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EDITED BY

Ty Beal,
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REVIEWED BY

Edward Joy,
University of London, United Kingdom
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Sustainable Nutrition Initiative hosted by the
Riddet Institute, New Zealand
Raquel Lozano,
Massey University, New Zealand

*CORRESPONDENCE

Kate Wingett
✉ kwin5980@uni.sydney.edu.au

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Quantifying pre-consumer food and nutrient losses from the Australian lamb and sheep meat value chain: a case study

Kate Wingett^{1*} and Robyn Alders^{2,3,4}

¹Faculty of Medicine and Health, University of Sydney, Sydney, NSW, Australia, ²Global Health Programme, Chatham House, London, United Kingdom, ³Development Policy Centre, Australian National University, Canberra, ACT, Australia, ⁴Institute for Climate, Energy and Disaster Solutions, Australian National University, Canberra, ACT, Australia

To achieve sustainable development, United Nation members have agreed to reduce food loss along the pre-consumer food supply chain. Food loss and waste is a significant challenge facing Australia and the world, with an estimated one third of all food produced locally being lost or wasted. Globally, Australia is the second largest producer of sheep meat and, locally in Australia sheep meat is the second largest meat industry. Previous assessments of Australian livestock industries estimate low levels of food product losses from the sheep meat chain. This case study aimed to quantify nutrient losses at the point of slaughter of Australian lambs and sheep, using a mass balance approach with secondary data. The results from this study align with this previous assessment with respect to the level of products and nutrients downgraded at the point of slaughter, except for the impact of cadmium contamination on adult sheep liver and kidney downgrades. In turn, cadmium contamination emerged as a key contributor to micronutrient losses, notably dietary folate equivalents, and vitamin A retinol equivalents (RE). There was moderate to high uncertainty in the outputs of the assessment, predominantly due to the absence of data. Addressing these challenges, particularly the absence of offal production data, is crucial as it influences the overall accuracy of the results. This study identifies areas for improvement in the Australian sheep meat value chain, including data governance, at both the macro and micro levels. It also serves as a foundational step in understanding how reducing food and nutrient losses in the Australian sheep meat value chain could contribute to food security and nutrition goals.

KEYWORDS

nutrient, food loss, Australia, sheep, lamb, abattoir

1 Introduction

In 2015, all United Nations members adopted the 2030 Agenda for Sustainable development (United Nations, 2015). The Agenda includes 17 Sustainable Development Goals (SDGs) that form a framework to achieve global health of people and the planet, both now and for future generations (United Nations, 2015). Achieving SDG 12, “responsible consumption and production patterns,” will optimize the use of natural resources and indirectly help to protect soils, water, the atmosphere and biodiversity, while simultaneously assisting with food security, nutrition and potentially, the economy (Food and Agricultural Organization, 2019). According to Food and Agricultural Organization (2009) “Food security

exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. The four pillars of food security are availability, access, utilization, and stability. The nutritional dimension is integral to the concept of food security”.

Despite Australia being one of the most food secure countries in the world, food insecurity affects a not insignificant proportion of the population. In the Australian Health Survey 2011–13, approximately 4% of respondents reported having run out of food and not being able to buy more food (Australian Bureau of Statistics, 2013b). It is thought the level of food insecurity in Australia is under-reported due to the sensitive nature of the question and the exclusion of homeless and very remote populations from the survey (Booth and Smith, 2001; Australian Bureau of Statistics, 2013b). Bowden (2020) found the level of food insecurity in the general population of Australia ranged from 4 to 13%. This review also noted that there was no regular monitoring of food security levels in the Australian population. The Foodbank Hunger Report presented a worsening picture with 3.7 million Australian households (approximately 36%) reporting food insecurity during 2022 (IPSOS, 2023).

Food insecurity has been negatively associated with health outcomes in children and the elderly in the United States (Gundersen and Ziliak, 2015). Canadian adults and adolescents who experienced food insecurity were more likely to suffer from nutrient inadequacy than those living in food secure households (Kirkpatrick and Tarasuk, 2008). Concurrently, it is estimated that 25% of pregnant women in Australia are anemic, with an estimated half of anemia cases worldwide being caused by iron deficiency (World Health Organization, 2020). Due to the public health impacts of micronutrient deficiencies in the Australian population, there is mandatory fortification of staple foods with folic acid, iodine, thiamine (B1) and vitamin D (Food Standards Australia New Zealand, 2019b).

Reducing food loss and waste has potential to positively impact food security and nutrition (Food and Agricultural Organization, 2019). Target 12.3 of SDG 12 is to halve retail and consumer food waste and reduce food loss along each step of the supply chain (United Nations, 2015). Globally and in Australia, it is estimated that one third of food produced is lost or wasted (Food and Agricultural Organization, 2011; Commonwealth of Australia, 2017). It is recognized that post-consumer food waste is collectively greater in quantity than pre-consumer food loss (Food and Agricultural Organization, 2011; ARCADIS, 2019). However, reducing pre-consumer food losses may still make a valuable contribution to achieving food security and optimizing natural resource management. Kuiper and Cui (2021) predicted, via modeling, that a 25% reduction in food loss in Australia, would lead to a reduction in primary production, land use and greenhouse gas emissions associated with food production, while simultaneously increasing food accessibility, availability of macro- and micronutrient, and increasing gross domestic product. Research on the role of reducing food loss and waste to achieve food security in Australian is very limited at this point in time and there is opportunity to explore this area further (Lai et al., 2022).

There are challenges in estimating food loss and waste and assessing its impact on the economy, community, and environment (Food and Agricultural Organization, 2011; Cattaneo et al., 2021; Hoehn et al., 2023). These challenges include defining what is considered food loss and waste, data availability, and balancing public

benefit and private cost in setting policy. To assist with some of the measurement challenges, the Global Food Loss Index has been developed as the indicator to monitor the world's progress toward the target of reducing food loss. In this indicator, food losses are defined as “all the crop and livestock human-edible commodity quantities that, directly or indirectly, completely exit the post-harvest/slaughter production/supply chain by being discarded, incinerated or otherwise, and do not re-enter in any other utilization (such as animal feed, industrial use, etc.), up to, and excluding, the retail level. Losses that occur during storage, transportation, and processing, also of imported quantities, are therefore all included. Losses include the commodity as a whole with its non-edible parts” (Food and Agricultural Organization, 2018).

The Australian Government (2024) has not published results on the contribution of Australian food loss to this indicator. According to the FAOs Food Loss and Waste Database (Food and Agricultural Organization, 2023d) and the FAOs Supply Utilization Accounts / Food Balance Sheets (Food and Agricultural Organization, 2023a), the two datasets used in modeling food loss for the Global Food Loss Index (Food and Agricultural Organization, 2023c) there are zero recorded losses of Australian sheep meat and edible offal or diversions of these products to animal feed or non-food uses. This is as the scope of “loss” in the Food Balance Sheets starts post-slaughter and “food” is defined as products that have been produced with the intention of being consumed by people (Food and Agricultural Organization, 2021d).

There has been a national baseline assessment of food loss and waste published (ARCADIS, 2019), based on the Food Loss and Waste Standard (Food Loss and Waste Protocol, 2016). The majority of food losses from livestock value chains were reported to occur during processing at the abattoir (ARCADIS, 2019). To date, these losses have been measured based on weight of product and/or economic value (Lane et al., 2015; Byran et al., 2016; ARCADIS, 2019; Shephard et al., 2022). Losses from the livestock industries were reported aggregated, including cattle, sheep, and pigs. A total of 123 kilotonnes of livestock products was reported as lost during manufacturing in base year 2015; accounting for approximately 2% of the supply of livestock products (ARCADIS, 2019). Food losses from the Australian livestock chains excluded all materials being diverted to pet food (ARCADIS, 2019) due to the inability to differentiate whether product food products downgraded to animal feed were destined for livestock or pet food supply chains (ARCADIS, 2019).

Animal source foods, including meat and offal, are energy and nutrient dense foods, rich in protein and micronutrients, including iron, zinc and vitamin B12, in high bioavailable forms (Murphy and Allen, 2003; Drewnowski and Fulgoni, 2008; De Bruyn et al., 2020; Beal and Ortenzi, 2022). Globally, food-based dietary guidelines include animal-source foods as part of a healthy diet (Food and Agricultural Organization, 2021a). Australian mutton, meat from an adult sheep, is more micronutrient dense than lamb, beef, pork or chicken meat (Williams et al., 2007) and lambs' liver and kidney are more micronutrient dense than mutton (Wingett et al., 2018). According to Supply and Utilization Accounts, each Australian has approximately 32g of sheep meat available each day (Food and Agricultural Organization, 2023a). According to the Australian Dietary Guidelines, this level of food supply accounts for approximately one-third of the recommended upper intake of lean red meat for Australian adults (National Health and Medical Research Council, 2013).

Australia is the second largest sheep meat producer in the world by weight (Food and Agricultural Organization, 2023b) and sheep meat is the second largest meat industry in Australia, based on weight of product and gross economic value of carcasses from slaughter (Australian Bureau of Statistics, 2022b). In financial year 2021–2022, there were approximately 70 million head in the national flock and 31,000 businesses in the industry (Australian Bureau of Statistics, 2023). The industry produced 513 kilotonnes (kt) of lamb carcase meat (meat from young sheep without any adult teeth in wear, typically up to 1 year old) and 164 kt of mutton carcase meat (meat from animals with at least one adult tooth in wear, typically 1 year-old or more) that was fit for human consumption. The majority of both lamb meat and mutton meat is exported (ABARES, 2020). Reducing pre-consumer food losses from the Australian sheep meat value chain has potential to significantly impact nutrient availability for both Australians and in those countries receiving Australian grown sheep meat and offal.

This study aimed to quantify the loss of nutrients from the direct human food chain at Australian sheep abattoirs and explore the underlying reasons for the nutrient losses, using national datasets. Better understanding of the quantity of food losses, with respect to nutrient composition and cause, is important to both sustainable management of nutrient flows to and from livestock production systems and to support food security through increasing nutrient-dense food availability at the societal level.

To contextualize the effect of the direct nutrient losses from the Australian sheep meat value chain on Australian food and nutrition security, the authors explored the impact of the losses with respect to satisfying the nutritional needs of women of reproductive age. This subset of the population was chosen as they have a heightened demand for nutrients before and during pregnancy and lactation, and deficiencies of micronutrients can have intergenerational impacts; as such women of reproductive age are considered nutritionally vulnerable (Allen, 2005; Tørheim and Arimond, 2013; Food and Agricultural Organization, 2021c). The World Health Organization (WHO) estimated 5.2–15.3% of Australian women of reproductive age were anemic in 2019 (World Health Organization, 2023) and that the prevalence of anemia in pregnant Australian women is 25% (World Health Organization, 2015). Carter et al. (2023) found the overall incidence of iron-deficiency anemia in pregnant women in far north Queensland in 2018 was 34.9%, with 48.7% of women identifying as Aboriginal or Torres Strait Islanders in the area experiencing iron-deficiency anemia during pregnancy.

2 Material and method

The Food Loss and Waste Accounting and Reporting Standard (FLWS) is a guidance document developed to facilitate countries (and other entities) to account for and report food loss and waste, including reporting against SDG12.3.1 (Food Loss and Waste Protocol, 2016). The FLWS states that each entity defines food loss depending on the reason for accounting and reporting the food loss (e.g., food security and nutrition, environmental assessment, economic assessment). The scope of the food loss is defined by material type (i.e., edible, inedible or both), destination or pathway of the materials, timeframe and boundaries of the food loss inventory (i.e., food category, life cycle stage and geography) (Food Loss and Waste Protocol, 2016). The

FLWS allows for holistic accounting and reporting of food loss, as the unit of measure for food loss can range from nutrients to money, to environmental indicators such as water use and greenhouse gas emissions.

Nutrient losses (by weight) from the pre-consumer Australian sheep meat value chain were quantified, based on the FLWS (Food Loss and Waste Protocol, 2016) using the principles of a material flow analysis (Brunner and Rechberger, 2017).

2.1 Scope

The scope of the food loss accounting and reporting included timeframe, material type, destination and system boundaries (food category, lifecycle stage and geography), as per the FLWS (Food Loss and Waste Protocol, 2016).

2.1.1 Timeframe

The base year was calendar year 2015, and as per the Food loss and waste accounting and reporting standard, this was an average of calendar years 2014–2016 (Food Loss and Waste Protocol, 2016) where the data were available. Disease prevalence data from abattoir monitoring included data from calendar years 2010–2016, due to only having access to published data from Export Production and Condemnation Statistics (Lane et al., 2015) from July 2010 – June 2013. All other timeframes were as per the Food loss and waste accounting and reporting standard (Food Loss and Waste Protocol, 2016).

2.1.2 Material type

Food only products from the Australian sheep meat value chain were the material types quantified, expressed both in raw weight of products and, weight of nutrients in the raw, edible components of the products. Products were considered food if they were listed in the Australia New Zealand Food Standards Code – Standard 2.2.1 – Meat and meat products (Australian Government, 2016), Handbook of Australian Meat (AUSMEAT, 2020) or on the AUSNUT database (Food Standards Australia New Zealand, 2014).

Nutrients included in this study were those included in AUSNUT 2011–13 – Food nutrient database, except for nutrients imputed as zero (Food Standards Australia New Zealand, 2014). Only an estimate of the total nutrient was included in cases where numerous forms of the nutrient appeared in the database. For example, folate, natural, total folates, and dietary folate equivalents were represented by dietary folate equivalents in this study (Table 1). In the AUSNUT database, the carcase meat nutrient values were derived using a recipe approach, based on analyzed data and, the lamb offal nutrient composition data was analyzed. In this instance, the recipe approach for muscle meat was utilized as the cuts of meat were analyzed for gross composition, fatty acid profile and nutrient profile individually and then combined to create the food nutrient profile.

We assumed adult sheep offal had the same nutrient composition as lamb offal as the authors were unable to find any published data on the nutrient composition of Australian adult sheep offal. This is most likely a conservative estimate of nutrient composition of adult sheep offal, based on the differences between lamb meat and mutton meat i.e., micronutrient levels increased in muscle meat as animals aged

TABLE 1 Nutrients included in the food and nutrient loss assessment of the Australian sheep meat value chain.

Macronutrients	Vitamins	Minerals	Fats and others
Energy with dietary fiber	Vitamin A retinol equivalents	Calcium	Cholesterol
Moisture	Thiamine (B1)	Iodine	Total saturated fat
Protein	Riboflavin (B2)	Iron	Total monounsaturated fat
Ash	Niacin derived equivalents	Magnesium	Total polyunsaturated fat
Total fat	Dietary folate equivalents	Phosphorus	Linoleic acid
Tryptophan	Vitamin B6	Potassium	Alpha-linolenic acid
	Vitamin B12	Selenium	C20:5w3 Eicosapentaenoic
	Alpha-tocopherol	Sodium	C22:6w3 Docosahexaenoic
	Vitamin E	Zinc	Total long chain omega 3 fatty acids
			Total trans fatty acids

Nutrients in bold were considered significant to Australian public health.

(Williams et al., 2007) and that vitamin A concentrations increase in liver tissue as animals age (Majchrzak et al., 2006).

The authors were particularly interested in nutrients they considered to be significant to Australian public health. Criteria for nutrients to be classified as significant to public health in this study included:

- nutrients where a 100 g raw serve of any of the lamb or mutton carcase cuts or offal pieces supplies at least 20% of the recommended daily intake for Australian men and women (aged 19–50 years) is considered a good source for Australians (Australian Government, 2018) and the nutrient is either,
- monitored by the World Health Organization (WHO) (World Health Organization, 2020), or
- there is a mandate to fortify staple foods with the nutrient in Australia (Food Standards Australia New Zealand, 2019b).

2.1.3 Destination

A pathways approach was taken when determining the flow of food products and nutrients through the Australian sheep meat value chain, rather than the preferred destination approach. This meant the initial paths taken by the food product on their way to their destination, either downgraded or fit-for-human consumption, were considered as the two options. The pathway approach was selected due to inadequate detail being included in published national data on the destination of products of the Australian sheep meat value chain. Food products and nutrients entered one of two pathways at the abattoirs, either fit for human consumption or unfit for human consumption (Figure 1).

2.1.4 Boundary

Four areas were considered in regards to the system boundaries of the food loss model – geography, organization, life cycle stage and, food category, as per the FLWS (Food Loss and Waste Protocol, 2016).

The geography was set to Australia, country code 036 (Statistics Division of the United Nations Secretariat, 2022). The organization was the sheep meat value chain. The sheep meat value chain was separated into lambs and adults to account for the variation in nutrient profile of the food products as animals age (Williams et al., 2007) and

the variation in the prevalence of disease and contamination as animals age (Animal Health Australia, 2021).

One life cycle stage was selected, the abattoir (Figure 2). This is the point in the supply chain where animals are processed into food and other products (Figure 3). This stage was chosen as this is the first step where losses from animal-source value chains are accounted for in the FLWS (Food Loss and Waste Protocol, 2016).

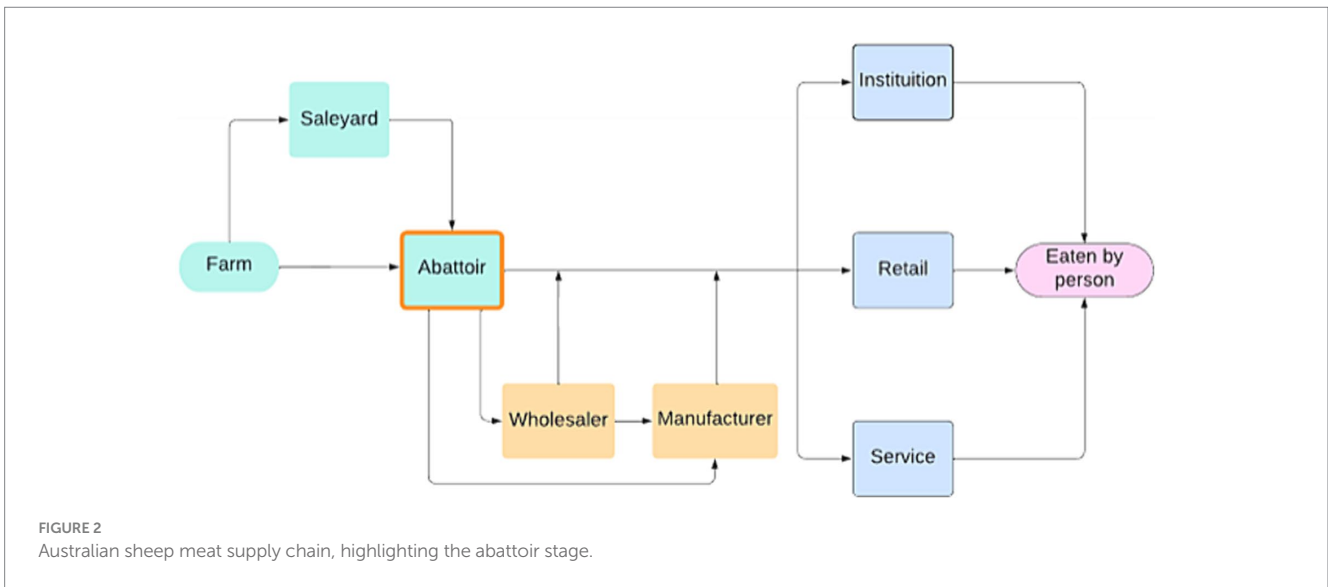
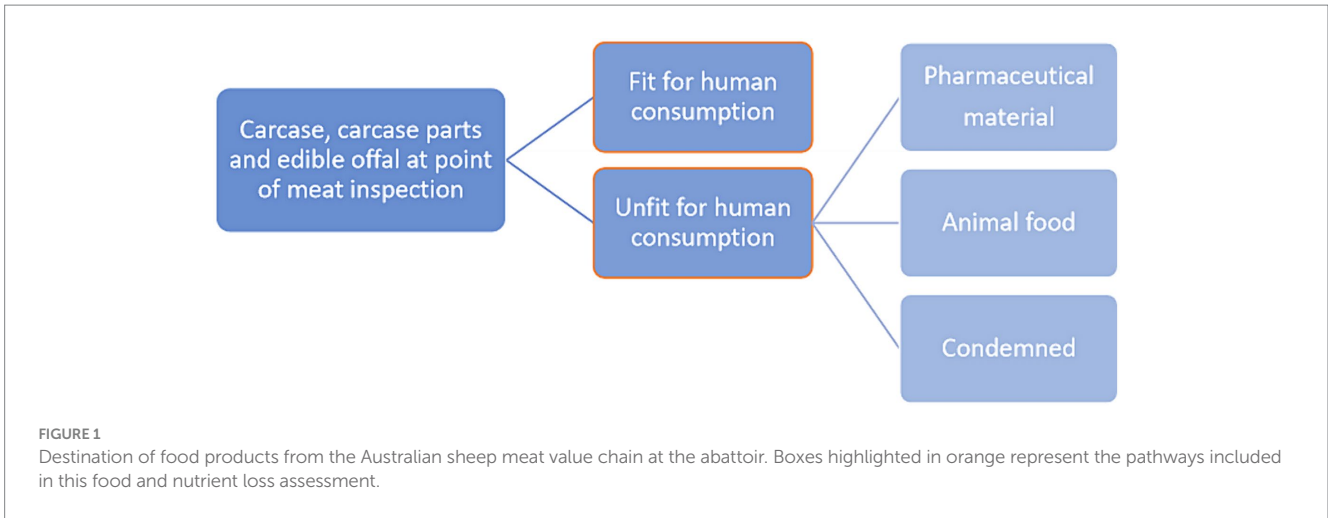
Food categories included were those that had published Australian weight data (including edible portion information) and food composition data, noting the substitution of lamb offal nutrient composition data for adult sheep offal nutrient composition (Table 2). Based on the available data, from here on in this manuscript offal refers to liver, kidney, heart, tongue, and brain.

Raw liver, kidney and heart weights were taken from analyzed data in Sentance (2011). These weights were not disaggregated by age, so we assumed the weight for lamb and adult sheep offal was the same. Tongue and brain raw weights were taken from analyzed data in Hutchison et al. (1987); this data is for lambs only and we assumed that adult sheep had the same tongue and brain weights as lambs (Table 3).

2.2 Quantification of food and nutrient loss from the Australian sheep meat value chain at the abattoir in base year 2015

Food and nutrient losses from the Australian sheep meat value chain were estimated using inference by calculation. The FLW Quantification Method Ranking Tool (Food Loss and Waste Protocol, 2016) was used to select the method to achieve the aims stated in the Introduction. Mass Balance was the highest ranked methodology, scoring 90/100, and the only “green” category, i.e., based on our answers to the FLW Quantification Method Ranking Tool questionnaire, this was the only method recommended for further consideration.

The mass balance principle sequentially accounts for the weight of food and nutrients that arrived at the abattoir in animals ready for slaughter through to the weight of the edible portion of food and nutrients that were passed as fit for human consumption (Figure 4). This process was performed for the Australian lamb and the adult



sheep meat (aka mutton) value chains. By combining the results of the Australian lamb and adult sheep value chains mass balance food and nutrient calculations, the combined food and nutrient flow for the Australian sheep meat value chain was determined.

Details on the calculations used to quantify ante-mortem and post-mortem direct nutrient losses from the Australian sheep meat value chain in 2015 are available in [Appendix 1](#). The following is a summary of the steps taken and the data sources used in these calculations.

To begin with, the number of lamb and mutton carcasses passed fit for human consumption was calculated from the dataset published by the Australian Bureau of Statistics, Livestock Products ([Australian Bureau of Statistics, 2020b](#)). Then, the ante-mortem and post-mortem populations were estimated, using these data and Export Production and Condemnation Statistics published in [Lane et al. \(2015\)](#).

Next, the prevalence of disease was calculated using data from the National Sheep Health Monitoring Project ([Animal Health Australia, 2021](#)) and the priority list of endemic diseases of the red meat industries ([Lane et al., 2015](#)). As a result, thirty (30) conditions were considered in this estimate of losses through the abattoir, with

variation in what product was downgraded depending on the condition ([Table 4](#)). The weight of raw product downgraded due to these conditions was then calculated, based on analyzed data from [Hernandez-Jover et al. \(2013\)](#), [Food Regulation Standing Committee \(2007\)](#), expert elicitation and the prevalence calculations. Then, the weight of liver and kidneys condemned due to cadmium contamination was calculated based on the Meat Notice: Establishment sourcing of stock to comply with importing country requirements for cadmium levels in offals ([Australian Government, 2015](#)). The condemnation rate of offal due to cadmium contamination was adjusted to take into consideration condemnation due to disease. The edible nutrient losses were then calculated using the method described in [Wingett and Alders \(2023\)](#). The number of Australian women of reproductive age whose annual supply of red meat and key nutrients could have been supplied by the downgraded products and nutrients was then calculated, based on the Australian Dietary Guidelines ([National Health and Medical Research Council, 2013](#)) and the Australian and New Zealand Nutrient Reference Values ([Australian Government and New Zealand Government, 2017](#)).

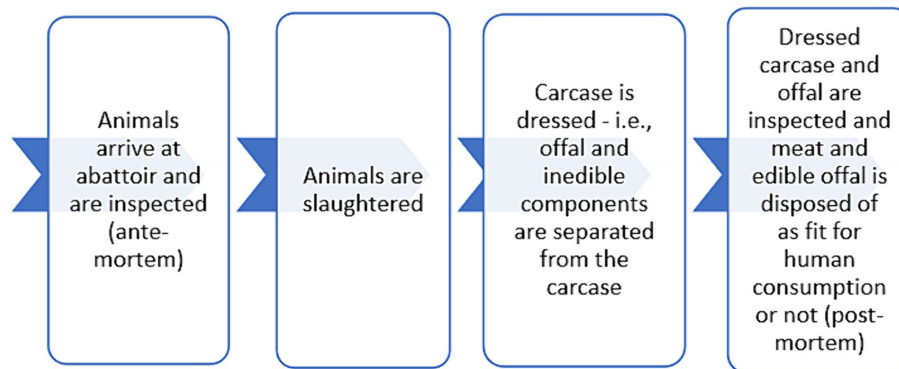


FIGURE 3
Processing flow at Australian sheep abattoirs.

As per the FLWS, an uncertainty assessment was performed on the results; a qualitative approach was taken to this assessment, based on the available data in the national datasets. Potential sources of uncertainty considered included systematic errors, assumptions, third-party data, model uncertainty and uncertainty in data used for inference (Food Loss and Waste Protocol, 2016).

3 Results

Overall, the Australian sheep meat value chain is very efficient at the processing stage, with generally low levels of food and nutrient losses, except for kidney and liver from the adult sheep value chain and, correspondingly, vitamin A RE and dietary folate equivalents. As expected, the lamb value chain was more efficient than the adult sheep value chain, with reduced levels of food loss by product and nutrient weight.

This mass balance analysis had an overall qualitative uncertainty assessment of medium-to-high. It is important to consider this when interpreting the results.

3.1 Sheep population in base year 2015

In 2015, 22.69 million lamb and 8.51 million mutton carcasses were passed as fit for human consumption. Approximately 99.92% of lambs that arrived at the abattoir passed ante-mortem inspection and had their carcasses passed as fit for human consumption at post-mortem inspection. Of the 0.08% of the lamb population that had full carcass condemnations, the majority occurred at post-mortem inspection, i.e., 99.04% of full carcass condemnations occurred at post-mortem inspection. Approximately 99.32% of adult sheep that arrived at the abattoir passed ante-mortem inspection and had their carcasses passed as fit for human consumption at post-mortem inspection. Of the 0.68% of the adult sheep population that had full carcass condemnations, the majority occurred at post-mortem inspection, i.e., 98.59% of the full carcass condemnations occurred at post-mortem inspection.

The ante-mortem populations for the lamb and adult sheep value chains were calculated to be 22.71 million and 8.57 million, respectively.

3.2 Raw weight of product losses in base year 2015

Ante-mortem condemnations were considered a “condition” for the remainder of the analysis, due to their relatively small prevalence compared with post-mortem downgrades, for both carcasses/carcass parts and offal pieces.

Less than 1% of carcass meat, kidney, heart, tongue, and brain being downgraded as not-fit-for human consumption. There were mildly elevated losses of lamb liver, with approximately 2% downgraded (Table 5).

The adult sheep value chain had a greater proportion of losses compared with the lamb value chain for all products. Product losses ranged from <1% (brain) to 96% (kidney) (Table 5). Adult sheep losses for carcass, heart, tongue, and brain were three-to-four-fold those for lamb. Losses for liver and kidney were markedly increased in the adult sheep chain compared with the lamb chain; approximately 26 times greater for liver and more the 1900 times greater for kidney.

Product losses of the adult sheep value chain were buffered by losses in the lamb value chain when the products for both value chains were combined (Table 5). This was due to there being a greater proportion of lambs being slaughtered in 2015 compared with adult sheep; for every adult sheep slaughtered approximately 2.5 lambs were slaughtered. Losses from the adult sheep value chain still formed a significant proportion of total carcass and edible offal pieces. Adult sheep kidney downgrades accounted for more than 99% of combined kidney losses (noting that nephritis was not included in the National Sheep Health Monitoring Project in 2015), 91% of combined liver downgrades, 70% of combined carcass downgrades, 60% of heart and tongue downgrades and, 59% of combined brain downgrades.

Total product losses from the Australian sheep meat value chain ranged from <1% of brains to 26% of kidneys. Less than 1% of carcass meat, heart, tongue, and brain were downgraded from the Australian sheep meat value chain during processing at the abattoir during 2015. Approximately 17% of livers and 26% of kidneys were downgraded as not-fit-for human consumption from the combined Australian sheep meat value chain during the same period (Table 5).

Based on the maximum intake of red meat in the Australian Dietary Guidelines (National Health and Medical Research Council, 2013), and the assumption that a healthy intake of offal is the same as that as carcass meat, the annual product losses from the combined

TABLE 2 Food categories included in the mass balance calculation of food and nutrient losses from the Australian sheep meat value.

Food name	AUSNUT* 2011–13 food id	HAM [^] number	CPC ⁺	ANZSIC [#] (Division and class)
Lamb, easy carve shoulder, untrimmed, raw	08A20691	4,990	21,115	C/1111
Lamb, forequarter chop, untrimmed, raw	08A20700	5,020	21,115	C/1111
Lamb, shank, untrimmed, raw	08A20679	5,030	21,115	C/1111
Lamb, diced, untrimmed, raw	08A20673	5,010	21,115	C/1111
Lamb, frenched cutlet/rack, untrimmed, raw	08A20707	4,930	21,115	C/1111
Lamb, loin chop, untrimmed, raw	08A20721	4,880	21,115	C/1111
Lamb, leg roast, untrimmed, raw	08A20714	4,830	21,115	C/1111
Lamb, chump chop, untrimmed, raw	08A20667	4,790	21,115	C/1111
Mutton, shoulder, untrimmed, raw	08A20753	4,992	21,115	C/1111
Mutton, leg roast, untrimmed raw	08A20791	4,830	21,115	C/1111
Lamb, tongue, raw	08D10183	7,010	21,155	C/1111
Lamb, liver, raw	08D10185	7,030	21,155	C/1111
Lamb, kidney, raw	08D10181	7,040	21,155	C/1111
Lamb, brain, raw	08D10177	7,070	21,155	C/1111

Sources: AUSMEAT, 2020, Department of Economic and Social Affairs (2015), Food Standards Australia New Zealand (2014), and Australian Bureau of Statistics (2013a). *AUSNUT 2011–13: is a food composition database developed to enable food, dietary supplement and nutrient intake estimates to be made from the 2011–13 Australian Health Survey. [^]HAM: Handbook of Australian Meat is an international red meat guide used to facilitate the use of accurate product descriptions in domestic and international trade. ⁺CPC: Central Product Classification is a complete product classification covering all goods and services. [#]ANZSIC: Australia and New Zealand Standard Industrial Classification.

Australian sheep meat value chain could provide approximately 310,000 adult Australians with all their red meat for the year.

3.3 Losses of nutrients key to public health available in base year 2015

As for product losses, there were proportionally more losses of nutrients key to public health from the adult sheep value chain than the lamb value chain. Nutrient losses from the lamb value chain ranged from <1% of thiamine (B1), iron, energy, and protein to 2% of dietary folate equivalents and vitamin A RE. The range of nutrient losses was greater for the adult sheep value chain (4% of energy to 57% vitamin A RE) but followed the same pattern as the lamb value chain. Again, nutrient losses from the Australian sheep meat value chain were skewed toward the lamb value chain, ranging from 1% of energy to 17% of vitamin A RE (Table 6).

The number of Australian women of reproductive age whose annual nutrient requirements could have been met with the downgraded products ranged from 66,000 for thiamine (B1) to 6.6 million for vitamin A RE. This calculation was based on the estimated average requirement for Australian women aged 19–50 years (National Health and Medical Research Council, 2013).

3.4 Causes of product and nutrient losses in base year 2015

In this section, the relative contributions of various conditions to the total product downgrades and quantity of nutrient losses at the abattoir in the base year 2015 were analyzed. The Australian lamb and adult sheep value chains were individually assessed, and their combined impact was considered.

The leading causes of lamb and mutton carcass downgrades were identified as arthritis (34%) and caseous lymphadenitis (CLA) (28%). In the combined Australian sheep meat value chain, arthritis continued to be the primary cause (23%), followed by CLA (21%). For specific organs, bladder worm (89%) and cadmium contamination (79%) emerged as the primary causes of downgraded lamb and adult sheep livers (Figure 5).

The study then estimated the relative contribution of each condition to the total amount of key nutrients downgraded. Cadmium contamination was consistently identified as a significant contributor, accounting for more than 50% of downgrades for vitamin A RE, thiamine (B1), dietary folate equivalents, and iron. When bladder worm was included, this percentage increased to over 70% (Figure 6). The causes of energy and protein losses were less concentrated than for micronutrients. However, cadmium and bladder worm still accounted for a substantial portion, contributing to 42 and 51% of downgraded energy and protein, respectively, in the combined Australian sheep meat value chain (Figure 6).

There were 11 conditions that contributed to less than 1% loss of any products and any nutrient from the lamb, adult sheep, or combined value chain. These conditions were anemia, bruising, dog bite, ecchymosis, hydatids, gangrene, muscle conditions, metritis, other causes, peritonitis, and wounds.

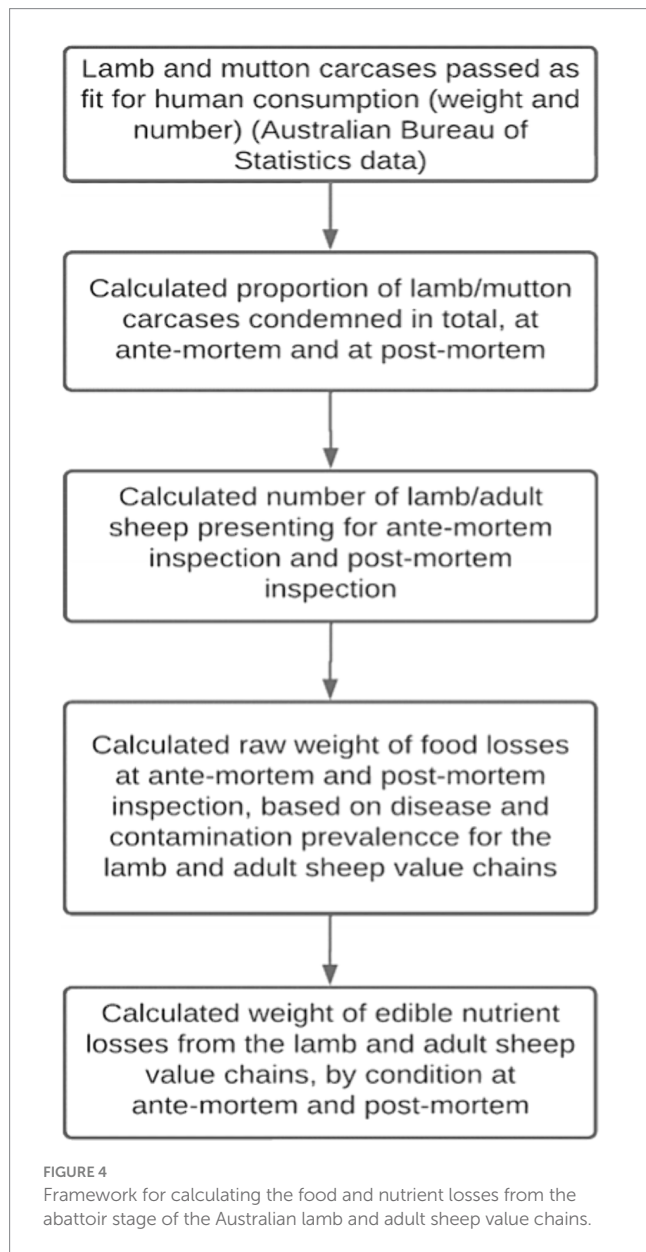
3.5 Uncertainties in the assessment of food and nutrient loss from the Australian sheep meat value chain

Uncertainties in the calculation of food and nutrient loss from the Australian sheep meat value chain were qualitatively rated on a five-point scale - very low, low, medium, high, very high - and a justification for the rating provided (Table 7). This method was

TABLE 3 Raw offal weights.

Raw offal piece	Weight (kg)
Liver	0.707
Kidney (x2)	0.149
Heart	0.251
Tongue	0.0955
Brain	0.093

Sources: Hutchison et al. (1987) and Sentance (2011).



selected as the Food Loss Waste Accounting and Reporting Standard recommends including a qualitative uncertainty assessment of the assessment as a minimum (Food Loss and Waste Protocol, 2016).

Factors taken into consideration in rating uncertainties included:

- the age of the data,

- type of data (analyzed, survey, recipe, secondary),
- the number of samples in the original data set, and
- data availability statement

Averaging the sub-total ratings, overall, the uncertainty in this mass balance analysis is medium-to-high.

4 Discussion

The results suggest that the Australian lamb value chain had minimal losses of both products and nutrients during processing in 2015 (Tables 5, 6). Downgrades affected less than 1% of all pre-slaughter products, except for liver, with a 2% downgrade rate. These results are consistent with the findings in the National Food Waste Baseline Assessment (ARCADIS, 2019). Nutrient downgrades were also less than 1% for thiamine (B1), iron, energy, and protein, but vitamin A RE and dietary folate equivalents each having 2% downgrade. On the other hand, the adult sheep value chain had low downgrades for most products, but major downgrades for liver (58%) and kidneys (96%) due to cadmium contamination, resulting in substantial losses of vitamin A RE (57%), dietary folate equivalents (39%), iron (10%), thiamine (B1) (8%), protein (5%), and energy (4%). Combining both value chains, nutrient and energy downgrades from products ranged from 1% for energy to 17% for vitamin A RE.

Bladder worm (89%) and cadmium contamination (79%) were the main causes of downgraded lamb and adult sheep livers, respectively. Conditions causing lamb kidney downgrades were directly related to conditions causing full carcass and offal condemnments, however adult sheep kidney downgrades were dominated by cadmium contamination (100%). The top five conditions for downgrades of heart, brain and tongue across the lamb and adult sheep value chains were reflective of the top five conditions causing full carcass and offal condemnments.

The medium to-high uncertainty in the food and nutrient loss calculations have arisen mostly due to assumptions that were made in cases where there was no data. These assumptions were generally conservative in nature and as such, the losses may be underestimated. The level of uncertainty highlights published data gaps in production volumes, destination, and nutrient composition of Australian sheep meat product, particularly of edible offal.

The losses of micronutrients key to public health in Australia reflect the disproportionate losses of edible offal from the Australian sheep meat value chain compared with carcass products, in particular liver and kidney. On a per gram basis, liver and kidney have a greater concentration of all micronutrients key to public health than carcass meat (Food Standards Australia New Zealand, 2014). In an individual lamb, liver absolutely contains greater amounts of vitamin A RE and dietary folate equivalents than the carcass, kidneys, heart, tongue and brain combined (Wingett and Alders, 2023). Cadmium contamination of liver and kidney in adult Australian sheep was the leading cause of losses of all nutrients key to Australian public health and energy. There are maximum cadmium levels in mammalian offal set in the Food Standards Australia and New Zealand and in export markets (Australian Government, 2020b). Based on the maximum levels of cadmium allowed in Australia in 2015, kidneys from adult sheep from all Australian states, except Queensland, were downgraded as not fit for human consumption. Livers from adult sheep from three states

TABLE 4 Carcass and offal downgrades by condition used in the mass balance calculation of food and nutrient losses from the Australian sheep meat value chain at the abattoir.

Condition	Carcass	Liver	Kidney	Heart	Tongue	Brain
Arthritis	×	✓	✓	✓	✓	✓
Caseous lymphadenitis	×	×	×	×	×	×
Dog bite	×	✓	✓	✓	✓	✓
Grass seed	×	✓	✓	✓	✓	✓
Sheep measles	×	×	×	×	×	×
Pleurisy	×	✓	✓	✓	✓	✓
Sarcocystosis	×	✓	✓	×	×	✓
Vaccination lesion	×	✓	✓	✓	✓	✓
Bladder worm	✓	×	✓	✓	✓	✓
Hydatids	×	×	×	×	×	×
Liver fluke	✓	×	×	×	×	×
Anemia	×	×	×	×	×	×
Bruising	×	✓	✓	✓	✓	✓
Company condemnns	×	✓	✓	✓	✓	✓
Ecchymosis	×	✓	✓	✓	✓	✓
Emaciation	×	✓	✓	✓	✓	✓
Fever	×	×	×	×	×	×
Gangrene	×	×	×	×	×	×
Gross contamination	×	✓	✓	✓	✓	✓
Jaundice	×	×	×	×	×	×
Malignancy	×	✓	✓	✓	✓	✓
Metritis	×	×	×	×	×	×
Muscle condition	×	✓	✓	✓	✓	✓
Other causes full carcass condemnns	×	✓	✓	✓	✓	✓
Peritonitis	×	×	×	×	×	×
Pyemia	×	×	×	×	×	×
Septic pneumonia	×	×	×	×	×	×
Wounds	×	✓	✓	✓	✓	✓
Ante-mortem	×	×	×	×	×	×
Cadmium	✓	×	×	✓	✓	✓

Red cross (×) indicate the food product was accounted for as downgraded whenever the condition was present, regardless of whether the carcass was condemned or trimmed. Purple cross (×) indicate the product was only accounted for as downgraded whenever the condition was present, and the carcass was condemned. Green tick (✓) indicate the food product was accounted for as fit-for-human consumption when the animal had the condition.

were also downgraded due to cadmium contamination (Western Australia, South Australia and Victoria), with restricted export markets for the remaining three states (Tasmania, New South Wales and Queensland) (Australian Government, 2015).

In 2020, a new Meat Notice - Establishment sourcing of stock to comply with import country requirements for cadmium levels in offal – was published (Australian Government (2020b)). This set policy for the management of cadmium levels in liver and kidney from adult sheep and cattle based on sub-regions of states, rather than at the state level (Australian Government, 2020a). Applying the conditions in this new Meat Notice to the 2015 food loss estimation, the percentage of kidneys eligible for harvest from adult sheep would have increased

from 4 to 27% and for liver from 45 to 47%. Subsequently, there would have been a 3% increase in dietary folate equivalent availability and a 5% increase in Vitamin A availability.

Soil cadmium is transferred to livestock via ingestion of plants and soil. Cadmium then bioaccumulates in the kidneys and liver. Soils can be contaminated with cadmium through application of rock phosphate fertilizers, sewage sludge and industrial wastes (Ismael et al., 2018; Australian Government, 2022; Mubeen et al., 2023). Australian soils have low levels of natural cadmium and fertilizer application is the most significant contributing source of the cadmium to the Australian sheep meat value chain (Warne et al., 2007; MacLachlan et al., 2016).

TABLE 5 Percentage of products downgraded at the abattoir in base year 2015, relative to the amount of product available from animals presented for ante-mortem inspection in the Australian lamb-, adult sheep- and combined sheep meat value chains.

Product	Lamb value chain loss as % total available at ante-mortem	Adult sheep value chain loss as % of total available at ante-mortem	Combined value chain loss as % of total available at ante-mortem	Number of Australian adults whose red meat intake could have been met with the combined losses
Carcase	<1	2	<1	170,099
Liver	2	58	17	105,815
Kidney	<1	96	26	33,856
Heart	<1	<1	<1	185
Tongue	<1	<1	<1	70
Brain	<1	<1	<1	66

TABLE 6 Losses of nutrients key to public health at the point of slaughter, as a percent of total available at ante-mortem from the Australian lamb, adult sheep, and combined value chains in base year 2015.

Nutrient	Lamb value chain loss as % total available at ante-mortem	Adult sheep value chain loss as % of total available at ante-mortem	Combined value chain loss as % of total available at ante-mortem	Number of women of reproductive age whose annual nutrient requirements could have been met with the combined losses
Vitamin A retinol equivalents	2	57	17	6.6 million
Thiamine (B1)	<1	8	3	66,000
Dietary folate equivalents	2	39	12	261,000
Iron	<1	10	4	211,000
Energy	<1	4	1	n/a
Protein	<1	5	2	145,000

The number of Australian women of reproductive age (19–50 years) whose nutrient requirement could have been met with the nutrients lost from the combined Australian sheep meat value chain losses in the base year was calculated, based on estimated average requirements.

In Australia, the level of cadmium in fertilizers is regulated by the jurisdictions and is set at 300 mg cadmium per kilogram of phosphorus. With growing interest in circular bioeconomies, cadmium levels in organic fertilizers and soil amendments, such as biosolids, also needs to be managed to minimize the risk of further increasing soil cadmium in agricultural areas, particularly where rock phosphate fertilizers have been previously applied (Alders et al., 2021; Fertilizer Australia, 2024). This may include regulation of cadmium levels in these products, much as rock phosphate fertilizers are regulated (NSW Government, 2014).

The authors recommend that when the regulated level of cadmium in fertilizer and organic soil amendments is next reviewed, the impact of cadmium on liver and kidney downgrades and nutrient availability is taken into consideration. Gains in reducing food and nutrient loss have been made with the change of the Meat Notice (Australian Government, 2020b); reducing regulated cadmium limits in fertilizers and soil amendments also has the potential to positively influence nutrient availability.

The prevalence of cadmium contaminated kidneys and livers in the Australian sheep meat value chain was determined via calculation, taking into consideration the age and location of the sheep and the Meat Notice on cadmium disposition (Australian Government, 2015). This was due to there being no published data on the prevalence of cadmium contamination of sheep liver and kidneys. Consideration

should be given to including cadmium downgrades in the National Sheep Health Monitoring Project to gain a more accurate understand of the scale of the impact of cadmium contamination on nutrient availability from the Australian sheep meat value chain.

Bladder worm was the second highest ranked condition responsible for downgrades of nutrients key to Australian public health from the Australian sheep meat value chain. This condition is caused by the dog tapeworm, *Taenia hydatigena*. Sheep become infected from eating tapeworm eggs that an infected dog has passed in its faces; dogs become infected by eating infected raw offal or scavenging on infected carcasses (Animal Health Australia, 2021). The prevalence of the condition can be significantly reduced through regular de-worming of dogs, prompt disposal of any fallen stock to reduce scavenging, not feeding dogs raw offal and, wild dog and fox control. Mitigations for bladder worm will also be effective for controlling sheep measles and hydatids (Animal Health Australia, 2021; Shephard et al., 2022). The condition is not clinically evident in live sheep or dogs. This means sheep producers will only be aware they have the condition in their flock when feedback from the abattoir is provided. Currently, this occurs in Australia for producers that sell sheep directly to slaughter at one of the 10 Australian abattoirs participating in the National Sheep Health Monitoring Project (Animal Health Australia, 2021). Consideration should be given to reorientating this monitoring project to a surveillance program,

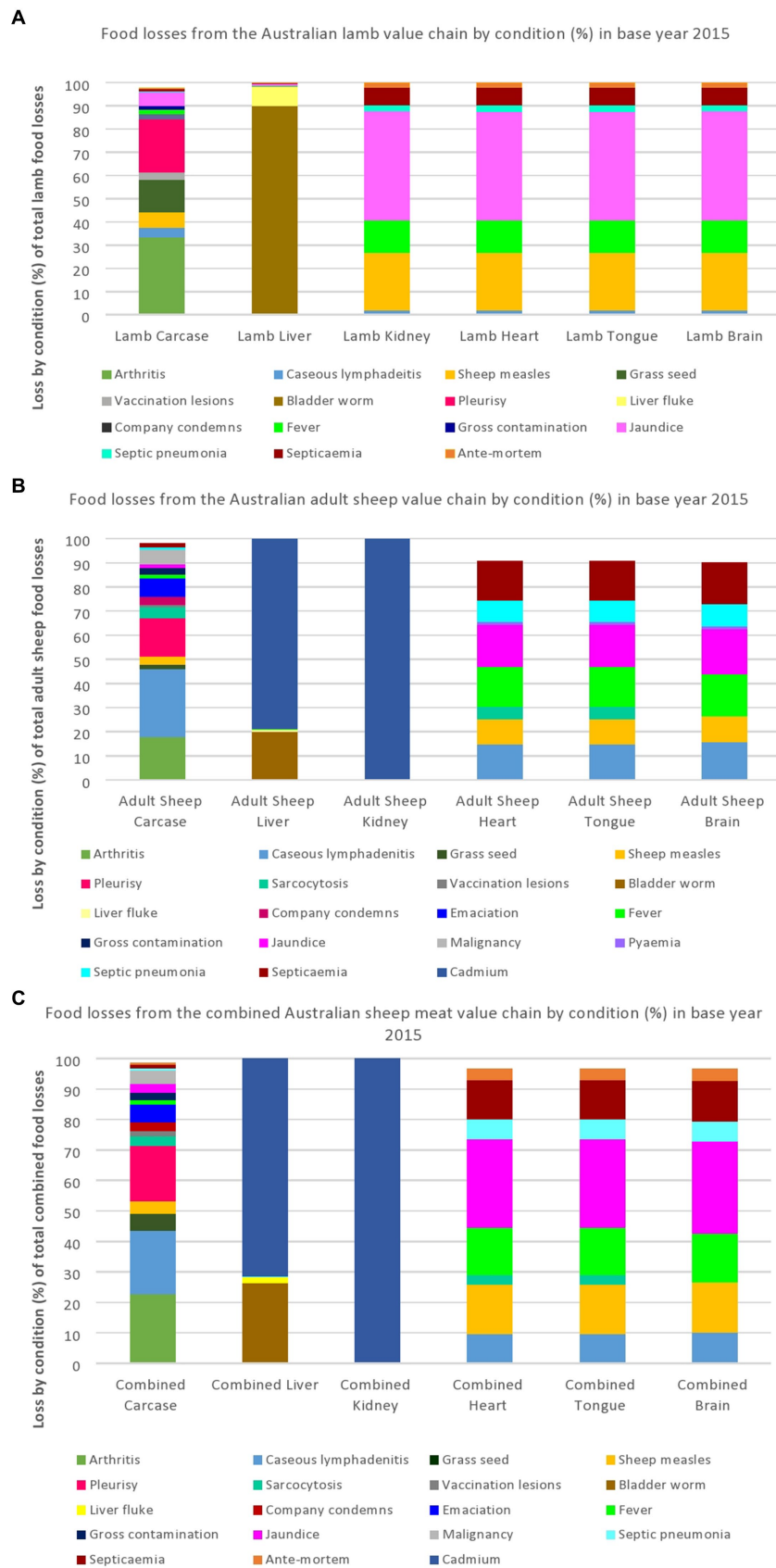


FIGURE 5 Cause of losses at the abattoir from the Australian lamb (A), adult sheep (B) and combined (C) value chains in base year 2015, represented as a proportion of total losses of products by weight. Some categories do not total to 1.0 as losses from conditions that accounted for less than 1% of the total losses of each product were not included. CLA, caseous lymphadenitis.

including expanding feedback to all producers, regardless of sale method. This is based on the contribution bladder worm infection has on nutrient availability from the Australian sheep meat value chain.

Neither cadmium or bladder worm were included in the report from Shephard et al. (2022) on priority endemic diseases for the Australian sheep and cattle industries. This report ranked conditions on economic impact the conditions had on the industries. Consideration should be given to ranking conditions not only on economic impact, but also the impact the condition has on food and nutrient availability at the society level. This will assist when assessing the Australian sheep meat value chain's contribution to food security and natural resource management (if the assessment is using nutrients as the functional unit).

Improvements in data availability and quality would increase the accuracy of quantifying food and nutrient losses from the Australian sheep meat value chain. Issues with data quality affecting food loss and waste assessments are well documented (Food and Agricultural Organization, 2011; Xue et al., 2017; Hoehn et al., 2023). The FAO's Global Livestock Environmental Assessment Model, known as GLEAM, aims "to quantify production and use of natural resources in the livestock sector and to identify environmental impacts of livestock in order to contribute to the assessment of adaptation and mitigation scenarios to move toward a more sustainable livestock sector" (Food and Agricultural Organization, 2021b). GLEAM currently does not include offal in its calculations. This is due to the lack of reported information from any of its member states on offal production globally (Food and Agricultural Organization, 2022). The impact of this on assessing the sustainability of livestock systems is marked, not only from a nutritional perspective as the results of this food loss assessment have shown, but also from a natural resource management perspective.

Wiedemann and Yan (2014) found that by including edible offal in the functional unit when calculating greenhouse gas emissions, the liveweight required on farm for each kilogram of retail product was reduced by 12%. Wingett and Alders (2023) conservatively estimated edible offal accounted for 12% of the total weight of edible components, 10% of the edible protein and 5% of edible energy of an Australian lamb. Not including edible offal when assessing the costs and benefits of livestock systems will over-estimate the relative impact of animals on the natural environment and underestimate the nutrient availability from livestock systems. This is particularly evident when performing nutritional life cycle assessment (McAuliffe et al., 2018; Damerou et al., 2019). Cases of successful reduction of food loss and waste are reported to have had strong government support (Kuiper and Cui, 2021). Developing commercially viable systems to capture offal production data and downgrades (including cause and magnitude) should be a priority for both the meat industries and governments.

Greater transparency in agricultural data sharing would improve the accuracy in this food loss assessment. The inclusion of full carcass condemnations in the Livestock Products, Australia series published by the Australian Bureau of Statistics would assist with this process. This information is captured in the equivalent national statistical series in New Zealand (Statistics New Zealand, 2021). The rate of full condemnations is comparable between the two countries, and both are low, with less than 1/100 adult sheep being condemned and less than 1/1000 lambs being condemned. This shows the high standard

of the Australian and New Zealand sheep meat production and could be used as an indicator for animal health and welfare at the national level for the industry. Publication of data on the number of animals, disaggregated by species, age and sex, that are processed at knackeries (establishments that slaughter animals for animal food only) would also be of benefit to understanding the magnitude of product and nutrient losses from Australian livestock systems, as well as gaining a fuller understanding of animal health and welfare.

Further consideration needs to be given to the assumption in the 'State of Food and Agriculture 2019 – Moving forward on food loss and waste reduction' report (Food and Agricultural Organization, 2019), Global food loss index accounting and reporting (Food and Agricultural Organization, 2018) and the Australian national food waste baseline (ARCADIS, 2019) that a product that was intended to be food (e.g., edible offal) but is diverted to another supply chain (e.g., monogastric animal feed) and later enters the food chain in another form (e.g., chicken or pork) is a neutral outcome from a food systems perspective. The results of this mass balance analysis show that the downgrade of offal is a significant contributor to the downgrade of nutrients from the Australian sheep meat value chain. Australians eat very little nutrient-dense offal, less than 0.4g per person per day, compared with 48.4g of red meat and 48.7g of poultry meat (Australian Bureau of Statistics, 2022a). However, a serve of chicken breast is not equal nutritionally to a serve of lamb liver. Although chicken breast has similar fat, protein and energy content to lambs' liver, liver has significantly greater concentrations of micronutrients key to Australian public health, i.e., iron, vitamin A RE, thiamine (B1) and dietary folate equivalents. Additionally, there is an environmental impact from raising chickens (e.g., soybean meal being imported from South America as a feed input for the Australian chicken meat industry (Copley and Wiedemann, 2023)) that would not have occurred if the lamb and sheep offal had entered the food chain directly, rather than through nutrient recycling. Further research is recommended to understand the end points of products in Australian sheep meat value chain and the consequences of this nutrient recycling. This is supported by recommendations in the National Food Waste Baseline Final Assessment Report for further research into diversion of livestock products into the pet food supply chain (ARCADIS, 2019).

Based on the results of this food loss analysis, the Australian sheep meat value chain is very efficient at conserving food products and nutrients at the point of slaughter, except for kidney and liver condemnation due to cadmium contamination and the subsequent loss of dietary folate equivalents and vitamin A RE. However, these results have an overall uncertainty rating of medium-to-high. Greater transparency in agricultural data sharing would reduce this uncertainty. Further research into improved data collection on offal production and updating and expanding offal nutrient composition data will significantly improve the accuracy of this food and nutrient loss analysis. Quantifying pre-consumer waste of offal (e.g., offal fit for human consumption that is diverted to pet food or rendering due to market influences) will be of value in further understanding nutrient flows in the Australian sheep meat value chain and the impacts on food security, nutrition, and the environment. Government support for these actions will improve the likelihood of success and subsequently the sustainability of the Australian sheep meat value chain.

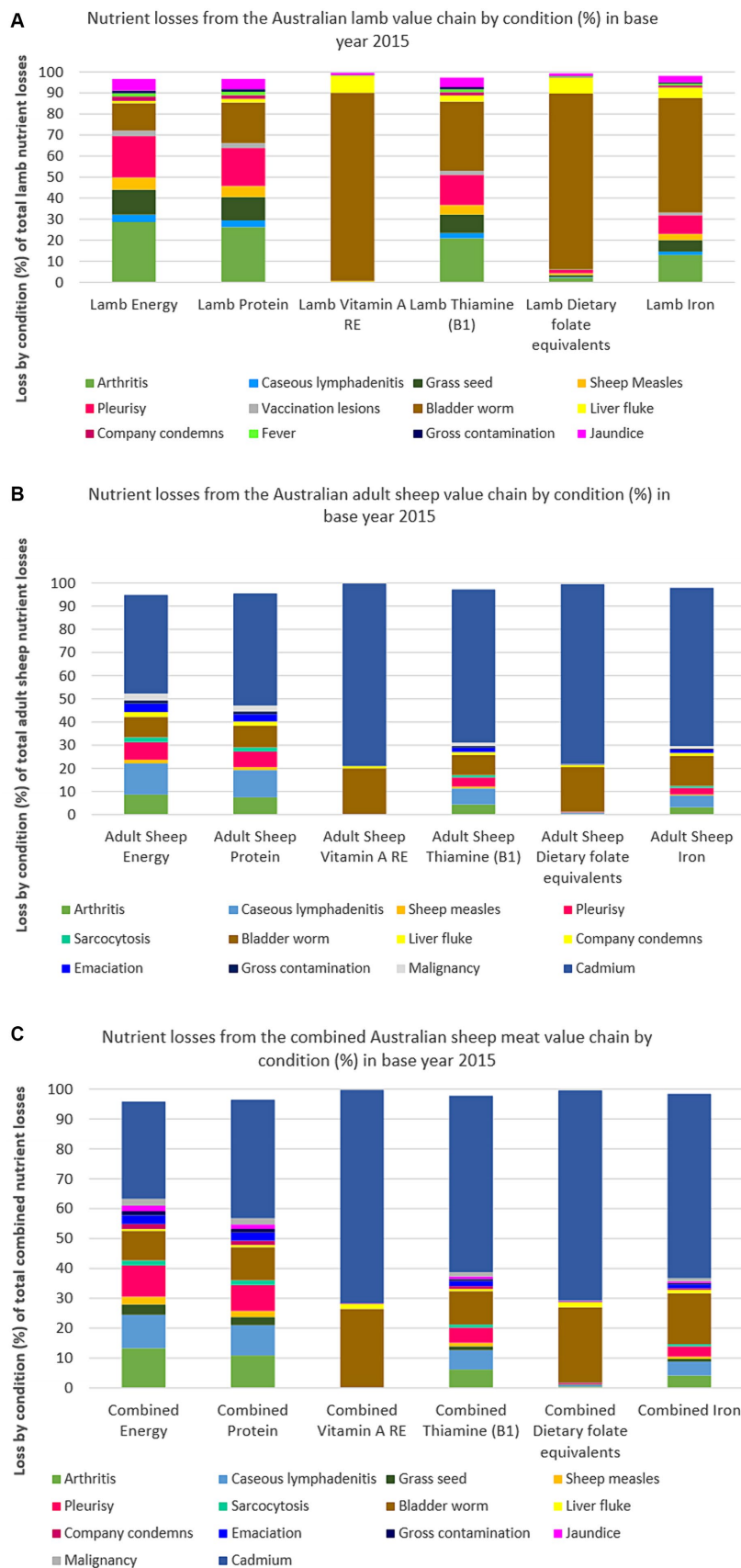


FIGURE 6 Cause of nutrient losses at the abattoir from the Australian lamb (A), adult sheep (B) and combined (C) value chains in base year 2015, represented as a proportion of total losses of nutrients from the lamb value chain. Some categories do not total to 1.0 as losses from conditions that accounted for less than 1% of the total losses of each nutrient were not included. CLA, caseous lymphadenitis.

TABLE 7 Uncertainties in calculating food and nutrient losses from the Australian sheep meat value chain for base year 2015.

Source of uncertainty		Rating		Justification
Population	Number of lambs and adult sheep slaughtered, and carcasses passed as fit for human consumption	Very low	Sub-total uncertainty rating for population: Low-to-medium	Data used is from surveys undertaken by the Australian Bureau of Statistics and reported to have good national coverage (Australian Bureau of Statistics, 2020a) There is no published Australian data on the number of animals processed at knackeries
	Full carcass condemnation rates	High		Based on secondary data published in Lane et al. (2015) from 2011 to 2013 and collected only from export – registered processing plants not in the timeframe required to establish a base year level
	Weight of carcasses available ante-mortem and post-mortem	Very high		Calculated values based on data that has high uncertainty
	Weight of carcass available fit-for-human consumption	Very low		Data used is from surveys undertaken by the Australian Bureau of Statistics and reported to have good national coverage (Australian Bureau of Statistics, 2020a)
Prevalence of diseases/ conditions that cause downgrade of food products	Diseases/conditions included that cause downgrading of carcasses and/or offal	High	Sub-total uncertainty rating for prevalence of disease/conditions: Medium-to-high	Due to no published data being available on nutrient composition of lung and gut, the conditions of lungworm, pneumonia and knotty gut monitored as part of the National Sheep Health Monitoring Project were not included in the assessment of food and nutrient losses from the Australian Sheep Meat Value Chain Not all conditions that cause downgrades are monitored in the National Sheep Health Monitoring Project Export Production and Condemnation Statistics Database does not capture domestic abattoirs or knackeries
	Disease prevalence causing trimming and/ or condemnation of carcasses and offal	Medium		Researchers were provided access to the national sheep health monitoring project data (Animal Health Australia, 2021). This data is collected on a continuous basis in sheep processing plants across Australia. Export Production and Condemnation Statistics data is secondary data from 2011–2013 and does not include domestic abattoirs Animals that are processed at knackeries are not captured by National Sheep Health Monitoring Project or Export Production and Condemnation Statistics Prevalence of downgrades due to cadmium based on incomplete secondary data, with assumptions made on activities in domestic abattoirs, based on regulation of export registered abattoirs (Australian Government, 2015)

(Continued)

TABLE 7 (Continued)

Source of uncertainty		Rating		Justification
Weight of food products downgraded	Weight of downgraded carcass meat per condition	Medium	Sub-total uncertainty rating for weight of product downgraded: High	Analyzed data used (Hernandez-Jover et al., 2013). This data was collected from one processing plant over a period of 6 months.
	Number of offal edible offal pieces passed as fit for human consumption	Very high		Calculated values based on data that has high uncertainty as no published data on total offal production in Australia.
	Offal condemnation rates	Very high		Calculated values based on data that has high uncertainty as no published data on offal condemnation rates in Australia
	Offal weights	Medium		Data is based on measurement, but is not disaggregated by age (Sentance, 2011) or is only for lamb (Hutchison et al., 1987) and both data sets are more than ten years old No published data available for thymus, lungs, blood, head meat, runners, caul fat and kidney fat
	Edible parts of lamb carcass conversion factor	Medium		Data is based on measurement and sample numbers of ten or less and data published more than ten years ago (Food Standards Australia New Zealand, 2019a)
	Edible parts of mutton carcass conversion factor	High		Very limited published data on gross composition of mutton cuts and/or carcass so assumed composition was the same for mutton as lamb (Food Standards Australia New Zealand, 2019a)
	Edible parts of offal pieces conversion factors	High		Data is more than 35 years old (Hutchison et al., 1987).
Nutrient composition of downgraded food product	Nutrient composition of lamb carcass meat	Medium	Sub-total uncertainty rating for nutrient composition of downgraded product: High	AUSNUT data used – this is a combination of analyzed and recipe data (Food Standards Australia New Zealand, 2014). Data is based on ten or less analyzed samples and is more than ten years old
	Nutrient composition of mutton carcass meat	High		Based on average of values of two cuts of mutton included in AUSNUT database (Food Standards Australia New Zealand, 2014). This data is based on ten or less analyzed samples and is more than ten years old.
	Nutrient composition of lamb offal	High		AUSNUT data used – this is analyzed data (Food Standards Australia New Zealand, 2014). Due to the age of this data, it is no longer included in the current Australian Food Composition Data (Food Standards Australia New Zealand, 2019a). No published Australian data available for thymus, lung, spleen, blood, head meat, stomach and intestines, caul fat and kidney fat
	Nutrient composition of adult sheep offal	Very high		Assumption the nutrient composition of adult sheep offal was the same as lamb offal, as there is no published data on the nutrient composition of any offal from adult Australian sheep

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: Some of the data analyzed in this study was obtained from Animal Health Australia and the following restrictions apply – data from the National Sheep Health Monitoring Project is only available to the researchers. Requests to access National Sheep Health Monitoring Project datasets should be directed to: aha@animalhealthaustralia.com.au. Generated datasets are available on request. The generated raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

KW: Conceptualization, Data curation, Methodology, Writing – original draft. RA: Conceptualization, Writing – review & editing.

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Conflict of interest

KW declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. RA declares a potential conflict of interest in that she owns a merino sheep farm (which is not her primary source of income), however, her farm does not produce prime lambs.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fsufs.2024.1304275/full#supplementary-material>

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