Review of the carbon footprint of beef and sheep meat

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Contents

Abbreviations used

CF	Carbon Footprint
CH_4	Methane
CO_2	Carbon dioxide
FU	Functional Unit
GHG	Greenhouse Gas
GWP	Global Warming Potential
LCA	Life Cycle Assessment
LW	Live Weight
N_2O	Nitrous Oxide
NZ	New Zealand
NRF	Nutrient Rich Food Index

1. Executive Summary

This short report is a literature review of published studies on the carbon footprint (CF) of beef and sheep meat. All studies included an assessment of the CF (total greenhouse gas emissions) measured in carbon dioxide equivalents (CO_2e), using different system boundaries (cradle-to-farm-gate or cradle-to-grave). The studies also explored different functional units (FU), such as kg of live weight (LW) and kg of product.

For the cradle-to-farm-gate analysis (i.e. all stages contributing to the product leaving a farm), the average beef footprint was 14.1 kg CO_2e / kg LW, with country averages ranging from 6.7 (New Zealand dairy beef) to 31 kg CO_2e / kg LW (UK). Among the different cattle management systems summarised from multiple countries, dairy-beef (i.e. beef derived from dairy cattle) showed the lowest CF (average of 10.1 kg CO_2e / kg LW). The average lamb footprint was 14.2 kg CO_2e / kg LW, with country averages ranging from 6.0 (NZ) to 23.1 (Spain) kg CO_2e / kg LW.

For studies covering the cradle-to-grave (i.e. all stages through to a consumer) system boundary, the beef average was 23.1 kg CO_2e / kg beef with country averages ranging from 20.7 (Australia) to 32.7 (USA) kg CO_2e / kg beef. The lamb average was 20.4 kg CO_2e / kg lamb, ranging from 16.1 (Australia) to 26 (Tunisia) kg CO_2e / kg lamb.

Across all studies, there were large differences in methodology (e.g. use of different GHG factors for the Global Warming Potential for 100-years [GWP100] from different IPCC assessment reports over time), data quality and completeness. To enable a better comparison within/between countries, a recalculation of the footprints using the same GWP and allocation methods would be necessary. Not all studies cited in this review considered the full life cycle of the product. Generally, the three last stages (retail, consumer and waste) are often neglected. Thus, care needs to be taken when comparing the results for the “cradle-to-grave” analyses.

2. Background

In examining the sustainability of different products, it is important to consider the effects of all contributing stages to their production, as well as the impact of the transportation, retail and consumer stages. The most appropriate tool to evaluate these aspects is Life Cycle Assessment (LCA). LCA provides a holistic approach to evaluate the environmental performance of a production system. It can cover the whole life cycle of the product ("cradle-to-grave" boundary), including all inputs and emissions related to the manufacturing, processing, transport, consumption and waste stages of a product, although it is sometimes restricted to the farm-gate stage ("cradle-to-farm-gate" boundary). LCA can also be used for comparative purposes when, for example, companies would like to compare their product with competing products. For this to occur, the same methodology and system boundary need to be used to assess both products. The system boundary outlines which part of the life cycle will be examined and is used to ensure that the same "products" are being compared.

LCA studies can account for a range of environmental impacts (including resource depletion, water and human health impacts) (JRC 2011). However, given concerns about the effects of climate change, many studies focus on the emissions of greenhouse gases (GHGs) and express them as "per kg product". This is commonly referred to as the carbon footprint of the product. While this is an appropriate unit when comparing similar products, it is not recommended when comparing food options with different nutrient contents. In order to provide a fairer comparison, products should be compared considering the functionality they provide which, in the case of food, are the essential nutrients. Studies recommend the use of "g of proteins" or a nutritional index (Castañé et al., 2017; Hess et al., 2017; McAuliffe et al., 2018) to provide a proper comparison among alternative foods where the critical constituent is protein, or multiple key essential nutrients.

The purpose of this short report is to provide a summary of information from published LCA studies (peer-reviewed) for beef and sheep meat comparing their carbon footprint. This report is structured according to the different meats in both cradle-to-gate or cradle-to-grave boundaries.

3. Method

We conducted a structured review focusing on the carbon footprint of beef and sheep meat. The literature search was performed using "Web of Science", "Science Direct" and "Google Scholar". The search was carried out using all combinations of the following keywords: "life cycle assessment"; "LCA"; "carbon footprint"; "meat"; "beef"; "lamb"; "sheep";. We also screened the references of studies retrieved. There were no restrictions regarding the year of the publication. Papers were separated by the meat type and LCA boundary ("cradle-to-farm-gate" or "cradle-to-grave"). All studies found were screened for relevance based on the title. Relevant titles were then screened by abstract, and the full text was then reviewed. Our search resulted in 56 publications (full list available in Appendix 1). Note that in some cases, one study assessed more than one farm or management system (e.g. conventional versus organic beef) (Table 1).

Table 1: Number of studies and carbon footprint estimates for the different protein sources

Protein source	Number of Studies	Number of Footprints
Beef	43	159
Sheep	13	42

Food systems can produce a mix of products (e.g., a dairy farm producing milk and meat). The disaggregation (or allocation) of total environmental emissions between products is a common challenge faced by LCA practitioners. The decision of which allocation method to use depends on the goal and scope of the project and can be different among the different protein sources. Another factor influencing the footprint is the metric used, such as Global Warming Potential (GWP). The GWP100 method uses the global warming potential of 28, 265 and 1 for CH_4, N_2O and CO_2, respectively, based on the latest IPCC factors (IPCC, 2006). The GWP for a 100-year period (GWP100) is a standard metric for comparing emissions of different greenhouse gases and is constantly being reviewed and updated (and consequently producing changing footprint estimates). Furthermore, all the studies have used GWP100, while other options are available for assessing the emissions over different time-frames (e.g. Global Temperature Potential [GTP] for 20 years, and more recently GWP* for differentially accounting for the short-lived gases, such as methane [CH4]). In this review, we didn't adjust published results for the allocation and GWP factors within/between the different protein sources.

For each publication, a specific study code was assigned. The following characteristics were recorded in the database: author, year, country, meat type, allocation method, GWP method, functional unit and carbon footprint result. The carbon footprint is commonly expressed in units of carbon dioxide equivalents per functional unit (FU) (kg CO_2e / FU). The total GHG emissions are then typically partitioned according to the various contributing gases in units of CO_2e (i.e., % of the total footprint related to methane [CH_4], nitrous oxide [N_2O] and CO_2).

4. Results and Discussion

4.1 Beef

The average beef footprint at the farm-gate was 14.10 kg CO_2e / kg LW, with country averages ranging from 6.68 (Dairy Beef in NZ) to 31 (UK) kg CO_2e / kg LW (Figure 1). The most updated CF for NZ beef (weighted average among all farm classes: 8.97 kg CO_2e / kg LW – Ledgard et al., 2021) is at the low end of the range, with error terms indicating no significant difference between the bottom half of the countries in Figure 1. Apart from NZ, the lowest average values were found in the Nordic countries (Norway, Denmark and Sweden - Figure 1), which were mainly associated with studies analysing “dairy-beef” (i.e., beef from dairy animals) system only. The “dairy-beef” CF for NZ is 6.68 kg CO_2e / kg LW (Ledgard et al., 2021), being the lowest value found in the literature. To further investigate this cattle management system effect, we also classified the papers by the cattle management system based on the information available in each study. The classifications were:

1) Conventional: mostly grass-based management (included extensive/intensive management with/without the use of supplementary feeds)
2) Feedlot: animals are on a feedlot after weaning
3) Organic: organic production systems
4) Dairy-beef: beef derived from dairy animals
5) Crop-livestock rotation system: land is rotated between different crops and pasture over time.

Among the different cattle management systems, dairy-beef showed the lowest carbon footprint (CF) (average of 10.10 kg CO_2e / kg LW), which explains the low CF values associated with the Nordic countries (studies related to dairy-beef production). The use of dairy animals for beef production could potentially reduce the CF of NZ beef by up to 22% (van Selm et al., 2021). As reported in many beef cattle studies (Florindo et al., 2020; Payen et al., 2020), CH_4 is the most significant GHG using GWP100 (Figure 1), with an average contribution of 72% to the total footprint of beef (Figure 1), followed by N_2O and CO_2 (21% and 7%, respectively).

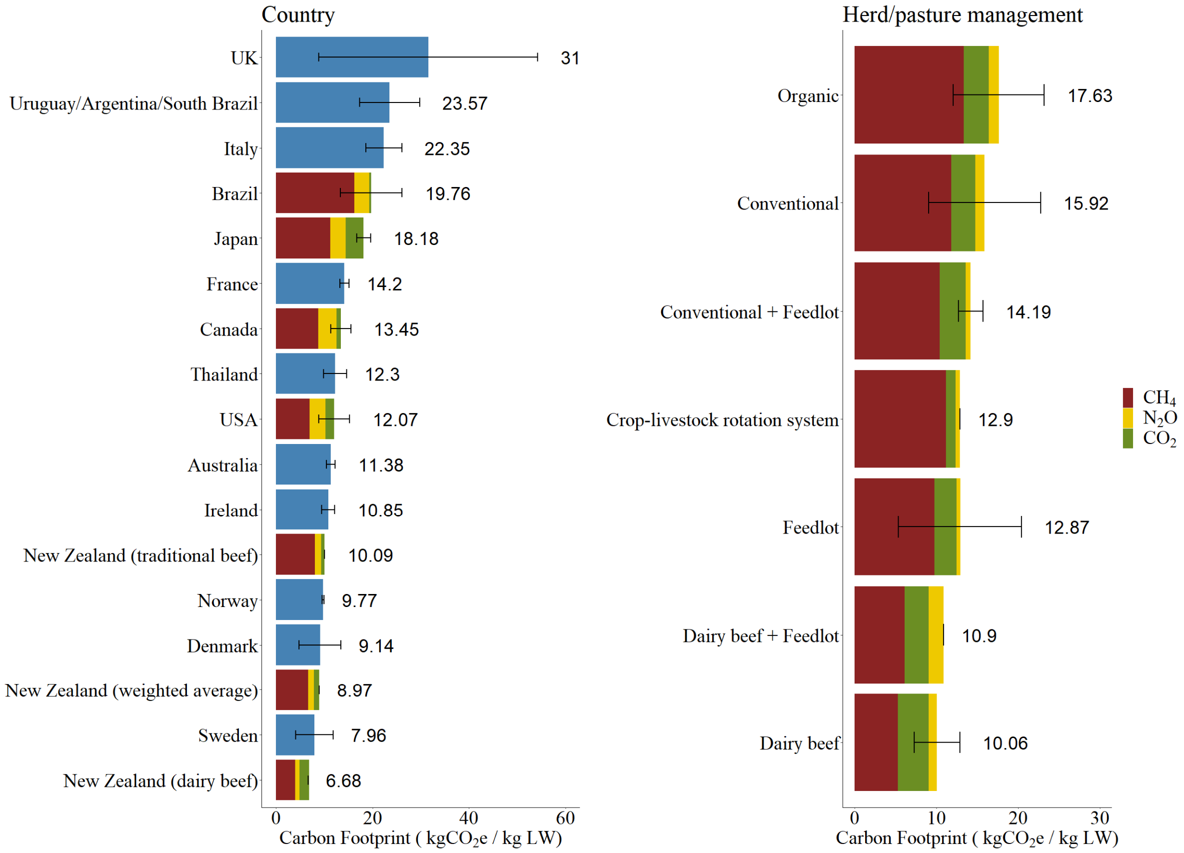

Figure 1: Cradle-to-farm-gate carbon footprint (kg CO_2e per kg LW) for beef production in different countries and by different cattle management systems using Live Weight (LW) as a functional unit. Error bars denote the standard deviation. Note that there were differences between countries in number of reported studies. Blue bars represent where data were not available for calculating the greenhouse gas breakdown.

For the “cradle-to-grave” boundary, the footprint unit changes from kg LW to kg of meat. The average beef footprint for the full life cycle (i.e. cradle-to-grave) was 23.1 kg CO_2e / kg beef, ranging from 20.70 (Australian beef to USA consumer) to 32.70 (UK) kg CO_2e / kg beef (Figure 2). The most recent CF for NZ products was 21.86 kg CO_2e / kg meat (average of beef exported to the USA and Japan – Ledgard et al., 2021). The error bars associated with the average values indicate no significant differences between studies, although the USA results indicated a wider range with some high estimates. As for the GHG contribution analysis, CH_4 was the most important GHG using GWP100, contributing 61% of the total footprint, followed by N_2O and CO_2 at 36% and 3%, respectively (Figure 2). As the farm-gate boundary represents a significant share of the total footprint (e.g. 94% for NZ beef to a European consumer - Payen et al., 2020), CH_4 remains the most relevant GHG in the full life cycle of beef production.

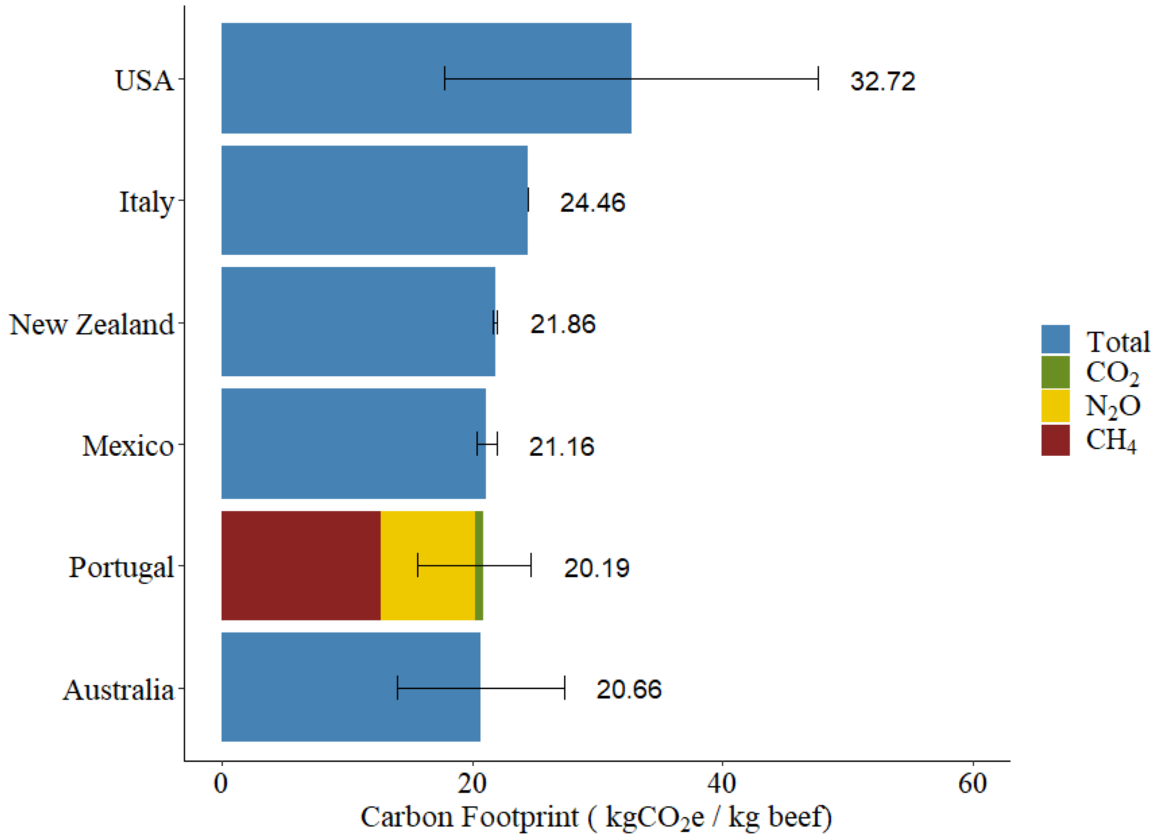

Figure 2: Cradle-to-grave carbon footprint (kg CO_2e per kg beef) for beef production in different countries, using kg of beef as a functional unit. Error bars denote the standard deviation. Blue bars represent where data were not available for calculating the greenhouse gas breakdown.

4.2 Lamb / sheep meat

The average lamb/sheep meat footprint at the farm-gate boundary was 14.20 kg CO_2e / kg LW, with country averages ranging from 6.01 (NZ) to 23.13 (Spain) kg CO_2e / kg LW (Figure 3). The animals were classified into two different categories based on the description from the papers reviewed. Generally, “sheep meat” (which includes lamb + mutton) had the lowest average CF (8.10 kg CO_2e / kg LW), with the average for lamb being higher at 14.20 CO_2e / kg LW. This difference in the sheep classes is dependent on the allocation methodology applied. Most studies used economic allocation, which assigned a larger proportion of emissions on the higher value lamb products. Sheep, like cattle, are ruminants, and therefore CH_4 (mainly via enteric fermentation) contributed up to 70% of their total footprint (using GWP100), followed by N_2O and CO_2 at 18% and 12%, respectively (Figure 3).

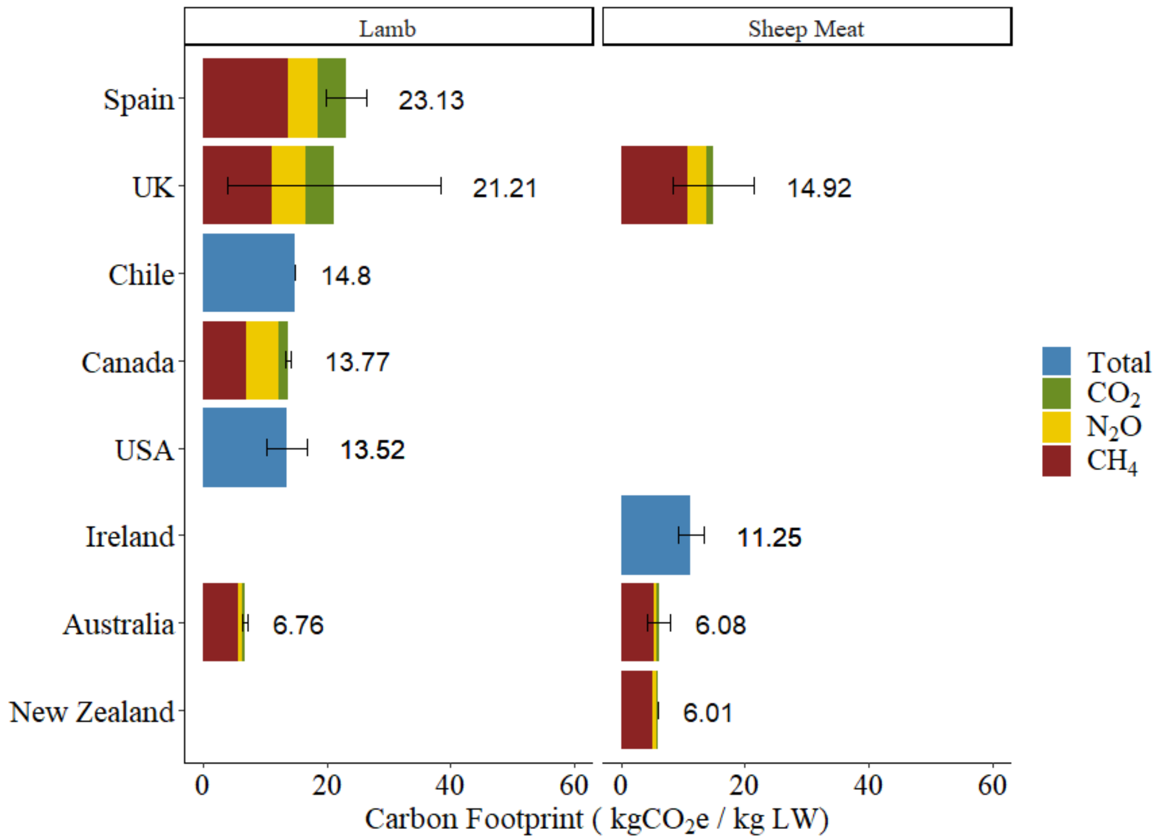

Figure 3: Cradle-to-farm-gate carbon footprint (kg CO_2e per kg LW) for the sheep production in different countries, divided into lamb and sheep meat (including mutton). Error bars denote the standard deviation. Blue bars represent where data were not available for calculating the greenhouse gas breakdown.

The average lamb footprint for the full life cycle was 20.4 kg CO_2e / kg lamb, ranging from 14.65 (NZ) to 26 (Tunisia) kg CO_2e / kg lamb (Figure 4). No data were available for calculating the GHG breakdown, but the lamb footprint would likely follow the same pattern as the beef, with CH_4 as the most important GHG at both the cradle-to-farm-gate and cradle-to-grave boundaries.

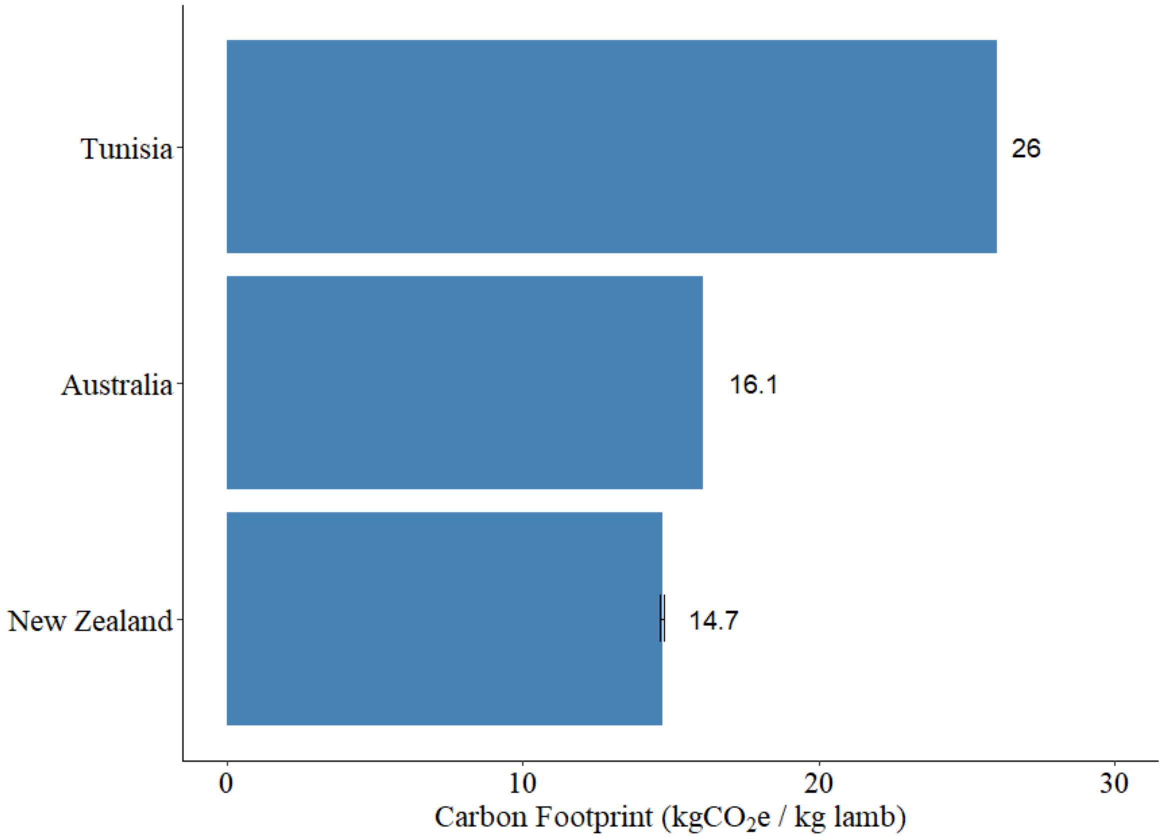

Figure 4: Cradle-to-grave carbon footprint (kg CO_2e per kg lamb) for lamb production in different countries.

5. Limitations

The various published studies showed considerable differences in the methodologies used (GWP factors and allocation) and the completeness of the life cycle. To enable a better comparison within/between countries, a recalculation of the footprints using the same GWP and allocation methods would be necessary (Mazzetto et al., 2021). This is especially relevant for sheep. Recent studies (e.g. Weideman et al., 2015) applied a biophysical allocation method between wool and sheep meat that places more emphasis on the wool (and less on meat) when compared to economic allocation methods. A similar issue can be found among different sheep meat types, because in earlier studies economic allocation was used between meat cuts (whereas the current methodology does not distinguish between different meat cuts) resulting in lamb having a higher economic value and consequently higher calculated emissions per kg than mutton.

The use of different GHG metrics can have a significant impact on the final footprint values, especially for the ruminant products. Assessing the results using GTP would result in lower calculated footprint values since CH_4 is a “short-lived” gas, and has a lower CO_2-equivalent factor than that currently used for GWP100 (i.e. 4 vs. 28 kg CO_2e/kg CH_4 for GTP and GWP100, respectively). For example, the carbon footprint of NZ lamb to the farm gate would decrease by approximately 80% with GTP100.

Not all studies cited in this review considered the full life cycle of the product. Generally, the three last stages (retail, consumer and waste) are often neglected. Thus, care needs to be taken when comparing the results for the "cradle-to-grave" analyses. Additionally, the cradle to grave studies varied in the final market where the product was consumed and therefore created differences associated with differences in distance of transport to markets as well as emissions within market countries (e.g. per unit of electricity used).

6. Conclusions

This study completed a structured review of data relating to the carbon footprint of beef and sheep. The most updated NZ footprints for both beef and sheep meat (Ledgard et al., 2021) were in the lower range of values found in the literature. The studies reviewed had large differences in methodology, system boundaries analysed, and in the quality of the data used. Where such comparisons are needed, they should be based on the use of the same functional unit and methodology, as done for evaluating the carbon footprint of milk for different input managements or comparing results among different countries (Lorenz et al., 2019; Mazzetto et al., 2021).

7. Acknowledgements

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9. Appendix 1 – Papers used in the review

Beef

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