Meat Loss and Environmental Impact

A study of the meat processing industry of Sri Lanka (2014 – 2024)

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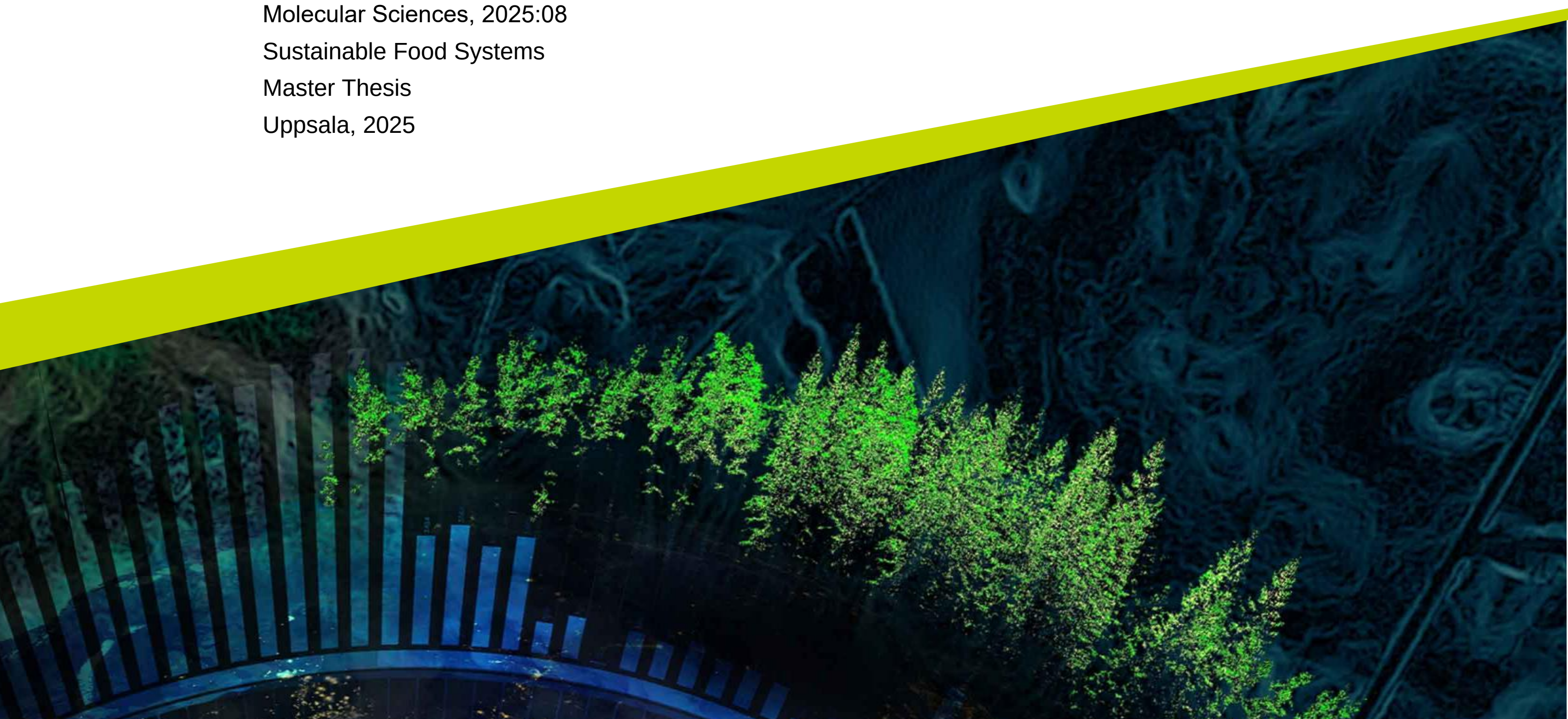

Meat Loss and Environmental Impact: A study of the meat processing industry of Sri Lanka (2014 – 2024)

Köttförlust och miljöpåverkan: en studie av köttbearbetningsindustrin i Sri Lanka (2014-2024)

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Abstract

The global challenge of food loss and waste (FLW) continues to undermine environmental sustainability and food security, particularly in low and middle-income countries. Meat loss is crucial among food categories because it is relatively less economically viable and poses a significant burden. In Sri Lanka, processed meat products, especially sausages and meatballs, form a major share of the meat industry, However, little is known about the extent of meat loss during the processing stage or its environmental implications.

This study estimated the extent of processed meat loss during the processing stage in Sri Lanka's processing sector and its associated carbon footprint. Data was collected from seven industry facilities over eleven years period (2014 to 2024) through structured data requests on production volumes and product wastages during processing stages, supported by secondary literature. Results indicated an average meat loss of 2,400,000kg annually, 10.3% of production volume. Fluctuations were observed in meat loss percentages within the range from 9.9% to 11% during 11 years. Calculations were made to estimate the carbon footprint based on the Sri Lankan-specific emission factor of 0.3 kg CO_2e per kilogram of chicken meat, which reflects the emission only up to the raw meat availability stage. A 60% minimum meat content assumption, derived from SLS 1218:2001 for comminuted meat products, was applied to estimate the actual meat lost. The estimated carbon emissions from processing-stage losses in 2024 amounted to approximately 550 tonnes CO_2e, highlighting a significant environmental burden. This value excludes emissions from further processing activities and thus represents a conservative estimate. Nevertheless, it remains within the range of total emissions reported in international lifecycle studies of poultry products.

This study provides a baseline for understanding processing-stage meat loss and its environmental implications in Sri Lanka. It highlights the need for standardized data collection and integrating Life Cycle Assessment (LCA) tools tailored to Sri Lanka’s context to improve accuracy and facilitate cross-sector comparisons. These insights can also guide future interventions aimed at reducing emissions and enhancing resource efficiency through industry automation, cold chain improvements, and employee training in Sri Lanka’s meat processing industry.

Keywords: meat loss, meat processing, Sri Lanka, carbon footprint, food loss and waste, greenhouse gas emissions

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Abbreviations

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FAO	Food and Agriculture Organization	9
FLW	Food Loss and Waste	9
DAPH	Department of Animal Production and Health	10
GHG	GreenHouse Gas	14
LCA	Life Cycle Assessment	14
SLS	Sri Lanka Standards	23
ISO	International Organization for Standardization	23

1. Introduction

This chapter introduces the problem followed by the problem statement, research objectives, research questions, scope, and delimitations for the project, all of which serve as a guide for the report.

Beyond economic impacts, meat loss carries serious environmental consequences (Cole & McCoskey, 2013). Meat production is inherently resource-intensive, requiring substantial amounts of water, land, and feed, and contributing markedly to greenhouse gas emissions, biodiversity loss, and deforestation (FAO, 2013). Poore and Nemecek (2018) estimate that approximately 15% of global food-related greenhouse gas emissions derive from supply chain losses, particularly during post-harvest handling, storage, transportation, and processing. Losses during meat processing may have an especially large environmental impact because meat production generates significantly higher greenhouse gas emissions per unit than most other foods (Capper, 2011). Additionally, decomposing discarded meat releases methane, a potent greenhouse gas, further increasing the carbon footprint of the meat industry.

Globally, meat production has more than tripled over the past five decades, driven by increasing incomes, urbanization, and changing dietary preferences (FAO, 2019). The global meat market continues to expand, with forecasts indicating a sustained demand for processed and value-added meat products such as chicken sticks, chicken patties, burgers, kebabs, nuggets, and rolls (Mohammadi et al., 2023). However, alongside this growth, food loss and waste (**FLW**) has emerged as a critical challenge, affecting all stages of the food supply chain (Kilibarda et al., 2023). According to the Food and Agriculture Organization (**FAO**) (2011), nearly one-third of all food produced is lost or wasted annually, with variation in loss points across different economic contexts. In developed countries, FLW predominantly occurs at the retail and consumer levels due to over-purchasing, strict food quality and safety standards, and misinterpretation of labeling (Parfitt et al., 2010). In contrast, in developing countries, losses tend to occur earlier in the supply chain due to inefficient production, inadequate transportation, and improper processing techniques (Filippini & Srinivasan 2019).

The meat industry in Sri Lanka plays a vital role in the country's economy, contributing significantly to food security, employment, and agricultural development (Alahakoon et al., 2016). Livestock farming is widely practiced across various regions, influenced by cultural, market, and climatic factors (Filippini & Srinivasan 2019; Bandara et al. 2021). The poultry sector, in particular, has shown significant growth in recent years, propelled by increasing consumer demand and government support for commercialization (Alahakoon et al., 2016). Between 2004 and 2013, Sri Lanka's total meat production rose by approximately 51%, from 119,620 metric tons to 185,490 metric tons, primarily driven by poultry. Furthermore, during this period, the per capita poultry availability notably increased from 4.00 kg/year to 7.09 kg/year while the supply of beef, pork, and mutton remained relatively stable. More recent data indicate a slight decline in beef production, with per capita availability recorded at approximately 1.25 kg/year in 2022, while the poultry sector continues to grow (DAPH, 2023). Meanwhile, the swine sector, mainly located along the western coast, has seen a 5% reduction in the pig population (DAPH, 2023).

Dietary preferences in Sri Lanka have increasingly shifted towards processed meat products such as sausages, bacon, ham, salami, and meatballs (Weerahewa et al., 2018). These products are often prepared through techniques like salting, curing, fermenting, smoking, or by adding preservatives to enhance flavors or extend shelf life (De Barcellos et al., 2011). According to the Sri Lankan Department of Animal Production & Health (**DAPH)** in 2022, processed meat production has increased by 110% from 2014 to 2022. Urbanization, rising disposable incomes, and the expansion of international fast-food franchises such as KFC, Pizza Hut, and McDonald's have further fuelled the demand for processed meats (Weerahewa et al., 2018).

Despite the increasing consumer demand, the Sri Lankan meat processing industry faces significant operational challenges such as operating with outdated facilities, inadequate infrastructure, poor cold chain systems, and inefficient preservation technologies (Kassahun et al., 2023). The processing stage is particularly critical, as it directly influences product quality, safety, and shelf life (FAO, 2013). However, Kilibarda et al. (2023) highlight that inadequate processing conditions, especially about temperature regulation and hygiene, are linked to microbial contamination, spoilage, and subsequent financial losses. Furthermore, Xue et al. (2017) emphasize that many developing countries, including those in South Asia, remain significantly underrepresented in food loss data collection and research, limiting the ability to design evidence-based interventions and track the scale of processing inefficiencies over time.

This context emphasizes the need to better understand meat losses at the processing stage in Sri Lanka, both from an economic and environmental perspective. Despite global and regional insights, empirical data specific to Sri Lanka's meat processing inefficiencies remain limited, making it difficult to develop targeted solutions to reduce losses and environmental impacts.

1.1 Problem Statement and Research Objectives

Meat loss during the processing stage poses a significant challenge for both the economy and the environment. As Kotykova and Babych (2019) note, process inefficiencies can lead to significant profit losses, reduced industry competitiveness, and increased costs for consumers. In a developing country, like Sri Lanka, where infrastructure and technology may be limited, these losses may have broader consequences for food security and economic development

(Ishangulyyev et al., 2019). Although meat represents a relatively small proportion of global food waste by volume, it has a disproportionately high environmental impact due to the resource-intensive nature of meat production (Stoll-Kleemann & Schmidt, 2017; Karwowska et al., 2021).

Despite the global need to reduce meat losses, there is a notable lack of empirical data on the extent of meat losses at the processing stage. In the context of Sri Lanka, where processed meats such as sausages and meatballs are increasingly popular, there is limited understanding of how much meat is lost during processing, or what environmental consequences such losses carry. Existing studies have mainly focused on food loss at the consumer and retail levels, leaving a critical gap in understanding processing inefficiencies where significant losses occur. This gap in the data makes it difficult to design targeted interventions or quantify the real impact on the environment. Xue et al. (2017) also emphasize that developing regions, particularly in South Asia, remain significantly underrepresented in food loss research, particularly at the processing stages. Without reliable, disaggregated data, policymakers, industry stakeholders, and researchers are unable to make evidence-based decisions to reduce waste or improve system efficiency.

Accordingly, this study aims to quantify meat losses occurring during the processing stage in selected meat processing companies and to estimate their associated environmental impacts through carbon footprint analysis. By providing baseline insights into meat loss trends and their environmental implications, the study aims to support more efficient and sustainable practices within the country's growing meat industry.

1.2 Research Questions

1. What is the extent of meat loss during the processing stage in Sri Lankan meat processing companies?
2. What is the estimated carbon footprint associated with meat losses at the processing stage?

1.3 Scope

The focus is restricted to losses occurring specifically during the processing stage within registered processing facilities, acknowledging that upstream and downstream losses are outside the scope of this research.

Furthermore, the analysis emphasizes processed meat products, largely reflecting the commercial operations predominantly driven by companies producing sausages and similar products in Sri Lanka. The analysis primarily covers the poultry, beef, and pork sectors, which are the major contributors to the country's processed meat supply.

In line with the FAO's definition of food loss and waste, meat loss in this context refers to edible meat originally intended for human consumption that is lost or discarded at various points during processing. All processing stages such as receiving, trimming, grinding, marination, curing, forming, cooking, packaging, and cold chain storage, are considered potential points where such losses may occur. This approach aims to capture losses across the entire processing chain within the selected establishments.

This study evaluates the environmental impact of these losses by estimating the carbon footprint associated with the lost meat, using globally recognized, nationally relevant emission factors.

1.4 Delimitations

While this study aims to provide an initial assessment of meat loss and its environmental impact within Sri Lanka's meat processing industry, several delimitations are acknowledged:

The scope is primarily limited to chicken-based processed products, reflecting the dominant meat type in the local industry and available data, and therefore may not capture variability in loss for other meats. Additionally, the study assumes that all meat identified as "lost" is not reused, due to the unavailability of relevant data on secondary use practices such as reprocessing or animal feed conversion. The study also deliberately avoids invisible losses such as cooking loss, freezing loss, and thawing loss through the processing stage.

These delimitations were considered in the study design and data interpretation, and the findings are intended as a baseline for further research and refinement.

2. Literature review

This chapter provides a comprehensive overview for understanding the extent of meat loss during the processing stage and its associated environmental impacts, particularly in the context of Sri Lanka. It explores previous research on food loss and waste, the environmental footprint of meat production, carbon emission estimation methods, and factors influencing meat processing efficiency in both global and regional settings.

2.1 Meat Loss and GHG Emissions

Many studies, such as those by Gilligan et al. (2023), Wang et al. (2023), and (Halloran et al., 2014) state that there is limited research and literature specifically focused on the meat processing industry, due to the lack of systematic measurements of meat loss, the complexity of operations, resource constraints (e.g., technical or financial), and institutional barriers such as a focus on production efficiency and low awareness or neglect of food loss. However, Costa et al. (2018) observed an upward trend in the number of studies emerging in this area. This claim is supported by Cahyana et al. (2019) who concluded that the number of studies on food waste in supply chains has increased over the past 12 years, after reviewing 108 articles on the topic.
Table 1 summarizes key international studies related to meat loss percentages and environmental impacts, highlighting differences in methodology, scope, and data availability.

Table 1; Summary of selected literature on meat loss and GHG emission during processing

Study	Country	Focus Area	Methodology	Loss % (processing)	Notes
Wang et al. (2023)	China	Meat supply chain loss	Surveys, interviews, scaled with national data	Not available	Highest loss in distribution (37.8%), beef and chicken loss 9.5%)
Wei et al. (2023)	China	GHG emissions (cradle to gate)	Process-based LCA, secondary data	Not available	Chicken – 4.42 kg CO_2e/kg Pork – 3.83 kg CO_2e/kg Beef highest emissions

Alshabanat et al. (2021)	Saudi Arabia	Food Loss (8 food groups)	FAO model + surveys	Red meat – 5%, Poultry – 6%	Focus on food self-sufficiency and waste reduction
Read et al. (2020)	USA	Env. Impact of FLW	Secondary data from reports	6.0%	Total meat loss 22.6%, 11% at consumption, 4% retail
Xue et al. (2017)	Global	FLW data review (202 studies)	Literature review	Not available	Most studies from high-income countries, gaps in developing countries

A study by Wang et al. (2023) quantified the losses along the animal products (meat, dairy, aquatic products, and eggs) supply chain during 2015 - 2019 in China. The meat category consisted of major livestock varieties of pork, beef, lamb, and chicken, accounting for over 85% of the national production average. They gathered self-reported data from 510 enterprises in 23 provinces, based on the FAO (2019) definition of food loss. Data collection methods were questionnaires and semi-structured interviews with farmers, processors, and distributors. Reported data were used to calculate the loss, not direct measurements. The national production averages were utilized to scale up the results. The overall meat loss rate was 6.4%, with the highest losses in distribution (37.8%) and storage (22.5%). The highest total loss percentage of meat was beef and chicken (9.5%), followed by lamb and pork. Meat loss in the processing stage was not captured due to data scarcity. They have some key assumptions such as accurate self-reporting, representativeness of sampled regions, and uniform production practices. Further, the authors emphasized that developing countries often lack the quality and quantity of food loss data.

Wei et al. (2023) conducted a process-based Life Cycle Assessment (**LCA**) to quantify the greenhouse gas (**GHG**) emissions of meat (beef, mutton, pork, and chicken) in China. Secondary data were extracted from national statistics, databases (like CLCD), IPCC guidelines, and previous studies under different farming scales at the provincial level. GHG emissions from primary production until processing (cradle to gate) were calculated. The emission co-efficient for pork was extracted from local sources while for other meats followed Poore and Nemecek (2018) due to data gaps. According to their findings total GHG emissions from China's livestock sector reached 429 million tons CO_2e in 2018, with beef having the highest emission intensity (19.56 kg CO_2e/kg), followed by mutton (10.02 kg CO_2e/kg), chicken (4.42 kg CO_2e/kg), and pork (3.83 kg CO_2e/kg). Also, emissions were provincial-specific. In this study, the authors heavily rely on secondary sources to carry out their research.

FLW in Saudi Arabia's food supply chain was estimated by Alshabanat et al. (2021), covering eight major food groups. Camel and lamb were considered red meat, while poultry was another category. The food balance sheet data in 2016 was merged with extensive surveys to gather data. The declining edible portion of food available for human consumption is considered food loss and waste along the supply chain. The calculations were done according to the FAO model, which is based on FLW percentage and mass flow at each stage for the entire supply chain. At the processing stage loss of red meat and poultry was 5% and 6%, respectively. The authors concluded that this research establishes an overall FLW baseline aiming to boost food self-sufficiency and reduce import dependency (ibid).

Read et al. (2020) conducted a study to assess the environmental benefits of halving FLW along the U.S. food supply chain. FLW is defined as the portions of food that are produced but not consumed and occur at various stages such as production, processing, distribution, and consumption. Not a direct weighing process for the data and predominantly relies on existing studies and reports. As per the findings, total meat loss was approximately 22.6% throughout the supply chain. The estimated loss rates are about 3.7% during production, 6.0% during processing, 4.0% at the retail level, and 11.0% at the consumption stage. This study highlighted that meat production is resource intensive and reducing food losses leads to a significant decrease in the footprint of the food system (ibid).

Based on the review of such studies, we can conclude that most apply internationally recognized FLW definitions, measurement standards, and content-specific assumptions. According to the FLW protocol, measuring methods include diaries, direct measurement, interviews and surveys, mass balance, proxy data, records, and waste composition analysis. However, direct measurements and surveys are commonly used to gather data. Bräutigam et al. (2014) state that most FLW studies are central to the European context, especially comprehensive studies conducted in Switzerland and France. In developing countries, systematic and detailed research is limited and the focus in these countries tends to be on the quantitative estimates from broad FAO models rather than detailed, localized studies. Xue et al. (2017) emphasized after reviewing 202 publications on FLW data up to 2015, that most studies have been conducted for high-income countries focusing on retail and consumption stages. Often relying on outdated literature rather than direct measurement, leading to high uncertainty and a lack of comprehensive data across the full supply chain (ibid).To the best of our knowledge, meat loss during processing has not been examined before in Sri Lanka.

2.2 Meat Processing Industry in Sri Lanka

The processed meat market in Sri Lanka has a slow, restrained growth due to various factors such as rising health consciousness among consumers, increasing competition from alternative protein sources, and stricter regulations on meat production and, processing (Statista, 2025). However, the market is expected to experience moderate growth driven by the demand for convenience and ready-to-eat meat products (Statista, 2025). Additionally, the sub-markets of comminuted meat products (sausages, meatballs, and cold meat), cured meat (ham and bacon), formed meats (nuggets, meat fingers, drumsticks), and roast meat products are also contributing to the overall market growth. (Statista, 2025).

As stated in the Annual Report of DAPH in 2023, there were 15 poultry processing establishments, and 13 poultry further processing establishments registered under DAPH. Total value-added chicken meat products manufactured by further processing establishments amounted to 21,000 metric tons. Exports of chicken meat and meat products were recorded as 1,500 metric tons and 240 metric tons of poultry meat and meat products were imported to the country during 2023.

According to Alahakoon et al. (2016), while demand for chicken is increasing due to its perception as a healthy option, beef and pork consumption is limited due to cultural and religious restrictions. Even though the swine sector is one of the main livestock sub-sectors placed next to the poultry sector in Sri Lanka, pork consumption is heavily influenced by ethnoreligious beliefs among Sri Lankans, leading to a suppression of pork consumption and the overall processing and demand for pork and beef products in the market (Alahakoon et al. 2016).

2.3 Key Drivers of Meat Loss During Processing

This section explores the primary factors contributing to meat loss during processing, with a particular focus on food safety issues, operational inefficiencies, and infrastructure-related challenges. Drawing on both global research and context-specific findings from Sri Lanka, it aims to outline where losses may occur and what factors might be driving them.

2.3.1 Quality and Safety Compliance

Poore and Nemecek (2018) state that processors and retailers strictly adhere to quality and safety standards. When the meat products do not comply with safety protocols or do not meet the quality specifications, they need to be discarded. It leads to meat loss during manufacturing (Kilibarda et al. 2023).

2.3.2 Heat Treatment Effects on Meat Quality

The components and properties of meat products change significantly with temperature. Meat undergoes thermal treatment to improve it's aroma, texture, and structure and to inactivate undesirable microbes (Ježek et al., 2019). Longer cooking time and temperature increase protein denaturation, leading to moisture loss and shrinkage. It results in the reduction of the quantity of meat (Purslow et al., 2016). Severe thermal shocks cause significant deterioration in the quality of the product (Vinnikova et al., 2019). Choi et al. (2016) conducted a study to evaluate the meat loss of chicken steak at different elevated temperatures and cooking methods. Cooking loss was increased with higher temperatures and longer cooking time, and they have found that Faster high-temperature treatments like superheated steam are better at minimizing meat loss. Duranton et al. (2011) demonstrate the effect of high-pressure high-temperature (HPHT) processing (e.g. 500 MPa at 115°C) on sausages. HPHT is a more reliable method than a conventional heating method to reduce meat loss by retaining structure and moisture in sausages.

2.3.3 Microbial Spoilage and Cross-Contamination

Cross-contamination of carcasses directly or indirectly leads to a loss in meat quality. Poor hygiene practices cause cross-contamination among the different batches of the meat products. (A. Shaltout, 2024). Berkel et al. (2004) mention that inadequate sanitation facilities create an unfavourable processing environment for meat. Álvarez-Astorga et al. (2002) reported that processed meats (hamburgers, sausages) contain higher levels of mesophilic bacteria than raw poultry cuts (thighs, wings). This finding is reconfirmed by the FAO (2013) report, which states that this is often due to the preparation of a product mixture where the meat surface is exposed to air and microbes. (Vihavainen & Björkroth, 2007) highlighted the consequences of lactic acid bacteria (LAB) in the spoilage of broiler meat during processing. The major spoilage organisms identified Lactobacillus, Leuconostoc, and Carnobacterium can thrive in cold temperatures and modified atmospheres. The highest LAB count was found inside the air-chilling area. It was approximately 10 times greater than in other parts of the facility. When LAB populations exceed 10^7 CFU/g, rapid spoilage occurs, leading to meat loss and significant economic consequences (ibid).

2.3.4 Systemic and Technological Issues in Processing Facilities

Álvarez-Astorga et al. (2002) state that most of the manufacturers are using automated meat processing methods. It involves continuous conveyor systems that are often exposed to air. It becomes more vulnerable to increasing meat contamination with airborne pathogens, were already prevalent. Further, limited human intervention in automated systems restricts the frequent inspection of contamination signs in the products, not as workers manually working on processing (*ibid*).

2.3.5 Packaging-related Losses

Research Scholar et al. (2017) emphasized that packaging in processed meat helps prevent dehydration, lipid oxidation, discoloration, and off-odours. Furthermore, modified atmosphere packaging is the most commonly used method for meat products among the various available packaging techniques. In the Belgian food industry, Dora et al. (2020) identified improper filling, sealing issues, and damaged packaging as causes of product loss. Although these represent a minor portion of total losses, the cost of reworking them is high. (Kilibarda et al., 2023) highlighted that improper packaging materials and design can lead to mechanical damage and microbial contamination of the products.

2.3.6 Human Errors in Handling and Operations

Dora et al. (2020) investigated the causes of meat loss in Belgium through a comprehensive survey of 47 food processing companies, including those in the meat sector. They found that human error was identified as a major issue by 75% of the participating companies. In meat processing, such errors commonly occur during cutting and packaging, often due to improper handling, inadequate training, or insufficient knowledge of food handling practices. Furthermore, Dora et al. (2020) noted that defective meat is frequently either discarded or reworked, depending on the company and product type. Although the extent of loss varies, defects represent a substantial portion of overall waste in the meat industry.

2.3.7 Improper Storage and Temperature Control

Chilling and freezing are crucial in meat processing. Because it ensures product hygiene, appearance, safety, and nutritional quality (Rinwi et al. 2024). The approximate temperature of 4°C is considered optimal to prevent protein denaturation and reduce the risk of microbial growth. Meat can be chilled in different methods which have different effects on meat loss (Zhou et al. 2010). Xu et al. (2012) revealed that rapid chilling (RC, -20 °C for 30 min, followed by 0 to 4 °C) is better than conventional chilling (0 to 4 °C) for pork meat. This directly contributes to reducing meat loss during processing. Freezing is especially important for preserving meat freshness (Ockerman & Basu 2004). Fast freezing is preferable to slow freezing, as it minimizes cellular damage by forming smaller ice crystals (Chaboud & Daviron 2017) Freezing typically begins at -5°C, and is most effective between -18°C and -20°C, where up to 98% of water content is frozen and microbial activity is significantly reduced (Zhou et al. 2010). Furthermore, highlights those freezing temperatures can not completely eliminate biochemical reactions such as enzymatic activity and oxidation, which are slowly impacting meat quality. However, manufacturers must adopt precise and consistent chilling and freezing protocols to reduce meat loss, prevent microbial contamination, and avoid chilling injuries during storage and transportation (Kilibarda et al. 2023).

Despite meat loss or waste occurring throughout the supply chain, its extent depends on the region and economy (Magalhães et al. 2021). In Sri Lankan context, quantification of meat loss is allowed to identify the hotspot in meat processing.

2.4 Impact of Meat Loss

2.4.1 Environmental Impact

FLW affect food security and pose a threat to the global economy, while also triggering environmental degradation and wasting time (Chaboud & Daviron, 2017). Increasing losses lead to the excessive utilization of natural resources, resulting in water depletion, land degradation, biodiversity loss, and GHG emissions (Kummu et al., 2012). Although meat and meat products contribute less to the water footprint compared to cereals and pulses, their negative impact on the land footprint is substantial (FAO, 2013). Poore and Nemecek (2018) assessed the environmental impact of food loss, including meat (beef, pork, poultry, etc.) throughout the global supply chain using LCA. Their results showed that the processing stage contributes significantly to additional GHG emissions. Processing meat products contributes approximately 0.3 to 1.1 kg of CO_2-equivalent per 100 grams of protein, a rate higher than that for processing many other food products.

The FAO (2013) reported that the processing and transport stages of chicken and pig production contribute to 7% and 6% of total GHG emissions, respectively. Djekic et al. (2016) further observed that meat processing is among the most waste-generating stages, producing both liquid and solid waste, and noted the excessive energy use in heating and cooling systems. Roy et al. (2012) confirmed that the meat processing industry releases various air pollutants, including sulfur dioxide, nitrogen oxides, and carbon dioxide. This is largely due to the inefficient use of raw materials and poor waste management practices. Ramanathan et al. (2022) noted that beef discoloration is a major cause of meat loss. A mere 1% reduction in beef discoloration in the USA could save approximately 23.95 billion Liters of water, 98.88 billion megajoules of energy, and reduce CO_2-equivalent emissions by 0.4 million tons annually.

According to Wei et al. (2023), meat loss during processing has a significant environmental impact. In their study, they quantified the GHG emissions from four major meat products in China and found that beef had the highest emission intensity (19.6 kg CO_2e/kg), followed by mutton (10.0 kg CO_2e/kg), chicken (4.4 kg CO_2e/kg), and pork (3.8 kg CO_2e/kg). In total, the Chinese meat industry emitted approximately 429 million tons of CO_2 in 2018. Similarly, Jeong et al. (2022) reported that 16.55 kg CO_2e is emitted per kilogram of live cattle, and 27.86 kg CO_2e per kilogram of live pig. Producing 1 kg of beef results in 27.9 kg CO_2e, while pork production results in 12.75 kg CO_2e. These findings underscore the environmental cost of meat loss, especially for high-emission products like beef and pork.

Every way of disposing of food waste landfills, incineration, composting, or anaerobic digestion produces harmful effects such as greenhouse-gas emissions, eutrophication, and acidification (Barrion et al., 2023).

2.4.2 Nutritional and Food Security Impact

Alahakoon et al. (2016) highlighted vital nutrients (e.g., protein) are essential for the human body are lost when meat or meat products are wasted. Furthermore, despite developments in the meat sector, meat loss and waste continue to undermine these gains. FAO (2022) emphasized that a reduction in the availability of protein and essential nutrients impacts food security and diets. Moreover, avoiding meat loss preserves essential nutrients and supports efforts to reduce undernutrition and dietary deficiencies.

2.4.3 Economic Impact

Dora et al. (2020) emphasized that meat accounts for 20% of the total cost of food waste, largely due to its high unit price. The studies conducted across 17 countries by the World Resources Institute (WRI) and Waste and Resources Action Programme (WRAP) have shown that investing in FLW reduction results in significant economic returns for producers (Nicastro & Carillo, 2021). The economic burden is further confirmed by FAO (2015) by stating that, especially among smallholder producers, meat loss translates to direct income loss in developing countries.

However, Koester (2014) stated that FLW reduction methods are not always economically viable. When stakeholders respond to economic trade-offs, it is sometimes more financially viable to accept the loss rather than implement preventive methods. Wang et al. (2023) emphasized that China’s total meat loss is approximately 4.9 million tons, based on their average national production. These losses are associated with 26.2 million of energy and 56.4 million of protein potential for adults regarding the Chinese Dietary Reference Intake.

3. Methodology

This chapter outlines the methodological approach used to assess meat loss during the processing stage and estimate the associated carbon footprint in Sri Lanka's meat industry. It describes the research design, data collection methods, and analytical techniques applied to quantify processing-stage losses and evaluate their environmental impact.

3.1 Research Design

A quantitative research approach was adopted to analyze meat losses during processing stages and their associated carbon footprint across a representative set of meat processors in Sri Lanka. The research focused on processed meat products, primarily chicken sausages and meatballs, which dominate Sri Lanka's processed meat sector. Historical data spanning from 2014 to 2024 was collected to track long-term patterns and trends.

To provide a clear overview of the research process, a visual representation of the study's methodological framework is presented in Figure 1 below. This figure summarizes the key steps undertaken throughout the study.

Figure 1; Research workflow for quantifying meat processing losses and estimating carbon footprint

As illustrated in Figure 1, the research began focusing on losses occurring within registered meat processing facilities in Sri Lanka. Data collection was carried out using both primary sources and secondary sources. The meat loss data were then processed to calculate annual loss percentages, followed by an estimation of the associated carbon footprint using Sri Lanka-specific emission factors.

3.2 Unit of Analysis

The unit of analysis for this study was the processing stages within the meat processing facilities in Sri Lanka. This study examined total meat losses occurring in the entire chain from the point of meat receiving to the dispatch of processed products. These loss values included trimmings, residuals left on machinery, rejected batches, and product offcuts. In line with FAO's definition of food loss, such material was treated as processing-stage losses, regardless of whether it was discarded, reused, or redirected for other uses. This allowed the quantification of relative meat losses and the assessment of the environmental impact through carbon footprint estimation.

3.3 Overview of the companies approached.

An overview of the meat processing companies approached for this study is presented in Appendix 1. Appendix 1 summarizes their key characteristics such as the types of meat processing, scale of operation, processing activities, certifications, and data availability. Among 11 companies approached, only 7 companies provided data while others declined to participate in the study, didn't have a proper waste measuring system, or didn't respond.

The majority of participating companies processed only chicken, reflecting its dominance in the meat processing industry of Sri Lanka (DAPH, 2023). However, companies such as C2, C3, C6, and C8 also handle pork, and C3, C6 and C8 process beef in addition to chicken.

The sample included companies of varying operational scales, small (C1, C9, C10), medium (C4, C6, C7), and large-scale processors (C2, C3, C5, C8). Larger companies typically produce a wider variety of products, including fresh meat cuts, formed and canned products, and ready-to-eat meat items alongside the main comminuted products such as sausages and meatballs.

Regarding certification status, most companies held Sri Lanka Standard (**SLS**) certification, with several also certified for ISO 14001 - certification for compliance with the international standard for environmental management systems. Halal certification was also confirmed in most cases, especially among those processing only chicken, aligning with national consumption preferences and religious norms.

The data availability also varied across companies. Most shared records from 2014 to 2024, though C3 and C7 provided slightly shorter datasets starting in 2015 and 2017 respectively. Despite its large scale and diverse product range, C8 declined to share its data, while C9 and C11 didn't have recorded data, and C10 did not respond to our request.

This variation in product type, company scale, and certification highlights the diversity of Sri Lanka's meat processing industry and helps to understand the results that will be discussed in the following sections.

3.4 Data Collection

This study employed both primary and secondary data sources. Primary data were obtained from 11 meat processing companies, representing a significant share (≈90%) of the industry. A convenience sampling approach was used due to accessibility constraints and industry confidentiality. Companies were directly contacted through formal communication channels (primarily emails) and structured data requests were submitted for monthly or annual figures on total production volumes (kg), the total amount of loss (product) during processing (kg) and types of meat processing. Additional qualitative data regarding processing methods, machinery used, operational scale, and facility-level certifications were also collected to support an interpretation of waste variations across facilities.

Secondary sources such as FAO reports and databases, and peer-reviewed literature were reviewed to obtain appropriate emission factors for the estimation of carbon footprint.

3.5 Data Analysis

3.5.1 Calculation of Extent of Meat Loss

Average meat loss during the processing stage per year for 7 processing companies was calculated using the following two equations;

Average Meat Loss per Year = Total Waste (kg)/ No. of year

This helped to assess the overall efficiency of the meat processing sector.

For each year, from 2014 to 2024, the total annual meat loss percentage was calculated using the following equation:

$$Total\ loss\ \% = \frac{Total\ Waste\ (kg)}{Total\ Production\ (kg)} * 100$$

This helped to identify patterns and trends in waste percentages across companies over the 11 years.

3.5.2 Carbon Footprint Estimation

The environmental impact of the quantified meat losses was assessed by estimating the associated GHG emissions. The carbon footprint of these losses was calculated using the following equation:

$$\begin{aligned} Carbon\ Emission\ (kgCO_2eq) \\ = Total\ Waste\ (kg) * \ Minimum\ Meat\ Content\ (\%) \\ * Emission\ Factor\ (kgCO_2eq) \end{aligned}$$

Since the majority of the loss data in this study included processed meat products such as sausages and meatballs, it was necessary to estimate the actual meat content in the reported losses. This was achieved by applying Sri Lanka Standard (SLS 1218:2001), which requires a minimum total meat content of 60% (by mass) for comminuted meat products.

For the emission factor, this study used the country-specific value for Sri Lanka reported in FAOSTAT (2020), which is 0.3 kg CO_2e/kg of chicken meat. This figure reflects emissions from the cradle to the raw meat stage, including activities such as feed production, manure management, and on-farm energy use. It does not account for downstream emissions such as those from transport, retail, or consumer use.

This emission factor was considered primarily because it is specific to Sri Lanka, offering a more accurate contextual basis than global averages like FAO (2013). The selection aligns with the fact that the majority of participating companies in this study processed chicken as their primary input, aligning with the FAOSTAT categorization (FAO, 2020). Moreover, this figure provides a baseline, acknowledging that actual emissions from further processing (e.g., trimming, cooking, packaging) are likely to be higher. However, due to the unavailability of stage-specific emission data for further processing of meat in Sri Lanka, such downstream impacts could not be included. Therefore, while this estimate does not capture the full cradle-to-gate carbon burden, it offers a grounded and transparent reference point for assessing the emissions linked to meat losses at the processing stage in the Sri Lankan context.

4. Results

This chapter presents the results obtained from the data provided by seven meat processing companies in Sri Lanka. The structure follows the key research questions, focusing on the extent of processing-stage meat losses and their associated carbon footprint.

4.1 Extent of Meat Loss at the Processing Stage

The average meat loss during the processing stage for processing companies was 2,400,000kg per year and 10.3% as a percentage of the total production volume. Meat loss percentages showed moderate variation over the 11-year period. Figure 2 illustrates the annual meat loss percentages reported by each participating company over the 11-year period from 2014 to 2024.

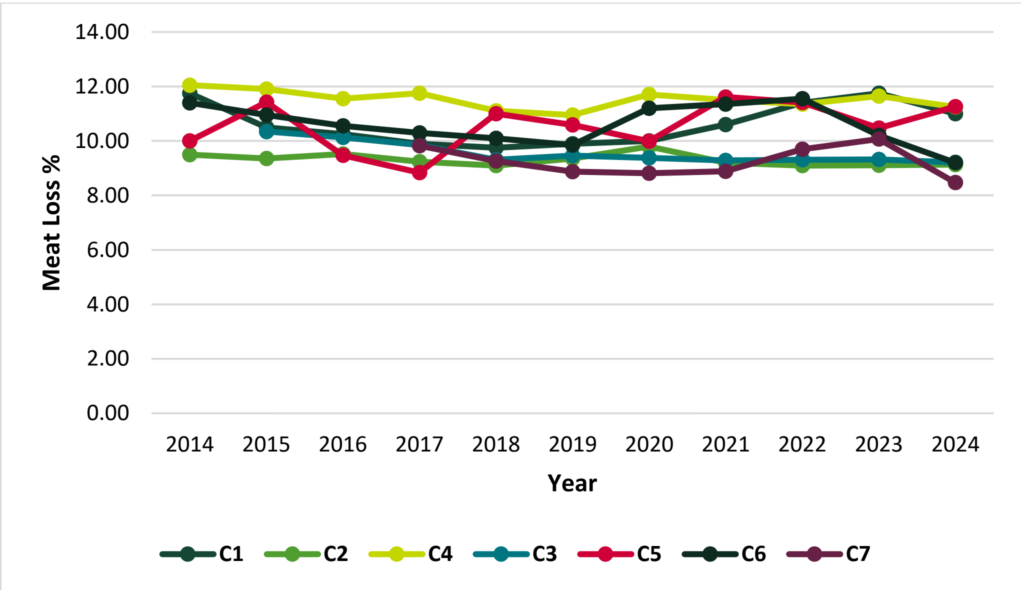

Figure 2: Annual meat loss % (2014–2024) reported by seven meat processing companies.

The graph highlights that most companies maintained losses within the range of approximately 9.9% to 11%. Despite year-to-year fluctuations, the overall pattern shows consistent processing losses throughout the period.
Figure 3 presents the aggregated linear trend of meat loss percentages across all seven companies during the period.

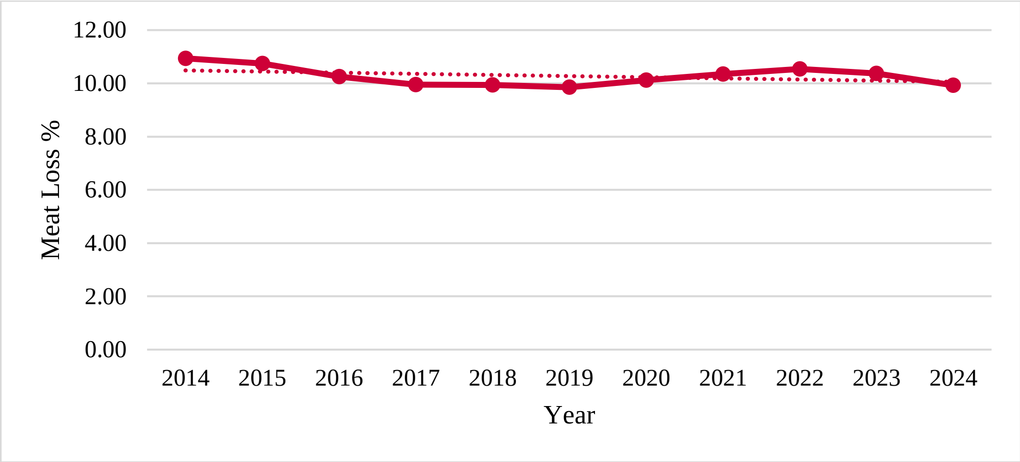

Figure 3; Overall trend in meat loss percentages (2014–2024) of the industry

The trendline in Figure 3 indicates a gradual decline in the average meat loss of the industry. Average processing-stage meat loss has declined by 9.2% from 2014 to 2024. There are a few notable fluctuation points in this trend, including a temporary decline from 2014- 2018, followed by a slightly upward trend from 2020-2022 and a sharp decline observed from 2023-2024.

4.2 Carbon Footprint Estimation of Meat Losses

The estimated carbon footprint associated with meat losses at the processing stage in Sri Lanka's meat industry reached approximately 550 tonnes CO_2e, based on the data reported by the participating companies. Figure 4 presents a year-on-year trend in estimated carbon emissions resulting from lost meat during processing from 2014 to 2024.

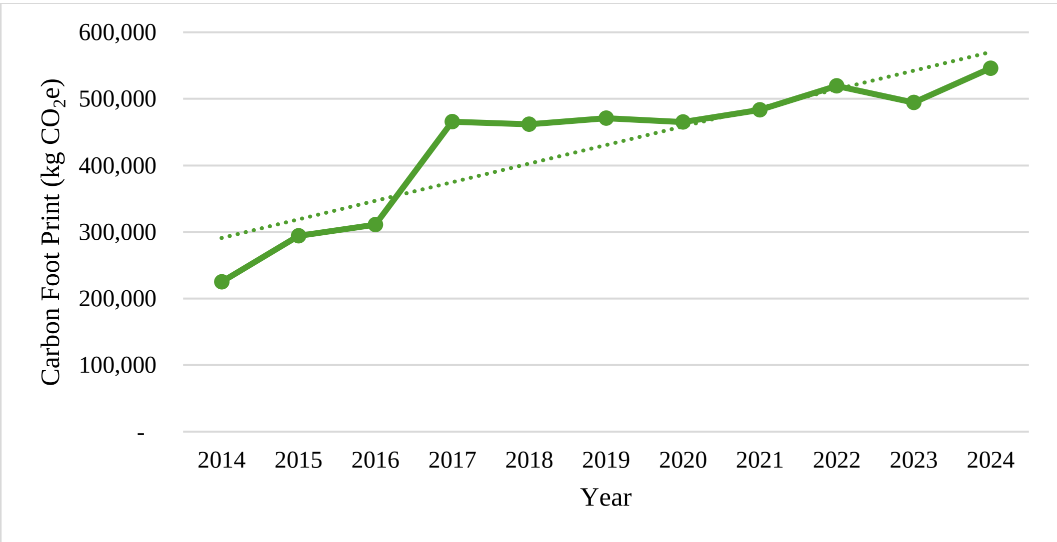

Figure 4; Estimated carbon emissions from processing stage meat losses (2014–2024)

The graph shows a steady increase in total emissions over time, rising from approximately 225 tonnes CO_2e in 2014 to about 550 tonnes CO_2e in 2024**,** representing a 142% increase over the period.

5. Discussion

This chapter interprets and critically reflects on the key findings presented in the previous chapter. It evaluates how the results relate to existing literature, explores possible explanations behind observed trends, and addresses the research questions in detail. The discussion also considers methodological limitations and implications for the meat processing industry in Sri Lanka.

This study aimed to quantify meat loss occurring during the processing stage of Sri Lanka’s meat industry and estimate the associated carbon footprint using contextually appropriate emission factors.

5.1 The extent of meat loss during the processing stage

The average meat loss during the processing stage for the processed meat industry was estimated as 2,400,000kg per year, 10.3% of total processed meat production volume. Variations in company practices, machinery conditions, and operator skill levels may contribute significantly to the range of 9.9% - 11% of annual meat loss.

Between 2014 and 2024, the average meat loss across participating companies declined from approximately 10.9% to 9.9%, representing a relative reduction of about 9.2%. This trend indicates a few fluctuations across the industry. The period from 2014 to 2018 may reflect earlier investments resulting in reduced meat loss. The COVID-19 pandemic caused a temporary rise in meat loss from 2020 to 2022 due to the disruption of the production process and labor shortages. Post-pandemic recovery led to a sharp decline in meat loss from 2023 to 2024. Despite fluctuations, the overall reduction trend indicates modest but meaningful gains in processing efficiency over the past decade. However, inconsistent data reporting and the absence of data by meat type, product category, or processing step have caused challenges in evaluating precise sources of loss.

While losses were not disaggregated by processing step (e.g., trimming, grinding), companies confirmed that reported figures included physical losses such as trimmings, leftover materials on machinery, and defective batches. These were classified as processing-stage losses based on FAO definitions. Though some materials may have been repurposed or reprocessed, they were excluded from their originally intended use and thus considered a form of food loss.

The dominance of chicken-based products in the dataset, supported by both company reports and national production figures from FAO (2020), further justifies the focus on poultry meat. In addition, the majority of the companies were Halal certified, which aligns with the exclusion of pork and confirms the negligible contribution of pork to overall loss volumes. Environmental certification - ISO 14001 may also be another reason for the relatively consistent and improving performance observed across the years, as certification requires systematic environmental management, including waste minimization.

Moreover, based on the Sri Lankan Diary guidelines (2022), this annual meat loss is equivalent to approximately 360,000kg of protein and 2.38 billion kilocalories, sufficient to meet the annual protein needs of around 20,000 adults and the annual energy requirement of approximately 3000 adults, respectively.

5.2 Estimated carbon footprint

The carbon footprint estimation of 550 tonnes CO_2e in 2024 represents the baseline for Sri Lanka's processed meat sector. Between 2014 and 2024, estimated carbon emissions associated with meat losses during processing increased from approximately 225 tonnes CO_2e to 550 tonnes CO_2e, representing a relative increase of over 142%. This substantial rise reflects not only the expansion of Sri Lanka's processed meat production but also persistent inefficiencies in waste management practices across the sector. Several factors may explain this upward trend. First, the overall production volume of processed meat increased significantly over the decade, increasing the amount of lost meat and, consequently, associated emissions. This is especially true as the industry shifted toward higher output to meet growing consumer demand, particularly for comminuted products like sausages and meatballs. Second, the COVID-19 pandemic (2020 - 2022) likely disrupted production processes, labor availability, and supply chains, contributing to temporary increases in both meat loss and emissions. These disruptions align with broader regional patterns noted by FAO (2022) in developing countries. The Sri Lanka-specific emission factor of 0.3 kg CO_2e/kg for chicken meat introduces some uncertainties in our estimated carbon footprint value. According to Poore and Nemecek (2018) and Kang et al. (2025), the carbon footprint in primary production is higher than in the processing stage. The primary production accounts for 83% of total emissions with the largest share from feed and manure. The processing stage losses account for 16% of the total emission, indicating it is an electricity-intensive stage. Hence, our estimate may overstate the emissions for processing alone. Further, if losses included pork or beef, using only the chicken-specific emission factor (0.3 kg CO_2e/kg) would significantly underestimate emissions. Because beef has a far higher footprint (27–30 kg CO_2e/kg) and pork ranges from 5–7 kg CO_2e/kg (Poore & Nemecek, 2018). Thus, the actual carbon impact could be much higher depending on the waste composition

Despite uncertainties, this estimated carbon footprint is representative of upstream inefficiencies within Sri Lanka's processing facilities and can be considered to provide a minimum benchmark.

5.3 Limitations and data gaps

This study faced several important limitations that affected the depth and generalizability of its findings. One of the most significant limitations was the lack of emission factors specific to the further processing stage in Sri Lanka, limiting the accuracy of the environmental impact assessment.

The study was based on data from a limited number of registered or well-known meat processing facilities in Sri Lanka, excluding informal or unregulated processors who may experience even higher rates of meat loss. Lack of an official registry or a publicly available database encompassing the full scope of the meat processing industry. In terms of data collection, companies have followed different practices in tracking meat losses and their reporting inconsistencies have limited the comparability of data across companies. Moreover, the study depended entirely on data provided by the participating companies without third-party verification. This may raise concerns about accuracy and the potential for underreporting due to reputational or compliance pressures.

A further limitation was the lack of detailed categorization in the reported data by product type (sausage, meatball) or by the specific processing stage, such as at trimming, grinding, marination, or cooking stages. This limited the ability to conduct product-specific analysis or identify the critical loss points in the production process. The data collection process itself also had some limitations. Since the data were collected remotely, primarily through emails, which restricted opportunities for clarification, on-site observation for validation, or follow-up inquiries on processing practices. Additionally, Different companies used different terminologies or classifications for "meat loss," requiring extra effort to harmonize definitions and ensure consistent interpretation. The gathered information regarding the disposition of lost meat, whether it was reprocessed, used in animal feed, or discarded was unavailable. As a result, all losses were treated as final, which may have led to overestimating the environmental impact.

5.4 Opportunities for Improvement and Policy Implications

Despite above mentioned limitations, the findings of this study highlight several actionable areas where there is a need for intervention to reduce processing-stage meat losses and their associated environmental impact. One of the most impactful strategies would be an investment in automation and cold chain upgrades. As in developed country contexts, automation and upgradation in refrigeration technologies significantly reduce avoidable losses by minimizing handling-related losses and preserving product quality throughout the production line. In addition to technological advancements, capacity building through employee training should be prioritized to improve human handling practices and hygiene protocols and mitigate contamination-related discards. Another critical area for intervention is the adoption of a standardized reporting mechanism. Developing and implementing a uniform definition and loss reporting system would enhance data comparability, and transparency and ultimately support decision-making at both company and policy levels. Finally, broader adoption of ISO 14001 like environmental management systems, may promote systematic waste monitoring and reduction practices across the sector.

Together, these interventions represent feasible and impactful strategies for enhancing resource efficiency, environmental stewardship, and long-term competitiveness within Sri Lanka's meat processing industry.

6. Conclusion and Recommendations

This final chapter brings together the key findings of the study and presents concluding insights in light of the research objectives. It reflects on the scale of meat loss during processing in Sri Lanka, its environmental implications, and the relevance of these results within national and global contexts. The chapter also outlines actionable recommendations aimed at improving efficiency, reducing environmental burdens, and guiding future policy and research efforts within the meat processing industry.

This study offers the first empirical evidence of processed meat loss in Sri Lanka's meat processing industry. The carbon footprint associated with lost meat provides valuable insights into an untapped area of FLW research. Data were collected from seven well-known meat processing companies over eleven years. An average of 2.4 million kg of processed meat was lost per year, accounting for approximately 10.3% of production volume. Despite a 9.2% decline in the meat loss trend from 2014 to 2024, the loss remained relatively consistent across the companies. These findings highlight the need for improved efficiency and waste reduction interventions.

The environmental implications associated with meat loss were significant. The estimated carbon footprint was approximately 550,000 kg CO2e in 2024 alone. The remarkable upward trend in the carbon footprint is by over 142% from 2014 to 2024. While country-specific carbon emission factor strengthens contextual relevance, the estimated carbon emission value may be higher than the actual value due to the inclusion of upstream stages and the exclusion of the emission factor for pork and beef.

Despite uncertainties with data inconsistency, limited product-specific data, and self-reported data, this study contributes a baseline for stakeholders and policymakers. Reducing meat loss not only improves the food systems and enhances resource efficiency but also significantly reduces GHG emissions, and aligns with global targets such as Sustainable Development Goal 12.3, which calls for halving food waste and reducing food loss along the production and supply chains by 2030. Finally, Sri Lanka's meat processing sector can contribute meaningfully to a more sustainable and climate-resilient food system.

The findings of this study highlight several actionable areas for improvement within Sri Lanka's meat processing sector. First, there is a need for a standardized data collection and reporting system. Future research should adopt standardized methods and definitions for measuring meat loss across processing stages to improve data reliability, enable comparability, and support evidence-based policymaking. Developing and implementing national guidelines, including clear definitions and data recording templates, will be essential, and collaboration between regulators such as DAPH and industry stakeholders is recommended to co-develop practical and industry-accepted guidelines. Second, future research should aim to incorporate LCA tools tailored to Sri Lanka's context to enable a more holistic and stage-specific understanding of carbon emissions across the value chain, including further processing, packaging, and transport. Third, policy support is vital to support technological upgrades; tax reliefs, and low-interest loans could facilitate investments in modern, energy-efficient processing machinery and improved cold chain infrastructure. Finally, operational improvements at the processing facility level, including enhanced employee training, strengthened quality control practices, and ensured regular maintenance of equipment, are critical to reduce avoidable losses and improve processing efficiency.

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Popular Science Summary

Have you ever wondered what happens to the meat that doesn't end up on your plate, like in sausage or meatball? In Sri Lanka, a surprising amount of meat is lost during processing through trimmings, machinery waste, or rejected batches. This waste not only costs money and loss of opportunity to feed people, but also wastes resources such as water, feed, and energy used to raise these animals.

This study looked into how much meat is lost during processing in Sri Lanka's meat industry as well as how this waste affects the environment. The average amount of meat lost during processing each year is 2,400,000kg, which could feed around 226,700 people every day or about 1.03% of the country's population. The environmental pollution of 550,000 kilograms of carbon emissions in 2024 alone is the same amount of pollution generated by driving a petrol car around the Earth 70 times.

According to these results, reducing meat loss can help save money, protect natural resources, and reduce environmental damage. The study suggests improving data collection, and standardizing the waste reporting methods to make it easier to monitor the progress more effectively.

In addition, reducing meat loss in Sri Lanka's processing plants isn't just good for business, it's an essential step toward a more sustainable future for the environment and the country's food security.

Appendix 1: An overview of the meat processing companies

COMPANY CODE	TYPES OF MEAT PROCESSED	SCALE OF THE COMPANY	LOCATION (DISTRICT)	CERTIFICATION			DATA AVAILABILITY
				HALAL	SLS MARK	ISO 14001	
C1	CHICKEN	SMALL	GAMPAHA	√	√	√	2014 – 2024
C2	CHICKEN & PORK	LARGE	COLOMBO	X	√	√	2014 – 2024
C3	CHICKEN, BEEF & PORK	LARGE	GAMPAHA	√	√	√	2015 – 2024
C4	CHICKEN	MEDIUM	GAMPAHA	√	√	X	2014 – 2024
C5	CHICKEN	LARGE	GAMPAHA	√	X	√	2014 – 2024
C6	CHICKEN, BEEF & PORK	MEDIUM	COLOMBO	√	X	√	2014 – 2014
C7	CHICKEN	MEDIUM	GAMPAHA	√	√	X	2017 – 2024
C8	CHICKEN, BEEF & PORK	LARGE	GAMPAHA	√	√	√	NOT AGREED TO PROVIDE DATA
C9	CHICKEN	SMALL	GAMPAHA	√	X	√	NO RECORDED DATA
C10	CHICKEN	SMALL	PUTTLAM	√	√	√	NOT RESPONDED
C11	CHICKEN	SMALL	PULLAM	√	X	X	NO RECORDED DATA

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