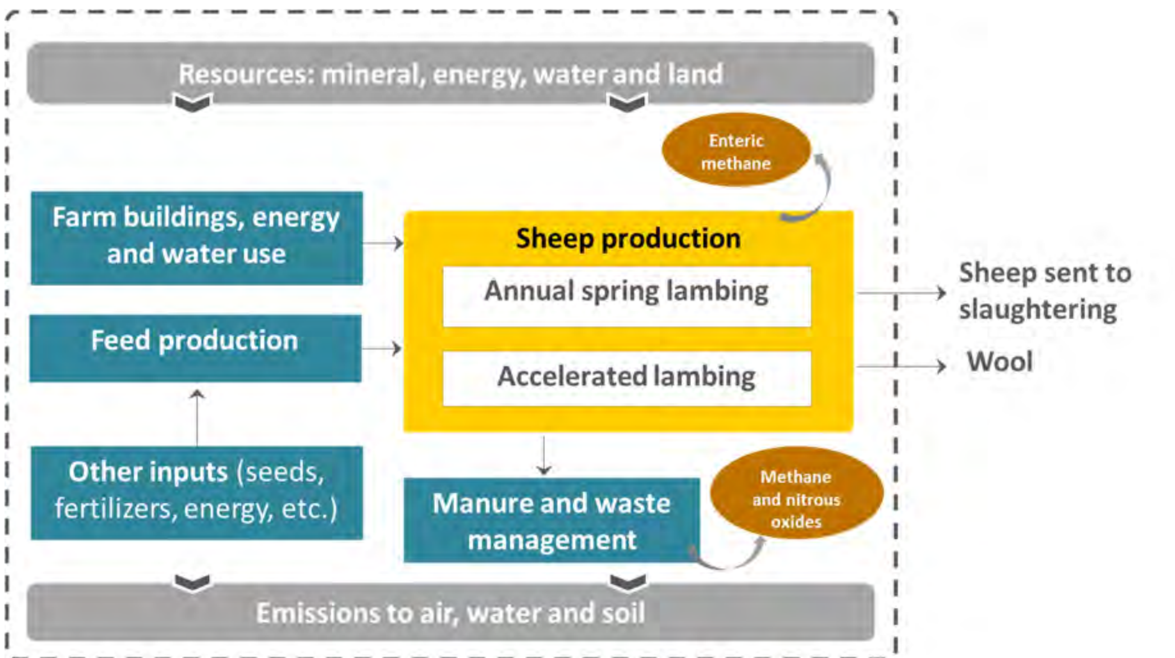

Figure 3.1 Boundaries of the cradle-to-farm gate Ontario sheep production system modelled in the life-cycle analysis

The processing stage to retail and consumer is excluded from this study. In fact, the functional unit considered in the study is the production of one kilogram of live weight Ontario-produced sheep ready to leave from the farm gate:

1. **Feed production**: extraction and processing of raw materials used to produce pesticide and synthetic fertilizers as well as their application on crops, manure spreading, direct emissions from agricultural soils, energy required for field operations and irrigation.

2. **Farm operations**: sheep and lamb rearing, energy consumption (electricity, heating and diesel fuel), buildings and water consumption.
3. **Enteric emissions**: methane emissions from the digestion process of adult sheep and lambs.
4. **Manure and waste management**: methane and nitrogen dioxide emissions produced during manure storage and treatment.

3.3 TEMPORAL AND GEOGRAPHIC BOUNDARIES

This study is intended to represent the current Ontario sheep production system and associated processes. Data was collected from the most recent reports and assumptions reflect current equipment, processes and market conditions. It should be noted, however, that certain processes within the system boundaries may take place anywhere or anytime. For example, fertilizer production can take place in North America or elsewhere in the world.

In addition, certain processes may generate emissions over a longer period of time than the reference year. For instance, fertilizer application in agricultural fields may lead to nitrous oxide (N_2O) emissions in air, which could be emitted years after the causal fertilizer application. These emissions are considered to be emitted during the year of activity.

Since the study represents sheep produced in Ontario, all data collection and process modelling aim to be as representative of the regional context, as much as possible. For example, unit processes used in the modelling rely on an electricity grid chosen on the basis of the activity's location.

3.4 ALLOCATION

LCA considers products through the functions they fulfill. Therefore, multifunctional products and processes must be considered carefully. When a process yields multiple outputs with different functions, the impacts of the process can either be allocated between the outputs or the system boundaries can be expanded to include the life cycle of the next function (i.e. product). The ISO 14044 guidelines indicate that allocation should be avoided whenever possible through the subdivision of processes or system expansion (clause 4.3.4.2). However, limitations in available data and/or project resources can render this process extremely complex, and an appropriate approach to dividing the impact across outputs must be judiciously considered.

Economic allocation was used to allocate the impacts of sheep production between the meat and the wool outputs. Based on market prices and average quantities produced annually, a factor of 99% was used for meat and 1% for wool.

For feed crops grown by sheep producers, manure is spread for its nutrient content. The feed production model therefore considers the impacts of spreading the fertilizers as well as the manure in the field which will be associated with nitrous oxide emissions. If the manure is sold or exported from the farm to another user, a cut-off approach is applied and the impact of spreading the manure and its associated nitrous oxide emissions are allocated to the user of the manure. It is important to note that this study assumed that all the manure is used efficiently in respect of the crop nutrient requirements and other aspects of nutrient management plan.

4. Data collection

4.1 Data sources

The quality of the LCA results depends on the quality of the data used in the evaluation. For this study, every effort was made to use the most credible and representative information available. The life cycle inventory (LCI) was established based on different data sources. Whenever possible, primary data was collected (measured data from study area, in this case); otherwise secondary data from databases, articles from literature and expert recommendations was used. In this study, the inventory data consists of as much primary data as possible, assembled from industry records and surveys.

The information used in this study was mainly based on data from OMAFRA publications, including a 2009-2011 analysis report on Ontario sheep enterprises, as well as an OSMA benchmarking study covering 2009 data and information for 34 Ontario producers. The model data and key hypotheses were validated by an extensive sheep producer located in Northern Ontario as well as sheep production experts from OSMA. Furthermore, a CECPA 2011 cost of production study for Quebec was used for specific population parameters as well as feed composition values. In accordance with LEAP guidelines, the IPCC (IPCC, 2006) was used as the default methodology for enteric and manure emissions, as well as for gross energy and feed intake requirements.

The main sources of data are summarized in Table 4.1. When no site-specific data were available, life cycle inventory databases—mainly ecoinvent v3.3—were adapted or used as is. The ecoinvent database is currently the world’s leading database with consistent and transparent, up-to-date life cycle inventory (LCI) data. Ecoinvent is internationally recognized by many experts in the field as one of the most complete LCI databases available, from quantitative (number of included processes) and qualitative (quality of the validation processes, data completeness, etc.) perspectives. The credibility and transparency of the database make it an advantageous option to publish the LCI datasets generated by this study.

Table 4.2 shows the ecoinvent processes used in the model that were adapted to be representative of sheep production in Ontario. As a last resort, when assumptions were necessary and activity data was not available, stakeholders and experts were consulted to determine specific values.

Table 4.1
Main data sources

Data	Source
Sheep population model	OMAFRA data (CECPA, 2013) (OSMA, 2009) Interview with producers
Farm infrastructure and energy use	OMAFRA analysis report (2010-2011)
Feed (consumption and composition) and water consumption	OMAFRA data (CECPA, 2013) OSMA information Interview with producers
Enteric emissions and manure emissions	(IPCC, 2006)
Gross energy and feed intake requirements	(IPCC, 2006)
Transport distances for background resources (fuels), electricity production at the plants	Ecoinvent data
Crop management practices, cultivation practises and fertilizer application rates	Ecoinvent data

Table 4.2
Adapted ecoinvent processes

Background processes	Description
Energy	For the background energy processes used in the main processes, the electrical grid mix was adjusted to reflect Ontario's electrical grid (i.e. the breakdown of different electrical sources to produce one energy unit (e.g. kWh) of electricity).
Crop production	The data for crop production (energy requirements, fertilization, on field emission factors, yield, pesticides and cultivation system, etc.) is based on ecoinvent data for the region of Québec (Canada).
Buildings and equipment	The model assumes a lifetime of 50 years for the sheds and accounts for periodic improvements and renovations.

4.2 INVENTORY DATA

The life cycle inventory data relates to the production of 1 kg of live weight Ontario-produced sheep meat. The following section lists the values of the main parameters used in the study, which are presented by main life cycle stage. This section also describes the main assumptions made for each life cycle stage.

4.2.1 SHEEP POPULATION MODELLING

In order to calculate the total GHG emissions from sheep products over a period of one year, it was necessary to define the animal population associated with the production of these products based on the FAO methodological guidelines for the environmental assessment of small ruminants supply chain.

Using data gathered from the OSMA and OMAFRA reports for sheep production in Ontario, two models were developed: an annual lambing production system and an accelerated lambing production system. The population parameters used in the model are presented in Table 4.3. The sheep population for both of these models were constructed from the following parameters:

- Number of ewe sheep (see Table 4.4)
- Number of lambs produced per ewe
- Lamb and sheep mortality rates
- Herd replacement rate (percentage of adult animals in the herd replaced by younger adult animals)
- Cull rates (percentage of adult sheep sent for processing)

Table 4.3
Sheep population modelling parameters

Parameter	Annual lambing	Accelerated lambing
Lambs per ewe	1.4	2
Lamb mortality	10%	12%
Adult ewe mortality	3%	3.5%
Adult ram mortality	5%	10%
Replacement rate	19%	19%
Ewe cull rate	16%	15%
Ram cull rate	20%	20%

Table 4.4
Sheep population

Population on farm	Population on farm (annual lambing)	Population on farm (accelerated lambing)
Adult ewes	584	482
Adult rams	19	19
Lambs weaned	818	964
Replacement ewe hogget	111	89
Replacement ram hogget	4	4
Ewe adults sent for processing	93	72
Ram adults sent for processing	4	4
Lambs sent for processing	703	871

The number of lambs per ewe is typically higher for larger commercial farms as opposed to smaller production systems as to ensure profitability.

Lamb mortality rates are usually slightly higher for accelerated lambing systems where lambs come from prolific breeds with higher mortality rates (OMAFRA, 2010). In addition, because ewes in accelerated systems lamb more frequently, they are exposed to a higher mortality rate and will therefore need to be replaced more often, hence explaining the higher replacement rates. A larger number of replacement ewes will therefore be necessary to maintain the productivity and fecundity of the sheep flock.

Based on these parameters and the number of adult sheep ewes and rams, the number of animals for each group was calculated as shown in Table 4.4. The number of adult sheep ewes for each system corresponds to the 2011 average for 20 Ontario farms (OMAFRA, 2013). In comparison to the annual lambing system, the accelerated lambing system comprises less adult sheep ewes but a larger number of lambs. Because ewes reproduce more frequently in accelerated lambing systems, the number of lambs sent for processing is 24% higher than in annual lambing systems, despite a lower number of female sheep.

Furthermore, the sheep live weight for each animal group was necessary to calculate the annual meat production. These live weights were based on the OMAFRA data and the 2009 OSMA benchmarking study and are presented in Table 4.5. The values were used to calculate the annual live weight sent for processing. It was assumed that lambs re weaned after 2.5 months in the annual lambing system as opposed and 1.75 months for the accelerated lambing system, and that lambs are sent for slaughter after 5 months and 3.5 months for the annual and accelerated lambing system, respectively.

Table 4.5
Sheep and lamb live weights

Parameter	Annual lambing	Accelerated lambing
Lamb at weaning (kg LW)	28.3	22.7
Lamb sent for slaughtering (kg LW)	41	47.6
Adult ewe (kg LW)	65.7	71.6
Adult ram (kg LW)	80.0	80.0

Although lambs are sent earlier to slaughter in the accelerated lambing system, the average weight is usually higher because most of their nutritional needs are met with grains as opposed to forages or pastures. Lamb weight values reflect an average over a full year of production; while a portion of lambs will be marketed at heavier weights, many are marketed for light-weight markets which account for most of the sales.

4.2.2 Gross energy and feed digestibility

Using a Tier 2 approach, as described in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, the gross energy intake, expressed in MJ/day/head, is calculated for each sheep subcategory to determine dry matter intake and emissions related to enteric fermentation of sheep production. The gross energy requirements, as displayed in Table 4.6, correspond to the amount of energy sheep and lambs need for maintenance, growth, lactation and pregnancy.

Table 4.6
Gross energy requirements (MJ/head/day)

Parameter	Annual lambing	Accelerated lambing
Ewe sheep	22.27	22.50
Ram sheep	25.62	26.44
Ewe lamb	11.61	14.12
Ram lamb	12.47	13.51

The IPPC equations used to derive the gross energy requirements are mainly based on IPCC coefficients as well as the animal live weight and feed digestibility parameter (portion of gross energy in the feed not excreted in the faeces is known as digestible feed). Therefore, sheep weight is the main parameter that influences gross energy requirement values. Requirement values are higher for the accelerated lambing system because average animal weights, especially lamb weights, are higher than in an annual lambing system.

The gross energy requirement is also influenced to a lesser extent by feed digestibility which varies according to the proportion of grains and forages incorporated in the diet of sheep and lambs. As the proportion of grains increases, feed digestibility will in turn increase, slightly reducing the gross energy requirement value. Since the quantity of methane emissions produced is based on the gross energy requirement, this means that feed digestibility also impacts the enteric methane emissions produced by the animal. As such, a diet composed of a larger proportion of grains reduces the enteric methane emissions produced by the animals.

4.2.3 Feed production

Feed intake by sheep is one of the most important parameters, from an economical and an environmental perspective. It can vary from farm to farm and over time and seasons. Sheep are grazing ruminants and they will graze on grass and other forages. Lamb and sheep performance is impacted by the quality of these roughages. Their diet mainly consists of forages to which the farmer adds a mix of grains produced by commercial feed suppliers.

Based on the judgment of the sheep producers interviewed, the vast majority of sheep producers in annual lambing systems grow and harvest most or all of their own forage and sometimes grow their own grains while the rest is purchased from local feed mills. As such, both models assume that 90%

of forages and 20% of the grains are grown on site by sheep producers and that the rest is purchased.

However, animals in the accelerated lambing system are fed a significantly higher proportion of grains. Producers in the accelerated lambing system typically own less acreage to grow their forages, as sheep and lambs are usually totally confined in the barn.

The data related to feed composition, based on Ontario reports and expert judgment, is summarized in Table 4.7. Feed composition varies between both lambing systems and between animal age classes. Adult sheep in the accelerated lambing system are fed a higher proportion of grains, which can reach up to 50% for lactating ewes, while adult sheep in the annual lambing system feed mostly on pasture and roughages.

Lambs generally require that a larger proportion of their diet be supplemented by grains. Between the first week and weaning, lambs are generally fed with a creep feed that is mainly composed of grains. During the last 2 months before slaughter, some lambs are fed at feedlots in order for them to reach their marketable weight. Most feedlots generally incorporate approximately 95% of grains in the lamb rations. Based on interviews with sheep producers, lambs in an accelerated lambing system will usually feed on 90% of grains and 10% of forages.

Table 4.7
Feed composition for lambs and adult sheep (annual lambing)

	Annual lambing		Accelerated lambing	
	Forage	Grain	Forage	Grain
Adult ewe	80%	20%	60%	40%
Adult ram	85%	15%	60%	40%
Replacement ewe	65%	35%	60%	40%
Replacement ram	65%	35%	60%	40%
Ewe Lamb	40%	60%	10%	90%
Ram Lamb	40%	60%	10%	90%

The proportions of each forage type (pastures, hay and maize silage) included in the sheep diet is based on the OMAFRA survey data (OMAFRA, 2009) and is presented in Table 4.8.

Table 4.8
Forage composition for the forage portion of sheep diets

Forages	Annual lambing	Accelerated lambing
Corn silage	17%	17%
Hay and haylage	47%	66%
Tillable pasture	22%	12%
Rough pasture	14%	4%

Corn silage and hay included in the model were both based on the ecoinvent data for maize silage and hay production specific to the province of Quebec. As such, fertilizer quantities added by the sheep farmers to grow these crops and their associated emissions were based on the Quebec dataset in ecoinvent. Indeed, the fertilizers added on crop fields generate nitrous oxide emissions because increases in available nitrogen enhance nitrification and denitrification rates.

Tillable and rough pastures were modelled assuming that all fertilization was achieved by sheep directly depositing manure on pastures. The model assumes that 65% of manure is deposited on pastures at the annual lambing farm, as opposed to 15% for the accelerated lambing farm. Consequently, dinitrogen oxide emissions resulting from manure deposition in pastures are included in the feed production stage. The emission factors used for these emissions are presented in Table 4.13 (section 4.2.7). However, dinitrogen oxide and methane emissions related to manure managed at the farm are included in the manure management stage.

Table 4.9 shows the proportion of grains incorporated in the sheep and lamb diet, based on 2011 Quebec data from the CECPA cost of production study (CECPA, 2013). The model assumes that the grain diet composition is identical between both systems.

Table 4.9
Grain diet composition

Grain	Grain diet composition
Corn	24%
Barley	59%
Oat	17%
Wheat	1%

The quantity of feed consumed by lambs and sheep was calculated based on these ratios and on the gross energy requirements of each animal group. All grains were modelled using the Quebec dataset for grains in the ecoinvent 3.3 database. The feed inputs were modelled using a value of 85% for dry matter content. Since protein and mineral supplements represented respectively 2% and 0.5% of the sheep diet and were therefore excluded from the study since they are not a significant part of the diet (CEPCA, 2013).

The quantity of diesel and oil used for agricultural operations, including harvesting, tillage and application of chemicals, are included in the feed production stage and are based on the ecoinvent dataset for Québec.

4.2.4 CARBON SEQUESTRATION FROM LAND USE

Soil carbon, mostly because of its organic content, is the largest terrestrial carbon pool (Scharlemann, 2014). The level of carbon in soils varies depending on the activity practised on the soil, soil type and climate. The activities determine the rate at which carbon is incorporated (through plant growth and the incorporation of organic material), and carbon is depleted through oxidation (which is greatly influenced by tillage practises).

When a change in activity occurs, the carbon level of soil will adapt over time and reach a new equilibrium between oxidation and carbon intake. For example, recent changes in tillage practises towards no-till and reduced-tillage lower the rate at which carbon is oxidized. This temporarily changes the steady state of the carbon flux, and the carbon content of the soils will increase until a new equilibrium is reached.

Because significant amounts of land are being transferred from conventional to reduced-till practices, large amounts of carbon are being transferred from the atmosphere to the soils. This sequestration can be attributed to the changes in farming practices.

Though reduced-tillage practises are becoming more and more common, uncertainty lies in the persistence of the sequestration. If tillage practises or land functions change, the stored carbon could eventually be released and the storage would be temporary. Also, the mitigation effect that temporary carbon sequestration and storage can have on climate change is open to debate (Kirschbaum, 2006), and the decision to integrate temporary carbon sequestration in LCA will vary from one study to another.

The Quantification Protocol for Conservation Cropping calculated the sequestered amount of carbon based on the adoption of conservation tillage practises in recent years and proposed sequestration factors for no-till farmed land, as shown in Table 4.10 (Government of Alberta, 2012).

Table 4.10
Data and emissions factor for carbon sequestration

Ecozone	Parkland	Dry prairie
Sequestration of soil organic carbon (t CO_2 eq./ha/year)	0.25	0.13
Average sequestration of soil organic carbon (t CO_2 eq./ha/year)	0.19	

Based on these factors, we can use an average factor of 0.19 tonne CO_2 eq./ha/year to estimate the sequestration potential of pastures. The Results section includes a discussion on the positive contribution of pastures to offset part of the GHG emissions. On the other hand, the cultivation of annual crops like corn involves tillage practises which reduce the carbon sequestration potential (OMAFRA, 2016).

4.2.5 Farm Infrastructure and Energy Use

Table 4.11 shows the data used in the model for farm operation parameters. The farm infrastructure and the energy use of the farm, comprising electricity consumption, heating and equipment fuels were modelled using the ecoinvent database. A single ecoinvent barn model was used even if barn materials might differ from one farm to another.

Table 4.11
Main data for farm operations

Factor	Annual lambing	Accelerated lambing
Barn (ft^2/ewe)	8	16
Barn (ft^2/lamb)	1.8	1.8
Electricity consumption, annual (kWh/ewe sheep)	58	99
Heating fuel consumption, annual (MJ/ewe sheep)	33	83
Equipment fuel consumption, annual (MJ/ewe sheep)	114	185
Bedding straw, annual (kg/ewe sheep)	124	124
Water consumption, sheep (L/ewe sheep/day)	7.6	7.6
Water consumption, lamb (L/lamb/day)	3.8	3.8

Each ewe sheep requires 8 ft^2 of barn space in annual lambing system as opposed to 16 ft^2 of barn space for the accelerated lambing system (OMAFRA, 2009). The additional space requirements for the accelerated lambing system can be explained by the fact that producers will provide more floor space for anticipated extra lambs from more prolific ewes. The barn size was calculated based on these space requirements and the number of sheep ewes.

In an accelerated lambing system, the calculated area for the barn is based on the space requirements for ewes of 12 ft^2 per dry ewe and 20 ft^2 per lactating ewe (or ewe in labour). On that note, OMAFRA recommends 20 ft^2 per lactating ewe in accelerated flocks for additional space for anticipated extra lambs from more prolific ewes. Assuming that 50% of the sheep flock are dried and the rest is in labour, the average space requirements calculated corresponds to 16 ft^2/ewe.

In the case of the annual lambing system, the barn itself is used more as an emergency facility than as a typical housing facility and most annual flocks are outwintered in Ontario. In addition, only a portion of lambs will be confined to a feedlot while the rest will be marketed directly off pasture. According to the sheep producers interviewed, the barn size is calculated based on 50% of the sheep population. Based on this, the space requirement for annual sheep is lower for the annual lambing system.

The energy used at the farm powers ventilation, lighting, heating and mechanical machinery (e.g. feed belt conveyors). The electrical grid mix used at the farm was adjusted to reflect Ontario's electrical grid (i.e. the fraction of each electrical source such as nuclear, gas and renewables needed to produce one energy unit (e.g. kWh) of electricity). Electricity and heating fuel expenses at the farm were based on the 2009 averages for 12 farms using an annual lambing system and 16 farms using an accelerated lambing system (OMAFRA, 2009) which were converted to the physical amount of energy consumed based on Ontario's electricity price (Hydro-Québec, 2011). Barns in annual lambing systems require very little heating in the winter while sheep in accelerated lambing systems are generally housed in heated buildings during the winter. Based on the OMAFRA data, electricity and heating fuel consumption is approximately twice higher for the accelerated lambing farm.

Several farm operations require the use of diesel fuel and oil, for livestock transportation, manure removal, feed delivery to the animals and waste removal from the barn (Chen et al. 2015). The quantities of diesel and oil used for sheep operations were based on the 2009 averages for annual and accelerated farms (OMAFRA, 2009), which were converted to the amount of energy consumed based on Ontario's mean fuel price of $1.3/L (Statistics Canada, 2017). As noted earlier, the quantity of diesel and oil used for agricultural operations (harvesting, tillage, application of chemicals) is included in the feed production stage.

Based on the OMAFRA data, the amount of fuel for machinery and equipment is significantly higher in the accelerated lambing system. Since sheep and lambs are mostly confined in an accelerated lambing system, more manure and waste are generated at the farm and feed ingredients need to be mechanically delivered to the animals using diesel-powered machinery. This results in more energy-intensive farm operations for the accelerated lambing system.

The quantity of purchased fertilizer for all forages and grains produced at the sheep farm was modelled using the ecoinvent data for fertilizing requirements specific to the province of Quebec. As mentioned, the model assumes that no synthetic fertilizers are added to the tillable and rough pastures because fertilization is achieved by the sheep-deposited manure on pastures.

Farmers will usually spread bedding material across their barn, which will play an important role on the sheep's well-being and comfort. The amount of straw used for bedding is based on Quebec data from 2011, where 22.5 tonnes of straw were used in average for bedding purposes for an average herd of 517 mature ewes (CECPA, 2013). Water consumption differed between adult sheep and lambs and is based on recommendations from OSMA's document "Nutrition, feeding and the digestive system."

4.2.6 Enteric methane

Ruminant animals like cattle and sheep produce enteric methane due to enteric fermentation of the food ingested in the animal's digestive tract or rumen. According to the Global Livestock Environmental Assessment Model developed by the FAO, the global emission intensity for beef production is 295 kg CO_2 eq. per kg of protein, as opposed to 201 kg CO_2 eq. per kg of protein for small ruminants like sheep.

The emission factors are presented in 0 and the emission model for enteric methane is described in Appendix A.

Table 4.12
Enteric methane emission factors (kg CH_4/head/year)

	Annual lambing	Accelerated lambing
Ewe sheep	9.49	9.59
Ram sheep	10.92	11.27
Ewe lamb	3.43	4.17
Ram lamb	3.68	3.99

The reference manual of the IPCC Guidelines provides default emission factors to estimate methane emissions from enteric fermentation. However, a Tier 2 approach was used based on the IPCC Guidelines to calculate methane emission factors based on methane conversion factors and gross energy intake for each sheep category, including ewe and ram sheep as well as ewe and ram lambs. Since the quantity of methane emissions produced is based on the gross energy requirement, the higher energy requirements for sheep and lambs in the accelerated lambing system translate into higher enteric emission factors.

4.2.7 Manure management

The manure management stage includes methane and nitrous oxide (direct and indirect) caused by the storage and treatment of manure. In an annual lambing system, since sheep and lambs spend most of the time on pastures, most of the manure is directly deposited on the pastures. Therefore, the model assumes that 35% of all the manure generated will be managed at the farm and the rest is deposited directly on pastures. For the accelerated lambing system, the model assumes that 85% of the manure generated by the animals is managed at the farm since most animals are confined in the farm. Therefore, the manure management stage only considers the dinitrogen oxide and methane emissions related to the manure managed at the farm. The dinitrogen oxide emissions resulting from manure deposition in pastures are included in the feed production stage.

Methane is produced from anaerobic fermentation of stored manure. Different parameters, including the type of manure management, the quantity of volatile solids excreted in manure and the methane-producing capacity have an impact on the amount of methane produced. Nitrous oxide emissions result from direct emissions during manure storage and from indirect emissions produced by nitrogen leaching and volatilization. Again, parameters related to the type of manure management system and the nitrogen excretion rates, as well as emission factors are used to calculate the amount of N_2O produced.

The emission factors used to estimate these emissions are summarized in Table 4.13 and the emission models are described in detail in Appendix A.

Table 4.13
Manure emission factors (kg animal^{-1} yr^{-1})

Manure emissions		Ewe sheep	Ram sheep	Ewe lamb	Ram lamb
Annual lambing	CH_4	0.134	0.155	0.063	0.068
	N_2O (direct)	0.102		0.029	
	N_2O (indirect)	0.010		0.003	
	N_2O (pasture, range and paddock)	0.146		0.041	
Accelerated lambing	CH_4	0.314	0.369	0.172	0.164
	NO_2 (direct)	0.274		0.057	
	NO_2 (indirect)	0.027		0.006	
	N_2O (pasture, range and paddock)	0.161		0.033	

The emission models for enteric emissions and manure management are summarized in Table 4.14, and a full description can be found in Appendix A.

Table 4.14
Emission models used in the study

Emission type & Source	Model	Description
Enteric CH_4	IPCC model (2006), Chapter 10, Tier 2 approach	Appendix A, section 10
CH_4, manure management	IPCC model (2006), Chapter 10, Tier 2 approach	Appendix A, section 11
N_2O, manure management	IPCC model (2006), Chapter 10, Tier 2 approach	Appendix A, section 12
N_2O, deposited on pastures	IPCC model (2006), Chapter 11, Tier 2 approach	Appendix A, section 13

5. Impact assessment method

The life cycle impact assessment (LCIA) classifies and combines each product system's input and output flows of materials, energy and emissions by the type of impact their use or release has on the environment. These flows, which interact with the environment, are then evaluated for the potential effects they may have on different environmental issues.

The LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks. No data normalization was completed in order to avoid impact category comparisons. In addition, the indicators were not weighted, and all five damage categories were considered separately to avoid aggregation, which can bias the interpretation of the results.

The environmental indicators reported in this study are briefly described below.

5.1 Environmental indicators

5.1.1 Climate change

The climate change impact indicator, or carbon footprint, measures the amount of greenhouse gases emitted to the environment. It is calculated based on the 2013 Global Warming Potential (GWP) factors published by the IPCC in the Fifth Assessment Report (AR5). The indicator is expressed as Global Warming Potential for a time horizon of 100 years (GWP100) in kilograms of carbon dioxide equivalents (CO_2 eq.). The greenhouse effect is a natural phenomenon: greenhouse gases trap part of the sun's rays, keeping some of the heat inside the atmosphere and making life on earth possible (average temperature of 15°C). According to the IPCC, human activities intensify the concentration of greenhouse gases (e.g. CO_2) in the atmosphere, which trap more solar radiation and consequently modify the temperature on earth. This phenomenon is known as climate change. The indicator measures kilograms of CO_2 eq. (carbon dioxide equivalent), the reference unit to which other greenhouse gas emissions are converted.

5.1.2 Energy use

This indicator, expressed in megajoules (MJ) of non-renewable primary energy, measures the amount of non-renewable energy extracted from the earth contained in the fossil energy carrier (coal, oil and natural gas) or uranium ore. The result corresponds to the sum of the High Heating Value (HHV) of all the non-renewable energy carriers extracted and used during the life cycle of sheep production system.

5.1.3 Land use

The land use indicator is a measure of the amount of land occupied by the activities related to the sheep production life cycle such as feed production. It is expressed as the total area of land used during one year (m^2·year).

5.1.4 WATER CONSUMPTION

The water consumption indicator evaluation is a method covered by the ISO 14046 standard. This indicator is simply the sum of all fresh water withdrawals in each watershed minus all water returns to the same watershed. Consequently, water evaporated, included in the final product or exported in another watershed is considered consumed and no more available for the other users downstream the initial watershed.

5.2 EQUIVALENT FACTORS

In order to communicate the results, reference benchmarks in this study were expressed as equivalent factors for each impact category which reflect daily life activities such as the distance travelled by car, the area of forested areas transformed to parking lots, litres of oil, or the number of showers. These benchmarks expressed as equivalent factors provide non-LCA expert audiences with a meaningful and accessible way of presenting the information on the environmental impacts of sheep production.

- Climate change indicator results (kg CO_2 eq.) are presented in car travel kilometres or number of cars on the road. A factor of 1 kg CO_2 eq. is equal to 5.6 km, while one car on the road generates in average 4.7 tonnes CO_2 eq. each year.
- Energy use indicator results (in MJ of non-renewable primary energy) are presented in barrels of crude oil based on an oil energy content of 42 MJ/kg and an oil density of 0.8 kg/L and a barrel volume of 159 L.
- Water consumption indicator results are presented in a number of Olympic-size swimming pools. A factor of 2.5 million litres of water is equal to the water volume of one Olympic-size swimming pool.
- Land use indicator results are presented in a number of American football fields, each of which covers an area of 5351 m^2.

It is important to note that these equivalents are meant as tools to help compare the impact results (e.g. comparing the contributions of life cycle stages).

5.3 CALCULATION TOOL

SimaPro 7.3.3 (www.pre.nl) was used for LCA modelling. It links the reference flows with the life cycle inventory database and computes the complete life cycle inventories of the systems. The final life cycle inventory result was calculated by combining foreground data (intermediate products and elementary flows) and generic datasets, providing cradle-to-gate background elementary flows to create a complete inventory of both systems.

5.3.1 SENSITIVITY ANALYSES

The model assumptions on feed composition and number of lambs per ewe were tested out through sensitivity analyses in order to better understand their influence on baseline results. These sensitivity analyses helped identify the main drivers and levers in the environmental profile of Ontario sheep production and results are presented in Section 7.

6. LIFE CYCLE IMPACT ASSESSMENT

This section presents the results of the environmental LCA for sheep production in Ontario for four impact indicators: climate change, energy use, land use and water consumption. The information provided in this section should only be used within the context of the boundaries and assumptions of the study and in consideration of this study's limitations. The following sections also present the results for each impact indicator.

6.1 OVERALL RESULTS FOR ONTARIO SHEEP PRODUCTION

The results of the average environmental profile of one kilogram of live weight Ontario-produced sheep are summarized in Figure 6.1. The average is calculated based on the annual and accelerated lambing models, assuming that 50% of Ontario sheep farms use an annual lambing system and 50% use an accelerated lambing system. The production of one (1) kilogram live weight sheep leads to an emission of 10.6 kg CO_2 eq. Based on a total production of 167 000 sheep ewes in Ontario in 2017, this translates into an annual 137 000 tonnes of CO_2 eq. for the province of Ontario, the equivalent of 7.7 x 108 kilometres of car travel or 30 000 cars on the road for one year.

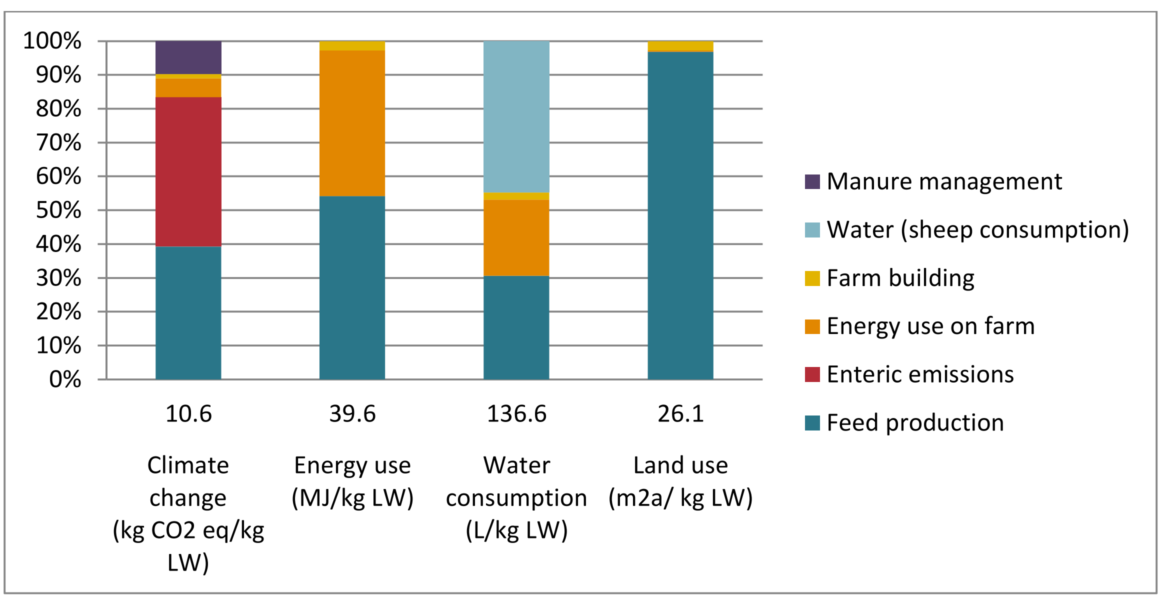

Figure 6.1 Environmental footprint profile of an average kilogram live weight Ontario-produced sheep

Among the life cycle stages, enteric emissions and feed production contribute to the majority of climate change impacts, representing respectively 44% and 39% of impacts for the climate change indicator. The production of one (1) kilogram live weight sheep requires an average 136.6 litres of water and 39.6 MJ of energy. Based on the overall annual production in the province of Ontario, these translate into an annual 1.77 x 109 litres of water, the equivalent of 700 Olympic-size swimming pools, and 5.14 x 108 MJ of energy, the equivalent of 88 000 barrels of crude oil. The water consumed by sheep and lambs accounts for 45% of the water consumption indicator and 97% of the land use impacts are represented by the feed production stage. The production of one (1) kilogram live weight sheep consumes 26.1 m^2·a of land. Based on the overall annual production in Ontario, this translates into an annual 3.38 x 108 m^2·a of land use, the equivalent of 63 000 American football fields.

6.2 CLIMATE CHANGE RESULTS

Table 6.2 displays the contribution of climate change by life cycle stage for both annual and accelerated lambing systems. The production of 1 kg of live weight sheep results in the emission of 11.7 kg CO_2 eq. for the annual lambing system and of 9.5 kg CO_2 eq. for the accelerated lambing system. Looking at the entire farm on an annual basis, these results correspond to the annual emission of 412 tonnes of GHG for the annual lambing farm and 447 tonnes of GHG for the accelerated lambing farm which translate respectively in approximately 75 500 km and 85 000 km of car travel.

Results indicate that enteric emissions are the main contributor, representing 39% (accelerated lambing) to 48% (annual lambing) of the overall impact. The second main contributor is the feed production stage, representing approximately 39% of the impact category. The manure management stage represents 7% and 14% of overall climate change impacts while the energy used on the farm contributes to approximately 6% of impacts. The farm infrastructure stage accounts for an insignificant portion of GHG emissions.

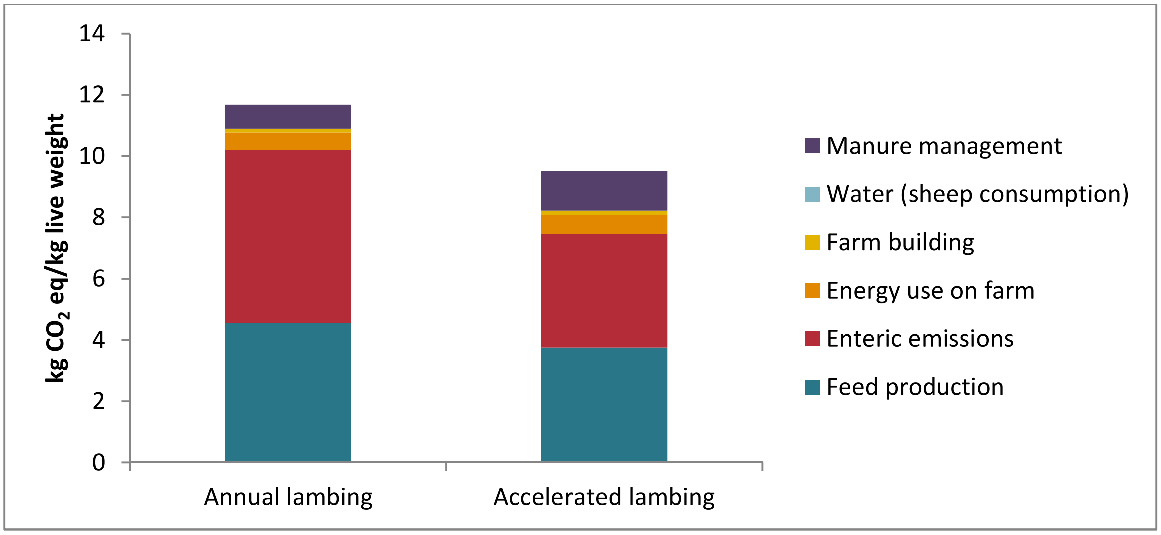

Figure 6.2 Contribution of each life cycle stage to the climate change impact for 1 kg of live-weight Ontario-produced sheep

6.2.2 Enteric emissions

Enteric fermentation is the main contributor to GHG emissions, mostly attributable to the gross energy requirements of sheep and lambs which will vary according to animal weight and the type of diet fed to the animals. The enteric emission factor, as expressed in kg CO_2 eq. $head^{-1}$ $year^{-1}$, is higher for adult sheep as opposed to lambs because of higher gross energy requirements and a higher proportion of gross energy in feed converted to methane. Appendix A provides all details on how enteric emissions are calculated.

As seen in Figure 6.3, adult ewes in an annual lambing system are responsible for 80% of enteric emissions while lambs produce approximately 20% of enteric emissions. For the accelerated lambing system, these proportions change to 76% for adult sheep and 24% for lambs. This difference can be explained by the fact that the accelerated lambing system modelled includes less adult ewes and a higher number of lambs.

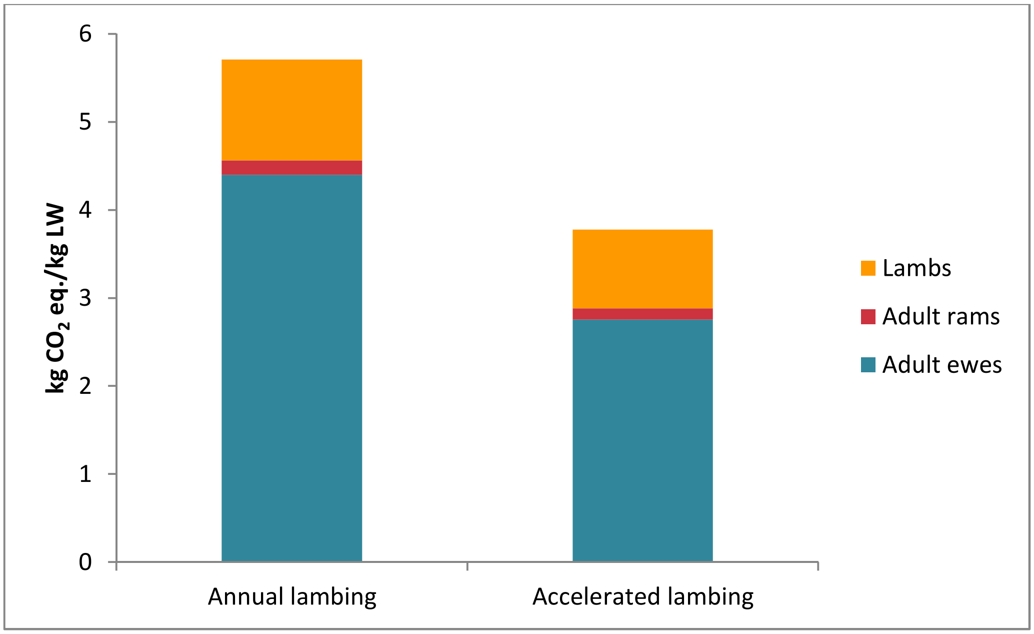

Figure 6.3 Contribution of animal groups to climate change impacts related to enteric emissions

The accelerated lambing system reduces enteric emissions by 1.9 kg CO_2 eq./kg LW, a reduction of 35% compared with the annual lambing system. The higher number of lambs per ewe in the accelerated system translates into a higher productivity since more lamb meat can be sent to processing. Although the accelerated lambing system will produce more enteric emissions on an absolute basis, the amount of enteric emissions produced per kg of live weight produced is smaller than for the annual lambing system. This explains why ewes in the accelerated system have a higher enteric emission rate per head, even though the number of ewes per kg of live weight produced is much smaller, hence reducing the relative quantity of enteric methane emitted.

While productivity is a key factor to explain differences between the two systems, feed composition also influences enteric emissions. Since pasture-based diets reduce feed digestibility, the amount of enteric methane emissions produced will be greater, as in the case of the annual lambing system. A sensitivity analysis was performed in Section 5.1 in order to better understand the contribution of feed composition to enteric emissions.

6.2.3 Feed production

Feed is an important contributor to climate change, representing 39% of the total climate change impact results. The accelerated lambing system reduces emissions from feed production by 0.8 kg CO_2 eq./kg LW, a reduction of 18% compared with the annual lambing system. Although the accelerated system uses more feed per head, the impacts are counterbalanced by an overall increase in productivity, allowing feed to be used more efficiently than in the annual lambing system.

In order to contribute to a better understanding of the results, Table 6.4 shows the distribution of climate change impacts between the different feed ingredients.

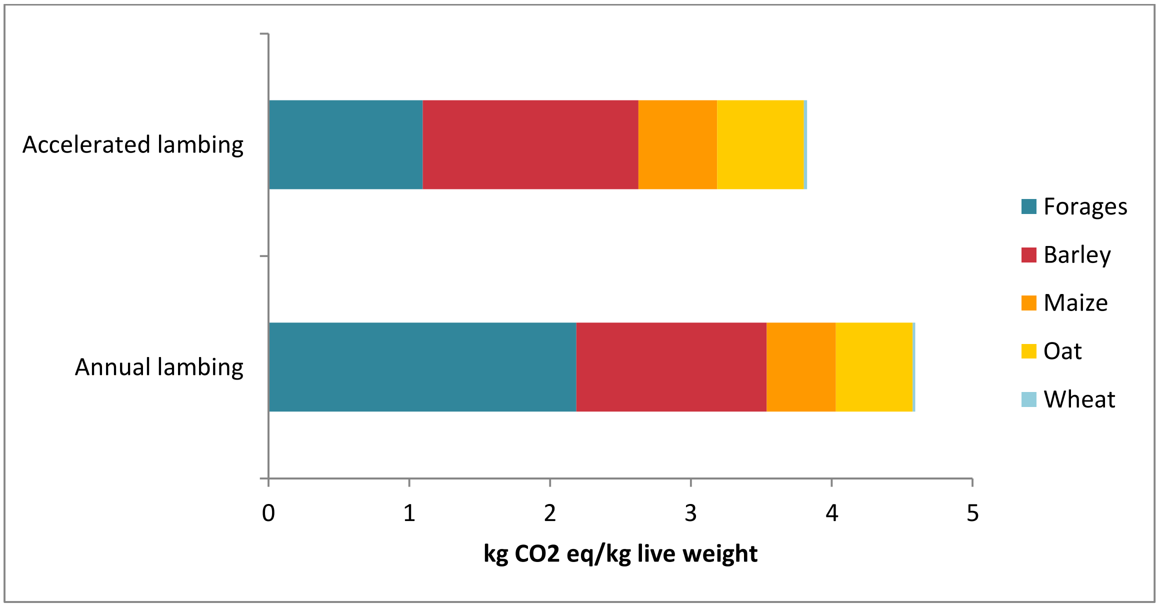

Figure 6.4 Contribution of feed ingredients to the climate change impact of the feed production life stage for 1 kg of live-weight Ontario-produced sheep

It is interesting to notice how differences in diets between lambing systems influence the climate change impact results. For the annual lambing system, the contribution of forages to the overall impact is greater because adult sheep feed composition is approximately 80% of forages as opposed to 60% for the accelerated lambing system. The grain portion of the diet accounts for most of the impacts, with barley as the main contributor since it represents 59% of the grains fed to sheep and lambs.

To understand how impact results vary between both systems, Figure 6.5 describes the climate change impact generated from the production of 1 kg of each feed in the sheep's diet formulation. For each feed ingredient, the impact results shown include the portion of feed that was produced on site as well as the portion of feed that was purchased. The comparison does not take into account the calorific or nutritional value of the feed but only the impact of producing 1 kg of the feed crop.

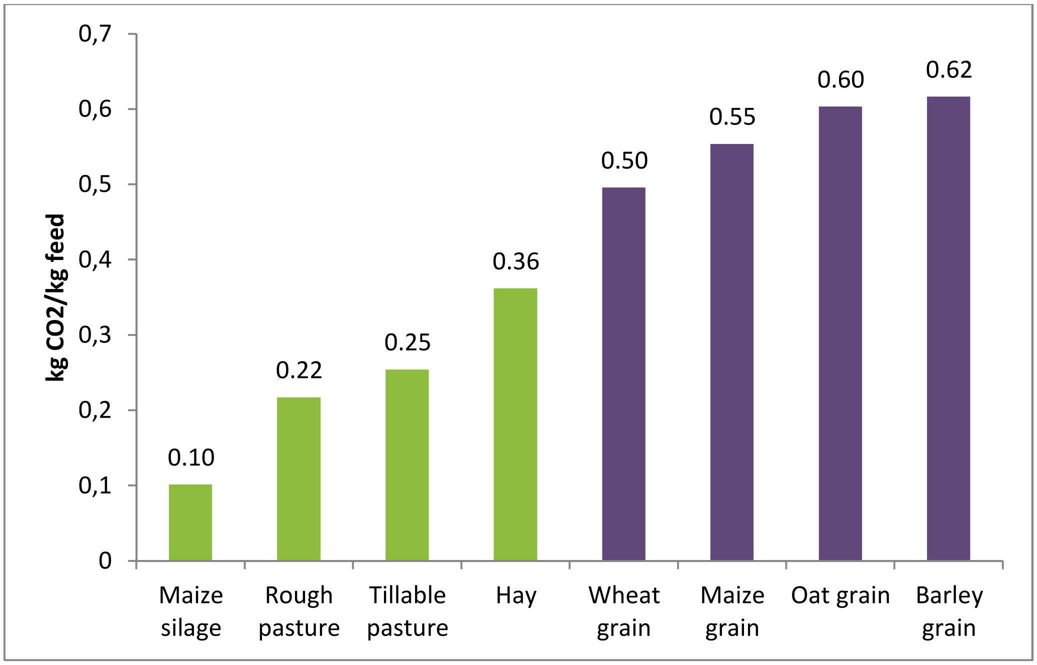

Figure 6.5 Comparison of climate change impacts for the production of 1 kg of feed ingredients

Grain production has a significantly greater impact than pasture and maize silage production. This can be explained by the higher fertilizer application rate associated with grain production, which generates GHG emissions during the production stage of fertilizers and emissions when they are applied on crops. N-fertilizers significantly contribute to GHG emissions due to the natural gas usage for their production and significant emissions of nitrous oxide resulting from fertilizer application, and carbon dioxide in the specific case of urea.

However, not all fertilizers convey the same environmental impacts. Indeed, fertilizer production and emissions at application are specific to the fertilizer since production processes differ between fertilizer types. The degradation of these chemicals in air, soil and water varies as well. Therefore, some fertilizers are more efficient in providing crop nutrients with fewer impacts.

In addition to implementing nutrient management planning to optimize the quantity of fertilizer used, selecting fertilizers that generate lower environmental impacts would also contribute to reducing the impacts on the feed crop life cycle. However, further investigation into the fate analysis of these chemicals in air, soil and water is strongly recommended in order to inform producers on the right source of fertilizers to apply.

Grain production is also more energy-intensive, relying on the use of fossil fuels, particularly diesel in tractors and harvesting machinery, oil in dryers and natural gas in the manufacture and application of synthetic fertilizers. On the other hand, forages and pastures generally require less fertilization and machinery, which reduces the overall GHG emissions. The GHG emissions associated with the production and manufacturing of these fertilizers can therefore be greatly reduced by incorporating sheep manure in the fertilization plan of pastures and forages.

As previously mentioned, although grain production has a greater impact than forages, feed digestibility is higher for grains, which ultimately reduces the amount of enteric emissions produced by the animals. In order to have a better understanding of this counter-effect, a sensitivity analysis on the proportion of grains in the sheep diet was performed in Section 5.1.

6.2.4 MANURE MANAGEMENT

Emissions related to the storage and treatment of sheep manure represent 7% (annual lambing system) and 14% (accelerated lambing system) of climate change impacts. The fact that manure is managed in dry storage systems in aerobic conditions contributes to limit the amount of methane emissions which are produced during the anaerobic decomposition of manure.

Climate change impacts for this stage are higher for the accelerated lambing system because larger quantities of manure are managed at the farm (85% of total manure generated by sheep), hence resulting in more emissions. On the other hand, for the annual lambing system, only a small amount of manure is actually managed on the farm since sheep and lambs spend most of their time grazing on pastures where they deposit the manure. Indeed, 65% of the manure generated at the annual lambing system is deposited by sheep on grazing pastures and is therefore not managed at the farm. Although the manure management stage is not a major contributor to the global environmental impact, a well-managed nutrient management plan at the sheep farm could lead to a more efficient use of sheep manure for the fertilization of on-farm crops and pasture, therefore reducing the quantity of purchased fertilizers. The following section aims at analyzing the nutrient management plan, including the manure produced by sheep.

Based on the data available from the OSMA and OMAFRA reports and the expertise of the producers interviewed, the nutrient management plan used by sheep producers was analyzed in order to evaluate potential areas for improvements.

Nitrogen is an essential element to promote plant growth and metabolism. Nitrogen-deficient pastures or crop fields will therefore provide lower quality feed to grazing sheep and lamb (OMAFRA, 2015). As underlined in the GLEAM report, high quality feed will improve feed digestibility and foster the productivity of the system. As a consequence, nutrient management plays an important role in mitigating climate change impacts.

Forages and crops grown on-site by sheep producers will typically be fertilized by using the manure produced by sheep as well as purchased synthetic fertilizers. Sheep manure shows relatively low levels of phosphorous and sheep producers will therefore need to purchase a quantity of synthetic fertilizers to supplement the crop with the appropriate levels of fertilization (OMAFRA, 2015). The fertilizer requirements for crops and forages are based on the ecoinvent data for the province of Quebec.

In this study, it was assumed that for grain production, the fertilization practises of sheep producers were similar to the average practices of other farmers. However, for pasture management, it was assumed that nutrient requirements were essentially provided by manure (either through direct deposit of grazing animals or spreading). Any surplus of manure was assumed to be sold or exported to other users.

In order to have a better sense of the management of nitrogen inputs at the sheep farm, a nitrogen mass balance was performed, nitrogen (N) requirements, as expressed in kilograms of nitrogen per kilograms of feed and shown in Table 6.1, and the total quantities of feed produced at the sheep farm are shown in Table 6.2. Again, this analysis is based on the assumption that 90% of the forages and 20% of the grains consumed by sheep are produced on site.

Table 6.1
Nitrogen-requirements of feed ingredients

	N-requirements (kg N/kg feed)	Source
Tillable pastures	0.036	(CRAAQ, 2003) and yields based on OMAFRA 2009 data
Rough pastures	0.034	
Corn silage	0.022	ecoinvent v3.3
Hay	0.007	
Barley	0.021	
Maize	0.022	
Oat	0.019	
Wheat	0.034	

Table 6.2
Total feed quantities consumed by sheep at the farm level (kg)

	Annual lambing	Accelerated lambing
Tillable pastures	57 598	20 830
Rough pastures	36 498	7 196
Corn silage	45 052	29 919
Hay	122 040	114 374
Barley	15 480	23 378
Maize	6 283	9 471
Oat	6 362	9 621
Wheat	267	404

Based on these values, it is possible to estimate the total quantity of nitrogen necessary for the fertilization of the feed ingredients produced at the sheep farm by multiplying the nitrogen requirements and the total feed quantities consumed by the sheep flock. Results are presented in Table 6.3.

Table 6.3
Nitrogen mass-balance
(90% forages and 20% grains produced at the sheep farm)

Total N-requirements (kg N)		
	Annual lambing	Accelerated lambing
Tillable pastures	2098	759
Rough pastures	1237	244
Corn silage	986	655
Hay	817	766
Barley	331	500
Maize	137	207
Oat	119	180
Wheat	9	14
Total	**5735**	**3325**
Nitrogen (kg) from manure	**7581**	**6988**
Nitrogen (kg) net surplus at the farm	**1846**	**3663**

Assuming that all the manure generated is used to fertilize the pastures and crop fields at the sheep farm, this would imply that an excess of 1.8 tonne (annual lambing) and 3.7 tonnes (accelerated lambing) of nitrogen per hectare per year is applied on these fields. The calculated nitrogen surplus would be higher for the accelerated lambing system because most of the sheep diet is composed of grains, of which only 20% are produced on the sheep farm. Therefore, unless a portion of the manure is sold, the quantity of sheep manure generated is too large to be spread entirely on the pastures and crop fields at the sheep farm. As mentioned, the sheep models assume that the portion of manure not deposited on the pastures is sold or exported.

The nitrogen surplus is less significant for the annual lambing system because most of the sheep diet is composed of forages, of which 90% are produced at the sheep farm. Nevertheless, sheep manure still provides more nitrogen than the amount required to fertilize the feed crops and pastures. In this study, it is assumed that the manure produced by sheep and lamb that exceeds the pasture nutrient requirements is sold to other farmers. Manure can offset an equivalent quantity of synthetic fertilizers purchased with all the environmental impacts associated with their production and use. Consequently, it is important to ensure that all manure produced is used as efficiently as possible on the farm and elsewhere. This is especially true of producers who own or rent a small land base and who purchase a significant portion of their feed.

If the total quantities of forages and grains consumed by sheep were all produced at the farm and no feed ingredient needed to be purchased, the analysis shows that the sheep manure does not provide the quantities of nitrogen necessary for the fertilization of these crops and pastures. Table 6.4 shows the results for this analysis.

Table 6.4
Nitrogen mass-balance (all forages and grains produced at the sheep farm)

Total N-requirements (kg N)		
	Annual lambing	Accelerated lambing
Tillable pastures	2331	843
Rough pastures	1374	271
Corn silage	1095	727
Hay	908	851
Barley	1656	2501
Maize	687	1036
Oat	596	901
Wheat	45	68
Total	**8693**	**7199**
Nitrogen (kg) from manure	**7581**	**6988**
Nitrogen (kg) net deficit (negative) at the farm	**-1112**	**-211**

The analysis shows that the purchase of synthetic fertilizers would be necessary to compensate the nitrogen deficit of approximately 1.1 tonne (annual lambing) and 0.2 tonne (accelerated lambing) per year.

Based on this analysis, although not all the feed nutrient requirements can be provided by manure, there is a significant opportunity to close the loop of nutrients for feed production and reduce the use of synthetic fertilizers which would indirectly reduce the environmental impacts related to their production and use.

6.2.5 Energy use on farm

The GHG emissions related to the energy used on farms account for approximately 6% of overall climate change impacts. Figure 6.6 displays impact results for the energy inputs used on farms.

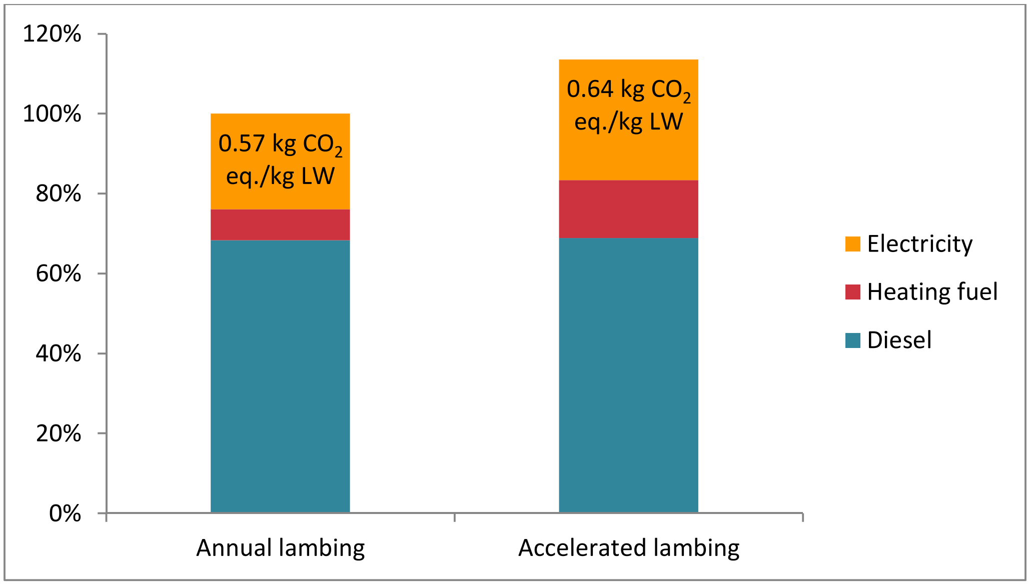

Figure 6.6 Relative contribution of farm energy inputs to overall climate change impacts (kg CO_2 eq./kg LW)

The quantity of diesel used in machinery and vehicles is responsible for 68% (annual lambing) and 61% (accelerated lambing) of climate change impacts related to the energy used on farms. Take note that only the diesel purchased not allocated to feed production is considered here. The diesel used in agricultural equipment for feed production is included in the feed production life cycle stage. While energy impacts related to diesel consumption are similar between both systems, the impacts related to electricity and heating fuel consumption at the farm are respectively 26% and 85% higher than in the annual lambing system. This can be explained by the fact that sheep in accelerated lambing system are usually confined in barns as opposed to pastures, hence resulting in higher energy consumption at the farm, including barn heating during winter.

6.2.6 Key Findings

Key findings that recommendations could address:

- Since feed production impacts vary greatly according to the type of feed, it is important to carefully consider the type of crop to feed the sheep, to ensure their nutritional needs and achieve sustainable farming.
- Since sheep producers generally grow several of the feed ingredients included in the sheep diet, they can influence the impacts of feed crop production and significantly reduce their GHG emissions.
- Synthetic fertilizer production and emissions from field application drive the impacts from the crop production. N fertilizers generated greater potential impacts, especially due to the nitrous oxide emissions at application. Therefore, an optimal and efficient nutrient management plan is important to improve fertilizer use efficiency. Optimizing the use of manure for fertilization needs is a good way to reduce the use of synthetic fertilizer.

- The nutrient management plan (NMP) should include periodic soil sampling and soil testing to identify which nutrients are deficient and target those nutrients for application. Fertilizer application rates should be based on agronomic requirements, production economics and reduced environmental impacts for optimal timing and placement. NMP are also a tool to ensure that all the manure is used as efficiently as possible on the farm and elsewhere.
- Some fertilizers can generate fewer environmental impacts than others. Selecting fertilizers with fewer environmental impacts could significantly reduce GHG emissions. In conjunction with nutrient management planning, further investigation into the fate of the chemicals in the environment is strongly recommended in order to inform producers of the appropriate fertilizer sources to apply.

6.3 Energy use results

This indicator, expressed in megajoules (MJ) of non-renewable primary energy, measures the amount of energy extracted from the earth contained in a fossil energy carrier (coal, oil and natural gas) or uranium ore. Figure 6.7 shows the contribution of each life cycle stage of the studied system to the energy use impacts for both lambing systems.

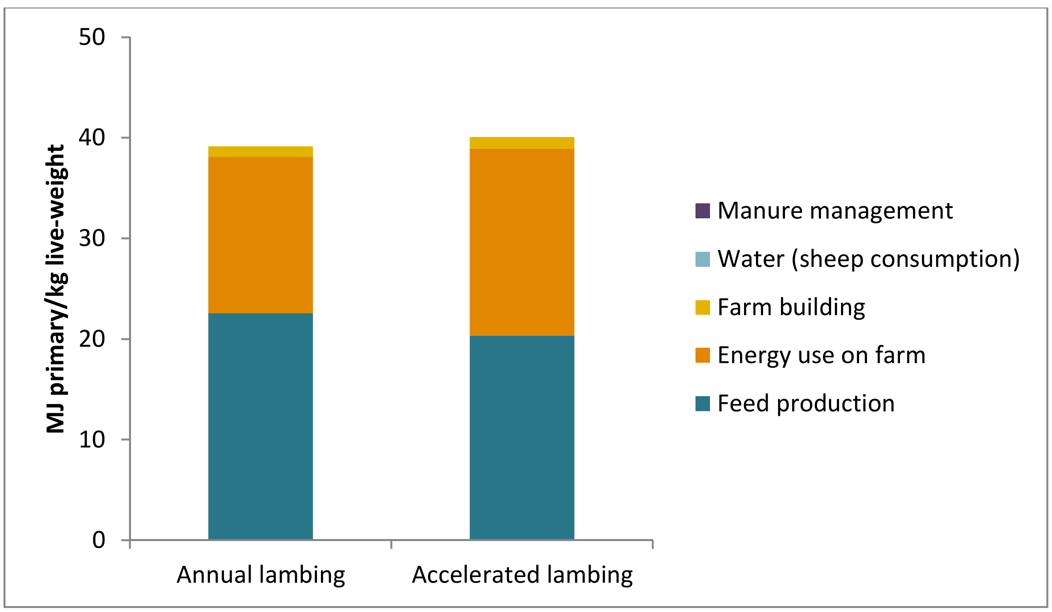

Figure 6.7 Contribution of each life cycle stage to the energy use impacts for 1 kg of Ontario-produced sheep

The production of 1 kg of live weight sheep results in 39 MJ and 40 MJ of primary energy extracted from the earth for the annual and the accelerated lambing system, respectively. Looking at the entire farm on an annual basis and from a life cycle perspective, these results correspond to the consumption of 1 380 000 MJ and 1 880 000 MJ of primary energy for the annual and accelerated lambing farms, which translate in approximately 236 and 321 barrels of crude oil, respectively.

The potential impacts on non-renewable resources are caused by the consumption of fossil fuels and the energy consumption mainly occurs over two main life cycle stages: 1) energy consumption for farm operations; and 2) feed production (and upstream steps; mostly synthetic fertilizer production).

The feed production stage generates 58% (annual lambing) and 51% (accelerated lambing) of energy use impacts, mostly due to significant fertilizer consumption. Indeed, natural gas is the main feedstock for ammonia production (used for N fertilizer production), and the production of N and P synthetic fertilizers require important electricity inputs.

The farm operations stage creates 40% and 46% of the energy use impacts for the annual and accelerated lambing system respectively, due primarily to the electricity consumed at the farm for ventilation, lighting and other functions.

KEY FINDINGS

Key findings that recommendations could address:

- Optimizing mechanical delivery of feeds to sheep and lambs (especially in the accelerated lambing system) by reducing distances between feed storage and sheep and lambs.
- Implementing farm energy efficiency measures for space heating, ventilation and lighting is important levers for sheep farmers.
- Installing on-farm renewable energy production capacity, or buying green electricity, could also help reduce the consumption of non-renewable resources.
- Synthetic fertilizer production is a main contributor to non-renewable resource consumption due to the natural gas used as feedstock for N fertilizer production and the electricity consumed for the production of N and P fertilizers. Therefore, optimal nutrient management is important to reduce their use.

6.4 LAND USE RESULTS

The land use indicator measures the amount of land occupied by the activities related to sheep production life cycle. It is expressed as the total area of land used during one year ($m^2 \cdot y$). The production of 1 kg of live weight Ontario-produced sheep requires approximately 32.7 $m^2 \cdot y$ for the annual lambing system and 19.4 $m^2 \cdot y$ for the accelerated lambing system. Figure 6.8 presents the contribution of each life cycle stage of the studied system to the land use impacts.

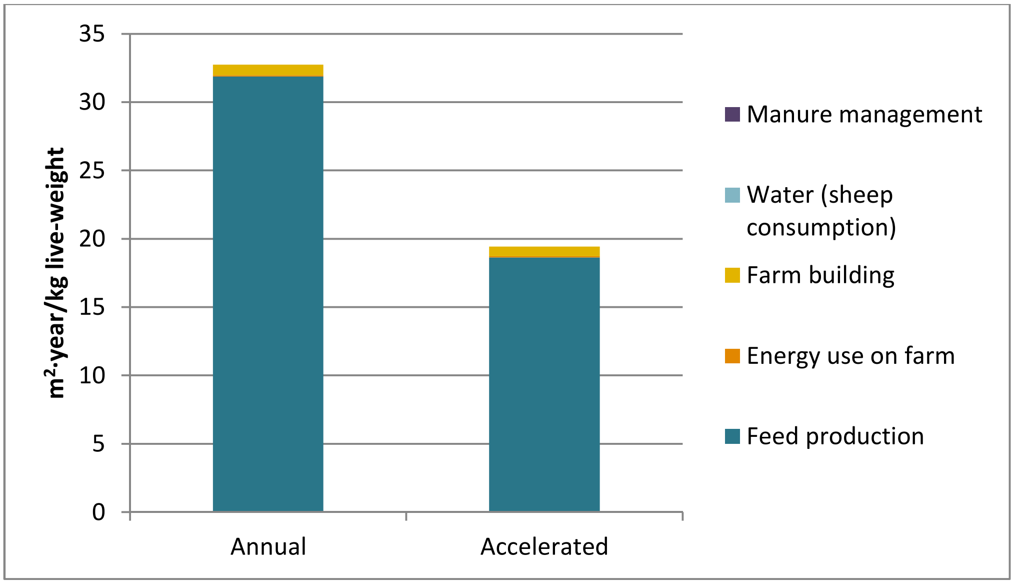

Figure 6.8 Contribution of each life cycle stage to the land use impacts for 1 kg of Ontario-produced sheep

The results indicate that the agricultural land devoted to the feed production stage contributes to 97% of the overall potential impacts to land use impacts.

The land occupied to produce forages accounts for 69% (annual lambing system) and 41% (accelerated lambing system) of the land use impacts. This significant difference can be explained by the fact that forages constitute the main feed in an annual lambing system. Pastures generally have lower yields than grain crops, leading to larger agricultural area occupancy. In the case of the accelerated lambing system, the grain crops used to feed the sheep and lambs contribute to 60% of land use impacts.

Based on data from the OSMA benchmarking study (2009), between 32% (accelerated) and 37% (annual) of the total pasture area used at the farm is considered as rough pasture. This means that they are potentially not suitable for other agricultural activities. These represent 4.7 m^2·y/kg LW for annual lambing and 0.7 m^2·y/kg LW for accelerated lambing. The advantage of using rough pasture is to produce food from land that would otherwise be unproductive. The positive aspect of rough pastures is not captured by this indicator, but increasing the use of rough pasture still can be highlighted as a relevant measure to decrease the overall environmental footprint of sheep production in Ontario.

KEY FINDINGS

Key findings that recommendations could address:

- Since the main requirement of land is associated with the feed production stage, optimizing land use by improving yields as well as maximizing the use of rough pasture constitutes an important lever for producers.

6.5 WATER CONSUMPTION RESULTS

The water consumption indicator is the sum of all fresh water withdrawals in each watershed minus all water returns to the same watershed. It includes drinking water, irrigation water and water for and in industrialized processes (including losses of cooling water).
The overall water consumption totals 144 L (annual lambing) and 129 L (accelerated lambing) for the production of 1 kg of live weight sheep in Ontario. Looking at the entire farm on an annual basis, these results correspond to the use of approximately 5100 m^3 of water for the annual lambing farm and 6070 m^3 for the accelerated lambing farm which translate respectively in the water volume of 2 and 2.4 Olympic swimming pools. Figure 6.9 shows the contribution of each life cycle stage of the studied system to water consumption.

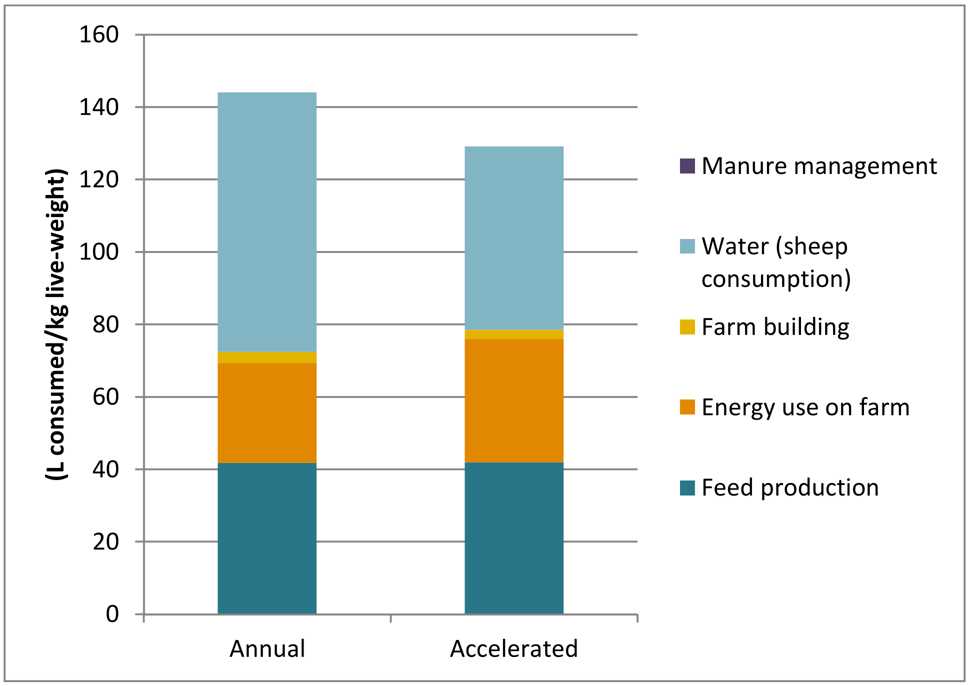

Figure 6.9 Contribution of the life cycle stages to the water consumption category for 1 kg of Ontario-produced sheep

The main contributor to the overall water consumption indicator is the water consumed by the animals, representing 50% (annual lambing) and 39% (accelerated lambing) of total water use impacts. Feed production stage is also an important contributor due to the volumes of water used to irrigate feed crops, representing 29% (annual lambing) and 32% (accelerated lambing) of total water use impacts. However, it is assumed in this study that irrigation is not commonly used in Ontario. This explains the relatively small contribution of irrigation to water consumption indicator.

Water consumption associated with energy use is mainly explained by the evaporation of water in dams used for the production of hydroelectricity, as well as the evaporation of cooling water in thermo-electric power plant. This is considered as indirect water consumption related to electricity consumption at the farm.

KEY FINDINGS

Key findings that recommendations could address:

- Because of the meteorological condition in Ontario, irrigation is not a large contributor to the water consumption footprint. Farmers should limit the use of irrigation as much as possible to avoid losing this great advantage. Watering system should be carefully calibrated and inspected to limit losses and avoid leak.

7. SENSITIVITY ANALYSES

7.1 SENSITIVITY ANALYSIS 1: INCREASING THE PROPORTION OF GRAINS IN ADULT EWE DIET IN THE ANNUAL LAMBING SYSTEM

In order to evaluate the impact of increasing the proportion of grains in the diet of adult sheep, a sensitivity analysis was performed to compare the impacts of two different diets given to adult sheep in an annual lambing system. The low-grain diet corresponds to the one modelled in the annual lambing system where adult sheep feed on 80% of forages and 20% of grains. On the other hand, the high-grain diet is composed of 60% of forages and 40% of grains. This analysis aims to highlight how enteric emissions and feed production impacts balance out in the end. Results for the climate change impacts can be seen in Figure 7.1.

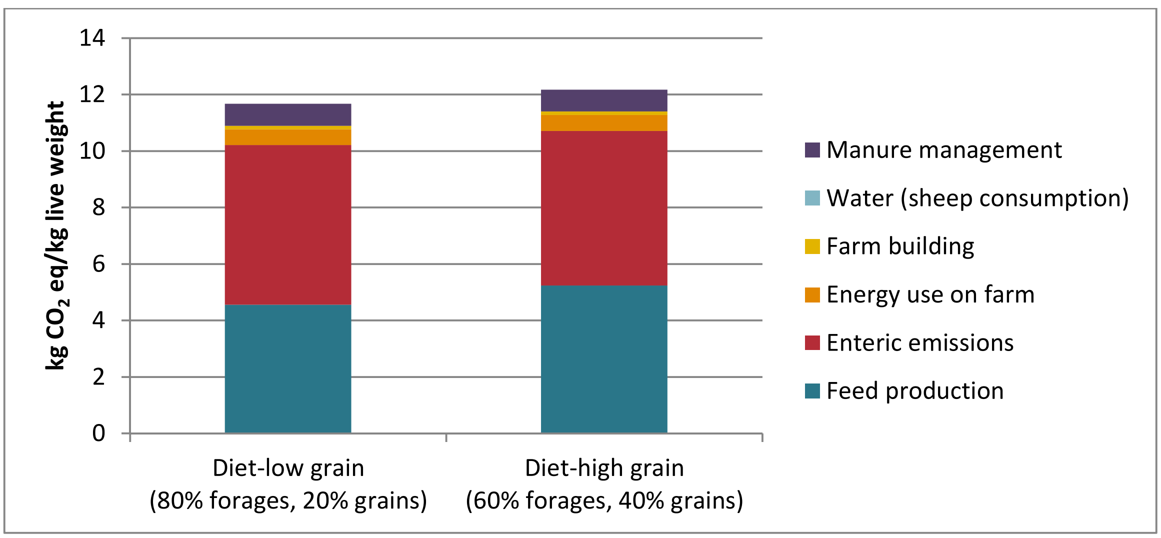

Figure 7.1 Comparison of climate change impacts for 1 kg of live-weight Ontario-produced sheep based on two different diets

By increasing to 40% the amount of grains fed to ewe sheep, climate change impacts increase by 4%, from 11.7 to 12.2 kg CO_2 eq./kg LW. For a population of 584 adult ewes, this translates into an additional annual emission of 17.6 tonnes of CO_2 eq. by switching from a low-grain sheep diet to a high-grain sheep diet.

The feed production stage and the enteric emission account for the major changes in impacts between both diets. Indeed, the climate change impacts associated to the feed production phase increase by 15%, from 4.6 to 5.2 kg CO_2 eq./kg LW. This can be explained by the higher fertilizer application rate associated with grain production, which is associated with GHG emissions during the production phase of fertilizers and GHG emissions when they are applied on crops. The climate change impacts associated to enteric emissions only decrease by 3%, from 5.7 to 5.5 kg CO_2 eq./kg LW.

Although high-grain-based diets allow to reduce the amount of enteric emissions produced, this carbon footprint reduction (0.18 kg CO_2 eq./kg LW) is small compared to the carbon footprint increase (0.68 kg CO_2 eq./kg LW) associated with the feed production phase, as seen in Figure 7.2.

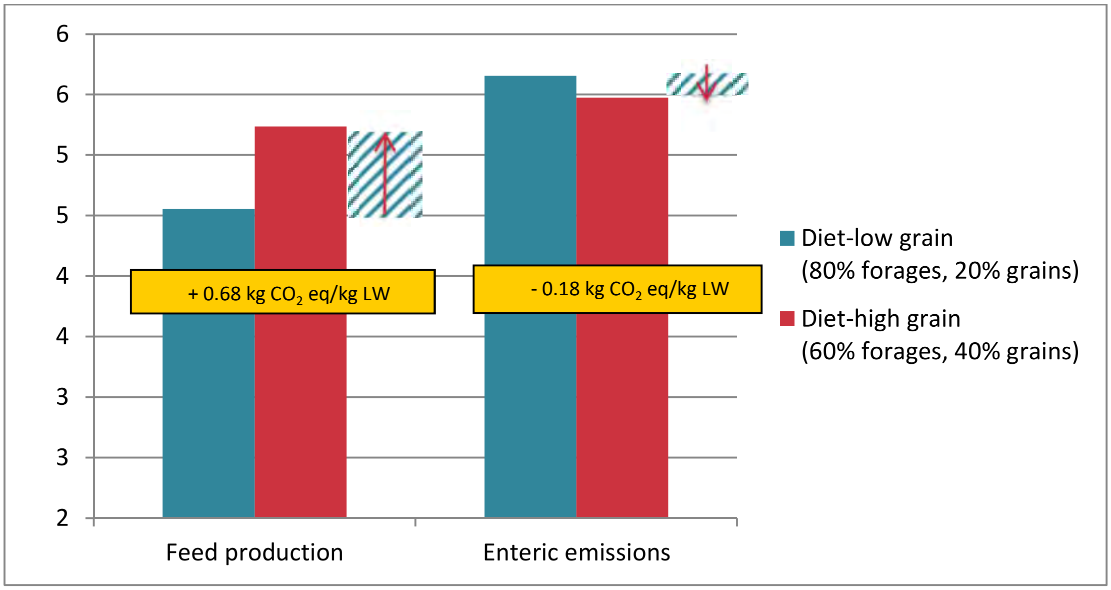

Figure 7.2 **Comparison of enteric emissions and feed production life stages for two different diets**

Therefore, based on these results, increasing the proportion of forages in the diet of sheep improves the carbon footprint of sheep production using an annual lambing system. The positive impact of grain feed on reducing enteric emissions is counterbalanced by the increase in environmental impacts related to grain production. Although forage-based diets seem to increase enteric emissions, growing conditions that promote high forage productivity and digestibility are likely to limit these emissions.

However, this sensitivity analysis assumes that the productivity of the farm is unchanged. As demonstrated before, productivity is a key parameter for the environmental footprint of lamb production. Hence the impact of any measure on productivity should always be carefully assessed.

GHG OFFSET THROUGH CARBON SEQUESTRATION

While feed production produces greenhouse gases, forage and crop plants in turn sequester carbon dioxide as organic matter in soils through root growth. Because perennial forages and pastures develop more extensive root systems and require less tillage than annual crops like grains, they sequester more carbon dioxide and increase the amount of soil organic carbon. This explains the positive environmental contribution of grasslands to beef production through carbon sequestration (BCRC, 2015). On the other hand, annual crops contribute much less to soil carbon reserves. Therefore, the net impact of sheep production, considering the carbon sequestration potential of feed plants, will depend on the relative storage and release of greenhouse gases by plants, soil and sheep.

Due to a lack of established models to calculate carbon sequestration and losses arising from pasture management, carbon sequestration is rarely considered in the models developed for livestock LCA studies. As such, the GLEAM model developed by the FAO does not include carbon sequestration from pastures in its assessment of greenhouse gas emissions from ruminant supply chains. However, based on soil organic carbon sequestration rates of 5 ± 30 g C/m^2/year, the authors estimated that grasslands in the European Union would represent a sink of 11.5 ± 69.0 million tonnes CO_2 eq. per year (FAO, 2013). Considering GLEAM's approximate annual emission of 390.5 million tonnes CO_2 eq. by the ruminant sector in the European Union, this means that carbon sequestration could reduce the total climate change impacts by up to 20%. However, large uncertainties are associated with these values. Nevertheless, we can expect that the environmental impacts related to forage production are overrepresented and could be countered by the sequestration potential of pastures. This implies that annual lambing systems, associated with a higher proportion of pastures and forages in the sheep diet would further benefit from the positive contribution of pasture to carbon sequestration.

The average sequestration factor of 0.19 tonne CO_2 eq./ha/year, as proposed in the Quantification Protocol for Conservation Cropping (Government of Alberta, 2012), can be used to evaluate the GHG offset through carbon sequestration in pastures. Based on the annual quantity of forages consumed by lambs and sheep and the ecoinvent data for forage yields presented in Table 7.1, it is possible to estimate the carbon sequestration potential of forage fields.

Table 7.1
Forage yields and quantities produced at the farm

Forages	Yield (kg/hectare)	Quantity of forage produced at farm and consumed by sheep (kg forage)	
		Annual Lambing	Accelerated lambing
Corn silage	36 330	45 052	29 919
Hay and haylage	6 500	122 040	114 374
Tillable pasture	2 059	57 598	20 830
Rough pasture	2 214	36 498	7 196

The yield values for corn silage and hay are based on the ecoinvent dataset for the province of Quebec while the pasture yields are based on OMAFRA's 2009 Sheep Lambing System Summary report (OMAFRA, 2009). Assuming that only rough pastures contribute to carbon sequestration, the acreage associated to rough pastures can be calculated to estimate the quantity of carbon sequestered. Corn silage is excluded because grains have a lower carbon sequestration capacity and tillable pasture and hay are also excluded because tillage practises significantly reduce the amount of sequestered carbon. As such, the sequestration of carbon in rough pastures for the annual and accelerated lambing systems would correspond to 3.13 and 0.63 tonnes of CO_2, translating into a reduction of 0.09 kg CO_2 eq./kg LW for the annual system and 0.013 kg CO_2 eq./kg LW for the accelerated system. Based on these numbers, the sequestration of carbon in pastures would potentially reduce climate change impacts by up to 1%, a result consistent with GLEAM's conclusions.

Interestingly, in the Eastern regions of Canada, soil carbon levels are decreasing as a result of the increasing conversion of pastures and hayland to fields used to produce annual crops (Agriculture and Agri-Food Canada, 2016). This implies that the shift from pasture production to annual crop production has generated greenhouse gas through loss of soil organic carbon. On the other hand, the Prairies have seen increases in soil organic carbon due to significant improvement in management practices, including the shift from conventional tillage to reduced or no-tillage which has contributed to a build-up of organic matter in the soil. Hence, for annual crops, management practices that reduce tillage have benefits for soil health since they increase organic soil content and reduce carbon losses to the atmosphere.

KEY FINDINGS

Key findings that recommendations could address:

- Management practices that promote reduced or no-tillage as opposed to conventional tillage increase organic matter in the soil and improve sequestration of atmospheric carbon.
- Management practices that improve forage productivity and reduce conversion of pasture lands to annual crops to promote soil health and carbon sequestration.

7.2 SENSITIVITY ANALYSIS 2: NUMBER OF LAMBS PER EWE

The impact results are most sensitive to parameters that affect the productivity of the system. The number of lambs per ewe is an important parameter that has a direct impact on the productivity of the system, as expressed by the total amount of sheep live weight that is sent for processing. The number of lambs per ewe used as a basis in the model corresponds to 1.4 lamb per ewe for the annual lambing system and 2 lambs per ewe for the accelerated lambing system. However, these values are likely to be different from one farm to another and do vary between studies. As such, a sensitivity analysis was performed to assess the impact of the number of lambs per ewe on climate change impact results.

Figure 7.3 shows the impact results for the two baseline scenarios and two annual lambing scenarios, one characterized by a 10% increase in the number of lambs per ewe and the other characterized by a 10% decrease in the number of lambs per ewe.

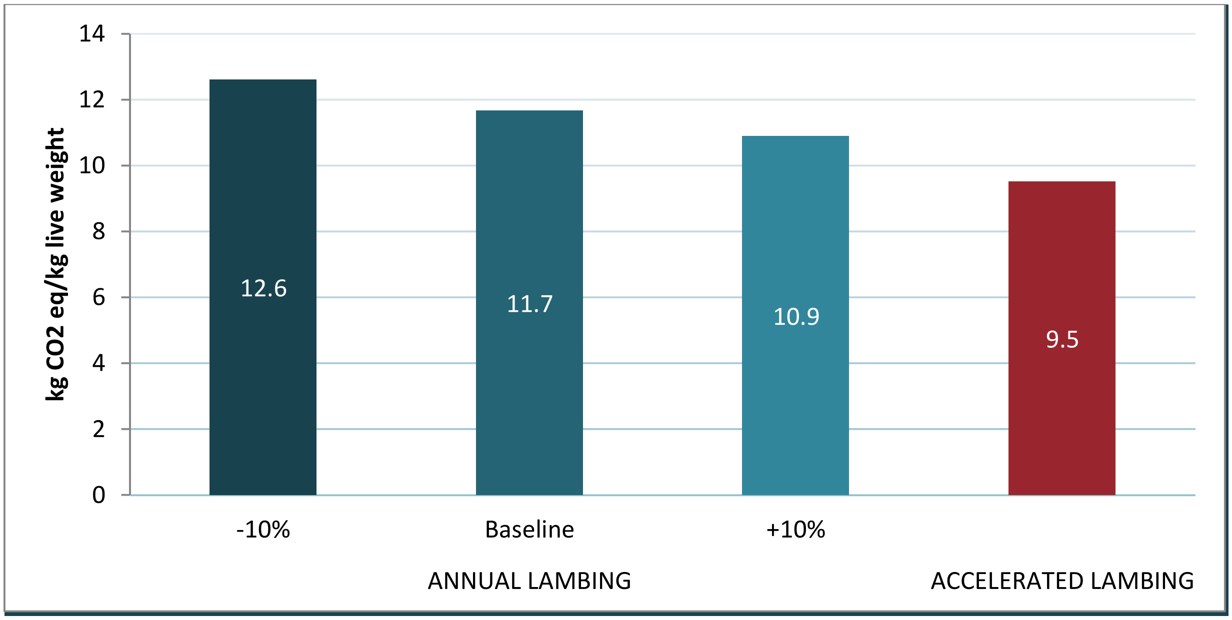

Figure 7.3 **Comparison of climate change impacts for annual lambing systems with different productivities**

Based on this analysis, an increase of 10% in the number of lambs per ewe allows to reduce the climate change impacts by approximately 7% in an annual lambing system.

Figure 7.4 shows the impact results for the two baseline scenarios and two accelerated lambing scenarios, one characterized by a 10% decrease in the number of lambs per ewe and the other characterized by a 10% increase in the number of lambs per ewe.

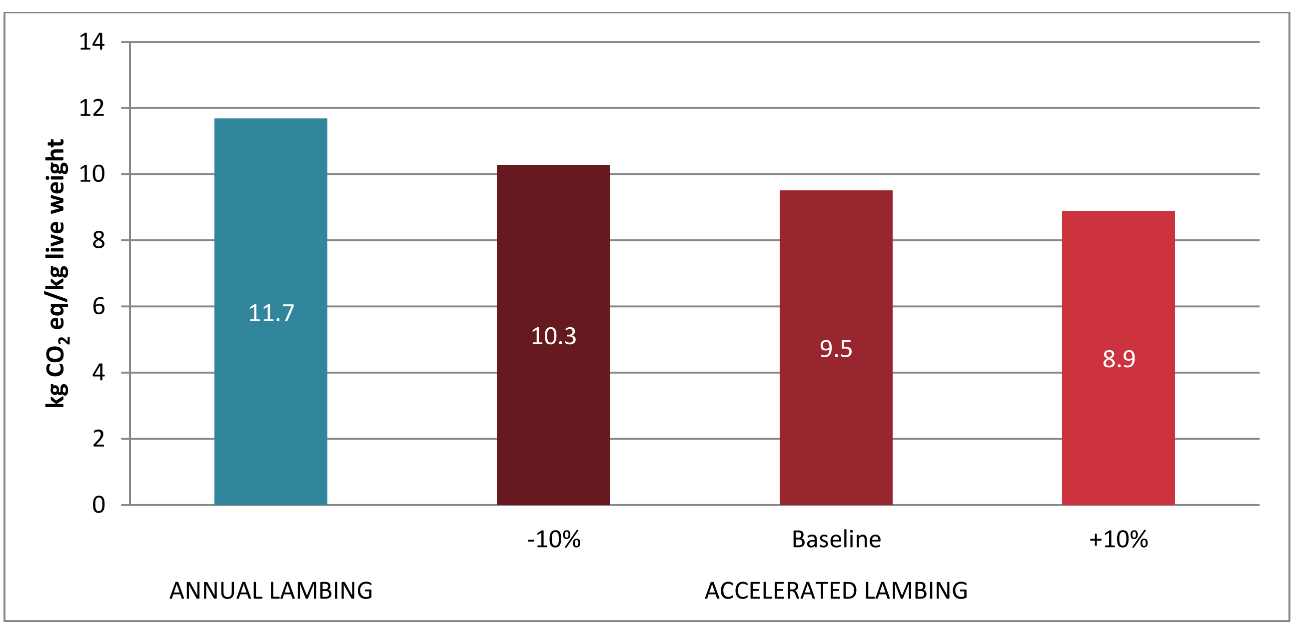

Figure 7.4 **Comparison of climate change impacts for accelerated lambing systems with different productivities**

In this case, a decrease of 10% in the number of lambs per ewe will increase the climate change impacts by approximately 8% in an accelerated lambing system.

Based on this analysis, the number of lambs per ewe for the accelerated lambing system needs to remain high to allow a significant reduction in the climate change impacts in comparison to an annual lambing system. In the case of annual lambing systems, producers who wish to reduce their carbon footprint also need to maintain or increase the level of productivity.

Management practices that promote animal growth rates and feed efficiency lead to higher levels of sheep meat produced per farm. They, in turn, reduce the quantity of feed required for sheep, the production time before slaughter, as well as the emissions of greenhouse gas.

8. COMPARISON WITH GLEAM RESULTS

It is interesting to compare the study's results with those of FAO's GLEAM report on Greenhouse gas emissions from ruminant supply chains. Based on the FAO's conversion factors to convert live-weight kilograms of sheep to the carcass and bone-free meat, and to convert bone-free meat to protein, results for Ontario range between 135 (accelerated lambing) and 166 kg CO_2 eq./kg protein (annual lambing). These results correspond to the lower range of the carbon footprint calculated by the FAO's GLEAM initiative, varying between 100 and 300 kg CO_2 eq./kg protein for 90% of global sheep production, with an average of 201 kg CO_2 eq./kg protein. This wide range reflects the diversity of production systems around the globe, some more productive than others. The average carbon footprint for Ontarian sheep is therefore significantly lower than the North American average emission of 260 kg CO_2 eq./kg protein measured in GLEAM, corresponding to one of the world regions with the highest carbon footprint per kg of protein.

The contribution of each life cycle stage to the overall climate change results in GLEAM is similar to the one seen in this study. Indeed, according to GLEAM results for small ruminant meat, enteric emissions account for 55% of climate change impacts (as opposed to an average of 44% for Ontario).

Several factors account for the variations in emission intensity of small ruminant meat across the globe. Regions located in temperate zones are characterized by poorer production conditions and low feed digestibility, causing lower yields and a higher emission intensity.

PRODUCTIVITY OF SYSTEMS

According to GLEAM, the productivity of systems is the key parameter explaining the large variations in emission intensities between regions. High-productivity systems such as the ones in Europe are characterized by high fertility and growth rates, low mortality rates and high feed digestibility. Indeed, regions with higher feed digestibility generally feed sheep with higher quality roughages, feed crops and concentrates. Higher feed digestibility implies that the amount of energy available to the animal increases per kg of feed intake, thus shifting the distribution of feed energy towards production and growth as opposed to maintenance functions. Although sheep in productive systems emit more enteric CH_4 per head due to higher feed intake, the size of the sheep herds can be reduced to produce the same amount of output, therefore reducing the emission intensity.

The model points out to the fact that feed digestibility affects the amount of enteric emissions produced. Indeed, since the energy content of feed ingredients influences the amount of methane produced from enteric fermentation, higher quality roughages, feed crops and concentrates will be characterized by higher feed digestibility. This allows more energy per kilogram of feed intake to be available to sheep and lambs, thus promoting productivity.

Furthermore, lower emission intensities can be explained by the herd structure. As the proportion of animals in the breeding herd increases, enteric emissions will increase as well since most of the feed energy will serve to maintain the breeding herd as opposed to promoting lamb production.

With regards to the feed production stage, rations incorporating higher proportions of grains and concentrates will usually be associated with higher emission intensities since grain production uses more N chemical fertilizers than forage production. Intensive grazing systems such as the ones in North America will rely on more fertilizers to boost the productivity of feeds; higher N inputs will inevitably translate in higher levels of N_2O emissions. On the other hand, for other regions where feed comes mostly from extensive pastures, manure will provide most of the N inputs necessary to fertilize the soil.

9. CONCLUSION

The streamlined LCA on sheep production has highlighted that the environmental performance of Ontario sheep producers is good when compared with the global average. Indeed, the average result for the climate change impact of approximately 150 kg CO_2 eq./kg protein in Ontario corresponds to the lower range of the carbon footprint calculated by the FAO's GLEAM initiative of 201 kg CO_2 eq./kg protein.

When comparing the environmental performance of annual and accelerated lambing systems, impact results indicate that the carbon footprint for the accelerated lambing system is 19% lower in comparison to the annual lambing system. The higher number of lambs per ewe in the accelerated system translates into a higher productivity, hence reducing the environmental impacts produced per kilogram of live weight in comparison to the annual lambing system. In the context of an anticipated increase in sheep production in the upcoming years, the LCA results suggest that opting for an accelerated lambing would minimize the environmental impacts related to the production increase. Nevertheless, the energy use impacts are lower for the annual lambing system, for which the environmental performance still surpasses the global average.

The comparison of feed ingredients indicates that grain production has significantly more impact than forages production. This can be explained by the higher fertilizer application rate associated with grain production, which generates GHG emissions during the production stage of fertilizers and when they are applied on crops. A sensitivity analysis performed on the composition of the sheep diet showed that while grains increase feed digestibility, which reduces the amount of enteric methane produced, the environmental impact related to grain production outweighs this positive contribution. Furthermore, it is likely that the environmental impacts related to forage production could be countered by the sequestration potential of pastures. While large uncertainties are associated with the estimation of this sequestration potential, it implies that annual lambing systems, associated with a higher proportion of pastures and forages in the sheep diet would further benefit from the positive contribution of pasture to carbon sequestration. This highlights the importance of using life-cycle analysis as a tool to assess the contribution and interaction of complex issues related to the life cycle of sheep production.

Measures to improve the environmental footprint of sheep production must be directed toward increasing sheep productivity, as seen in the accelerated lambing system. While this can be achieved by improving fertility and growth rates, and reducing mortality rates, the use of high-quality roughages, feed crops and concentrates also foster productivity.

Other measures related to farm operations, like implementing farm energy efficiency measures for space heating, ventilation and lighting, as well as optimizing fuel use efficiency of on-farm equipment and machinery are also important levers for sheep farmers. Water use impacts could be reduced by promoting the use of feed ingredients that require less irrigation. Although the manure management stage is not a major contributor to overall environmental impacts, the report shows that a well-managed nutrient management plan at the sheep farm can lead to a more efficient use of sheep manure for the fertilization of on-farm crops and pasture and therefore reduce the quantity of purchased fertilizers. For producers who own or rent a small land base and who purchase a significant portion of their feed, a portion of the sheep manure produced by sheep and lamb could be sold to other farmers to offset an equivalent quantity of fertilizers purchased.

The main goal of the report was to use a streamlined LCA to quantify the average environmental impact of sheep production in Ontario so that it can be used as a self-assessment tool for sheep producers to improve the environmental performance of their activities.

APPENDIX A
EMISSION MODELS

APPENDIX A – EMISSION MODELS

10. METHANE EMISSIONS FROM ENTERIC FERMENTATION

METHODOLOGY

Enteric fermentation by sheep generates methane emissions as food energy is lost during the digestion process. A Tier 2 characterization method was performed to calculate these emissions as outlined in the IPCC Guidelines for National Greenhouse Gas Inventories (2006). To estimate the total emissions, an emission factor for each sheep category was determined based on the gross energy intake (GE) and methane conversion factor (Y_m).

GROSS ENERGY INTAKE (GE)

The gross energy intake is the total amount of energy in the diet that is ingested by the animal. The enteric model recommended by the IPCC (2006) is derived from the energy for maintenance, energy for animal activity, energy for lactation, energy for pregnancy, digestible energy and energy for growth. The following equation (IPCC, 2006) was used to calculate the gross energy intake for each cattle category in each region studied:

$$\mathrm{GE} = \frac{\left(\frac{\mathrm{NE_m} + \mathrm{NE_a} + \mathrm{NE_l} + \mathrm{NE_p}}{\mathrm{REM}}\right) + \left(\frac{\mathrm{NE_{wool}} + \mathrm{NE_g}}{\mathrm{REG}}\right)}{\frac{\mathrm{DE\%}}{100}}$$

Where: GE = gross energy intake, MJ d^{-1}

NEm = net energy required by the animal for maintenance, MJ d^{-1}

NEa = net energy for animal activity, MJ d^{-1}

NEl = net energy for lactation, MJ d^{-1}

NEp = net energy for pregnancy, MJ d^{-1}

NEwool = net energy to produce wool, MJ d^{-1}

NEg = net energy for growth, MJ d^{-1}

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed

REG = ratio of net energy available for growth in a diet to digestible energy consumed

DE% = digestible energy as a percentage of gross energy, %

The following table summarizes the equations used to calculate the parameters found in the gross energy intake equation above.

Parameter	Equation	Source
Net energy required by the animal for maintenance (NE_m, MJ d^{-1})	$NE_m = Cf_i \times (BW)^{0.75}$ Where: Cf_i = 0.236 (for lambs) or 0.217 (for sheep), MJ $day^{-1}kg^{-1}$; BW = live body weight, kg 48.5 kg for lambs and 65.7 kg for sheep (annual lambing) 47.6 kg for lambs and 71.6 kg for sheep (accelerated lambing)	IPCC, 2006 - Eq. 10.3
Net energy for animal activity (NE_a, MJ d^{-1})	$NE_a = C_a \times BW$ Where: C_a = 0.009 (for housed ewes), 0.0107 (for flat pastures), 0.024 (for hilly pastures) or 0.0067 (for housed lambs), dimensionless;	Eq. 10.5 (IPCC, 2006)
Net energy for lactation (NE_l, MJ d^{-1})	$NE_l = \text{Milk} \times EV_{milk}$ Where: Milk = amount of milk produced, 2.1 kg of milk day^{-1} EVmilk = the energy required to produce 1 kg of milk, MJ kg^{-1}. A default value of 4.6 MJ kg^{-1} was used (AFRC, 1993).	Eq. 10.9 (IPCC, 2006)
Net energy for pregnancy (NE_p, MJ d^{-1})	$NE_p = Cf_{pregnancy} \times NE_m$ Where: $Cf_{pregnancy}$ = 0.077 (single birth), 0.126 (double birth) or 0.15 (triple birth)	Eq. 10.13 (IPCC, 2006)
Digestible energy - percentage of gross energy (DE%, %)	$DE\% = A \times 65 + B \times 74$ Where: A = percentage of sheep diet composed of pasture or forage; B = percentage of sheep diet composed of concentrates (see Table 4.7, Table 4.8 and Table 4.9 feed composition of sheep and lamb diets)	(Environment Canada, 2015)

Ratio of net energy available in a diet for maintenance to digestible energy consumed (REM)	$\mathrm{REM} = \left\{1.123 - (4.092 \times 10^{-3} \times \mathrm{DE\%}) + [1.126 \times 10^{-5} \times (\mathrm{DE\%})^2] - \left(\frac{25.4}{\mathrm{DE\%}}\right)\right\}$	Eq. 10.14 (IPCC, 2006)
Net energy to produce wool (NE_{wool}, MJ d^{-1})	$\mathrm{NE_{wool}} = \frac{\mathrm{EV_{wool}} \times \mathrm{Production_{wool}}}{365}$ Where: EV_{wool} = the energy required to produce wool, MJ kg^{-1}. (weighed after drying but before scouring). A default value of 24 MJ kg^{-1} is used for this estimate (AFRC, 1993). Production wool = annual wool production per sheep, 2097 kg yr^{-1} per ewe	Eq. 10.12 (IPCC, 2006)
Net energy for growth (NE_g, MJ d^{-1})	$\mathrm{NE_g} = \frac{WG_{lamb} \times (a + 0.5b\,(BW_i + BW_f))}{365}$ Where: WG_{lamb} = weight gain (BW_f-BW_i), kg yr^{-1}; BW_i = live body weight at weaning, 28.3 kg (annual lambing) and 22.7 kg (accelerated lambing) BW_f = live body weight at 1-year old or at slaughter (live weight) if slaughtered prior to 1 year of age, 48.5 kg (annual lambing) and 47.6 kg (accelerated lambing) Where: a = 2.5 (intact males), 4.4 (for castrates) or 2.1 (for females), dimensionless; Where: b = 0.35 (intact males), 0.32 (for castrates) or 0.45 (for females), dimensionless;	Eq. 10.7 (IPCC, 2006)

Ratio of net energy available for growth in a diet to digestible energy consumed (REG)	$\text{REG} = \Big\{1.164 - (5.160 \times 10^{-3} \times \text{DE\%}) + [1.308 \times 10^{-5} \times (\text{DE\%})^2] - \left(\frac{37.4}{\text{DE\%}}\right)\Big\}$	Eq. 10.15 (IPCC, 2006)

METHANE EMISSION FACTOR ($EF_{CH4\ ent.ferm}$)

Finally, the methane emission factor specific to each cattle category was determined by the following equation (IPCC, 2006):

$$\text{EF}_{\text{CH}_4\text{ ent.ferm.}} = \left[\frac{\text{GE} \cdot \left(\frac{\text{Y}_\text{m}}{100}\right) \cdot 365}{55.65}\right]$$

Where: $EFCH_{4\ ent.ferm}$ = methane emission factor, kg CH_4 $head^{-1}$ day^{-1}

GE = gross energy intake, MJ $head^{-1}$ day^{-1}

Y_m = methane conversion factor, percent of gross energy in feed converted to methane, 4.5 for lambs (less than 1 year old) and 6.5 (for mature sheep)

55.65 = energy content of methane, MJ kg CH_4^{-1}

365 = number of days in a year

This emission factor was then multiplied with the total number of heads in each cattle category to evaluate the total methane emissions due to enteric fermentation.

11. Methane Emissions from Manure Management

Methodology

Methane emissions due to manure management systems were calculated according to the IPCC (2006) Tier 2 characterization method. To estimate the total emissions, an emission factor for each sheep category was calculated based on the volatile solid excretion rate (VS), the maximum methane producing capacity of the manure (B_o), the methane conversion factors for each manure management system ($MCF_{s,x}$) and the fraction of sheep manure handled using specific manure management system ($MS_{(T,S,k)}$).

Methane emission factor

The methane emission factor ($EF_{CH4\ manure}$) specific to each sheep category was determined with the following equation (IPCC, 2006):

$$EF_{CH_4\ manure} = (VS_T \cdot 365) \cdot \left[B_{O(T)} \cdot 0.67 \cdot \sum \frac{MCF_{S,k}}{100} \cdot MS_{(T,S,k)} \right]$$

Where:
$EF_{CH4\ manure}$ = methane emission factor, kg CH_4 head^{-1} day^{-1}
VS_T = volatile solid excretion rate, kg VS day^{-1}
365 = number of days in a year, day
B_o = maximum methane producing capacity of manure, m^3 CH_4 kg VS^{-1}
0.67 = conversion factor of m^3 CH_4 to kg CH_4
$MCF_{S,k}$ = methane conversion factor for each manure management system S by climate region k, %
$MS_{(T,S,k)}$ = fraction of the animal's manure handled using specific manure management system (a value of 1 is used since we assume that 100% of the manure is managed using a solid storage system)

The emission factor was then multiplied by the total number of heads in each sheep category to evaluate the total methane emissions due to manure management.

Volatile solid excretion rate (VS)

The volatile solid content of manure corresponds to the portion of the feed consumed that is not digested and therefore excreted as both biodegradable and non-biodegradable organic material. The volatile solid excretion rate was calculated using the equation below (IPCC, 2006):

$$VS = \left[GE \cdot \left(1 - \frac{DE\%}{100}\right) + (UE \cdot GE) \right] \cdot \left[\frac{1 - ASH}{18.45} \right]$$

Where:
VS = volatile solid excretion rate, kg VS day^{-1}
GE = gross energy intake, MJ day^{-1}
DE% = digestible energy as a percentage of gross energy, %
UE = urinary energy, MJ head^{-1} day^{-1}

ASH = ash content of manure
18.45 = conversion factor for dietary gross energy per kg of dry matter, MJ kg^{-1}

The following table summarizes the parameters that were first calculated in order to determine the volatile solid excretion rate for each cattle category.

Parameter	Equation / Default value	Source
Gross energy intake *(GE, MJ d^{-1})*	$\mathrm{GE} = \frac{\left(\frac{\mathrm{NE_m} + \mathrm{NE_a} + \mathrm{NE_l} + \mathrm{NE_p}}{\mathrm{REM}}\right) + \left(\frac{\mathrm{NE_g}}{\mathrm{REG}}\right)}{\frac{\mathrm{DE\%}}{100}}$	Eq. 10.16 (IPCC, 2006)
Digestible energy - percentage of gross energy (*DE%, %)*	$\mathrm{DE\%} = \mathrm{A} \times 65 + \mathrm{B} \times 74$ Where: A = percentage of sheep diet composed of pasture or forage; B = percentage of sheep diet composed of concentrates (see Table 4.7, Table 4.8 and Table 4.9 feed composition of sheep and lamb diets)	(Environment Canada, 2015)
Urinary energy *(UE, MJ/head·day)*	$\mathrm{UE} = 0.04 \cdot \mathrm{GE}$ Typically, 0.04 GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet or for swine).	(IPCC, 2006)
Ash content of manure *(ASH)*	0.08 for sheep	(Environment Canada, 2015)

MAXIMUM METHANE PRODUCING CAPACITY OF MANURE (B_o)

The maximum methane producing capacity of manure is based on the sheep's diet and species. Estimations for B_o in developed countries were used in the calculations of the methane emissions due to manure management, as no country-specific data were available. The IPCC (2006) estimated the B_o to be 0.19 m^3 CH_4 kg VS^{-1} for sheep.

METHANE CONVERSION FACTORS FOR EACH MANURE MANAGEMENT SYSTEM ($MCF_{S,k}$)

The methane conversion factors indicate how much of the maximum methane producing capacity of manure is achieved. They are specific to each manure management system and are based on the temperature of the system and the retention time of organic material in the system. The IPCC (2006) gathered in a table $MCF_{S,k}$ values by temperature for manure management systems. Solid storage of sheep manure is the common method used to manage manure, where it is stored in stockpiles or in storage facilities and once it is well composted it is sprayed on hay (forage) fields and crop ground matured. Based on this management system and on an average annual temperature of Ontario that falls in the cool temperature category (below or equal to 14°C), the $MCF_{S,k}$ was the same across all regions and a value of 2% was used.

12. NITROUS OXIDE EMISSIONS FROM MANURE MANAGEMENT

12.1 DIRECT NITROUS OXIDE EMISSION FACTOR ($EF_{N2OD(MM)}$)

The direct nitrous oxide emissions specific to each sheep category was estimated with the following equation (IPCC, 2006):

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T \left(N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)}\right)\right] \cdot EF_{3(S)}\right] \cdot \frac{44}{28}$$

Where: $N_2O_{D(mm)}$ = direct nitrous oxide emissions from manure management, kg N_2O year^{-1}

$N_{(T)}$ = number of head of sheep in category T in the region, head

$Nex_{(T)}$ = annual average nitrogen excretion per head of category T, kg N animal^{-1} day^{-1}

Where $Nex_{(T)}$ is based on an N excretion rate of 0.42kg N/day/1000 kg live weight for both sheep and lambs (Environment Canada, 2015)

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each sheep category T that is managed in manure management system S

Where $MS_{(T,S)}$ =35% for solid storage and drylot manure management system (Environment Canada, 2015)

$EF_{3(S)}$ = emission factor for direct nitrous oxide emissions from manure management system S, kg N_2O-N/kg N in manure management system S

Where $EF_{3(S)}$ = 0.02 kg N_2O-N/kg N for solid storage and dry lot manure management system for sheep and lambs (Environment Canada, 2015)

S = manure management system

T = sheep category

44/28 = conversion of $(N_2O\text{-}N)_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions

12.2 INDIRECT NITROUS OXIDE EMISSIONS DUE TO MANURE MANAGEMENT SYSTEMS

METHODOLOGY

The indirect emissions of nitrous oxide are also produced during the storage and treatment of manure before it is spread on the land. These emissions were calculated using a Tier 2 characterization method (IPCC, 2006). The total indirect emissions are the sum of the nitrogen losses due to leaching and those due to volatilization from manure management systems.

NITROGEN LOSSES DUE TO LEACHING FROM MANURE MANAGEMENT SYSTEMS ($N_{LEACHING-MMS}$)

Nitrogen losses due to leaching are calculated with the equation below (IPCC, 2006):

$$N_{leaching-MMS} = \sum_{S}\left[\sum_{T}\left[\left(N_{(T)} \cdot Nex_T \cdot MS_{(T,S)}\right) \cdot \left(\frac{Frac_{leachMS}}{100}\right)_{(T,S)}\right]\right]$$

Where: $N_{leaching\text{-}MMS}$ = amount of manure nitrogen that leached from manure management systems, kg N year^{-1}

$N_{(T)}$ = number of head in sheep category T

$Nex_{(T)}$ = annual average nitrogen excretion per head of category T, kg N animal^{-1} year^{-1}

Where $Nex_{(T)}$ is based on an N excretion rate of 0.42 kg N/day/1000 kg live weight for both sheep and lambs (Environment Canada, 2015)

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each sheep category T that is managed in manure management system S

$Frac_{leachMS}$ = percent of managed manure nitrogen losses for sheep category T due to runoff and leaching storage of manure, %

Where $Frac_{leachMS}$ = 10% (IPCC, 2013)

INDIRECT NITROUS OXIDE EMISSIONS DUE TO LEACHING ($EF_{N2OL(MM)}$)

The indirect nitrous oxide emissions specific to each sheep category was calculated as follows (IPCC, 2006):

$$N_2O_{L(mm)} = \left(N_{leaching-MMS} \cdot EF_5\right) \cdot \frac{44}{28}$$

Where: $N_2O_{L(mm)}$ = indirect nitrous oxide emissions due to leaching and runoff from manure management, kg N_2O year^{-1}

EF_5 = emission factor for nitrous oxide emissions from nitrogen leaching and runoff, kg N_2O-N (kg N leached and runoff)$^{-1}$

Where EF_5 = 0.0075 kg N2O-N (default value, IPCC, 2006)

44/28 = conversion of (N_2O-N) emissions to N_2O emissions

NITROGEN LOSSES DUE TO VOLATILIZATION FROM MANURE MANAGEMENT SYSTEMS ($N_{VOLATILIZATION-MMS}$)

Nitrogen losses due to leaching are calculated with the equation below (IPCC, 2006):

$$N_{volatilization-MMS} = \sum_{S}\left[\sum_{T}\left[\left(N_{(T)} \cdot Nex_{T} \cdot MS_{(T,S)}\right) \cdot \left(\frac{Frac_{GasMS}}{100}\right)_{(T,S)}\right]\right]$$

Where: $N_{volatilization-MMS}$ = amount of manure nitrogen that is lost due to volatilization from manure management systems, kg N year^{-1}

$N_{(T)}$ = number of head in sheep category T

$Nex_{(T)}$ = annual average nitrogen excretion per head of category T, kg N animal^{-1} year^{-1}

Where $Nex_{(T)}$ is based on an N excretion rate of 0,42kg N/day/1000 kg live weight for both sheep and lambs (Environment Canada, 2015)

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each sheep category T that is managed in manure management system S

$Frac_{GasMS}$ = percent of managed manure nitrogen that volatilized as NH3 and NOX for sheep category T in the manure management system S, %

Where $Frac_{GasMS}$ = 12% (Table 10.22, IPCC, 2006)

INDIRECT NITROUS OXIDE EMISSIONS DUE TO VOLATILIZATION ($N_2O_{G(MM)}$)

The indirect nitrous oxide emissions specific to each sheep category was calculated as follows (IPCC, 2006):

$$N_2 0_{G(mm)} = \left(N_{volatilization-MMS} \cdot EF_4\right) \cdot \frac{44}{28}$$

Where: $N_2O_{G(mm)}$ = indirect nitrous oxide emissions due to volatilization from manure management, kg N_2O year^{-1}

$N_{volatilization-MMS}$ = amount of manure nitrogen that volatilized from manure management systems, kg N year^{-1}

EF_4 = emission factor for nitrous oxide emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N (kg NH_3-N+NO_x-N volatilized)$^{-1}$ (default emission value 0.01 from Table 11.3, IPCC, 2006)

44/28 = conversion of (N_2O-N) emissions to N_2O emissions

13. Nitrous oxide emissions generated by human-induced net nitrogen additions to soils

13.1 Nitrous oxide emissions from manure deposited on pastures

The nitrogen oxide emissions produced from the manure deposited on pastures is calculated with the equation below (IPCC, 2006):

$$N_2O - N_{PRP} = F_{PRP,CPP} \times EF_{3PRP,CPP}$$

Where: $N_2O\text{-}N_{PRP}$ = annual direct N_2O–N emissions from urine and dung inputs to grazed soils, kg N_2O–N yr^{-1}

$F_{PRP,CPP}$ = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr^{-1}

$EF_{3PRP,CPP}$ = emission factor for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, kg N_2O–N (kg N input)$^{-1}$ (default emission factor of 0.01 from Table 11.1 (IPCC, 2006))

Annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock ($F_{PRP,CPP}$)

The annual amount of N originating from urine and dung deposited on pasture is based on equation 11.5 of the IPCC guidelines (IPCC, 2006).

$$F_{PRP} = \sum_{T} \left[\left(N_{(T)} \times N_{EX(T)} \right) \times MS_{(T,PRP)} \right]$$

Where: $N_{(T)}$ = number of head in sheep category T

$Nex_{(T)}$ = annual average nitrogen excretion per head of category T, kg N animal^{-1} year^{-1}

Where $Nex_{(T)}$ is based on an N excretion rate of 0,42kg N/day/1000 kg live weight for both sheep and lambs (Environment Canada, 2015)

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each sheep category T that is managed in manure management system (value of 1 since all of the manure produced is spread on pastures and crop fields)

APPENDIX B
ANNUAL LAMBING- MODEL DATA

Population parameters				
Parameter	**Value**	**Unit**	**Note**	**Source**
Adult ewes (population)	584	adult ewes	2010 Annual lambing average (11 farms)	OSMA benchmarking data (2009-2010)
Adult rams (population)	19	adult rams		(CECPA, 2013)
Number of lambs per ewe	1,4	lambs per ewe		expert judgement
Lamb mortality	10%		2009-2010 average lamb mortality in Ontario	OSMA benchmarking data (2009-2010)
Lambs weaned (population)	818	lambs weaned	Calculated based on number of lambs per ewe and number of ewes	calculated
Dead lambs (poulation)	82	dead lambs	Calculated based on lamb mortality rate	calculated
Replacement rate	19%		Sum of ewe mortality rate and ewe cull rate	calculated
Replacement ewes (population)	111	replacement ewe hoggets	Calculated based on replacement rate	calculated
Replacement rams (population)	4	replacement ram hoggets	Calculated based on replacement rate	calculated
Ewe mortality	3%		Adult ewe mortality between 1 and 5% in Ontario	(OMAFRA, 2010)
Dead ewes (population)	18	dead ewes	Calculated based on ewe mortality rate	calculated
Cull rate (ewes)	16%		Percentage of adult ewes culled and sent for processing	expert judgement

Cull rate (rams)	20%		Percentage of adult rams culled and sent for processing	expert judgement
Slaughtered ewes (population)	93	ewes	based on ewe cull rate	calculated
Slaughtered rams (population)	4	rams	based on ram cull rate	calculated
Slaughtered lambs (population)	703	lambs weaned		calculated

Live-weight (LW) parameters				
Parameter	**Value**	**Unit**	**Note**	**Source**
Lamb at weaning	28,3	kg LW		(OMAFRA, 2010)
Adult ewe	65,7	kg LW		(OSMA, 2009)
Adult ram	80	kg LW		expert judgement
Lamb	41	kg LW		expert judgement (sheep producer)
Meat production (ewes)	6139	kg LW	Calculated based on ewe population and ewe weight	calculated
Meat production (rams)	304	kg LW	Calculated based on ram population and ram weight	calculated
Meat production (lambs)	28824	kg LW	Calculated based on slaughtered lamb population and lamb weight	calculated

Feed production parameters			
	Forage (%)	Grain (%)	**Source**
Adult ewe	80%	20%	expert judgement
Adult ram	85%	15%	expert judgement
Replacement ewe	65%	35%	expert judgement
Replacement ram	65%	35%	expert judgement

Ewe Lamb	40%	60%		expert judgement
Ram Lamb	40%	60%		expert judgement
Grain diet composition				
Corn grain	24%			(CECPA, 2013)
Barley grain	59%			(CECPA, 2013)
Oat grain	17%			(CECPA, 2013)
Wheat grain	1%			(CECPA, 2013)
Forage composition				
Corn silage	17%			(OMAFRA, 2009)
Hay and haleage	47%			(OMAFRA, 2009)
Tillable pasture	22%			(OMAFRA, 2009)
Rough pasture	14%			(OMAFRA, 2009)

Farm operations parameters				
Parameter	**Value**	**Unit**	**Note**	**Source**
Water intake				
Water intake for sheep	7,6	L/head/day		(OSMA. Nutrition, feeding and the digestive system)
Water intake for lambs	3,8	L/head/day		(OSMA. Nutrition, feeding and the digestive system)
Energy use on farm				
Average electricity consumption	3499	$/year	2009 average (12 annual farms) for Ontario farm based on a population of 500 ewes	(OMAFRA, 2009)

Electricity cost	0,12	$/kWh	2011 cost for Ontario	(Hydro-Québec, 2011)
Electricity consumed per year	29158	kWh		calculated
Total electricity consumption	58	kWh/ewe sheep	Calculated based on population of 584 ewes	calculated
Average heating fuel consumption	603	$/year	2009 average (12 annual farms) for Ontario farm (500 ewes)	(OMAFRA, 2009)
Fuel cost	1	$/L	2011 cost for Ontario	(Statistics Canada, 2017)
Heating fuel consumed per year	464	L		calculated
Heating fuel consumed per year	16634	MJ	Based on energy content of 35,86 MJ/L	calculated
Total heating fuel consumption	33	MJ/ewe sheep	Calculated based on population of 584 ewes	calculated
Average diesel Fuel and oil consumption	2060	$/year	2009 average (12 annual farms) for Ontario farm (500 ewes)	(OMAFRA, 2009)
Diesel Fuel and oil per year	1585	L		calculated
Diesel Fuel and oil per year	56824	MJ	Energy content of 35,86 MJ/L	calculated
Total diesel fuel and oil consumption	114	MJ/ewe sheep	Calculated based on population of 584 ewes	calculated
Farm infrastructure and bedding				
Space requirements (ewe)	7,5	ft2/sheep	farm ground space required for each ewe	expert judgement (sheep producer)

Space requirements (lamb)	1,8	ft2/lamb, farm ground space required for each lamb	According to Anita Obrien, barn is sized up for 50% of the flock size	expert judgement (sheep producer)
Straw for bedding	124	kg straw/ewe/year	Based on 0.75 lbs straw/ewe/day	expert judgement (sheep producer)

Gross energy (GE) parameters

$$GE = \frac{\left(\frac{NE_m + NE_a + NE_l + NE_p}{REM}\right) + \left(\frac{NE_{wool} + NE_g}{REG}\right)}{\frac{DE\%}{100}}$$

GE = gross energy intake, MJ d^{-1}

NEm = net energy required by the animal for maintenance, MJ d^{-1}

NEa = net energy for animal activity, MJ d^{-1}

NEl = net energy for lactation, MJ d^{-1}

NEp = net energy for pregnancy, MJ d^{-1}

NEwool = net energy to produce wool, MJ d^{-1}

NEg = net energy for growth, MJ d^{-1}

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed
REG = ratio of net energy available for growth in a diet to digestible energy consumed
DE% = digestible energy as a percentage of gross energy, %

Parameter	Value	Unit	Note	Source
GE (sheep ewe)	22,26720	MJ/day, gross energy	Eq 10.16	(IPCC, 2006)
GE (sheep ram)	25,61578	MJ/day, gross energy		
GE (ewe lamb)	11,61212	MJ/day, gross energy		
GE (ram lamb)	12,46666	MJ/day, gross energy		
REM (lamb)	54%		Eq 10.14	(IPCC, 2006)
REM (sheep)	53%			
DE% (lamb)	70,4	%		
DE% (sheep)	66,8	%		
REG (lamb)	33%		Eq 10.15	
REG (sheep)	32%			
Nem (lamb)	3,823841617	MJ/day	Eq. 10.3	(IPCC, 2006)
Nem (ewe sheep)	5,007647624	MJ/day		

Nem (ram sheep)	5,804665847	MJ/day		
Cfi (lamb)	0,236	MJ/day/kg	coefficient for lambs	
Cfi (sheep)	0,217	MJ/day/kg	coefficient for sheep	
Nea (lamb)	0,4387	MJ/day	Eq. 10.5	(IPCC, 2006)
Nea (ewe sheep)	0,70299	MJ/day		
Nea (ram sheep)	0,856	MJ/day		
Ca (housed ewes)	0,009	MJ/d.kg	coefficient for housed ewes	
Ca (flat pasture)	0,0107	MJ/d.kg	coefficient for flat pasture	
Ca (hilly pasture)	0,024	MJ/d.kg	coefficient for hilly pasture	
Ca (housed lambs)	0,0067	MJ/d.kg	coefficient for housed lambs	
Neg (intact males)	0,508956849	MJ/day	Eq. 10.7	(IPCC, 2006)
Neg (castrate)	0,538897534	MJ/day		
Neg (females)	0,615602055	MJ/day		
Weight gain (lamb)	12,7	kg		
Live bodyweight at weaning	28,3	kg		
Live bodyweight at 1-year old or at slaughter (live-weight) if slaughtered prior to 1 year of age	41	kg		
a (intact males)	2,5	MJ/kg	coefficient for intact males	
a (castrates)	4,4	MJ/kg	coefficient for castrates	
a (females)	2,1	MJ/kg	coefficient for females	
b (intact males)	0,35	MJ/kg^2	coefficient for intact males	
b (castrates)	0,32	MJ/kg^2	coefficient for castrates	
b (females)	0,45	MJ/kg^2	coefficient for females	
Nel	0,132328767	MJ/day	Eq. 10.10	(IPCC, 2006)

Daily milk production	2,1	kg/day	Average of 2 liters/day, milk density of 1035 kg/m3	http://www.ablamb.ca/images/documents/promotions/Sheep-industry-in-Alberta-facts.pdf
Net energy required to produce 1 kg of milk	4,6	MJ/kg	A default value of 4.6 MJ/kg (AFRC, 1993) can be used which corresponds to a milk fat content of 7% by weight	(IPCC, 2006)
Newool	0,90199726	MJ/day	Eq. 10.12	(IPCC, 2006)
Energy value of wool	157	MJ/kg	equation for energy requirements for fibre growth shall be adjusted to account for the efficiency of ME requirements for fibre growth using 157 MJ/kg fibre	(Environment Canada, 2015)
Quantity of wool produced per ewe	2,10	kg wool/ewe	Data from Québec 2011 cost study	(CECPA, 2013)
Nep	0,48373876	MJ/day	Eq. 10.13	(IPCC, 2006)
Cpregnancy	0,0966		pregnancy coefficient	
Double birth fraction	0,4		Fraction of births that are twins	Assumption
Single birth fraction	0,6		Fraction of births that are triplets	Assumption

Enteric emissions

$$EF_{CH_4\ ent.ferm.} = \left[\frac{GE \cdot \left(\frac{Y_m}{100}\right) \cdot 365}{55.65}\right]$$

Parameter	Value	Unit	Note	Source
CH4 emission factor (sheep ewe)	9,493068746	kg CH4/head/year	Tier 2 methane emission factor (Eq.10.21)	(IPCC, 2006)
CH4 emission factor (sheep ram)	10,92065422	kg CH4/head/year	Tier 2 methane emission factor (Eq.10.21)	
CH4 emission factor (lamb ewe)	3,427296579	kg CH4/head/year	Tier 2 methane emission factor (Eq.10.21)	
CH4 emission factor (lamb ram)	3,679514209	kg CH4/head/year	Tier 2 methane emission factor (Eq.10.21)	
Ym_lamb	4,5	%, methane conversion factor	per cent of gross energy in feed converted to methane	
Ym_sheep	6,5	%, methane conversion factor	per cent of gross energy in feed converted to methane	

Manure CH4 emissions

$$EF_{CH_4\ manure} = (VS_T \cdot 365) \cdot \left[B_{O(T)} \cdot 0.67 \cdot \sum \frac{MCF_{S,k}}{100} \cdot MS_{(T,S,k)}\right]$$

EFCH4 manure = methane emission factor, kg CH4 head-1 day-1

VST = volatile solid excretion rate, kg VS day-1

Bo = maximum methane producing capacity of manure, m3 CH4 kg VS-1

0.67 = conversion factor of m3 CH4 to kg CH4

MCFS,k = methane conversion factor for each manure management system S by climate region k, %

MS(T,S,k) = fraction of animal’s manure handled using specific manure management system (a value of 1 is used since we assume that 100% of the manure is managed using a solid storage system)

	Value	Unit	Note	Source

Parameter				
EFch4_manure (sheep ewe)	0,13434431	kg CH4 animal-1 yr-1	Eq. 10.23	(IPCC, 2006)
EFch4_manure (sheep rams)	0,15454726	kg CH4 animal-1 yr-1		
EFch4_manure (ewe lamb)	0,063279279	kg CH4 animal-1 yr-1		
EFch4_manure (ram lamb)	0,067936054	kg CH4 animal-1 yr-1		
Bo	0,19	m3 CH4 kg-1 of VS excreted		
MCF	2	%	methane conversion factors for each manure management system S	
MS	0,35		fraction of livestock category T's manure handled using manure management system S	Assumption

$$VS = \left[GE \cdot \left(1 - \frac{DE\%}{100}\right) + (UE \cdot GE)\right] \cdot \left[\frac{1 - ASH}{18.45}\right]$$

VS = volatile solid excretion rate, kg VS day-1
GE = gross energy intake, MJ day-1
DE% = digestible energy as a percentage of gross energy, %
UE = urinary energy, MJ head-1 day-1
ASH = ash content of manure
18.45 = conversion factor for dietary gross energy per kg of dry matter, MJ kg-1

Parameter	Value	Unit	Note	Source
VS (sheep ewe)	0,413047474	kg dry matter animal-1 day-1		Calculated
VS (sheep ram)	0,475162327	kg dry matter animal-1 day-1		Calculated
VS (ewe lamb)	0,194554917	kg dry matter animal-1 day-1		Calculated

VS (ram lamb)	0,208872377	kg dry matter animal-1 day-1		Calculated
UE	0,04		Typically 0.04GE can be considered urinary energy excretion by most ruminants	(IPCC, 2006)
ASH	0,08			(Environment Canada, 2015)

Manure N2O DIRECT emissions

$$N2O_{D(mm)} = \left[\sum_{S}\left[\sum_{T}\left(N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)}\right)\right] \cdot EF_{3(S)}\right] \cdot \frac{44}{28}$$

N2OD(mm) = direct nitrous oxide emissions from manure management, kg N2O year-1

N(T) = number of head of sheep in category T in the region, head

Nex(T) = annual average nitrogen excretion per head of category T, kg N animal-1 day-1
Where Nex(T) is based on an N excretion rate of 0,42kg N/day/1000 kg live weight for both sheep and lambs (Environment Canada, 2015)

MS(T,S) = fraction of total annual nitrogen excretion for each sheep category T that is managed in manure management system S

Where MS(T,S) =35% for solid storage and drylot manure management system (Environment Canada, 2015)

EF3(S) = emission factor for direct nitrous oxide emissions from manure management system S, kg N2O-N/kg

N in manure management system S

Where EF3(S) = 0.02 kg N2O-N/kg N for solid storage and drylot manure management system for sheep and lambs (Environment Canada, 2015)

S = manure management system
T = sheep category
44/28 = conversion of (N2O-N)(mm) emissions to N2O(mm) emissions

Parameter	Value	Unit	Note	Source
Direct N2O emissions (adult ewe)	0,102459588	kg N2O yr-1 head-1	Eq 10-25	(IPCC, 2006)
Direct N2O emissions (lamb)	0,028807625	kg N2O yr-1 head-1		

Nex(T) (mature ewes)	9,314508	kg N animal-1 year-1	average sheep weight based on lamb weight (1st year) and adut weight (4 next years). N excretion rate of 0,42 kg N/1000 kg/day	(Environment Canada, 2015)
Nex(T) (lambs)	2,618875	kg N animal-1 year-1	5/12 factor to account for fact that lambs are weaned after 5 months. N excretion rate of 0,42 kg N/1000 kg/day	(Environment Canada, 2015)
MS(T,S)	0,35		35% of manure is manaed in drylot and solid storage system	assumption
EF3(S)	0,02	kg N2O-N/kg N		(IPCC, 2006)

Manure N2O INDIRECT emissions
(emissions from N volatilisation and from N leaching)

$$N_{leaching-MMS} = \sum_{S}\left[\sum_{T}\left[\left(N_{(T)} \cdot Nex_{T} \cdot MS_{(T,S)}\right) \cdot \left(\frac{Frac_{leachMS}}{100}\right)_{(T,S)}\right]\right]$$

Nleaching-MMS = amount of manure nitrogen that leached from manure management systems, kg N year-1

N(T) = number of head in sheep category T

Nex(T) = annual average nitrogen excretion per head of category T, kg N animal-1 year-1
Where Nex(T) is based on an N excretion rate of 0,42kg N/day/1000 kg live weight for both sheep and lambs (Environment Canada, 2015)

MS(T,S) = fraction of total annual nitrogen excretion for each sheep category T that is managed in manure management system S

FracleachMS = percent of managed manure nitrogen losses for sheep category T due to runoff and leaching storage of manure, %

Where FracleachMS = 10% (IPCC, 2013)

Parameter	Value	Unit	Note	Source
Nleaching-MMS (adult sheep)	0,32600778	kg N yr-1		calculated
Nleaching-MMS (lamb)	0,091660625	kg N yr-1		calculated
FracLeachMS	10		typical range 1-20%	(IPCC, 2006)

$$N_2O_{L(mm)} = \left(N_{leaching-MMS} \cdot EF_5\right) \cdot \frac{44}{28}$$

N2OL(mm) = indirect nitrous oxide emissions due to leaching and runoff from manure management, kg N2O year-1

EF5 = emission factor for nitrous oxide emissions from nitrogen leaching and runoff, kg N2O-N (kg N leached and runoff)-1

Where EF5 = 0.0075 kg N2O-N (default value, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf)

44/28 = conversion of (N2O-N) emissions to N2O emissions

Parameter	Value	Unit	Note	Source
N2OL (adult sheep)	0,003842235	kg N2O yr-1		calculated
N2OL (lamb)	0,001080286	kg N2O yr-1		calculated
EF5	0,0075	kg N2O-N/kg N leached and runoff	default value 0.0075 kg N2O-N/kg N leaching or runoff	(IPCC, 2006)

$$N_{volatilization-MMS} = \sum_S \left[\sum_T \left[\left(N_{(T)} \cdot Nex_T \cdot MS_{(T,S)}\right) \cdot \left(\frac{Frac_{GasMS}}{100}\right)_{(T,S)} \right] \right]$$

Nvolatilization-MMS = amount of manure nitrogen that is lost due to volatilization from manure management systems, kg N year-1

N(T) = number of head in sheep category T

Nex(T) = annual average nitrogen excretion per head of category T, kg N animal-1 year-1
Where Nex(T) is based on an N excretion rate of 0,42kg N/day/1000 kg live weight for both sheep and lambs (Environment Canada, 2015)

MS(T,S) = fraction of total annual nitrogen excretion for each sheep category T that is managed in manure management system S

FracGasMS = percent of managed manure nitrogen that volatilized as NH3 and NOX for sheep category T in the manure management system S, %

Where FracGasMS = 12% (Table 10.22, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf)

Parameter	**Value**	**Unit**	**Note**	**Source**
Nvolatilization (adult sheep)	0,391209336	kg N yr-1 head-1		calculated
Nvolatilization (lambs)	0,10999275	kg N yr-1 head-1		calculated
FracGasMS	12	%		(IPCC, 2006)

$$N_2O_{G(mm)} = (N_{volatilization-MMS} \cdot EF_4) \cdot \frac{44}{28}$$

N2OG(mm) = indirect nitrous oxide emissions due to volatilization from manure management, kg N2O year-1

Nvolatilization-MMS = amount of manure nitrogen that volatilized from manure management systems, kg N year-1
EF4 = emission factor for nitrous oxide emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N2O-N (kg NH3-N+NOx-N volatilized)-1 (default emission value 0.01 from Table 11.3, IPCC, 2006)

44/28 = conversion of (N2O-N) emissions to N2O emissions

Parameter	**Value**	**Unit**	**Note**	**Source**
N2OG (adult sheep)	0,006147575	kg N2O yr-1		calculated
N2OG (lamb)	0,001728458	kg N2O yr-1		calculated

EF4	0,01	kg N2O-N -1	default value is 0.01 kg N2O-N (kg NH3-N + NOx-N volatilised)-1	(IPCC, 2006)

N2O emissions generated by manure in the system ‘pasture, range, and paddock’

$$N_2O - N_{PRP} = F_{PRP,CPP} \times EF_{3PRP,CPP}$$

N2O-NPRP = annual direct N2O–N emissions from urine and dung inputs to grazed soils, kg N2O–N yr-1

FPRP,CPP = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr-1

EF3PRP,CPP = emission factor for N2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, kg N2O–N (kg N input)-1 (default emission factor of 0.01 from Table 11.1 (IPCC, 2016))

$$F_{PRP} = \sum_{T} \left[\left(N_{(T)} \times N_{EX(T)} \right) \times MS_{(T,PRP)} \right]$$

N(T) = number of head in sheep category T

Nex(T) = annual average nitrogen excretion per head of category T, kg N animal-1 year-1
Where Nex(T) is based on an N excretion rate of 0,42kg N/day/1000 kg live weight for both sheep and lambs (Environment Canada, 2015)

MS(T,S) = fraction of total annual nitrogen excretion for each sheep category T that is managed in manure management system (value of 1 since all of the manure produced is spread on pastures and crop fields)

Parameter	Value	Unit	Note	Source
N2O–NPRP (sheep)	0,14637084	kg N2O yr-1 head-1		calculated
N2O–NPRP (lamb)	0,04115375	kg N2O yr-1 head-1		calculated
EF3PRP	0,01	kg N2O–N (kg N input)-1		(IPCC, 2006)
FPRP_sheep	9,314508	kg N yr-1 head-1		calculated
FPRP_lambs	2,618875	kg N yr-1 head-1		
MS(T,S)	1			assumption

Economic allocation (wool, meat)				
Parameter	**Value**	**Unit**	**Note**	**Source**
Wool price	1,6	$/kg greasy wool	Average price of wool in Canada (2015)	http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=30097
Meat (lamb) price	6,5	$/kg	Average price of lamb in Canada (2017)	http://aimis-simia.agr.gc.ca/rp/index-eng.cfm?report_format_type_code=21&action=gR&signature=AFA503F3291AB696BEC1B03287812550&pdctc=&r=80&pTpl=1&btnDownload=View
Meat (sheep) price	2,7	$/kg	Average price of sheep in Canada (2017)	http://aimis-simia.agr.gc.ca/rp/index-eng.cfm?report_format_type_code=21&action=gR&signature=AFA503F3291AB696BEC1B03287812550&pdctc=&r=80&pTpl=1&btnDownload=View
Quantity of wool produced per ewe	2,1	kg wool/ewe	Data from Québec 2011 cost study	(CECPA, 2013)
Total wool quantity produced	1224,6	kg wool sold	Based on population of 584 ewes	Calculated
Meat_lamb_produced	28824,2	kg meat sold	Based on lamb population and lamb live weight	Calculated
Meat_sheep_produced	6443,0	kg meat sold	Based onsheep population and sheep live weight	Calculated

Economic allocation factor (wool)	1%	Calculated
Economic allocation factor (meat)	99%	Calculated

Appendix C
Accelerated lambing - model data

Population parameters				
Parameter	**Value**	**Unit**	**Note**	**Source**
Adult ewes (population)	482	adult ewes	2010 Annual lambing average (11 farms)	OSMA benchmarking data (2009-2010)
Adult rams (population)	19	adult rams		(CECPA, 2013)
Number of lambs per ewe	2	lambs per ewe		expert judgement
Lamb mortality	12%		2009-2010 average lamb mortality in Ontario	OSMA benchmarking data (2009-2010)
Lambs weaned (population)	964	lambs weaned	Calculated based on number of lambs per ewe and number of ewes	calculated
Dead lambs (poulation)	116	dead lambs	Calculated based on lamb mortality rate	calculated
Replacement rate	19%		Sum of ewe mortality rate and ewe cull rate	calculated
Replacement ewes (population)	89	replacement ewe hoggets	Calculated based on replacement rate	calculated
Replacement rams (population)	4	replacement ram hoggets	Calculated based on replacement rate	calculated
Ewe mortality	4%		Adult ewe mortality between 1 and 5% in Ontario	(OMAFRA, 2010)
Dead ewes (population)	20	dead ewes	Calculated based on ewe mortality rate	calculated
Cull rate (ewes)	15%		Percentage of adult ewes culled and sent for processing	expert judgement

Cull rate (rams)	20%		Percentage of adult rams culled and sent for processing	expert judgement
Slaughtered ewes (population)	72	ewes	based on ewe cull rate	calculated
Slaughtered rams (population)	4	rams	based on ram cull rate	calculated
Slaughtered lambs (population)	871	lambs weaned		calculated

Live-weight (LW) parameters				
Parameter	**Value**	**Unit**	**Note**	**Source**
Lamb at weaning	22,7	kg LW		(OMAFRA, 2010)
Adult ewe	71,6	kg LW		(OSMA, 2009)
Adult ram	80	kg LW		expert judgement
Lamb	47,6	kg LW		expert judgement (sheep producer)
Meat production (ewes)	5176,68	kg LW	Calculated based on ewe population and ewe weight	calculated
Meat production (rams)	304	kg LW	Calculated based on ram population and ram weight	calculated
Meat production (lambs)	41474,594	kg LW	Calculated based on slaughtered lamb population and lamb weight	calculated

Feed production parameters			
	Forage (%)	Grain (%)	**Source**
Adult ewe	60%	40%	expert judgement
Adult ram	60%	40%	expert judgement
Replacement ewe	60%	40%	expert judgement
Replacement ram	60%	40%	expert judgement

Ewe Lamb	10%	90%		expert judgement
Ram Lamb	10%	90%		expert judgement
Grain diet composition				
Corn grain	24%			(CECPA, 2013)
Barley grain	59%			(CECPA, 2013)
Oat grain	17%			(CECPA, 2013)
Wheat grain	1%			(CECPA, 2013)
Forage composition				
Corn silage	17%			(OMAFRA, 2009)
Hay and haleage	66%			(OMAFRA, 2009)
Tillable pasture	12%			(OMAFRA, 2009)
Rough pasture	4%			(OMAFRA, 2009)

Farm operations parameters				
Parameter	**Value**	**Unit**	**Note**	**Source**
Water intake				
Water intake for sheep	7,6	L/head/day		(OSMA. Nutrition, feeding and the digestive system)
Water intake for lambs	3,8	L/head/day		(OSMA. Nutrition, feeding and the digestive system)
Energy use on farm				
Average electricity consumption	5828	$/year	2009 average (12 annual farms) for Ontario farm based on a population of 500 ewes	(OMAFRA, 2009)
Electricity cost	0,12	$/kWh	2011 cost for Ontario	(Hydro-Québec, 2011)

Electricity consumed per year	48567	kWh		calculated
Total electricity consumption	99	kWh/ewe sheep	Calculated based on population of 584 ewes	calculated
Average heating fuel consumption	1472	$/year	2009 average (12 annual farms) for Ontario farm (500 ewes)	(OMAFRA, 2009)
Fuel cost	1	$/L	2011 cost for Ontario	(Statistics Canada, 2017)
Heating fuel consumed per year	1132	L		calculated
Heating fuel consumed per year	40605	MJ	Based on energy content of 35,86 MJ/L	calculated
Total heating fuel consumption	83	MJ/ewe sheep	Calculated based on population of 584 ewes	calculated
Average diesel Fuel and oil consumption	3285	$/year	2009 average (12 annual farms) for Ontario farm (500 ewes)	(OMAFRA, 2009)
Diesel Fuel and oil per year	2527	L		calculated
Diesel Fuel and oil per year	90610	MJ	Energy content of 35,86 MJ/L	calculated
Total diesel fuel and oil consumption	185	MJ/ewe sheep	Calculated based on population of 584 ewes	calculated
Farm infrastructure and bedding				
Space requirements (ewe)	16	ft2/sheep	farm ground space required for each ewe	expert judgement (sheep producer)
Space requirements (lamb)	1,8	ft2/lamb, farm ground space required for each lamb	According to Anita Obrien, barn is sized up for 50% of the flock size	expert judgement (sheep producer)

Straw for bedding	124	kg straw/ewe/year	Based on 0.75 lbs straw/ewe/day	expert judgement (sheep producer)

Gross energy (GE) parameters

$$GE = \frac{\left(\frac{NE_m + NE_a + NE_l + NE_p}{REM}\right) + \left(\frac{NE_{wool} + NE_g}{REG}\right)}{\frac{DE\%}{100}}$$

GE = gross energy intake, MJ d^{-1}

NEm = net energy required by the animal for maintenance, MJ d^{-1}

NEa = net energy for animal activity, MJ d^{-1}

NEl = net energy for lactation, MJ d^{-1}

NEp = net energy for pregnancy, MJ d^{-1}

NEwool = net energy to produce wool, MJ d^{-1}

NEg = net energy for growth, MJ d^{-1}

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed
REG = ratio of net energy available for growth in a diet to digestible energy consumed
DE% = digestible energy as a percentage of gross energy, %

Parameter	Value	Unit	Note	Source
GE (sheep ewe)	22,49505841	MJ/day, gross energy	Eq 10.16	(IPCC, 2006)
GE (sheep ram)	26,43956905	MJ/day, gross energy		
GE (ewe lamb)	14,12054635	MJ/day, gross energy		
GE (ram lamb)	13,50676817	MJ/day, gross energy		
REM (lamb)	54%		Eq 10.14	(IPCC, 2006)
REM (sheep)	53%			
DE% (lamb)	73,1	%		
DE% (sheep)	68,6	%		
REG (lamb)	35%		Eq 10.15	
REG (sheep)	33%			
Nem (lamb)	4,276783024	MJ/day	Eq. 10.3	(IPCC, 2006)
Nem (ewe sheep)	5,341269613	MJ/day		
Nem (ram sheep)	5,804665847	MJ/day		
Cfi (lamb)	0,236	MJ/day/kg	coefficient for lambs	
Cfi (sheep)	0,217	MJ/day/kg	coefficient for sheep	

Nea (lamb)	0,31892	MJ/day	Eq. 10.5	(IPCC, 2006)
Nea (ewe sheep)	0,6444	MJ/day		
Nea (ram sheep)	0,72	MJ/day		
Ca (housed ewes)	0,009	MJ/d.kg	coefficient for housed ewes	
Ca (flat pasture)	0,0107	MJ/d.kg	coefficient for flat pasture	
Ca (hilly pasture)	0,024	MJ/d.kg	coefficient for hilly pasture	
Ca (housed lambs)	0,0067	MJ/d.kg	coefficient for housed lambs	
Neg (intact males)	1,009814384	MJ/day	Eq. 10.7	(IPCC, 2006)
Neg (castrate)	1,067493699	MJ/day		
Neg (females)	1,222317123	MJ/day		
Weight gain (lamb)	24,9	kg		
Live bodyweight at weaning	22,7	kg		
Live bodyweight at 1-year old or at slaughter (live-weight) if slaughtered prior to 1 year of age	47,6	kg		
a (intact males)	2,5	MJ/kg	coefficient for intact males	
a (castrates)	4,4	MJ/kg	coefficient for castrates	
a (females)	2,1	MJ/kg	coefficient for females	
b (intact males)	0,35	MJ/kg^2	coefficient for intact males	
b (castrates)	0,32	MJ/kg^2	coefficient for castrates	
b (females)	0,45	MJ/kg^2	coefficient for females	
Nel	**0,13**	MJ/day	Eq. 10.10	(IPCC, 2006)

Daily milk production	2,1	kg/day	Average of 2 liters/day, milk density of 1035 kg/m3	http://www.ablamb.ca/images/documents/promotions/Sheep-industry-in-Alberta-facts.pdf
Net energy required to produce 1 kg of milk	4,6	MJ/kg	A default value of 4.6 MJ/kg (AFRC, 1993) can be used which corresponds to a milk fat content of 7% by weight	(IPCC, 2006)
Newool	**0,9**	MJ/day	Eq. 10.12	(IPCC, 2006)
Energy value of wool	157	MJ/kg	equation for energy requirements for fibre growth shall be adjusted to account for the efficiency of ME requirements for fibre growth using 157 MJ/kg fibre	(Environment Canada, 2015)
Quantity of wool produced per ewe	2,097	kg wool/ewe	Data from Québec 2011 cost study	(CECPA, 2013)
Nep	0,61	MJ/day	Eq. 10.13	(IPCC, 2006)
Cpregnancy	0,11473		pregnancy coefficient	
Double birth fraction	0,77		Fraction of births that are twins	Assumption
Single birth fraction	0,23		Fraction of births that are triplets	Assumption
Enteric emissions				

$$EF_{CH_4\ ent.ferm.} = \left[\frac{GE \cdot \left(\frac{Y_m}{100}\right) \cdot 365}{55.65}\right]$$

Parameter	Value	Unit	Note	Source
CH4 emission factor (sheep ewe)	9,590211337	kg CH4/head/year	Tier 2 methane emission factor (Eq.10.21)	(IPCC, 2006)
CH4 emission factor (sheep ram)	11,27185581	kg CH4/head/year	Tier 2 methane emission factor (Eq.10.21)	
CH4 emission factor (lamb ewe)	4,167654514	kg CH4/head/year	Tier 2 methane emission factor (Eq.10.21)	
CH4 emission factor (lamb ram)	3,98649896	kg CH4/head/year	Tier 2 methane emission factor (Eq.10.21)	
Ym_lamb	4,5	%, methane conversion factor	per cent of gross energy in feed converted to methane	
Ym_sheep	6,5	%, methane conversion factor	per cent of gross energy in feed converted to methane	

Manure CH4 emissions

$$EF_{CH_4\ manure} = (VS_T \cdot 365) \cdot \left[B_{O(T)} \cdot 0.67 \cdot \sum \frac{MCF_{S,k}}{100} \cdot MS_{(T,S,k)}\right]$$

EFCH4 manure = methane emission factor, kg CH4 head-1 day-1

VST = volatile solid excretion rate, kg VS day-1

Bo = maximum methane producing capacity of manure, m3 CH4 kg VS-1

0.67 = conversion factor of m3 CH4 to kg CH4

MCFS,k = methane conversion factor for each manure management system S by climate region k, %

MS(T,S,k) = fraction of animal's manure handled using specific manure management system (a value of 1 is used since we assume that 100% of the manure is managed using a solid storage system)

	Value	Unit	Note	Source

Parameter				
EFch4_manure (sheep ewe)	0,313654869	kg CH4 animal-1 yr-1	Eq. 10.23	(IPCC, 2006)
EFch4_manure (sheep rams)	0,36865428	kg CH4 animal-1 yr-1		
EFch4_manure (ewe lamb)	0,171858741	kg CH4 animal-1 yr-1		
EFch4_manure (ram lamb)	0,164388552	kg CH4 animal-1 yr-1		
Bo	0,19	m3 CH4 kg-1 of VS excreted		
MCF	2	%	methane conversion factors for each manure management system S	
MS	0,85		fraction of livestock category T's manure handled using manure management system S	Assumption

$$VS = \left[GE \cdot \left(1 - \frac{DE\%}{100}\right) + (UE \cdot GE)\right] \cdot \left[\frac{1 - ASH}{18.45}\right]$$

VS = volatile solid excretion rate, kg VS day-1
GE = gross energy intake, MJ day-1
DE% = digestible energy as a percentage of gross energy, %
UE = urinary energy, MJ head-1 day-1
ASH = ash content of manure
18.45 = conversion factor for dietary gross energy per kg of dry matter, MJ kg-1

Parameter	Value	Unit	Note	Source
VS (sheep ewe)	0,397083503	kg dry matter animal-1 day-1		Calculated
VS (sheep ram)	0,466712133	kg dry matter animal-1 day-1		Calculated
VS (ewe lamb)	0,217571215	kg dry matter animal-1 day-1		Calculated

VS (ram lamb)	0,208114041	kg dry matter animal-1 day-1		Calculated
UE	0,04		Typically 0.04GE can be considered urinary energy excretion by most ruminants	(IPCC, 2006)
ASH	0,08			(Environment Canada, 2015)

Manure N2O DIRECT emissions

$$N2O_{D(mm)} = \left[\sum_{S}\left[\sum_{T}\left(N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)}\right)\right] \cdot EF_{3(S)}\right] \cdot \frac{44}{28}$$

N2OD(mm) = direct nitrous oxide emissions from manure management, kg N2O year-1

N(T) = number of head of sheep in category T in the region, head

Nex(T) = annual average nitrogen excretion per head of category T, kg N animal-1 day-1
Where Nex(T) is based on an N excretion rate of 0,42kg N/day/1000 kg live weight for both sheep and lambs (Environment Canada, 2015)

MS(T,S) = fraction of total annual nitrogen excretion for each sheep category T that is managed in manure management system S

Where MS(T,S) =35% for solid storage and drylot manure management system (Environment Canada, 2015)

EF3(S) = emission factor for direct nitrous oxide emissions from manure management system S, kg N2O-N/kg

N in manure management system S

Where EF3(S) = 0.02 kg N2O-N/kg N for solid storage and drylot manure management system for sheep and lambs (Environment Canada, 2015)

S = manure management system
T = sheep category
44/28 = conversion of (N2O-N)(mm) emissions to N2O(mm) emissions

Parameter	Value	Unit	Note	Source
Direct N2O emissions (adult ewe)	0,27356604	kg N2O yr-1 head-1	Eq 10-25	(IPCC, 2006)
Direct N2O emissions (lamb)	0,056856415	kg N2O yr-1 head-1		

Nex(T) (mature ewes)	10,24044	kg N animal-1 year-1	average sheep weight based on lamb weight (1st year) and adut weight (4 next years). N excretion rate of 0,42 kg N/1000 kg/day	(Environment Canada, 2015)
Nex(T) (lambs)	2,128315	kg N animal-1 year-1	5/12 factor to account for fact that lambs are weaned after 5 months. N excretion rate of 0,42 kg N/1000 kg/day	(Environment Canada, 2015)
MS(T,S)	0,85		85% of manure is manaed in drylot and solid storage system	assumption
EF3(S)	0,02	kg N2O-N/kg N		(IPCC, 2006)

Manure N2O INDIRECT emissions
(emissions from N volatilisation and from N leaching)

$$N_{leaching-MMS} = \sum_S \left[\sum_T \left[\left(N_{(T)} \cdot Nex_T \cdot MS_{(T,S)} \right) \cdot \left(\frac{Frac_{leachMS}}{100} \right)_{(T,S)} \right] \right]$$

Nleaching-MMS = amount of manure nitrogen that leached from manure management systems, kg N year-1

N(T) = number of head in sheep category T

Nex(T) = annual average nitrogen excretion per head of category T, kg N animal-1 year-1
Where Nex(T) is based on an N excretion rate of 0,42kg N/day/1000 kg live weight for both sheep and lambs (Environment Canada, 2015)

MS(T,S) = fraction of total annual nitrogen excretion for each sheep category T that is managed in manure management system S

FracleachMS = percent of managed manure nitrogen losses for sheep category T due to runoff and leaching storage of manure, %

Where FracleachMS = 10% (IPCC, 2013)

Parameter	Value	Unit	Note	Source
Nleaching-MMS (adult sheep)	0,8704374	kg N yr-1		calculated
Nleaching-MMS (lamb)	0,180906775	kg N yr-1		calculated
FracLeachMS	10		typical range 1-20%	(IPCC, 2006)

$$N_2O_{L(mm)} = \left(N_{leaching-MMS} \cdot EF_5\right) \cdot \frac{44}{28}$$

N2OL(mm) = indirect nitrous oxide emissions due to leaching and runoff from manure management, kg N2O year-1

EF5 = emission factor for nitrous oxide emissions from nitrogen leaching and runoff, kg N2O-N (kg N leached and runoff)-1

Where EF5 = 0.0075 kg N2O-N (default value, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf)

44/28 = conversion of (N2O-N) emissions to N2O emissions

Parameter	Value	Unit	Note	Source
N2OL (adult sheep)	0,010258727	kg N2O yr-1		calculated
N2OL (lamb)	0,002132116	kg N2O yr-1		calculated
EF5	0,0075	kg N2O-N/kg N leached and runoff	default value 0.0075 kg N2O-N/kg N leaching or runoff	(IPCC, 2006)

$$N_{volatilization-MMS} = \sum_S \left[\sum_T \left[\left(N_{(T)} \cdot Nex_T \cdot MS_{(T,S)}\right) \cdot \left(\frac{Frac_{GasMS}}{100}\right)_{(T,S)} \right] \right]$$

Nvolatilization-MMS = amount of manure nitrogen that is lost due to volatilization from manure management systems, kg N year-1

N(T) = number of head in sheep category T

Nex(T) = annual average nitrogen excretion per head of category T, kg N animal-1 year-1
Where Nex(T) is based on an N excretion rate of 0,42kg N/day/1000 kg live weight for both sheep and lambs (Environment Canada, 2015)

MS(T,S) = fraction of total annual nitrogen excretion for each sheep category T that is managed in manure management system S

FracGasMS = percent of managed manure nitrogen that volatilized as NH3 and NOX for sheep category T in the manure management system S, %

Where FracGasMS = 12% (Table 10.22, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf)

Parameter	Value	Unit	Note	Source
Nvolatilization (adult sheep)	1,04452488	kg N yr-1 head-1		calculated
Nvolatilization (lambs)	0,21708813	kg N yr-1 head-1		calculated
FracGasMS	12	%		(IPCC, 2006)

$$N_2O_{G(mm)} = (N_{volatilization-MMS} \cdot EF_4) \cdot \frac{44}{28}$$

N2OG(mm) = indirect nitrous oxide emissions due to volatilization from manure management, kg N2O year-1

Nvolatilization-MMS = amount of manure nitrogen that volatilized from manure management systems, kg N year-1
EF4 = emission factor for nitrous oxide emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N2O-N (kg NH3-N+NOx-N volatilized)-1 (default emission value 0.01 from Table 11.3, IPCC, 2006)

44/28 = conversion of (N2O-N) emissions to N2O emissions

Parameter	Value	Unit	Note	Source
N2OG (adult sheep)	0,016413962	kg N2O yr-1		calculated
N2OG (lamb)	0,003411385	kg N2O yr-1		calculated

EF4	0,01	kg N2O-N -1	default value is 0.01 kg N2O-N (kg NH3-N + NOx-N volatilised)-1	(IPCC, 2006)

N2O emissions generated by manure in the system 'pasture, range, and paddock'

$$N_2O - N_{PRP} = F_{PRP,CPP} \times EF_{3PRP,CPP}$$

N2O-NPRP = annual direct N2O–N emissions from urine and dung inputs to grazed soils, kg N2O–N yr-1

FPRP,CPP = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr-1

EF3PRP,CPP = emission factor for N2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, kg N2O–N (kg N input)-1 (default emission factor of 0.01 from Table 11.1 (IPCC, 2016))

$$F_{PRP} = \sum_T \left[\left(N_{(T)} \times N_{EX(T)} \right) \times MS_{(T,PRP)} \right]$$

N(T) = number of head in sheep category T

Nex(T) = annual average nitrogen excretion per head of category T, kg N animal-1 year-1
Where Nex(T) is based on an N excretion rate of 0,42kg N/day/1000 kg live weight for both sheep and lambs (Environment Canada, 2015)

MS(T,S) = fraction of total annual nitrogen excretion for each sheep category T that is managed in manure management system (value of 1 since all of the manure produced is spread on pastures and crop fields)

Parameter	Value	Unit	Note	Source
N2O–NPRP (sheep)	0,1609212	kg N2O yr-1 head-1		calculated
N2O–NPRP (lamb)	0,03344495	kg N2O yr-1 head-1		calculated
EF3PRP	0,01	kg N2O–N (kg N input)-1		(IPCC, 2006)
FPRP_sheep	10,24044	kg N yr-1 head-1		calculated
FPRP_lambs	2,128315	kg N yr-1 head-1		
MS(T,S)	1			assumption

Economic allocation (wool, meat)				
Parameter	**Value**	**Unit**	**Note**	**Source**
Wool price	1,6	$/kg greasy wool	Average price of wool in Canada (2015)	http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=30097
Meat (lamb) price	6,5	$/kg	Average price of lamb in Canada (2017)	http://aimis-simia.agr.gc.ca/rp/index-eng.cfm?report_format_type_code=21&action=gR&signature=AFA503F3291AB696BEC1B03287812550&pdctc=&r=80&pTpl=1&btnDownload=View
Meat (sheep) price	2,7	$/kg	Average price of sheep in Canada (2017)	http://aimis-simia.agr.gc.ca/rp/index-eng.cfm?report_format_type_code=21&action=gR&signature=AFA503F3291AB696BEC1B03287812550&pdctc=&r=80&pTpl=1&btnDownload=View
Quantity of wool produced per ewe	2,1	kg wool/ewe	Data from Québec 2011 cost study	(CECPA, 2013)
Total wool quantity produced	1010,8	kg wool sold	Based on population of 584 ewes	Calculated
Meat_lamb_produced	41474,6	kg meat sold	Based on lamb population and lamb live weight	Calculated
Meat_sheep_produced	5480,7	kg meat sold	Based onsheep population and sheep live weight	Calculated

Economic allocation factor (wool)	1%	Calculated
Economic allocation factor (meat)	99%	Calculated

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Lamb Survival
Do you have a problem?

Delma Kennedy
Sheep Specialist – Genetics, Reproduction and Performance Programs
Ontario Ministry of Agriculture, Food and Rural Affairs

One of the things that we struggle with in the Ontario industry is diversity; diversity of production systems, diversity of breeds and diversity of markets. This diversity creates many opportunities but makes it more difficult for producers to determine what production results are "normal" or "good".

Every flock has lamb mortality and there are many reasons why lambs do not survive. This complexity makes it more difficult to determine if there are things that could be changed in the flock to improve lamb survival. The other frustrating problem is that even if all dead lambs are post-mortemed, often the results are inconclusive. In an extensive health study done in Quebec in 1999 and 2000, 68% of the lambs which died in the first 2 days of life had an inconclusive diagnosis when post-mortemed. Diagnostics have improved in the past ten years and should be done routinely to ensure identification of problems that are identifiable. Dwyer reported that lamb mortality can be categorized into the following areas:

1. Trauma in birth process
2. Failure to adapt to postnatal life
    I. Inability to maintain body temperature
    II. Low lamb vigour
    III. Poor maternal bond
3. Infectious disease
4. Functional disorders
5. Predation

There are many factors that influence and potentially cause problems in the areas listed above. For example nutrition of the ewe during gestation, sanitation, ventilation, disease, ewe and lamb bonding, size of litter and birth weight. With lambs dying from a variety of different things it is even more difficult to determine what a "good" lamb survival rate is for your particular sheep operation.

Actual Mortality Rates

In a literature review of research from around the world of different sheep breeds and different production systems, Dwyer (2008) found that estimates of pre-weaning mortality ranged from 10 – 30% and that most of the mortality was in the first 3 days of life. A number of sources of Canadian mortality data over the past 30 years find average mortality rates of 12 – 16%. A survey of sheep diseases in Canada done in 1982 and 1983 of 116 farms across Canada estimated that total lamb mortality was a conservative 12.1%. The causes of mortality were grouped into twelve areas with 38% of lambs dying of unknown causes. A productivity and health management survey of 64 Ontario sheep producers was done in 1999. Fischer and Menzies (2008) found an average total mortality of 11.9% with

5.5% stillborn, 5% mortality pre-weaning and 1.9% mortality post weaning. The table below shows the average mortality recorded by Ontario producers on the Sheep Flock Improvement Program for the major breeds and across all breeds recorded on the program.

Average Mortality Sheep Flock Improvement Program 2007-2009

Breed	# Born	Born per lambing	% Mummified	% Stillborn	%0-10 days	%11-50 days	%51-100 days	Total % Mortality
Dorset	1187	1.54	0.1	4.0	3.1	1.8	0.8	9.7
Suffolk	650	1.59	0.2	1.7	6.8	2.5	0.9	12.1
Rideau	6011	2.19	0.3	3.4	6.9	3.1	1.1	14.8
Crossbred	3771	1.84	0.1	2.5	7.1	2.9	2.2	14.9
All breeds	12880	1.91	0.2	3.1	6.4	2.8	1.5	14.1

An extensive survey of sheep health was done in Quebec in the years 1999 - 2001. A portion of this study focused on lamb mortality.

Pre-weaning Mortality

	%
Average mortality per flock	15.8
Median mortality per flock	14.5
Minimum mortality per flock	6.8
Maximum mortality per flock	31.7
Total number of lambs born	4148
Percent mortality 0 – 2 days	9.6
Percent mortality 0 – 10days	11.8
Percent total mortality pre weaning	15.4

Adapted from Belanger et al (2001)

This study shows an average mortality of 15.8% which is quite similar to the average results recorded on the Sheep Flock Improvement Program. However this study also reported the range of mortality among the participating flocks. There was a large range in the mortality on each farm with a low of 6.8 % and a high of 31.7%. As a result, a range of 10 - 30 % appears to be a reasonable guess at what the mortality range might be expected to be in Ontario flocks.

Achievable Mortality Rates

After extensive research in reproductive performance, Shelton and Willingham (2002) state that 10 percent mortality after birth is a practical minimum under farm production conditions. Veterinarians often state that total mortality of 10% or less is an achievable, realistic number. In the Quebec study one flock had a pre-weaning mortality rate of 6.8% illustrating that a 10% total mortality rate is possible. The advantages and risks of lambing on grass or lambing in the barn are different but as Dwyer (2008) found in a review of literature, a similar range of average pre-weaning mortality is reported of 10 - 30% regardless of the system. It is also expected that more prolific flocks will have more mortality. In a nine year summary of mortality at Spooner research station, Berger reported that on average 9.9% of the lambs were born dead or died before weaning. The range of mortality between years was 5.6% - 15%. The average litter size per year ranged from 1.96

– 2.36. This illustrates that even with prolific flocks a pre-weaning mortality of 10% is definitely achievable, with a total lamb mortality of 10% still possible.

On Farm

It is important to keep mortality records. Due to the fact that mortality can be a result of many different factors it is difficult to identify problems without records. If your mortality is high it is also important to do post-mortems and record the results to provide information that can be used to identify problems, trends and possible solutions. Due to the fact that mortality is caused by many factors, it can be discouraging that the solution is often not found very easily. In the same Quebec study, Arsenault (2002) reports on post-mortem results which illustrate this problem in the table below.

Post-Mortem Diagnosis of Lambs

	Number of Lambs (% lambs)			
Post-Mortem Diagnosis	**0 - 1 day**	**2 - 10 days**	**11 - 60 days**	**Number of Flocks Affected**
No diagnosis	187 (68.0)	31 (41.3)	12 (22.2)	27/29
Congenital Abnormality	12 (4.0)	6 (8.0)		13/29
Trauma/distocia	25 (9.1)	-	-	12/29
Infectious Problems				
Chlamydia abortion	5 (1.8)			3/29
Coxiella Burnetii	3 (1.1)			3/29
Toxoplasmosis	5 (1.8)			4/29
E. Coli	2 (0.7)			1/29
Undetermined Agent	13 (4.7)			5/29
Inhaled Amniotic fluid	5 (1.8)	4 (5.3)		7/29
Respiratory problems				
Bacterial pneumonia	2 (.07)	10 (13.3)	25 (46.3)	13/29
Pluerisy	1 (.04)			1/29
Immature lungs	1 (.04)			1/29
Gastro-Intestinal Problems				
E. Coli Diarrhea		3 (4.0)	1 (1.9)	2/29
Coccidiosis			3 (5.6)	3/29
Cryptosperosis		2 (2.7)		2/29
Enterotoxemia			2 (3.7)	2/29
Nonspecific diarrhea	3 (1.1)	7 (9.3)		5/29
Gastric problems		2 (2.7)	1 (1.9)	2/29
Septicemia	7(2.6)	9 (12.0)	5 (9.3)	11/29
Peritonitis	1 (0.4)	2 (2.7)		3/29
Nutrition Problems				
Nutritional myopathy		1 (1.3)		1/29
Polio			1 (1.3)	1/29
Others	2 (.08)		5 (9.3)	6/29
Total	274 (100.0)	76 (100.0)	54 (100.0)	27/29

Adapted from Arsenault (2002)

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Notes:

Due to the fact that so many post-mortems result in an inconclusive diagnosis, it is also important to keep other flock records that may help determine management changes that could improve lamb survival. Statistical analysis of the Quebec data determined that the risk of mortality in the first 10 days was greater for a lamb if it had a low birth weight (<4.0kg), was born to a ewe over 4 years of age or was a male from a litter of 3 or more lambs.

Analysis of Lamb and Ewe Variables Relative to Lamb Mortality

Variables		0 - 10 days		11 - 30 days	
		# lambs	% mortality	# lambs	% mortality
Lambs					
Sex	Male	1202	12.8	982	4.0
	Female	1143	11.6	957	2.4
Birthwt	0-2.5	317	69.7	80	10.0
	2.6-3.0	177	27.1	109	7.3
	3.1-3.5	265	20.0	191	5.2
	3.6-4.0	362	8.3	310	2.9
	4.1-4.5	454	5.3	410	2.4
	> 4.5	920	3.4	865	2.2
Ewes					
BCC	< 2.5	336	23.8	239	2.9
	2.5 - 3.0	1879	15.3	1493	3.6
	> 3.0	280	14.3	233	1.3
Age	1	855	15.9	656	2.1
	2	430	16.7	340	2.7
	3	294	11.4	335	3.9
	4+	768	18.4	600	4.2
Litter size	1	1050	9.1	906	1.7
	2	1171	16.3	919	3.9
	3+	274	43.8	140	9.3

Adapted from Belanger et al (2001)

This means that changes in factors such as the average age of your flock, average birth weight and body condition score of your ewes at lambing might influence the mortality rate of your flock. Lamb mortality has the potential to have a large influence on the profitability of an operation. As a result, even though it can be discouraging at times, it is important to remain dedicated to reducing mortality and doing post-mortems on lambs in your flock.

Conclusion

Mortality is influenced by a large number of environmental factors that are often difficult to control under farm conditions. In order to ensure that lamb mortality is minimized it is necessary to keep production records that measure mortality rate and to continually monitor the risk areas in your operation that contribute the most to mortality. Every farm should have an optimum goal of 10% total lamb mortality and some operations will be able to achieve a lower mortality rate. Every farm operation with a pre-weaning mortality rate of more than 10% should be looking for opportunities to improve lamb survival.