UNIVERSITY OF BORÅS

Risk Factors of Food Loss and Waste, and Life Cycle Assessment of waste management strategies in the Brazilian Leafy Vegetable Supply Chain

Nathalie Garavito Realpe

Borås, Sweden.

August 2023.

This thesis comprises 30 ECTS credits and is a compulsory part in the Master of Science with a Major in Management and Engineering of Environment and Energy – Project Manager in Environment and Resource Recovery Towards the Circular Economy, 120 ECTS credits

Risk Factors of Food Loss and Waste, and Life Cycle Assessment of waste management strategies in the Brazilian Leafy Vegetable Supply Chain

Nathalie Garavito Realpe, nathalie.garavito@hb.se

MSc in Management and Engineering of Environment and Energy

Project Manager in Environment and Resource Recovery Towards the Circular Economy

Master thesis

Subject Category: Resource Recovery

University of Borås
School of Engineering
SE-501 90 BORÅS
Telephone +46 033 435 4640

Company Tutor:	Pedro Brancoli.
Company Address:	University of Borås. Allégatan 1.
	503 32 Borås, Sweden.
School Tutor	Yves Andres.
School Address:	IMT Atlantique, 4 Rue Alfred Kastler.
	44300 Nantes, France.
Date:	August, 2023
Keywords:	Behavioural causes, carbon footprint, causal mapping, mitigation strategies, prevention, root-cause analysis, take-back agreements.

Abstract

Food loss and waste (FLW) occurring early in the food supply chain (FSC) leads to increased resource wastage, including land, water, fertilisers, pesticides, fuel, packaging, energy, and labour. Targeting FLW prevention benefits various aspects such as food security, productivity, economic growth, climate change mitigation, resource conservation, and food waste management. Understanding the causes of FLW and their environmental impact is crucial for the design of effective solutions and their prioritisation. The purpose of this study was to investigate the risk factors and underlying causes of FLW in leafy vegetables (LV), mainly lettuce, throughout the Brazilian FSC, spanning from harvest to retail. Additionally, the study evaluated the environmental impact of waste management strategies applicable in the context of the case study. To achieve this, the research methodology encompassed a case study conducted among small-scale producers and retailers in the city of Tupã, Brazil. A comprehensive approach was adopted by integrating a systematic literature review of global FLW causes and those specific to the Latin American context. This approach was complemented by exploratory research, involving interviews with various stakeholders along the FSC, coupled with rigorous root-cause analysis. Moreover, the study employed a Life Cycle Assessment (LCA) methodology to offer an immersive perspective, determining the environmental implications associated with different approaches to treating lettuce waste in the case study. Findings revealed that the root causes of FLW in the case study encompassed normalised unfair trading practices, notably take-back agreement (TBA) conditions, and the absence of supportive policies and incentives for FLW reduction. These root causes manifested in the absence of formal agreements between retailers and local producers, leading to the return of unsold or substandard items without compensation. Furthermore, supermarkets exert power over product quality but evade responsibility for proper storage or encouraging the utilisation of unsold products. Another category of significant causes, designated by the author as "major causes," encompassed causes such as unpreparedness for adverse weather conditions, lack of skilled labour, and stringent visual quality standards. These factors were pivotal risk contributors that potentially motivate various other causes of FLW. To tackle root and major causes of FLW of LV, this study proposed specific measures encompassing fair trade agreements, policy enhancements, protective measures for producers, skill development, and flexible standards. Moreover, by implementing an attributional LCA methodology, the study underscored the importance of source reduction in preventing the environmental impact of food waste for the specific context of the case study. According to the results obtained, for each kg of lettuce that is not produced, 0.065 kg CO2eq are avoided. These findings also highlighted the environmental efficacy of animal feed production, which is a cost-efficient strategy, widely prevalent in the city studied, presents a carbon footprint of -0.013 kg CO2eq/kg of waste. Other common solutions implemented at the case study, such as anaerobic digestion and composting exhibit less favourable carbon footprints, measuring 0.019 and 0.006 kg CO2eq/kg of lettuce, respectively. Landfilling emerges, as expected, as the least desirable option with a considerably higher carbon footprint of 0.423 kg CO2eq/kg. To summarise, this study highlights the environmental advantages of prioritising prevention and higher waste hierarchy levels. It underscores the need for context-specific evaluations when dealing with the intricacies of waste management systems. Moreover, the research emphasises the potential for innovative strategies, multi-stakeholder collaboration, and a holistic approach to address the complex issue of FLW, considering both the environmental impact and practical challenges in a real-world implementation.

Keywords: Behavioural causes, carbon footprint, causal mapping, mitigation strategies, prevention, root-cause analysis, take-back agreements.

Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CO2eq	Carbon Dioxide Equivalent
FFV	Fresh Fruits and Vegetables
FLW	Food Loss and Waste
FSC	Food Supply Chain
GHG	Greenhouse Gases
GWP	Global Warming Potential
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LPG	Liquefied Petroleum Gas
LV	Leafy Vegetables

1. Introduction

1.1 Presentation of the Company

The Swedish Centre for Resource Recovery (SCRR), at the University of Borås, conducts world-leading research, education, and innovation in improving and developing new methods and processes for material recycling and for refining waste and residual products into energy, materials, feed, and food. The SCRR consists of five research groups specialising in biotechnology, civil engineering, combustion, and thermal processes, polymer technology, and resource management. These research groups aim to solve environmental problems, develop sustainable processes, address housing challenges, optimise energy efficiency, and create environmentally friendly polymer materials.

Notably, the University of Borås stands out as it is the only university in Sweden with a distinct focus on developing resource recovery. Research on this area is vital for Sweden and the EU in order to achieve global sustainability goals outlined in Agenda 2030. Ensuring Sweden's international competitiveness in this field is crucial, prompting the university to prioritise research on this topic. Resource recovery encompasses the development of methods for reducing waste, as well as seeing waste and residual products as resources that can be used to recycle energy and materials, and further, developing materials to improve their recyclability.

The University of Borås possesses a well-established network for collaboration and knowledge exchange in resource recovery, both domestically and internationally. The university engages in coordinated activities at the departmental level and collaborates directly with individual researchers. Strong connections exist with businesses, industries, and the public sector, while partnerships with universities, research institutes, and companies are established nationally and globally. International connections are in place all over the world including in many European countries as well as South Africa, Indonesia, Turkey, China, Canada, Brazil, and India.

The SCRR has prior experience in addressing food waste in Brazilian street markets, particularly in quantifying specific fractions such as bread waste and developing sustainable waste prevention and treatment strategies. The group has collaborated with *Naturvårdsverket* (Swedish Environmental Protection Agency) since 2017, engaging in research projects, workshops, visits, and seminars in Brazil and Sweden.

The Swedish Environmental Protection Agency (*Naturvårdsverket)* is the public agency in Sweden that is responsible for environmental issues. The Agency carries out assignments on behalf of the Swedish Government relating to the environment in Sweden, the EU, and internationally. The Agency's role encompasses three main aspects: compiling knowledge, developing environmental policy, and implementing it effectively. This involves gathering information, supporting government decisions, and ensuring compliance with environmental regulations and national objectives.

The ongoing research project, titled "Food waste quantification and investigation of risk factors for waste generation at Brazilian street markets," conducted by the SCRR, follows a comprehensive framework. This framework includes waste quantification, hotspot identification, analysis of waste generation causes, design of waste prevention measures, and implementation and evaluation of those measures.

The project is led by the Resource Management (RM) Group of the University of Borås, which is renowned for its waste management expertise, waste quantification, intervention development, and impact measurement, such as LCA. By participating in this project, the group can develop its scientific method to the next stage. It is expected that the results from this project will be published as a scientific paper.

The RM Group focuses on how the food system can become more sustainable through the prevention of food waste. The research uses a framework that integrates the quantification of food waste, the investigation of the causes behind it, and the development and evaluation of different strategies for the prevention and valorisation of wasted food.

The mentioned project follows a framework developed by the RM group, comprising multiple essential steps to tackle food waste systematically. The first step involves quantifying food waste to gain insights into its volume and composition, enabling the identification of waste generation quantities, locations, and root causes. Previous investigations by the RM Group in two Brazilian cities, São Paulo and Ribeirão Preto, have successfully quantified food waste, providing valuable insights for this project.

The framework's second step focuses on identifying hotspots for preventive measures by considering desired outcomes such as environmental impacts, economic expenses, and food security. A prior study funded by Naturvårdsverket, and developed by the RM Group employed the life cycle assessment (LCA) methodology, revealing major environmental hotspots at the product level in street markets. Notably, leaves, flowers, and stems, as well as unavoidable food waste consisting of sugarcane bagasse and coconut, were identified as significant contributors to environmental impacts. To enhance the hotspot analysis, the project seeks to eventually incorporate additional indicators, including economic costs and nutritional value, which can lead to estimating economic costs and nutritional losses associated with food waste.

The third step, and the aim of this master thesis, involves the investigation of the underlying risk factors and causes of Food Loss and Waste (FLW), throughout the supply chain, focusing on the producer-retailer interface. Identifying risk factors and causes of FLW is vital for developing effective prevention and valorisation strategies. Therefore, this project seeks to analyse these risk factors, providing insights for targeted interventions, as well as analyse the environmental impacts associated with the prevention and valorisation strategies for the context of the study.

The evaluation of the environmental impact of each valorisation strategy considered for the local context of the case study will be done through a LCA, which has been previously used by the RM group in the study of waste management alternatives for products such as surplus bread from retail.

Finally, the last phase of the project proposes the development of FLW prevention competencies for Brazilian stakeholders. By providing technical assistance for waste quantification and supporting the development and implementation of prevention measures, the project aims to empower stakeholders. This project builds upon established methodologies and intends to further expand food waste quantification to other Brazilian cities, starting with street markets. Additionally, there is growing interest from other cities to quantify and characterise food waste from retail, households, and primary production, highlighting the importance of such investigations and the generation of data and evidence to enhance the decision-making.

1.2 Project Overview: Waste Prevention and Sustainable Management of Surplus Leafy Vegetables.

Although current food production is enough to meet the needs of the world's population, hunger, malnutrition, and food insecurity persist due to unequal access and distribution. Moreover, as the global population increases in number and affluence, there is an increasing need to ensure that food production keeps pace with future demands while also ensuring the sustainable use of resources (Taelman, Tonini, Wandl & Dewulf 2018; UN DESA 2021).

Paradoxically, approximately one-third of the food produced globally for human consumption (1.3 billion tons per year) is lost or wasted (Gustavsson, Cederberg, Sonesson, Van Otterdijk & Meybeck 2011). In developed countries, 40% of this waste occurs at retail and consumer stages (near the plate), whereas in developing countries over 40% of the food losses are believed to occur during the post-harvest and processing phases of the FSC (near the farm) (Flanagan, Robertson & Hanson 2019; Gustavsson et al. 2011).

To tackle this issue, initiatives like the Waste Framework Directive, established by the European Union (European Commission 2008), take a decisive stance in favour of waste prevention. However, in accordance with the waste hierarchy, waste management options such as reuse, material recycling, energy recovery, and disposal are also considered acceptable for resource recovery, with disposal in landfills being the least preferred option. However, since waste management systems rely on local circumstances, the waste hierarchy should be viewed as a broad approximation. To meet the requirements of the Waste Framework Directive (WFD), it is imperative to conduct a thorough examination of each specific local context (Strid & Eriksson 2014).

Furthermore, for governments and the private sector to define concrete actions, interventions, or policies to reduce FLW, it is necessary to investigate several concerns such as the locations and stages of the supply chain in which the food is being wasted and to what extent, the reasons why FLW occurs, and ways to reduce it, the costs involved, and, finally, who benefits from reducing FLW. (Dal'Magro & Talamini 2019; FAO 2019).

In response to this challenge, the RM Group has already accomplished a crucial initial phase of the project titled "Food Waste Quantification and Investigation of Risk Factors for Waste Generation at Brazilian Street Markets," which involves the quantification of food waste and the identification of hot spots for potential preventative measures. The insights gathered from the preceding stages of research within the Brazilian context clearly underscore the relevant role of leafy vegetables (LV) in the generation of waste and the subsequent environmental impacts associated with their loss and waste (Brancoli, Makishi, Lima & Rousta 2022).

With the aim of continuing the research project seamlessly, this study is primarily focused on promoting waste prevention and reduction, through the implementation of a holistic approach. To achieve this goal, the study is guided by two main objectives. The first objective involves a detailed exploration and prioritisation of the risk factors that contribute to FLW within the complex FSC, with a specific emphasis on the loss and waste of LV. Concurrently, the second aspect of this study focuses on assessing a range of options related to surplus lettuce management within the specific boundaries of the local case study. These options encompass a wide spectrum, including strategies to proactively reduce LV waste, as well as commonly implemented strategies such as animal feed production, anaerobic digestion, composting, and landfilling.

2. Background

2.1 Definitions of Food Loss and Waste

When analysing food losses (FL) and food waste (FW), there are different approaches, scopes, and methodologies that can make them difficult to compare (HLPE 2014). Generally speaking, the term “Food Loss” has been adopted in recent literature to refer to the decrease in food availability along the harvest, transport, storage, distribution, and packaging, up to, but excluding, the retail level (FAO 2019). Food waste on the other hand, has been defined as food that is “Removed from the human FSC” at the retail and consumption level and disposed of in a landfill, controlled combustion, sewer, litter/discards/refuse, co/anaerobic digestion, compost/aerobic digestion, or land application (UNEP 2021).

For the purpose of this study, the term Food Loss and Waste (FLW) will be adopted to refer to the reduction in the quantity or quality of edible food products intended for human consumption, (Gustavsson et al. 2011), regardless of the cause, stage of the FSC in which occurs, or the disposal method (animal feed, bioenergy, compost, etc.). This definition also considers FLW the food that becomes non-edible due to safety reasons in a further stage of the supply chain, or that is discarded as such due to cosmetic considerations (HLPE 2014). This approach aims to prioritise the prevention of FLW and avoiding surplus production and consumption, especially at the early stages of the FSC, which is considered the most efficient way to improve the loss and waste throughout the FSC (Flanagan, Robertson & Hanson 2019; Papargyropoulou, Lozano, K. Steinberger, Wright & Ujang 2014). Moreover, in the context of the evaluation of waste management strategies, only products no longer suitable for human consumption (FW) will be considered.

2.2 Benefits of reducing Food Loss and Waste

FLW results in the waste of resources employed in the food system during food production and distribution, such as land, water, fertilisers, pesticides, fuel, packaging, energy, and labour. It is also considered that the further the FLW occurs within the FSC, the greater the embedded environmental and economic cost, as it considers the resources utilised in previous steps (Gillman, Campbell & Spang 2019; Gustavsson et al. 2011; HLPE 2014).

According to Kummu et al. (2012), 23 to 24% of the total use of water, cropland, and fertilisers used in crop production are used in producing food that is lost and wasted. Additionally, it is estimated that FLW represents a global annual loss of approximately US$936 billion and a carbon footprint of 4.4 GtCO2 eq, which is equivalent to 8,9% of the global GHG emissions, almost comparable to the footprint of the global road transportation (FAO 2015b; Our World in Data 2016).

Therefore, by tackling the challenge of FLW at early stages of the FSC, several benefits can be achieved in terms of food security, productivity, economic growth, climate change, water depletion, land use, biodiversity loss, and the management of food waste (FAO 2019; UNEP 2021).

The United Nations' Sustainable Development Goals (SDGs) emphasise the significance of food waste through Goal 12 (Responsible consumption and production). This goal includes SDG Target 12.3, which aims to “By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" (UN General Assembly 2015).

Additionally, reducing FLW can play a significant role in achieving the Zero Hunger goal (SDG 2) and have a positive impact on other Sustainable Development Goals. These may include sustainable water management (SDG 6), climate change (SDG 13), marine resources (SDG 14), and terrestrial ecosystems, forestry, and biodiversity (SDG 15) (FAO 2019). However, while a quantitative target is established for the reduction of food waste at the retail and consumer level, a specific value for post-harvest food losses is left unspecified (Fabi & English 2019).

Private actors such as producers, intermediaries, and retailers can benefit from FLW reduction policies through increased efficiency and cost savings, but may be discouraged by perceived costs and lack of information on FLW reduction measures (Pimentel, Misopoulos & Davies 2022; Surucu-Balci & Tuna 2021). Therefore, public interventions, such as incentives and policies, are necessary to encourage FLW reduction and contribute to sustainability targets (FAO 2019; HLPE 2014). On the other hand, consumers can benefit from reduced food waste at the retail level, as the costs of losses are often passed on to them via higher final product prices.

2.3 Previous studies of Food Loss and Waste in Latin America

In the Latin American context, it is believed that most FLW occurs at early stages of the FSC, especially at the harvest and post-harvest stages, in which the causes are associated mostly to financial, managerial, and technical limitations, labour shortages, unfavourable climatic conditions, water availability, and retail's cosmetic standards (Gustavsson et al. 2011; Herrera-Quinteros & Jara-Rojas 2023; Lana 2020).

Various drivers contribute to these causes, spanning technological, managerial, behavioural, and structural aspects. Technological drivers involve issues with infrastructure, equipment, and packaging. Managerial drivers encompass inadequate food management practices, limited skills or knowledge, and inflexible procurement practices. Behavioural drivers include norms, attitudes, awareness gaps, and risk concerns. Structural drivers encompass demographic conditions, climate, policies, regulations, economics, and financing (Flanagan, Robertson & Hanson 2019).

According to Colombo et al. (2022), the retail sector has an important role in reducing FLW in the FSC since it has the power to promote changes in both food producers' and consumers' behaviours. Limited shelf life, aesthetic standards, and variability in demand are factors that contribute to food waste at the retail level (FAO 2019).

Collaboration among agents of the FSC, as highlighted by Bustos and Moors (2018), brings multiple benefits, including reduced resource consumption, mitigation of supply and demand uncertainties, and enhanced contract reliability. Furthermore, better collaboration between these agents would also address root causes of FLW in a more holistic manner (Colombo, de Oliveira, Pereira, da Silva & Delai 2020; Mena, Adenso-Diaz & Yurt 2011).

Therefore, to effectively address the FLW challenge and its causes it is necessary to implement an approach that considers the interactions among the various phases and agents involved in the FSC. According to Mena, Adenso-Diaz and Yurt (2011), There has been a lack of extensive investigation into the causes of waste, especially when it comes to the interaction between retailers and suppliers. Additionally, in-depth studies can help develop better strategies and resources that fit the unique context of each country (de Moraes & de Souza 2018).

To address this gap, this study aims to investigate risk factors within the FSC that contribute to the loss and waste of LV, focusing on the harvest, post-harvest, transportation, and retail stages, which are responsible for the majority of FLW throughout the FSC (Gustavsson et al. 2011). The focus of the research is to address the causes of FLW in the supplier/retailer interface. Waste at this stage has a notable impact since products have already gone through most of their value-adding activities, incurring costs and utilising energy resources. Furthermore, when products are discarded at this stage, they frequently find their way to landfills, exacerbating environmental pressures. With this in mind, an assessment of the ecological impact associated with prevalent waste management strategies will be conducted, aiming to advocate for the adoption of less impactful disposal methods, particularly when source reduction is unfeasible.

2.4 Analysing Root Causes of Food Loss and Waste: A Structured Approach

When analysing the root causes of a complex problem, a structured approach might involve the use of thinking process (TP) tools such as the Interrelationship Diagram (ID), and the current reality tree (CRT), as these are recognised viable mechanisms for solving problems and making decisions (Doggett 2006). These tools can be considered as a variant of causal maps, specifically used to investigate the rational structures of individuals (Fiol & Huff 2007).

The CRT approach relates multiple factors to address problems, identifying links between symptomatic factors and the core problem in the current state of a system (Doggett 2006). Causal maps are a valuable tool for categorising the undesired effects of a core problem and visualising the causal connections between them (Fiol & Huff 2007; Jenkins & Johnson 1997). The qualitative research conducted by Mena, Adenso-Diaz and Yurt (2011) has previously demonstrated the practical utility of current tree maps as a methodology for identifying the underlying causes of FW. However, this study remains the only one using this approach for the analysis of FLW.

Mena, Adenso-Diaz and Yurt (2011) found that most causes related to FLW demonstrate interdependencies, forming a complex web of interconnected factors and effects. Therefore, a structured, and more integrated approach is necessary to analyse the risk factors associated with FLW. The ID approach encourages multidirectional thinking, rather than linear thought patterns (Doggett 2006). This tool evolved from a sophisticated economic mathematical approach into the problem-solving field. It allows to easily identify, examine, and categorise cause-and-effect connections among critical issues for solving complex qualitative problems (Brassard & Ritter 1994). However, there is currently no study analysing FLW causes using this approach.

In the context of this study, it is crucial to clarify the distinction utilised between a risk factor and a cause. For the purpose of this study, the term "risk factor" refers to a situation or condition that increases the likelihood of the outcome happening (Merriam Webster Dictionary). On the other hand, a "cause" signifies a necessary factor that must be present for the outcome to happen (Doggett 2006).

2.5 Life Cycle Assessment in the Evaluation of Waste Management Strategies for Leafy Vegetables

Globally, there is a significant potential for reducing greenhouse gas emissions when food is utilized for consumption rather than energy production (Eriksson, Strid & Hansson 2015; Strid & Eriksson 2014). Other authors, including Guide Jr and Van Wassenhove (2009) and French and LaForge (2006), advocate for the implementation of closed-loop supply chains, aimed at efficiently managing product returns and enabling profitable resource recovery from those returned items (Mena, Adenso-Diaz & Yurt 2011).

The life cycle assessment (LCA) is a methodology widely utilised for the evaluation of environmental impacts of products, processes, or systems. This methodology has been implemented to compare different alternatives encompassing the entire FSC, considering the advantages and burdens in each scenario (Notarnicola et al. 2017).

Despite the importance and of LV waste management, there is limited scientific research focusing on the life cycle assessment (LCA) of disposal methods for this product category in the Brazilian context. Previously, Strid and Eriksson (2014) have implemented LCA to determine the environmental impact of lettuce waste and loss along the phases of the Swedish supply chain lettuce, from field to retail shelf. Moreover, Romero-Gámez, Audsley and Suárez-Rey (2014) implemented this tool to analyse the environmental effects of harvest waste from lettuce and escarole production in Spain.

However, a limited number of studies have directed their attention towards the assessment of distinct waste management tactics tailored to surplus lettuce, serving as a potential avenue for harnessing value from inevitable waste. Addressing this void in research, the present study employs the LCA methodology to comprehensively assess the environmental performance of diverse waste management strategies. Through the evaluation of these strategies, it is possible to propose waste management strategies that are appropriate for the Brazilian context.

2.6 Case Study: Brazilian FSC of leafy vegetables

For the case study, the city of Tupã in Brazil was chosen for its convenient access to local LV producers, enabling on-site visits to their properties. Tupã is centrally located in São Paulo state, approximately 520 km from the capital. With a population of 63,928 inhabitants (IBGE 2022), the city boasts a diverse economy spanning agriculture, industry, and services (Câmara Municipal da Estância Turística de Tupã 2023).

To effectively reduce food waste in the retail sector, it is imperative to gain a deeper understanding of waste patterns in the local context. Research conducted by de Brito Nogueira et al. (2020) in Brazilian fruit and vegetable markets, and corroborated by Brancoli et al. (2022), revealed that LV, constituted a significant proportion of avoidable waste generation, mainly attributed to stem removal and leaf damage.

LV include products such as lettuce, green onion, chicory, kale, spinach, mustard greens, cabbage, arugula, parsley, taro leaves, and other LV (Lana 2020), and are transported to the market shortly after being harvested due to their high perishability (Lana & Moita 2019). Natural causes of LV include wilting due to water loss, yellowing due to chlorophyll degradation, damaged tissues, and rot caused by fungi or bacteria (Lana & Moita 2020).

3. Scope and Objectives

Based on the context described in the previous sections, this master thesis aims to investigate FLW risk factors in the Brazilian leafy vegetable supply chain, focusing on the producer-retailer interface. Moreover, this study aims to employ the LCA methodology to compare several feasible alternatives for the valorisation of the leafy vegetable waste within the specific context of the case study.

Therefore, the primary research question that this investigation seeks to address is: What are the key risk factors present at the interface between producers and retailers, in the Brazilian context?

The second research question to be answered is: "Based on a life cycle assessment approach on the carbon footprint, what are the most suitable waste management strategies, for unsold leafy vegetables in the Brazilian context?"

Based on the identified research problems and background, the specific objectives of this master's thesis are as follows:

- Conduct a literature review to identify risk factors related to FLW generation in the Latin American food supply chain.
- Perform exploratory research through interviews with key stakeholders, including producers, retailers, and street market vendors, to investigate FLW risk factors and causes in the Case Study city.
- Analyse the relevance of the FLW risk factors at the producer-retailer interface, through a structured approach and employing an innovative methodology of causal mapping.
- Identify barriers and opportunities for FLW prevention in the study case.
- Provide insights into potential FLW prevention strategies for the Brazilian leafy vegetable supply chain.
- Evaluate the environmental performance of waste prevention and valorisation pathways for leafy vegetables, based on the life cycle assessment of their carbon footprint.

This master thesis presents a comprehensive investigation into the risk causes of FLW within the Brazilian Food Supply Chain (FSC) with a specific focus on LV. The study is structured into eight chapters, starting with an introduction outlining the research objectives and presenting the case study of the Brazilian FSC of LV. Chapter 2 provides essential background information on FLW, including definitions and previous studies, as well as the structured approach used to analyse the root causes of FLW and the waste management strategies available. Chapter 3 outlines the study's scope and objectives, while Chapter 4 discusses the research methods and materials utilised for the literature review, the exploratory research, and the risk factors analysis. Chapter 5 presents the results tied to the objectives of this study, related to the investigation of risk factors of FLW, while Chapter 6 offers a critical discussion of the findings, comparing them to the existing literature. Moreover, Chapter 7 presents the considerations and methods utilised for the Life Cycle Assessment of the chosen waste management alternatives implemented for surplus LV in the case study, as well as the results and discussion of the of the environmental impacts associated with each strategy. Finally, Chapter 8 provides the conclusions and practical recommendations obtained from this study.

4. Methods and materials – Risk Factors of Food Loss and Waste

As mentioned in previous chapters, the research methods used in the investigation of risk factors of FLW include a structured literature review, on-site exploratory research, and risk factors analysis through causal mapping. The purpose and explanation of the methods used are described below:

4.1 Structured Literature Review

A comprehensive literature review was conducted to examine the relevant literature concerning the topic of this study within the Latin American context. The review process involved a thorough search of academic databases, including "ScienceDirect" and "Google Scholar" for literature in English, "Periódicos Capes" for research in the Portuguese language, and "Redalyc" for material published in Spanish. Specific keywords related to the research topic, such as "Food supply chain, Food waste, Food loss, Food surplus, Food waste cause, Food waste source, food waste risk factors, Latin America, Brazil, Colombia, Mexico, Argentina, Chile, Peru, Bolivia, Venezuela," were used to refine the search. The review primarily included peer-reviewed scientific articles, books, and non-peer-reviewed sources such as reports and conference proceedings. Additionally, peer-recommended literature and related articles were consulted to enhance the scope of the study. The literature review served as the foundation for further exploratory research.

4.2 Exploratory Research

The exploratory research involved collecting qualitative data on-site through observations and interviews with the agents engaged in the food supply chain of LV in the selected location for the case study. The study specifically examined key actors in the lettuce, kale, parsley, scallion, arugula, coriander, mint, and cress supply chain, involved in the entire process from harvest to commercialisation of these products.

Interviewees were selected based on convenience and comprised a group of producers previously engaged in research done in collaboration with the Swedish Centre of Resource Recovery and the State University of São Paulo, campus Tupã. The study sample encompassed a range of participants, including micro-rural producers, small and medium-sized producers, employing conventional, hydroponic, and organic harvesting methods. In contrast, retailers were chosen based on their size and product offerings. Street market stalls, neighbourhood grocery stores, and medium-sized supermarkets were selected to represent the diversity of retailers in the region. At this phase, a checklist based on the literature considerations related to FLW (APPENDICES 1 and 2), and a semi-structured interview guide (APPENDICES 3 and 4) were implemented.

On-site observations encompassed the comprehensive monitoring of activities, from harvest to commercialization at the retail level, capturing significant points through photograph records and audio recordings. The observations were facilitated by a checklist for FLW causes. The FLW causes checklist guide comprises pertinent questions linked to on-site observations, shedding light on practices observed at both producer's and retailer's sites that could potentially contribute to the generation of FLW, based on the considerations made by Lana (2020) for the Brazilian leafy vegetable business.

The semi-structured interviews aimed to gain a comprehensive understanding of the issues related to the research topic, validate findings from the literature, and potentially uncover new factors contributing to FLW in the context of the study. The interview protocol, on the other hand, was developed in three stages. Initially, a draft was created by conducting a literature review and analysing previous studies on food waste and losses, with a particular focus on the contributions by Herrera-Quinteros and Jara-Rojas (2023), and Colombo et al. (2022) to qualitative research in this area. For this stage, a list of the risk factors of FLW identified in the Latin American context was utilized during the interview. The draft was then reviewed by the author, thesis supervisor, and a representative from the host University's Postgraduate Program in Agribusiness and Development. Based on their feedback, the draft was adjusted and tested in one interview with a local former agriculturalist, resulting in the modification of some question methods. The final interview questionnaire covered four main aspects:

- Sales and management information
- Production information/sales
- Food loss and waste information
- Food loss and waste knowledge and awareness

For this case study, a comprehensive examination was done involving a total of 6 producers and their associated retailers. A total of 11 interviews were conducted with managers and employees with responsibilities in food production, transportation, and retailing. Every interview, lasting around one hour, was personally conducted by a single researcher, and a companion, and recorded for further analysis. All interviews were conducted in person, involving site visits to locations such as production sites, supermarkets, or street fairs. During the site visits, opportunities appeared to interview not only the managers but also the workers directly engaged in the day-to-day operations of the LV supply chain. To ensure discretion, names and company data of the supply chain agents are kept confidential and will be used solely for academic purposes, considering the sensitive nature of waste-related information.

Secondary methods of data collection, including observations and company records, were employed selectively to complement or verify the information provided by the interviewees. During the interviews, waste records were requested, but only one producer was able to provide such records. In the case of other companies, the absence of these records made it challenging to obtain accurate data, leaving room for speculation.

4.3 Risk Factors Analysis

After identifying the risk factors associated with FLW in the case study, their significance was assessed through a structured approach. The data analysis methodology employed in this study relied on two essential Thinking Process (TP) Tools: the Interrelationship Diagram (ID) and the current reality tree (CRT), both commonly used in structured problem-solving approaches (Doggett 2006). Furthermore, a "Five Whys" approach was implemented to investigate any overlooked risk factors in the case study. Ultimately, the developed methodology will conclude in the construction of a causal map. This map will utilize a diagram to represent the risk factors affecting FLW, their interconnectedness, and the identification of root causes in the case study, based on the conclusions driven by the different TP tools employed. The methodology followed for this causal map is synthetised as a step-by-step process in APPENDIX 5.

4.3.1 Five why's approach.

To enhance the process of identifying cause-and-effect relationships, the "Five Whys" approach was implemented. By integrating this methodology into the risk causes analysis, the main goal is to investigate into often overlooked causes of FLW by exploring the reasons behind the apparent causes already identified in the exploratory phase of the study, and finally to identify the root cause behind the identified risk factors.

To perform a five-why's approach to the analysis of root causes, the first step is to determine the problem statement. Then, the next step is to ask successive "whys" to uncover the root cause, recording answers along the way. It is important to look for systemic causes among the last answers provided and settle on the most likely one. After confirming the analysis's logic, the goal is to develop corrective actions to remove the root cause (Serrat 2017).

4.3.2 Interrelationship Diagram

After obtaining the risk factors from the case study, the relationship between causes will be analysed through an Interrelationship Diagram (ID), which will aid in the determination of the priority of the risk causes. An ID is a tool used to portray cause-and-effect relationships among potential problem factors. It uses arrows to represent these relationships, with factors expressed in short sentences or phrases enclosed in rectangles or ovals. The arrow typically points from the cause to the effect or from the means to the objective, but it can be reversed if necessary. It can be either quantitative or qualitative, with the root cause identified through intuitive understanding or numeric identifiers indicating the strength of relations between factors (Doggett 2006).

4.3.3 The Current Reality Tree (CRT)

Finally, all the risk factors and causes will be interpreted as a Current Reality Tree (CRT) that will portray the cause-effect relationship between the root causes and the FLW problem. The CRT is a problem-solving tool that links multiple factors rather than isolated events, helping practitioners identify undesirable effects related to the core problem. It provides a clear depiction of a system's current state, highlighting the cause-and-effect factors contributing to specific circumstances. Arrows represent a sufficient relationship between entities, and ovals or ellipses are used to show interdependencies between causes. Looping conventions in the CRT allow for positive or negative amplification of effects (Doggett 2006).

4.3.4 Construction of the Causal Map

The Causal Mapping approach adopted for this study combines the mentioned tools to explain complex causal relationships behind FLW. The methodology developed by the author of this study involves constructing a proposed Causal Map through a designed step-by-step process, as described in APPENDIX 5.

Finally, the implementation of this novel methodology will result in a comprehensive causal map of risk factors related to FLW, categorising them as causes, effects, and root causes (refer to Figure 3).

5. Results – Risk Factors of Food Loss and Waste

The study's findings related to the investigation of the risk factors of FLW are organised into four parts. Firstly, a literature review on the causes and risk factors of FLW in Latin America was presented and analysed. Subsequently, the outcomes of the case study and the main findings from the on-site visits and interviews are discussed. Next, a comprehensive description of the identified risk factors contributing to the loss and waste of LV was provided, employing the proposed methodology for causal mapping to analyse the data. Lastly, the study identifies barriers and opportunities for FLW reduction in the case study.

5.1 Literature Review of Risk Causes of FLW and Good Practices in Latin America

A comprehensive literature review was conducted to examine scientific articles and technical reports related to FLW in the Latin American context. The main identified causes of FLW in the Food Supply Chain (FSC) were summarised in Table 1. The studies, largely conducted by the scientific community, governments, and the FAO (2015a), have raised awareness of FLW factors, quantified losses, investigated causes, and identified best practices for its reduction

In the Latin American context, the causes of FLW across the entire FSC, from harvest to consumption, have been extensively studied. Common factors contributing to FLW along the FSC included inadequate packaging, transportation practices, lack of refrigeration, improper handling, and insufficient quality control standards (Aliotte, Filassi & Oliveira 2021; Departamento Nacional de planeación 2016; FAO 2015a). Issues related to planning, logistics, infrastructure, and technology also played a significant role in FLW (FAO 2015a). Furthermore, climatic conditions, short shelf-life, and packaging damage were highlighted as major causes of FLW (Aliotte, Filassi & Oliveira 2021).

Several studies focusing on the post-harvest phase highlighted various factors contributing to FLW, particularly during handling, transportation, and storage of agricultural products. The findings emphasised the influence of factors such as high temperatures in Latin America and the Caribbean, leading to physical damage of fruits and lettuce (FAO 2015a). Other study stressed the effects of improper storage and handling activities in FLW (Péra, Gameiro, Bacchi, Rocha & Caixeta 2015). Labour problems, climate, plagues, and water availability were also cited as relevant factors (Herrera-Quinteros & Jara-Rojas 2023; Péra et al. 2015).

In contrast, some studies focused on the causes of FLW at the retail phase. Findings revealed common factors such as improper handling during distribution, inadequate packaging, refrigeration issues, and forecasting challenges (Aliotte, Filassi & Oliveira 2021; Colombo et al. 2020; de Moraes, de Oliveira Costa, Roberta Pereira, da Silva & Delai 2020; de Morais, Rodrigues, Gasparoto & Monteiro 2022; Dos Santos et al. 2020; Guarnieri, de Aguiar, Thomé & Watanabe 2021; Mustelier & Lorenzo 2021; Vilela, Lana, do Nascimento & Makishima 2003). Logistic shortcomings, including inadequate infrastructure and dishonesty among carriers and consumers, were also significant contributors to FLW (Dos Santos et al. 2020). Moreover, Ismael (2023) reported FLW at the retail level due to damages caused by high temperatures during transportation and storage.

Moreover, studies specifically centred on the supply chain of leafy vegetables have identified hostile climatic conditions, mechanical damage, and market grading as the primary causes of FLW at the post-harvest stage (FAO 2015a). At the retail phase, conditioning, climate, and lack of refrigeration have been identified as significant factors contributing to FLW (Aliotte, Filassi

& Oliveira 2021). Overall, these findings highlight the crucial role of climatic factors and temperature control in reducing FLW throughout the supply chain.

Various methodologies have been employed in FLW studies in the Latin American context, including analysis of secondary data, observations, direct quantification, and interviews with FSC agents. However, few studies analysed FLW as a product of interactions between different phases of the FSC (Colombo et al. 2022; Fehr & Romão 2001; Mena, Adenso-Diaz & Yurt 2011).

Overall, the analysis of these studies highlights the complex nature of FLW in Latin America, with causes occurring simultaneously at different stages of the FSC (as shown in Table 1). Addressing this issue necessitates comprehensive efforts and collaboration throughout the entire food supply chain, with a focus on training, capacity building, infrastructure improvement, and the adoption of sustainable practices.

Moreover, from the examined studies it can be highlighted the essential role of transportation practices in aggravating FLW along the entire FSC, especially when refrigeration infrastructure is lacking during long-distance transportation services. This phase of the FSC seems to be an important factor whenever food needs to be transported to remote locations and it is handled by third parties. Notably the absence of adequate refrigeration during transportation emerges as a recurrent challenge, leading to spoilage and deterioration of perishable goods like leafy vegetables.

This study's literature review on FLW in Latin American countries also revealed some of the good practices implemented for reducing FLW in the FSC. These practices included employee training and awareness, food waste management done by specialised teams, assertive demand forecasting, meal preparation with short-life products in stores, minimal stock purchase, food donation, and utilising leftovers as animal feed or fertiliser for the soil (de Morais et al. 2022). In other cases, strategies included careful packaging, proper covering of products on display, watering leafy vegetables throughout the day, and requesting only necessary supply (Dos Santos et al. 2020). The studies also addressed the positive effects of practices such as price reduction for product close to the expiration date and consumption by sellers (Dos Santos et al. 2020), transportation of the products during the night, avoidance of wooden packaging material for producers, and documentation of losses done by supermarket (Fehr & Romão 2001). A study conducted by Aliotte, Filassi and Oliveira (2021), specifically focused on FLW of leafy vegetables among other vegetables concluded that using refrigerated transport, adopting new packaging technologies, and providing training on post-harvest practices are vital for reducing FLW for this product category. Finally, Partnerships between retail, wholesale companies, and waste reduction associations were also highlighted as essential for successful implementation of the measures for FLW reduction (Guarnieri et al. 2021).

Table 1. Causes of FLW and risk factors from studies and reports in Latin America

Item	Cause (Risk factor)	Post-Harvest	Transportation	Retail	Street Market	References
A	Inadequate handling (producers/vendors/consumers)	X	X	X		Vilela et al. (2003), Fehr and Romão (2001),Aliotte, Filassi and Oliveira (2021), FAO (2015a), Guarnieri et al. (2021), Ismael (2023), Péra et al. (2015), Porat, Lichter, Terry, Harker and Buzby (2018), Vilela et al. (2003)
B	Inadequate packaging	X	X	X		de Morais et al. (2022), (Vilela et al. 2003), Araujo G. P. de; Lourenço (2018) Fehr and Romão (2001), Departamento Nacional de planeación (2016), Porat et al. (2018), FAO (2015a), Ismael (2023), and Péra et al. (2015).
C	Inadequate transportation/conditions of the vehicles	X	X	X		de Morais et al. (2022), (Vilela et al. 2003), Araujo G. P. de; Lourenço (2018) , Fehr and Romão (2001), Porat et al. (2018), FAO (2015a), Guarnieri et al. (2021), Péra et al. (2015)
D	Poor planning and accounting	X	X	X	X	Dos Santos et al. (2020), Colombo et al. (2022), Araujo G. P. de; Lourenço (2018), Henz (2017), Guarnieri et al. (2021), Aliotte, Filassi and Oliveira (2021), Ismael (2023), FAO (2015a), Péra et al. (2015)
E	Inadequate storage (refrigerated conditions)	X	X	X		Dos Santos et al. (2020), Vilela et al. (2003), Araujo G. P. de; Lourenço (2018), FAO (2015a), Aliotte, Filassi and Oliveira (2021), Ismael (2023), Péra et al. (2015)
F	Unpreparedness for adverse environmental/weather conditions/plagues	X	X	X		de Morais et al. (2022), Mustelier and Lorenzo (2021), Porat et al. (2018), Henz (2017), Guarnieri et al. (2021), FAO (2015a), Péra et al. (2015), Herrera-Quinteros and Jara-Rojas (2023)
G	Quality/cosmetic standards	X	X	X		de Morais et al. (2022), Colombo et al. (2022), Mustelier and Lorenzo (2021), FAO (2015a), Fehr and Romão (2001), 18, Péra et al. (2015), Herrera-Quinteros and Jara-Rojas (2023)
H	Inadequate storage (physical factors)		X	X		de Morais et al. (2022), (Vilela et al. 2003), Fehr and Romão (2001), Porat et al. (2018), FAO (2015a)
I	Delay between buying and selling / short shelf-life	X	X	X	X	de Morais et al. (2022), Dos Santos et al. (2020), (Araujo G. P. de; Lourenço 2018), Departamento Nacional de planeación (2016), FAO (2015a), Péra et al. (2015)
J	Lack of proper training for vendors and staff		X	X		Dos Santos et al. (2020), Fehr and Romão (2001), Ismael (2023), FAO (2015a)
K	Inadequate conditioning and conservation of the product	X	X			Colombo et al. (2022), Mustelier and Lorenzo (2021), Araujo G. P. de; Lourenço (2018), FAO (2015a)
L	External factors (roads infrastructure)		X			Fehr and Romão (2001), Henz (2017), Guarnieri et al. (2021), FAO (2015a)
M	Lack of incentives/certifications	X	X	X		Fehr and Romão (2001), Henz (2017), FAO (2015a)
N	Communication issues		X	X		Guarnieri et al. (2021), Ismael (2023), FAO (2015a)
O	Inadequate harvesting techniques	X				Araujo G. P. de; Lourenço (2018), Guarnieri et al. (2021)
P	Economic decisions	X		X		Araujo G. P. de; Lourenço (2018), FAO (2015a), Herrera-Quinteros and Jara-Rojas (2023)
Q	Inadequate display or shelving			X		FAO (2015a)
R	Lack of involvement of the producers in the transportation	X				Dos Santos et al. (2020)
S	Lack of technological resources		X			Henz (2017)
T	Inefficient marketing strategies			X		Dos Santos et al. (2020)
U	Distribution channels			X		Henz (2017)
V	Labour Shortage	X				Herrera-Quinteros and Jara-Rojas (2023)
W	Water availability	X				Herrera-Quinteros and Jara-Rojas (2023)
X	Inadequate storage (crossed pollution)			X		Péra et al. (2015)

5.2 Food Loss and Waste in the Brazilian Food Supply Chain: Case Study in Tupã, Brazil.

During the visit to the Tupã region of São Paulo, Brazil, multiple rural producers, and retail establishments were assessed to gather enough information for understanding the context in which the losses and waste of LV occur. Interviews, inspections, and documentation reviews were conducted to gain an overview of the status of FLW for LV.

This research encompassed interviews with rural producers (P), street market vendors (P/R), and retailers (R), aiming to gain insights into the distribution dynamics of LV, from harvest to retail (Figure 1). Table 2 presents a summary of the sampled participants in this case study, including information about their product type and an approximate suggestion of the business size, for the case of producers.

As a general observation, the city of Tupã is privileged to have a relatively large number of LV producers considering its small population size, by Brazilian standards. The availability of local products satisfies the community's needs, reducing the reliance on LV from other regions. The abundance of the products can also be evidenced in the big displays focused on leafy vegetables in most of the retailers visited (Figure 2). During the study period, local supermarkets were supplied by approximately eight local producers. Furthermore, the general population had the opportunity to purchase directly from producers at street markets twice a week, specifically on Thursdays and Sundays. These street markets were served by approximately ten microenterprises engaged in the production and distribution of LV.

In terms of FLW awareness, producers generally have limited awareness or consideration of the proportion of FLW that are generated. While some estimates were attempted by producers for food loss and waste (FLW) at the harvest and post-harvest phases, these are often overlooked.

On the other hand, retailers completely disregard the extent of loss and waste resulting from the commercialisation of LV. This is mainly due to the take-back agreement (TBA) between retailers and producers. In this informal and mostly verbal arrangement, there are no guarantees nor protection for the producers. They receive full payment only for the products that are actually sold in the supermarket. Moreover, producers they bear the responsibility for managing losses and surplus. Consequently, each producer is individually responsible for the transportation, arrangement, and maintenance of product freshness on the sales counter, irrespective of the availability of refrigeration facilities. As a result, efforts to minimise production surplus are hindered by retailers' desire to have abundant product displays.

According to Eriksson (2012), and Eriksson, Ghosh, Mattsson and Ismatov (2017), TBAs allows supermarkets to reduce waste costs by making the supplier responsible for goods that do not meet contractual requirements. This can include rejecting goods upon delivery. According to Cunha, Saes and Mainville (2015), the TBA, known as "*cláusula contratual de consignação*" in Brazil, serves as a contractual term for the retail sector to mitigate the risks associated with the perishability of agricultural products such as fresh fruits and vegetables (FFV).

In all instances, producers are primarily focused on cultivating LV. In some cases, producers may also grow additional fruits and vegetables or diversify their supply by purchasing the products from nearby distribution centres. The number of workers hired by the producers, as mentioned in Table 2, refers to qualified personnel directly involved in activities such as harvesting, packaging, and transporting LV. Administrative, quality control, and marketing tasks of the business are not included in this count, as they are not directly related to the production activity and are, in most cases, managed by the owners or the family members of the producer.

When it comes to retailers, information regarding the number of workers involved in the fruits and vegetables section may not be relevant, as their involvement in the commercialisation tasks for LV is limited or inexistent. However, it is relevant to identify the type of retailer for this study. There are two types of retailers that were considered for this study: neighbourhood grocery stores and local supermarkets, with the latter being the larger facility type in the city of the study case.

Table 2. Summary of the agents of the food supply chain of leafy vegetables studied as part of this research.

ID	Description	Number of workers
P1	Conventional and Hydroponic Producer	15
P2/R1	Organic Producer, and Street Fair Vendor	1
P3	Conventional and Hydroponic Producer	7
P4	Conventional and Hydroponic Producer	16
P5	Conventional and Hydroponic Producer	4
P6/R2	Conventional Producer, and Street Fair Vendor	4
R3	Neighbourhood Grocery Store	-
R4	Local Supermarket	-
R5	Neighbourhood Grocery Store	-
R6	Local Supermarket	-
R7	Neighbourhood Grocery Store	-

Figure 1. Food supply chain of leafy vegetables, within the scope of this study, from harvest to retail.

Figure 2. Arrangement of leafy vegetables for display at a local supermarket (R4) in Tupã, Brazil.

5.3 Analysis of Risk Factors of Food Loss and Waste

In the case study, local LV producers do not have formal purchasing contracts with retailers, but rely on informal agreements where retailers hold no responsibility for the selling or marketing of LV. For freshness, producers frequently replace flawed or less fresh items at retailers' request, daily. This process also involves swapping unsold items with new ones and trimming/collecting unsold products. Quality standards lack a specific pattern, relying on retailers' perceptions, criteria, and personal consumer preference knowledge from both parties.

The implementation of take-back agreements (TBAs) in the region of the case study also creates a conflict in defining losses and waste. In this model, producers bear the responsibility for losses, which can be seen as an unintended consequence of mismanagement in the retail phase. For the city of the case study, although waste is primarily generated at the retail level, producers are left to deal with the consequences, including the proper disposal of unsold products.

5.3.1 Identification of Risk Factors

In the context of the investigation, this step was crucial as it involved interpreting the information derived from on-site observations and interviews to identify and compile a comprehensive list of risk factors related to FLW within the supply chain. Table 3 presents a compilation of the general risk factors identified in the case study, along with the actors where these factors were found.

By observing Table 3, it becomes apparent that the risk factors are not limited to specific stages such as production or retail; rather, they occur at both the production and retail phase of the FSC.

The risk factors presented in Table 3 were determined based on the answers to the interview questions from the "Food loss and waste information" section in APPENDICES 3 and 4, and they encompass all the factors identified by either the interviewees or the interviewers as situations or practices that directly or indirectly increase the likelihood of occurrence of FLW of LV in the region of the case study.

Table 3. Summary of risk factors and recurrence in the case study

Risk Factors	Cases
A. Lack of Incentives to Reduce FLW	P1, P2, P3, P4, P5, P6, R1, R2, R3, R4, R5, R6, R7
B. Lack of Registration and FLW Control	P2, P3, P4, P5, P6, R1, R2, R3, R4, R5, R6, R7
C. Breakage or Absence of the Cold Chain	P1, P2, P3, P5, P6, R1, R2, R3, R5, R6, R7
D. Poor Sales Planning or Forecasting	P1, P3, P4, P5, R2, R4, R5, R6
E. Short Shelf Life	P2, P3, P6, R1, R2, R4
F. Lack of Preparation for Plagues Control	P2, P4, P5, P6, R1, R2
G. Lack of Preparation for Adverse Weather Conditions	P3, P6, R2, R3, R4
H. Lack of Skilled Labour	P4, P5, P6, R2, R7
I. Excess Supply	P3, P5, P6, R2, R3
J. Improper Handling from Clients	P1, V3, V6
K. Infrastructure Limitations	P5, P6, R2
L. Strict Visual Quality Standards	P3, R6

To provide a comprehensive understanding, a detailed description of each risk factor is presented below, offering insights into their contextual relevance and relationship with other risk factors, causes, and effects:

A. **Lack of incentives for FLW reduction:** From a retail perspective, FLW may not seem to directly impact their business since the type of agreement with producers allows any surplus or spoiled LV to be managed by the producers, sparing grocery stores and supermarkets from economic losses. Consequently, there is often a limited emphasis on investing in a qualified workforce, establishing appropriate infrastructure for display, implementing temperature control measures, or promoting waste control initiatives such as promotions or discounted products.
On the other hand, producers assume the effect of the consequences associated with FLW due to their agreements with supermarkets, leading to what appears to be an unavoidable situation. While minimising FLW would be economically beneficial for producers, there is often a lack of awareness regarding the economic and environmental impacts of such losses on their own businesses. As a result, incentives to reduce FLW are frequently overlooked or considered unnecessary.
When asked if FLW represents a problem for her personally, the manager of retailer R3 responded that, in the case of LV, they don't suffer any economic loss from not selling, so it's not a problem that directly affects their business.

R3: "Well, here, most of our products have a take-back agreement, because thankfully nowadays there are many things that can be taken back: papaya, banana, leafy vegetables, *potatoes... There are many things that they (the producers) can take back, so I don't suffer much loss. It affects the producer more, as they sometimes incur the greatest loss..."*

B. **Lack of Register and Control of FLW:** Out of the producers interviewed, only one (P1) has designated an employee to be responsible for monitoring sales and maintaining computer records of returns, which can be regarded as losses. However, even this producer does not effectively track the proportion of returns within the supermarket, or the losses incurred during various stages such as harvesting, post-harvesting, classification, and packaging. In general, none of the producers have robust control over production, sales, and losses due to a lack of workforce allocated to tasks beyond production itself.
As mentioned earlier, the issue of loss and waste of LV is not given significant consideration, as producers primarily focus on meeting retail demands with high-quality products. Unfortunately, the absence of proper records contributes to a misconception regarding the quantity of losses, leading to excessive production and unidentified economic losses resulting from waste at the retail level, "what is not measured, cannot be managed."
During the interview, the operations manager of P1 presented the interviewers with a record of products returned by retail stores, as handled by the producer's own employees in accordance with customer quality requirements. However, it was observed that the register solely documents the quantity of returned products without comparing it to the number of products sold. Moreover, this data is exclusively stored in the company's digital files and is not shared with senior management, the owner, or stakeholders.
Another important finding is that FLW proportions and quantities at the retail stage can be easily calculated from the invoices for returned products. Tracking product exchanges allows for accurate measurement of the loss index and provides insights into producer-retailer dynamics. However, this approach is just a part of the solution to the larger issue associated with the major causes identified in this study and should not be implemented isolated but as a part of a comprehensive strategy.

C. **Break/Absence of the Cold Chain:** During hot seasons, uncovered truck deliveries and the absence of proper cooling methods can have a detrimental effect on certain merchandise, particularly LV. The lack of refrigeration leads to short shelf life, impacting the quality and durability of the vegetables and reducing the available marketing and consumption time. Deficient infrastructure such as supermarket shelves without refrigeration can cause issues with returns When items are processed and stored outdoors without proper cooling, they tend to deteriorate, especially in small grocery stores and street markets. In all the cases studied, there is some kind of partial break or absence of the cold chain, from harvest to storage, resulting in product deterioration and loss of quality before reaching their regular shelf-life duration. Improper storage and transportation of processed products also affect their quality, emphasising the need for appropriate temperature control along the supply chain, especially during hotter seasons. As supported by Table 3, this risk factor can be observed at both the producer and retail levels.

P4 regarding the slightly processed and packaged product: "This product is not good (taking the package of sanitised chopped leafy vegetables). Just by picking it up, I can tell. Even though its expiration date is still four days away, on the 20th, it is not good. Just by picking it up, I can tell because, look, it has warmed up. It could have heated up during transportation from the company to here. ... It might have stopped somewhere, turned off the car, and the car managed to heat up. In this case, I collect it, and there must be a replacement of the product..."

D. **Poor Sales Planning or Forecasting:** The responsibility for daily product replenishment and demand forecasting primarily lies with the producers, with minimal or no communication with retailers during this process. Producers highlighted the challenge of adjusting supply to meet demand without a formal control system, leading to potential imbalances between supply and demand and resulting in product waste during specific periods or seasons. Inadequate demand management and insufficient crop planning can lead to shortages during peak demand and excess production during periods of low demand.
   One retailer (R4) possesses an automated purchasing system for regular fruits and vegetables. However, this system is not implemented for demand prediction and purchasing in the case of LV, as the retailer perceives no financial loss if unsold. Although producers may have knowledge of the demand for their products based on experience, supermarkets and grocery stores are the ones with the expertise in understanding consumer patterns and employing the best methods to plan and forecast the supply and demand relationship.

P4, regarding the way orders are made and the lack of registration of FLW: "When needed, I prepare the orders depending on what my brother requests. It's always my brother who handles all the orders. He looks at what's available and says something like, "We have 10 packs of frisée lettuce... Let's send 5 more to the supermarket, so we have 15 in total, to provide a good quantity… But it's very much based on intuition, we assess it in the moment; it's a day-to-day thing. It's not possible to tell you how much is left at the end of the month. It also depends; sales are lower at the end of the month and higher at the beginning."

E. **Short Shelf life:** At the retail level, especially for street market vendors, the lack of efficient post-harvest refrigeration methods for LV results in compromised quality and reduced shelf life, thereby limiting their sale and consumption duration. On the other hand, for producers, the practice of removing roots from hydroponic lettuce, driven by consumer preference for rootless products, diminishes the product's resilience despite the roots' potential to prolong its shelf life. Finally, inadequate display or storage can lead to the deterioration of visual quality, resulting in leaves that are unsuitable for sale and resulting in substantial waste. Producers emphasized the necessity of refrigeration and hydration conditions to maintain the product quality at its optimum level. However, producers themselves are responsible for maintaining these optimal conditions for their products, even when they are displayed at the retail counters, which creates additional tasks and consumes both time and labour during the day.

P3 on product shelf life: "If I leave it (the product), for example, in the morning and don't water it during the day, forget about it. Even with refrigeration, it only lasts one day... in the other supermarket, our merchandise is in the refrigerator, cooled, and there's a display, but that display isn't even refrigerated..."

P3: "…. When planted in soil, lettuce lasts longer. There's no comparison... In water, it doesn't have all the vitamin composition that the plant needs, so we need to add iron, calcium, micro, and macronutrients to the water to provide all the vitamins the plant needs. But in the soil, you don't need to add those, although you need to fertilise. For example, harvested and refrigerated (lettuce) lasts four days, I believe it can still be sold... In water (hydroponic leaves), it's a little less, because when it's in water, people say there's a difference in colour."

P4 on products displayed outside the refrigerated counter: "The product lasts for two days outside the fridge because it's a hydroponic product... It can last a maximum of two days before it starts to wilt. It doesn't spoil, it just wilts. If you take the root and put it in water, it (the lettuce) becomes green again, as if it was just harvested."

F.Lack of Preparation for Plagues Control: During one of the interviews with the producers (P4), there was nearly a total loss of one crop due to phytosanitary issues, emphasising the challenges faced in maintaining plant health and the importance of effective pest and disease control strategies. Additionally, the presence of weeds within the cultivation area was observed in almost all the producers, indicating the need for crop control. Furthermore, the interviews conducted with various producers clearly revealed a noticeable deficiency in both technical expertise and human resources when it comes to pest prevention. Producers identified a shortage of skilled labour as a risk factor, as the lack of financial resources to hire trained personnel for proactive cultivation issues can lead to unnecessary losses.

P5 on product loss due to lack of pest prevention: "Using insecticides or fungicides is also meant to prevent loss... Personally, I only apply them occasionally when I start seeing pests. Perhaps our loss is greater because of this. Some people give the entire crop a treatment once a week, and it works... If I were using this method of applying it every week, I'm sure I wouldn't have these hole-ridden leaves. I don't do it because we are short-staffed here."

G. Lack of Preparation for Adverse Weather Conditions: The lack of preparation for adverse weather conditions, such as rain and inadequate protection against strong winds and storms, poses difficulties for producers. Pests and excessive rainfall also affect production and availability at the retail, especially during the rainy season. While it is widely recognised that the region frequently experiences losses caused by adverse weather conditions, implementing effective infrastructure measures like rainproof roofs or natural barriers such as large trees surrounding the crops is an expensive solution that typically has a limited lifespan due to the occurrence of abnormal storms in the area. Unfavourable weather conditions also affect the retail selling area, particularly in hotter seasons, affecting the quality and supply of LV. The absence of proper refrigeration systems at the retail level exacerbates this issue.

H. **Lack of Skilled Labour:** The implementation of vital enhancements in pest control, product cold-chain, production, and FLW prevention is hindered by the limited availability of skilled workers. Additionally, small-scale producers express a willingness to receive more training on good agricultural practices and diversify business models for efficient supply and demand management. However, significant barriers such as time constraints, labour shortages, and limited economic resources hinder their efforts. Addressing these challenges requires not only increasing the workforce but also training existing management and workers involved in the LV production on best practices to reduce FLW.

I. **Excess Supply:** During winter, there is an excess supply and low demand in the market. People tend to consume fewer fresh products, such as LV, during this time of year. Additionally, in the city of the case study, there are low harvesting yields during the hotter seasons, making it difficult to maintain consistent production during summer. According to one of the producers, in winter the product loss due to lack of demand can reach 20%, while in summer, it is reduced to about 1-2%. Moreover, the lack of proper sales planning and forecast exacerbates the situation. This risk factor can be also affected by the cultural tendency of having abundant displays at the fruits and vegetables section. According to Mena, Adenso-Diaz and Yurt (2011), the retailer's focus on cost and efficiency leads to overdelivering to avoid scarcity, increasing waste, especially during periods of low demand.

P4 about the fluctuations in demand: "During winter, sales are lower, so the surplus is much larger... We don't produce the same amount in winter and summer; we end up reducing it (the production) a bit. Because we end up wasting a lot, it's wasteful... Now, the middle of the year is the period when we produce the most (winter in Brazil) but there's less consumption. That's when we have to reduce the quantity produced."

R4, regarding the requirements of full shelves: "... I have had an agreement with him(the producer) for 20 years. I cannot afford to not sell, and the supplier also cannot afford not to sell. Neither of us can lose, but I can't afford to run out of stock. If that happens, it becomes a serious problem."

J. **Improper Handling from Clients:** Producers and retailers agree that some waste occurs due to improper handling of products by customers in the markets. The rooted culture of touching and handling vegetables by customers results in damage and loss of quality, making it difficult to control this behaviour and increasing the risk of waste.

V4: "... It happens like this; I think it's a matter of culture. I don't think it would work here, this thing you mentioned, this thing of touching. A very difficult thing is the pear... In our culture, we can't just rely on looking with our eyes. We already put-up signs saying, 'do not squeeze,' especially in the fruit section."

K. **Infrastructure Limitations:** The lack of economic resources for micro and small producers restricts the capacity of producers to implement improvements and invest in technologies aimed at improving crop efficiency and reducing FLW. These include the establishment of refrigeration chambers, the implementation of barriers to mitigate adverse climate conditions, and the production of sanitised products.

L. **Strict Visual Quality Standards:** Most supermarkets in the region have an unofficial requirement that LV must be in perfect aesthetic condition, without any minor defects or imperfections. This can create a risk factor as products in excellent condition may be discarded or removed from the sales counter due to minor aesthetic flaws, even if they are still edible and nutritious. Producers are obligated to remove products with ‘low’ visual quality from display counters, even if they are still suitable for consumption. As per the feedback gathered from retailers, products with poor visual appearance are rejected by consumers. Given the abundant supply in the city, the key factor for successful sales lies in the high quality of the products, which makes them stand out from the competition.

P3 about product with nutritional value but low aesthetic quality that has to be donated or disposed: “…In the other market, we explained that we don't offer promotions because of the product's quality... However, sometimes I even offer it to someone from the staff who helps unload the truck. I offer it and say, 'Look, I have to remove it because of the quality of our product, but it can still be consumed...' Then I offer it there, and they take it. I donate it; otherwise, I'll take it home and give it to the chickens.”

5.3.2 Five Whys Approach

Consequently, the risk factors identified in Chapter 5.3.1 and their associated causes were analysed using the 'Five Whys' approach, as presented in Table 4. For this, each risk factor was examined to understand the reasons behind its occurrence. The root causes, highlighted in bold font, for each sequence of causes were found to be either the take-back agreement conditions or the lack of public policies and incentives to reduce FLW..

The analysis in Table 4 primarily focused on the identified risk factors, but it also acknowledges the inclusion of potentially overlooked minor causes that can act as enablers for FLW risk factors found in the case study. Additionally, it is evident that some risk factors are associated with each other, indicating that certain identified risk factors are both causes and effects of others.

5.3.3 Causal Map

Finally, following the analysis of the cause and effect of isolated risk factors, a comprehensive diagram (Figure 3) was constructed to create a causal map that represents the interconnections between the identified risk factors and highlights their relationships and relevance, including the overlooked causes.

In Figure 3, the light grey boxes represent the identified risk factors contributing to the loss and waste of LV, while the white boxes symbolise unseen causes and effects that indirectly or directly create the conditions for the occurrence of the identified risk factors. This model, different from the causal mapping model by Mena, Adenso-Diaz and Yurt (2011), demonstrates that cause-effect relations can occur independently of each other, rather than strictly adhering to the pattern of inclusive causes, in which two causes need to happen in order to the expected effect to take place.

At the bottom of the causal map, the root causes identified in Table 4 are represented. As mentioned in the previous chapters, Root causes are fundamental factors responsible for the existence of a problem, and addressing them is crucial for effective problem-solving (Doggett 2006). As mentioned above, the root causes of FLW of LV in the case study were identified as the lack of public policies and incentives to reduce FLW, and the take-back agreement conditions. Therefore, the measures taken to correct these risk causes can significantly reduce the generation of FLW of LV.

Table 4. 'Five Whys' analysis on the risk factors generating loss and waste of leafy vegetables in the case study.

Risk Factor	Why	Why	Why	Why	Why
A. Lack of Incentives to Reduce FLW	No Economic Losses From FLW in Retail	**Take-back agreement conditions**			
B. Lack of Registration and FLW Control	H. Lack of skilled labour	A. Lack of incentives to reduce losses and waste	Lack of Awareness of the Economic and Environmental Effects of FLW	**Lack of Public Policies and Incentives to Reduce FLW**	
C. Breakage or Absence of the Cold Chain	G. Lack of Preparation for Adverse Weather Conditions	L. Infrastructure Limitations	A. Lack of Incentives to Reduce FLW	**Take-back agreement conditions**	
D. Poor Sales Planning or Forecasting	H. Lack of skilled labour	A. Lack of Incentives to Reduce FLW	**Take-back agreement conditions**		
E. Short Shelf Life	Excess Product on shelf	Excess Supply	D. Poor Sales Planning or Forecasting	Lack of Involvement from Retail	**Take-back agreement conditions**
F. Lack of Preparation for Plagues Control	H. Lack of skilled labour	A. Lack of Incentives to Reduce FLW	**Lack of Public Policies and Incentives to Reduce FLW**		
G. Lack of Preparation for Adverse Weather Conditions	L. Infrastructure Limitations	A. Lack of Incentives to Reduce FLW	Lack of Awareness of the Economic and Environmental Effects of FLW	**Lack of Public Policies and Incentives to Reduce FLW**	
H. Lack of Skilled Labour	A. Lack of Incentives to Reduce FLW	**Lack of Public Policies and Incentives to Reduce FLW**			
I. Excess Supply	D. Poor Sales Planning or Forecasting	Lack of Involvement from Retail	**Take-back agreement conditions**		
J. Improper Handling from Clients	Cultural Habits	Lack of Awareness of the Economic and Environmental Effects of FLW	**Lack of Public Policies and Incentives to Reduce FLW**		
K. Infrastructure Limitations	A. Lack of Incentives to Reduce FLW	**Lack of Public Policies and Incentives to Reduce FLW**			
L. Strict Visual Quality Standards	Lack of Awareness of the Economic and Environmental Effects of FLW	**Lack of Public Policies and Incentives to Reduce FLW**			

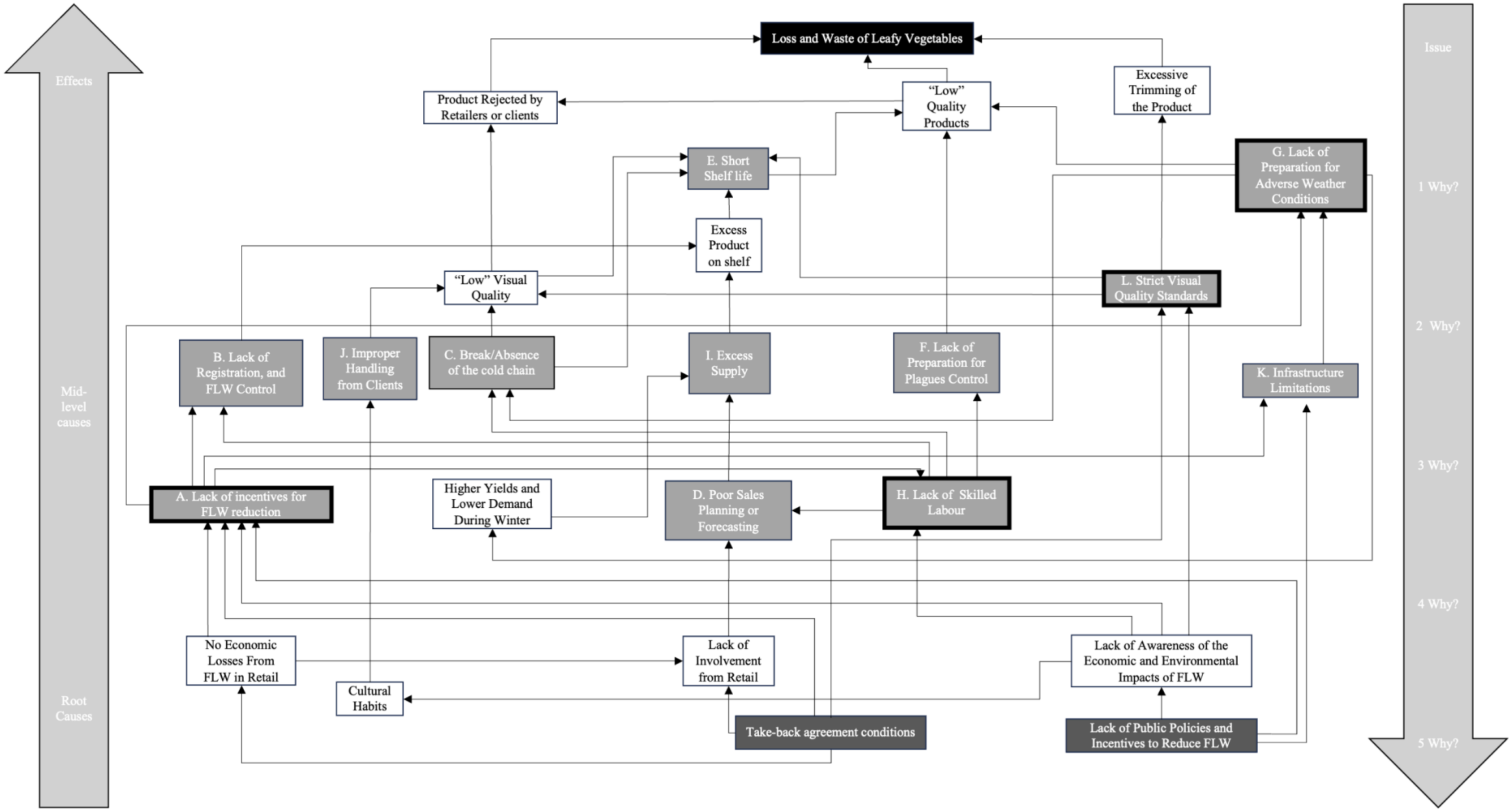

Figure 3. Causal Map of Risk Factors, including a current tree map structure and interrelationship connections between causes.

Moreover, the causal map presented in Figure 3, demonstrates graphically through interrelationship associations that a single risk factor can simultaneously be the enabler of multiple effects that contribute to FLW. Notably, certain risk factors, like Lack of Preparation for Adverse Weather Conditions, Lack of Skilled Labour, and Strict Visual Quality Standards, contribute to three or more effects simultaneously and were considered "major causes" for the purposes of this study. These major causes have a significant impact on the generation of FLW and were prioritised for the proposal of mitigation measures.

Additionally, specific risk factors such as "Product Rejected by Retailers or Clients," "Short Shelf Life," and "Excessive Trimming of the Product" are identified as direct causes of FLW and were classified as "major effects" highlighted with a thick border. While they directly contribute to FLW, addressing these major effects effectively requires tackling the underlying causes behind them. Thus, it is essential to address them as effects rather than causes.

5.4 Barriers and Opportunities

5.4.1 Social Risk Factors

In this context, a social risk factor is referred to by the author as a specific aspect or condition within the social component dynamic that influences indirectly the occurrence of FLW. Although these factors may not be directly associated with FLW, they provide valuable insights into the challenges faced by stakeholders in the food supply chain, emphasising the producer-retailer dynamics.

One social risk factor that stands out is the lack of formalisation of commercial relations between LV producers and retailers. Based on the interview findings, producers have internal control over the quantities to be delivered to each distribution channel. However, they predominantly rely on verbal contracts with the retailers and are responsible for projecting and estimating demand in supermarkets and grocery stores, which is not their primary activity. This highlights the absence of formal and structured contractual arrangements between producers and retailers, leading to inefficiencies and uncertainties in inventory management and meeting market demands.

Additionally, the case study revealed unhealthy competition among producers, with unfair market practices and a need to adapt to customer demands, particularly in small supermarkets. Fierce competition was observed, with smaller producers offering lower prices but inconsistent supply. Some producers expressed frustration with "adventurous" competitors who enter the market with limited seasonal products and significantly lower prices, forcing established producers to lower their prices in response. This creates stress, reduces income, and negatively impacts the quality of life of well-established LV producers in the region.

Another significant social risk factor identified is the challenging relationship with supermarkets. The interviews revealed that dealing with large supermarkets is often difficult but necessary for sales due to the extensive customer base served by these markets. This suggests that conflicts or difficulties in the communication between producers and retailers can have an impact on the efficiency and effectiveness of the supply chain, potentially leading to increased FLW.

Lastly, the research emphasised frequent replenishment and high turnover as a social risk factor. Supermarkets engage in frequent restocking throughout the day, typically 2 to 3 times, based on demand, given the rapid turnover of products at the sales counter. This dynamic emphasises the challenges faced by producers in managing product availability and reducing waste due to fluctuations in customer preferences and buying patterns. Despite this being the supermarkets' responsibility, producers are compelled to ensure constant product availability on the counter, which consumes their valuable time and resources. Additionally, frequent restocking, coupled with large display areas, enables an excess of supply at retailers, leading to a focus on quantity rather than the quality of product display.

5.4.2 Motivation and awareness towards FLW

During the interviews done with both producers and retailers, it could be observed that producers of LV are motivated by several factors to minimise the loss and waste associated with their products. Firstly, economic considerations play a significant role. By minimising waste, producers can avoid financial losses by utilising every part of their harvest. Additionally, they can reuse harvest residues as soil fertiliser, contributing to soil fertility and reducing the need for additional fertilisers. Additionally, producers are concerned about the waste disposal of the unsold products. Which is why producers cooperate with neighbouring farms and producers to exchange excess products or utilise them as animal feed at their own farms.

On the other hand, retailers have their distinct motivations for reducing the loss and waste of LV. Typically, their primary motivation is economic, as they aim to maximize sales and generate profits. However, unlike producers, retailers are not directly impacted by the loss and waste of LV in the same way, due to the nature of the TBA between them and producers. However, there is an ethical and social responsibility driving retailers to minimise waste. By donating unsold products to charitable organisations, retailers ensure that edible food is not wasted and can benefit those in need. However, such practices from the retail side are discouraged and not actively implemented with LV surplus or damaged product.

5.4.3 Good Practices

During on-site visits to producers and retailers, we identified a range of effective practices for reducing losses and waste, particularly in the production phase. These strategies encompass practices such as efficient morning harvesting, reusing harvest residues for soil fertility, direct delivery to retailers, cooperative surplus utilisation, careful sorting and packaging locations, crop protection against evaporation, reduction of direct solar radiation with shade nets, maintaining leaf moisture through water spray and foam boxes, minimal processing to reduce losses, and breathable packaging with micro-perforations. Additionally, selected LV undergo minimal processing and are packed in trays for extended shelf life under proper refrigeration conditions. These practices collectively demonstrate successful approaches to minimising losses and waste, promoting sustainability and efficient resource management throughout the supply chain.

5.4.4 Waste Disposal Methods

Producers and retailers employ various methods to handle the waste of unsold or damaged LV. One common approach is to reuse the harvest residues by mixing them with the soil using tractors. This not only contributes to soil fertility but also prepares the ground for planting a new crop. Cooperation with neighbouring farms is another effective strategy, as producers can donate excess LV to other producers or use them as feed for animals within the same city, and sometimes within the same property, thus reducing waste, and vehicle transportation needs.

When it comes to some retailers, especially the ones who are simultaneously producers and street market vendors, donation plays a crucial role in minimising waste. Unsold LV that are still suitable for consumption are usually donated to local charity organisations supporting children's nutrition or used as animal feed, such as for pigs or chickens. However, Brazil lacks a regulatory framework for FLW, leading to concerns and costs in food donations due to tax limitations. This discourages producers and retailers from donating LV to organisations (Matzembacher, Vieira & de Barcellos 2021), and often leads to informal means of donation.

Error! Reference source not found. provides a summary of the most common LV waste disposal methods observed in both producers and retailers during the case study. It is evident that conventional organic waste disposal practices such as municipal collection and landfilling are not widespread among producers in the city under investigation. This can be attributed to the semi-urban nature of the region, where farm-level nature-based solutions are culturally preferred.

Furthermore, since producers typically reclaim unsold or spoiled products, they have the option to dispose of them in a more environmentally friendly manner without relying on municipal waste management services that still implement landfills to manage organic waste. It is important to clarify that landfills play a significant role in solid waste management in the city. As of 2022, the majority of urban solid wastes collected in Brazil are disposed of in landfills (ABRELPE 2012), and Tupã holds its own landfill within the city limits. Moreover, the city of Tupã currently lacks access to biological or thermal treatment facilities for both organic and inorganic waste disposal.

Table 5. Most common practices for waste disposal of leafy vegetables in the case study.

Producers	Retailers
Donation for Animal Feed: As the most common practice among producers, unsold or undesirable leaves and products are donated for animal feed, particularly for pigs and chickens, ensuring utilisation rather than waste.	Donation to Charity Organisations: Retailers donate unsold products with good aesthetic quality but low demand to charity organisations, minimising waste while supporting those in need.
Reuse in Soil: After animal feed, the most common practice observed in the post-harvest is the mixing of remaining leafy vegetable residues left after the harvest with the soil using tractors, contributing to soil fertility and the planting of a new crop. Simulating the nutrient recovery obtained from composting.	Donation to Employees: Instead of discarding unsold or excess products, one of the retailers provides the opportunity for employees to take them home. However, this was not a commonly adopted practice.
Open-air Disposal: Leaving leafy vegetable residues in organic waste piles can lead to partial the anaerobic decomposition of the leaves, resulting in the unintended generation of methane and CO_2.	
Donation to Charity Organisations: Producers donate unsold products with good quality to charity organisations, minimising waste while supporting those in need, especially children.	
Use in Worm Farming: Residue from leafy vegetables processing can be repurposed in worm farming, transforming waste into useful resources.	

6. Discussion – Risk Factors of Food Loss and Waste

6.1 Risk Factors of Food Loss and Waste of Leafy Vegetables

Based on the cause-effect relations, and the interrelations between the risk factors illustrated in the causal map (Figure 3), a comprehensive overview of the identified risk factors and their relevance in the context of FLW in the case study is presented as a prioritisation pyramid (Figure 4).

At the top of the priority pyramid lie the root causes, serving as the foundation for all other FLW-related issues in the supply chain. These root causes are deeply rooted in the structural aspects of the system and demand specific policy and regulatory interventions. However, implementing such measures may involve external interventions and collaboration with different stakeholders beyond the FSC (Pimentel, Misopoulos & Davies 2022), which could potentially lead to longer implementation timelines. Nevertheless, these external interventions hold the potential for greater effectiveness in addressing the structural causes of FLW (Flanagan, Robertson & Hanson 2019).

Moreover, positioned in the middle of the diagram are the major causes, identified as the priority causes in Chapter 5.3.2. These causes, being of managerial nature, give rise to multiple secondary causes simultaneously. Hence, they can be addressed through focused measures that involve both retailers and producers and even consumers (Flanagan, Robertson & Hanson 2019). Moreover, by effectively tackling these major causes, the impact of most mid-level causes can be addressed.

Finally, located at the base of the pyramid are the mid-level causes, which can be attributed to either technological, managerial, or behavioural factors. Given that these mid-level causes are also influenced by other priority factors, addressing the major causes becomes essential to effectively mitigate their impact.

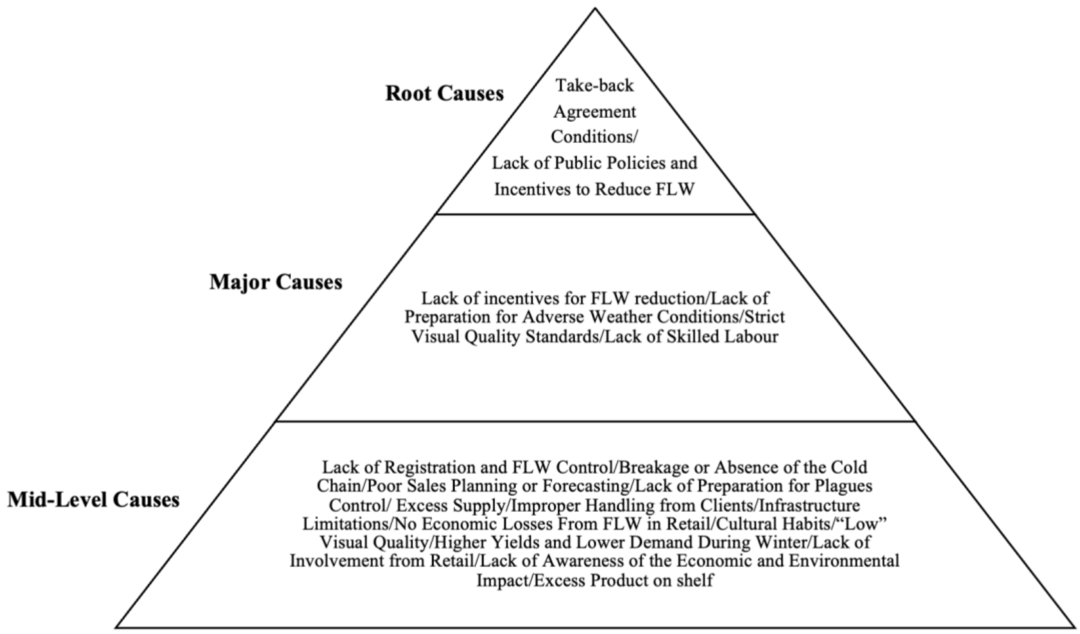

Figure 4. Prioritisation pyramid for the identified risk factors and causes of FLW of leafy vegetables.

6.1.1 Root Causes of FLW

Two key root causes emerged. The first, "Take-back Agreement Conditions," highlights contractual terms between producers and retailers as significant contributors to FLW. These terms impact retail involvement, disincentivise waste reduction, and enforce strict quality standards. Literature by Eriksson et al. (2017), Parfitt, Barthel and Macnaughton (2010), Strid and Eriksson (2014), and Colombo et al. (2022) reinforce this notion. Retailers benefit economically from rejecting imperfect products, shifting waste burden to producers. Market concentration and power imbalances lead to unfair practices, disproportionately affecting smaller producers. This practice is common in Brazil, where rejected products are often not returned to producers (Matzembacher, Vieira & de Barcellos 2021). (Matzembacher, Vieira & de Barcellos 2021). It is important to highlight that while the risk factor associated with Take-back Agreement Conditions (TBAs) may be perceived as a consequence of the absence of policies safeguarding producers, this particular factor holds significant influence on FLW, as observed by the author of this study and reinforced by the literature review.

The second root cause is the "Lack of FLW Reduction Policies and Incentives," where absent supportive measures contribute to FLW. Governments, as highlighted by the HLPE (2014), play a key role in regulating contracts, organising markets, and addressing seasonality. Despite initiatives like the Brazilian Association of Supermarkets, compiling food waste reports (ABRAS 2022), adherence is inconsistent in the case study. Only one supermarket in the case study follows this practice, however excluding monitoring of LV waste due to no economic benefit for the retail from this effort.

6.1.2 Major causes of FLW

When examining the major causes from Figure 4, and their consequential effects, certain factors have a notable impact on both producers and retailers. Among them, is the Lack of incentives for FLW reduction. As identified by the author, this cause is an effect of not only the lack of public policies and incentives to reduce FLW, but also of the lack of awareness towards FLW of retailers, producers, and consumers. Additionally, this behaviour is driven by the lack of economic consequences for retailers, which is a result of their significant market control (Pimentel, Misopoulos & Davies 2022) and the terms and conditions of the TBA.

Moreover, the "Lack of Preparation for Adverse Weather Conditions" stands out as a significant factor, highlighting the importance of improved readiness to mitigate the adverse effects of unfavourable weather on harvest yields and product preservation. This entails addressing the challenges brought mostly to producers, but also to retailers about by heavy rains, storms, and hot weather. According to HLPE (2014), climatic factors sometimes incentive producers to overproduce to mitigate effects such as uncertainties of weather, pest attacks, uncertainties of demand from retailers, and to ensure adherence to contractual obligations with the buyers. On the other hand, Mena, Terry, Williams and Ellram (2014) affirm that some retailers in the UK implement the practice of changing the quality specifications in response to the weather and seasonal changes in order to avoid waste.

Similarly, the risk factor related to the "Lack of Skilled Labour" highlights the importance of having competent workers who can effectively manage tasks such as registration, FLW control, cold chain management, sales planning, forecasting, and plague control. According to (Herrera-Quinteros & Jara-Rojas 2023) labour shortage is one of the main factors that increases FL among small-scale producers in Chile. However, in the context of Latin America, this was the only study mentioning the lack of human resources as a cause of FLW.

Furthermore, the influence of "Strict Visual Quality Standards" imposed by retailers and clients is noted, leading to increased FLW of good quality LV with minor imperfections. According to Parfitt, Barthel and Macnaughton (2010), these stringent quality standards often discourage small producers from supplying their products to the market, contributing to FLW. Likewise, a study by de Brito Nogueira et al. (2020) in Brazilian street markets, revealed that high levels of FLW of LV may be the result of removing stems and discarding wilted leaves to enhance appearance.

In conclusion, contrary to the affirmations made by Gustavsson et al. (2011), it is important to note that some of the causes identified as prioritary, such as those related to lack of skilled labour and strict visual quality standards, are not solely confined to the post-harvest and harvest phases. Instead, these causes have also been observed to have their origin and contribution to FLW at the retail level. This underscores the significance of conducting a comprehensive multistakeholder analysis to enhance our understanding of the factors influencing FLW and to devise effective strategies for its reduction.

6.2 Prevention Strategies

In Table 6, the significant causes of FLW in the LV supply chain are identified, classified by actors involved, and accompanied by proposed mitigation measures to reduce FLW. Proposed mitigation measures aim to minimise the adverse effects resulting from these causes in the short, medium, and long term. It is worth noting that addressing root causes proves to be the most challenging as it entails policy changes, stakeholder involvement, and the establishment of defined norms and rules for effectively and sustainably tackling the issue. Therefore, the author suggests that efforts in the short and medium term should be invested in addressing major causes at a local level to demonstrate the effectiveness of such measures to tackle the FLW issue.

Table 6. Summary of prioritised causes of FLW of leafy vegetables and proposed mitigation measures.

Identified Risk Factors	Actor	Mitigation measures
Take-back Agreement Conditions	Policy makers	Formal purchasing agreements with fair conditions with producers, restrictions on returned products (e.g., returns with a fee after received), promoting collaboration from retailers in the demand projection and supply management, and closed-loop supply chain of surplus product.
Lack of Public Policies and Incentives to Reduce FLW	Policy Makers	Relaxation of terms and conditions for food donation, public policies promoting the measurement and report of food loss and waste of leafy vegetables and updated and accessible statistics on the economic and environmental impact of food loss and waste of leafy vegetables.
Lack of Preparation for Adverse Weather Conditions	Producers/ Retailers	Installation of protective structures such as natural barriers, and shade protection; marketing campaigns to promote seasonal fresh fruits and vegetables, and promotions; Inventory control and production forecast and planning.
Lack of Skilled Labour	Producers/ Retailers	Partnerships with Educational Institutions, food loss and waste awareness campaigns among employees, implementation of inventory policy, involvement of retailer’s workers in product display tasks, training in good practices of fresh fruits and vegetable handling.
Strict Visual Quality Standards	Retailers	Flexibility in quality standards, secondary channels use or surplus by other retailers, ownership of unsold products from the retail, price and promotion policies.

6.2.1 Measures to mitigate the effects of the Take-back Agreement Conditions

Formal purchasing agreements with fair conditions with producers: This mitigation measure involves establishing formal contracts between retailers or buyers and producers. The agreements should ensure fair conditions for both parties, including aspects such as pricing, quantities, quality requirements, and delivery schedules. By having clear agreements in place, it promotes transparency, trust, and a mutually beneficial relationship between the buyers and producers, reducing uncertainties and potential causes of waste.

Restrictions on returned products: By implementing restrictions on returns, such as charging a fee after products have been received, it discourages frivolous or unnecessary returns. For instance, if a product returns to the producer after it has been displayed on the shelf, the retailer will give back the product with 95 to 90% of its original value. This encourages retailers to be more mindful of their unsold products, reducing the likelihood of products being returned and subsequently wasted.

Promoting collaboration from retailers in the demand projection and supply management: By involving the retail in these practices and sharing information, such as demand projections and inventory levels, it helps to align supply with demand more effectively. Improved collaboration can lead to better inventory management, reduced overproduction, and enhanced coordination throughout the supply chain, thereby minimising food waste.

Closed-loop supply chain of surplus product: This strategy aims to create a circular system where by-products or unsold LV are reintroduced into the supply chain for alternative uses, such as composting or processing into other products. This approach maximises resource utilisation by producers, as they already take responsibility for handling residual products. Additionally, it effectively reduces the disposal of unsold or unused LV in open air waste piles.

6.2.2 Measures to mitigate the effects of the Lack of Public Policies, and Incentives to reduce FLW.

Relaxation of terms and conditions for food donation: This mitigation measure involves implementing policies that relax the terms and conditions surrounding food donation. Often, businesses are hesitant to donate surplus food due to concerns about liability or strict requirements. By easing these restrictions and providing incentives, such as tax benefits or legal protections, access to credits, FLW awareness, and recognition, businesses are encouraged to donate excess food rather than dispose of it.

Public policies promoting the measurement and report of FLW of leafy vegetables: By promoting comprehensive data collection and reporting of FLW indicators, policymakers gain valuable insights into the extent and nature of FLW in the LV sector, at the local level. Although producers could use these insights to visualise FLW reduction as a strategy, normally retail is the one that has more resources and should be emphasised in the managerial strategies.

Updated and accessible statistics on the economic and environmental impact of FLW of leafy vegetables in the FSC: Accessible data regarding the costs associated with food loss and waste, as well as the environmental footprint, allows stakeholders to make informed decisions and prioritise waste reduction efforts. It also helps policymakers evaluate the effectiveness of existing initiatives and develop evidence-based strategies to mitigate FLW.

6.2.3 Measures to mitigate the effects of Lack of preparation for adverse weather conditions.

Installation of natural barriers and shade protection: Natural barriers, such as windbreaks or hedgerows, can shield crops from strong winds and minimise the risk of physical damage. Shade protection, such as netting or structures, helps to regulate temperature and reduce the impact of excessive heat or sunlight, and heavy rains on FFV. By implementing these measures, the vulnerability of crops to adverse weather conditions is reduced, leading to lower losses and improved quality.

Marketing campaigns to promote seasonal FFV: Marketing campaigns can highlight the benefits of consuming fruits and vegetables that are in season, such as better flavour, nutritional value, and reduced environmental impact. Such campaigns can create market demand, leading to improved sales and less waste at the retail level.

Promotions: By offering attractive pricing or additional value, retailers can stimulate consumer demand, leading to increased sales and potentially reducing the likelihood of LV becoming unsold and wasted. Promotions can also help to optimise inventory management, ensuring that perishable items are sold before their quality deteriorates.

Inventory control and production forecast and planning: Plan crop planting and harvesting schedules based on historical weather patterns and anticipated weather changes to maximize production efficiency.

6.2.4 Measures to mitigate the effects of skilled labour

Partnerships with Educational Institutions: Especially in the city of the case study, it is vital to collaborate with the agricultural faculty of the local university to create internship programs that provide students with practical experience in leafy vegetable production. This fosters a skilled workforce while benefiting from fresh ideas and perspectives.

FLW awareness campaigns among employees: This mitigation measure involves conducting awareness campaigns to educate and train employees about the issue of food loss and waste (FLW) at the producer and retail levels. These campaigns can include workshops, training sessions, and visual material to promote a culture of waste reduction within the organisation.

Implementation of inventory policy: This policy outlines guidelines for proper inventory management, including accurate tracking of stock, and efficient rotation of LV by retail workers. By establishing clear protocols and procedures, retailers can optimise inventory levels, prevent overstocking, and minimise the risk of perishable items becoming unsellable and wasted.

Involvement of retailer's workers in product display tasks: By involving retail employees in the process of arranging the products on the shelf, they become more mindful of handling FFV, ensuring proper organisation, rotation, and timely removal of damaged or nearing spoiled items. Their involvement can help improve product visibility and reduce mishandling.

Training in good practices of FFV handling and harvesting techniques: These trainings can cover aspects such as proper storage techniques, temperature control, handling fragile produce, and recognising signs of spoilage. For producers, this includes training on proper harvesting techniques, post-harvest handling, storage, and transportation practices. By equipping employees with the necessary skills and knowledge, they can handle LV more effectively, and maintain product quality.

6.2.5 Measures to mitigate the effects of Strict Quality Standards

Flexibility in quality standards: By allowing for slight variations in appearance or cosmetic imperfections that do not affect the safety or nutritional value of the product, such as yellowing of the lettuce leaves, retailers can prevent unnecessary discarding of perfectly edible food. This flexibility can include re-evaluating grading criteria and working closely with suppliers to find a balance between visual appeal and minimising waste.

Secondary channels use or surplus by other retailers: Another mitigation measure involves exploring secondary channels for the use or redistribution of unsold products that do not meet strict visual quality standards. This can include selling these products at discounted prices to discount stores, food banks, or neighbouring retailers who are willing to accept products with lower quality for a reduced price and make them more affordable for people in need.

Ownership of unsold products from the retail: By taking ownership of unsold products, retailers can actively manage and control their destination whenever is no longer apt for selling. This measure involves assuming responsibility for unsold items and finding suitable ways to repurpose or redistribute them. Retailers can explore options such as donating to food banks or local charities, repurposing for other food products (e.g., using slightly blemished produce in prepared meals or juicing), or partnering with organisations that specialise in reducing food waste.

Price and promotion policies: This can include offering discounts or promotions on these products, highlighting their value, and encouraging customers to purchase them. By adjusting pricing and promotional strategies, retailers can increase the demand for products that may otherwise go to waste due to their appearance for more affordable prices for the population who prioritise quantity over quality.

7. Life Cycle Assessment for the Evaluation of Waste Management Strategies

To enhance the case study's depth, a life cycle assessment (LCA) methodology was employed to evaluate the available strategies for the management of 1 kg of lettuce waste (excluding packaging) at the retail phase. The analysis was based on the net carbon footprint emitted with the implementation of each alternative. The subsequent sections outline the objectives, scope, inventory analysis, and outcomes derived from the LCA, and the Life Cycle Impact Assessment (LCIA).

7.1 Goal and Scope – Life Cycle Analysis

The primary goal of this LCA study was to compare the greenhouse gas (GHG) emissions of various food waste management scenarios for unsold LV in Tupã, Brazil. The alternatives studied were source reduction (prevention), animal feed production, anaerobic digestion, composting, and landfilling. To achieve this, the study adopts an attributional approach, utilising average data for both upstream and downstream processes, including product substitution.

The comparison will focus on greenhouse gas emissions expressed in CO2eq. By analysing these scenarios, the study seeks to provide valuable insights into the most sustainable and environmentally friendly approaches to handling LV waste in Tupã.

The findings pretend to inform policymakers, businesses, and stakeholders about effective waste management strategies for surplus leafy vegetables. Additionally, the study targets LV producers, retail managers, policymakers, legislators, and the academic community to provide insights on the most sustainable waste management alternatives available.

7.2 Inventory Analysis – Life Cycle Analysis

In this study, five different scenarios were examined (Figure 5). A system expansion approach was adopted to address co-products' multifunctionality and services, facilitating an evaluation of management options by considering the avoided environmental impacts of substituted products. Calculations for each scenario are presented in ANNEX V - LCA Calculations.

The inventory for the LCA relies on background data from the Ecoinvent database, version 3.5, with a cut-off model, and the modeling was conducted using SimaPro 9.1. The characterisation methods are built upon ReCiPe 2016 V1.04 midpoint method, Hierarchist version.

Based on the scope presented in Figure 5, the proposed scenarios for animal feed production, anaerobic digestion, and composting include transportation from retail to the producer. In this scenario, it was assumed that the producer collects the unsold products from the retailers and brings them back to their facilities using the shortest roundtrip route starting at the producer's location. The average distance considered was 12.425 km (Maps 2023). The transportation vehicle considered was a small diesel truck (<7.5 tonnes) with a Euro 3 standard engine and a maximum loading capacity of 5 tonnes. Refrigeration during transportation is not implemented.

7.2.1 Source Reduction

The modeling of the source reduction scenario serves as the reference point, aiming to prevent surplus lettuce production altogether. This approach focuses on achieving the highest level of the waste management hierarchy, by avoiding the production of one kilogram of lettuce. As an assumption for this scenario, it was considered a 20% of surplus production to compensate for typical losses in the production of fruits and vegetables in Latin America (Gustavsson et al. 2011). Moreover, the method of lettuce production considered was conventional (planted in soil), and not hydroponic.

Lettuce production emissions encompass a range of factors, including pre-farm machinery, pesticides, herbicides, fertilisers, and road transportation. Additionally, on-farm activities such as farm machinery operation and irrigation (Gunady, Biswas, Solah & James 2012). These activities were modelled utilising the EcoInvent database, which estimates the inherent emissions associated with the processes involved with lettuce production.

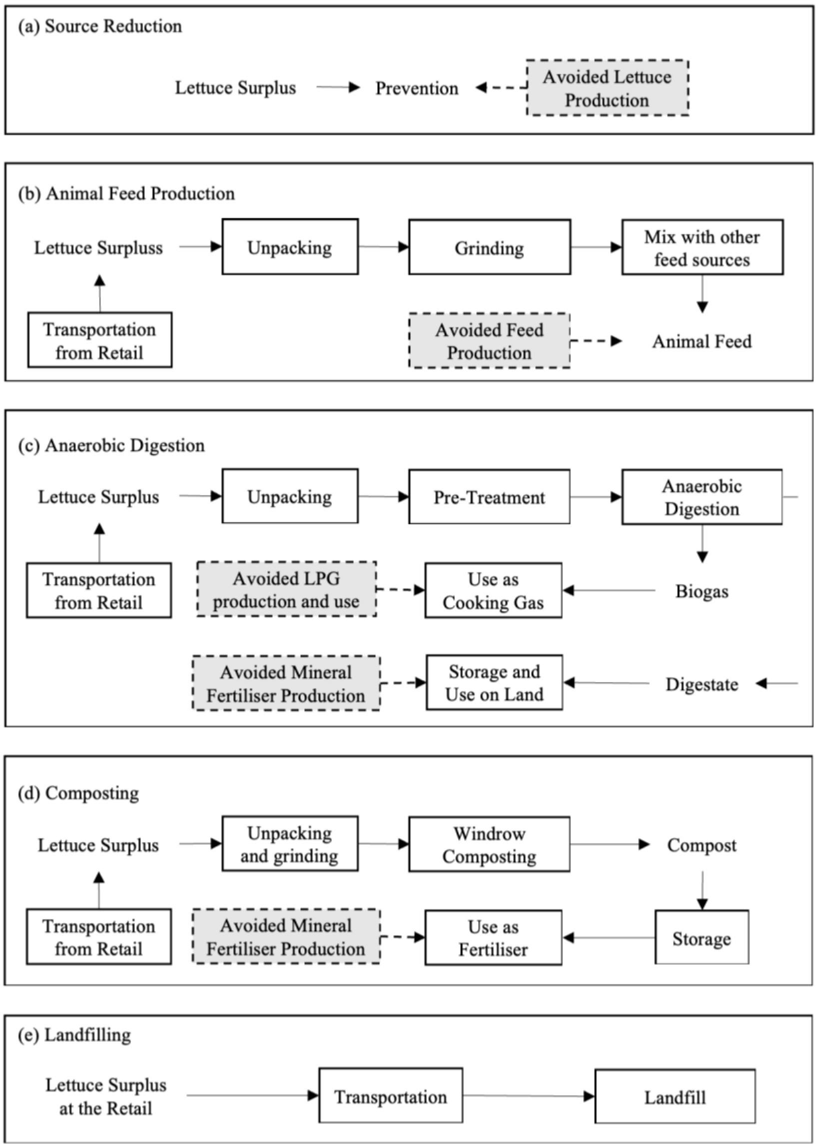

Figure 5. System boundaries for prevention and the valorisation and waste management scenarios considered in this study. The dashed lines and dashed boxes represent the substitution of products in the market. (a) Shows the source reduction of lettuce. (b) The use of surplus lettuce as animal feed. (c) The anaerobic digestion process (d) The composting process, and (e) Shows the landfilling process.

7.2.2 Animal Feed Production

In this scenario, it was assumed that the lettuce is transported from the retailer to the producer's location, before being sent to nearby farmers who raise chickens. Upon arrival at the consumption site, the lettuce is manually unpacked, ground, and mixed with other types of feed to achieve a more balanced diet for the animals. The chicken feed primarily comprises ground corn, along with leftover toast or bread crumbs, potato peels, raisins, and vegetable scraps like carrot and radish leaves (Secretaria de Estado de Meio Ambiente 2015). For the modelling, it was considered that due to its low protein content, the surplus lettuce is used as a replacement for part of the energy content and energy content of the regular feed. For this case, it is considered that 1 kg of raw lettuce, contains about 0.540 MJ (Tabela Brasileira de Composição de Alimentos - TBCA 2023).

7.2.3 Anaerobic Digestion

In this scenario, any surplus lettuce at the retailer is collected and returned to the producer. The waste is then treated using anaerobic digestion to produce non-upgraded biogas and digestate as fertiliser. The assumption was that all surplus lettuce is treated using decentralised biodigesters at the producer's site to produce biogas, which will serve as a substitute for domestic uses. Additionally, the residual digestate from anaerobic digestion will be utilised as on-site fertiliser for cultivating LV, eliminating the need for transportation and packaging. During the use phase, the gas is assumed to undergo complete combustion, ensuring an efficient oxidation (Schlag & Zuzarte 2008). To determine the potential amount of biogas produced for each kilogram of surplus lettuce input, Equation 1, adapted from Eriksson, Strid and Hansson (2015) was implemented. The biogas yield from anaerobic digestion was calculated considering 3.9% as the proportion of volatile solids (VS) in raw lettuce, and the biogas production factor (0.84 m3 Biogas/kg VS), which was obtained experimentally by Zhu, Yogev, Keesman and Gross (2021).

$$Biogas\ Yield = VS * \frac{Nm^3\ CH_4}{kg\ VS} \tag{1}$$

To generate biogas, it was assumed that the facility doesn't rely on heat or electricity to function, based on a commercial biodigester model for the decentralised biogas production (Homebiogas 2023). Moreover, manual unpacking does not require energy in the drying process. The only loss of yield was assumed to be the 3.5% dry matter that ended up in the digestate (Uppsala Vatten 2013). Moreover, the average fugitive emission rate was considered as 3.1% of the CH4 gas production rate (Flesch, Desjardins & Worth 2011). The anaerobic digestion's biogas composition is assumed to be of 59% CH_4 and 41% CO_2, as the composition obtained by Zhu et al. (2021) for the same AD system as the one proposed. Emissions from biogas burning in domestic activities was calculated through stoichiometry to achieve complete methane combustion into CO_2 (Dubrovskis & Plume 2017).

For the calculations of the system expansion of avoided products, it was considered that the raw biogas, with an energy content of 6.5 kWh/m3 (Swedish Gas Technology Centre Ltd - SGC 2012), replaces LPG, which has an energy content of 12.91 kWh/kg. The amount of fertiliser substituted was calculated based on the nitrogen content of each food product. For this case scenario, the emissions from the stabilisation of such digestate are negligible. According to Zhu et al. (2021), lettuce waste presents a nitrogen content of 3.86% and 0.84% of phosphorus per dry weight. As for the contributions of digestate to GHG emissions, it was considered an emission factor of 1.5% of N applied with the digestate, reacting into N_2O, a powerful GHG (Tonini, Hamelin, Wenzel & Astrup 2012).

7.2.4 Composting

In the city of the case study, it was a common practice to leave the surplus lettuce on the soil to take advantage of the nutrients remaining in the disposed vegetable. The most similar scenario in this case would be a windrow composting. In the composting scenario, it was assumed that the process is conducted manually without requiring pumping or mixing energy. Approximately 30% of the dry portion of the surplus lettuce input is transformed into the final organic fertiliser yield (Nilsson 2013; Plazzotta, Cottes, Simeoni & Manzocco 2020). Emission factors associated with this process itself are outlined in Table 7. No additional water requirement was accounted for in this scenario due to lettuce's high-water content. In this scenario, it was assumed that the produced compost will replace an equivalent quantity of organic fertilisers, determined by their nitrogen and phosphate content. Avoided fertiliser quantities are calculated based on the nitrogen and phosphates content in the compost, as done for the AD scenario.

Table 7. Process Inventory for the composting of 1 kg of lettuce waste.

Inputs	**Value**	**Units**	**Comment**	**Source**
Transportation from retail	0.012425	tkm	Transportation from the retail, back to the farm in a non-refrigerated truck.	(Maps 2023)
Outputs	**Value**	**Units**	**Comment**	**Source**
Organic Compost	30	%	Based on dry organic waste basis	Nilsson (2013); (Plazzotta et al. 2020)
CO2 emissions	0.134	kg/kg	Based on dry organic waste basis	Fei, Jia, Chen and Ling (2022)
CH4 emissions	0.000063	kg/kg	Based on dry organic waste basis	Fei et al. (2022)
N2O emissions	0.000022	kg/kg	Based on dry organic waste basis	Fei et al. (2022)

7.2.5 Landfilling

Although landfilling is not a common practice among producers in the case study, it was analysed as a reference to study the suitability of more spread practices such as donation for animal feed and open-air composting. In the scenario involving landfilling of 1 kg of surplus lettuce, the waste management process was simulated as a sanitary landfill on SimaPro. At the landfill, energy consumption resulting from landfill operations was modeled using EcoInvent database, incorporating Brazilian data for low-voltage energy consumption in the south-eastern region. The calculated average distance between retail stores, where products are returned to the producer and subsequently to the local landfill, is 4.44 km. The landfill itself is located within the city limits.

Within this framework, food waste deposited in landfills undergoes anaerobic digestion by microbes, leading to the production of methane—a potent greenhouse gas. An assumption was made that 15% of produced methane would be captured in a methane capturing facility to mitigate the impact of the methane release (Björklund 1998) at the landfill and then oxidised into carbon dioxide, assuming a flare efficiency of 100%. This facility's primary focus is on mitigating methane levels that can pose risks within landfills and serves as a viable alternative to energy recovery plants, which are scarce in the country. (de Azevedo et al. 2018; Gutierrez-Gomez, Gallego, Palacios-Bereche, Tofano de Campos Leite & Pereira Neto 2021). As for the emissions by the use of fuel in machinery for maintaining and compacting the landfill, these were assumed to be 14 g CO2e/kg food waste, as reported by (Eriksson, Strid & Hansson 2015).

7.3 Results and Discussion – Life Cycle Impact Assessment

According to the standard ISO 40040:2006, the Life Cycle Impact Assessment (LCIA) aims to understand and evaluate the magnitude of the potential environmental impacts of a product and the processes involved (ISO 2006). In that regard, this section presents the study results and interpretation as a function of the Global Warming impact category.

Among the five scenarios explored, a clear trend emerged in the reduction of greenhouse gas emissions within alternatives with higher priority levels in the food waste hierarchy, such as prevention and donation for animal feed. Moreover, alternatives for resource recovery such as anaerobic digestion and composting, presented similar performance in terms of carbon footprint. Lastly, from all the waste management alternatives, landfill showed to generate the highest carbon footprint, as evidenced in Table 8.

In Figure 6, it can be seen the significant difference between food waste prevention and landfilling (0.488 kg CO2eq). Furthermore, the similarities between the environmental impact of animal feed production and anaerobic digestion can be observed.

Table 8. The greenhouse gas emissions associated with each waste management strategy.

Unit	Source Reduction (prevention)	Animal feed Production	Anaerobic Digestion	Composting	Landfilling
kg CO_{2eq}	-0.065	-0.013	0.019	0.006	0.423

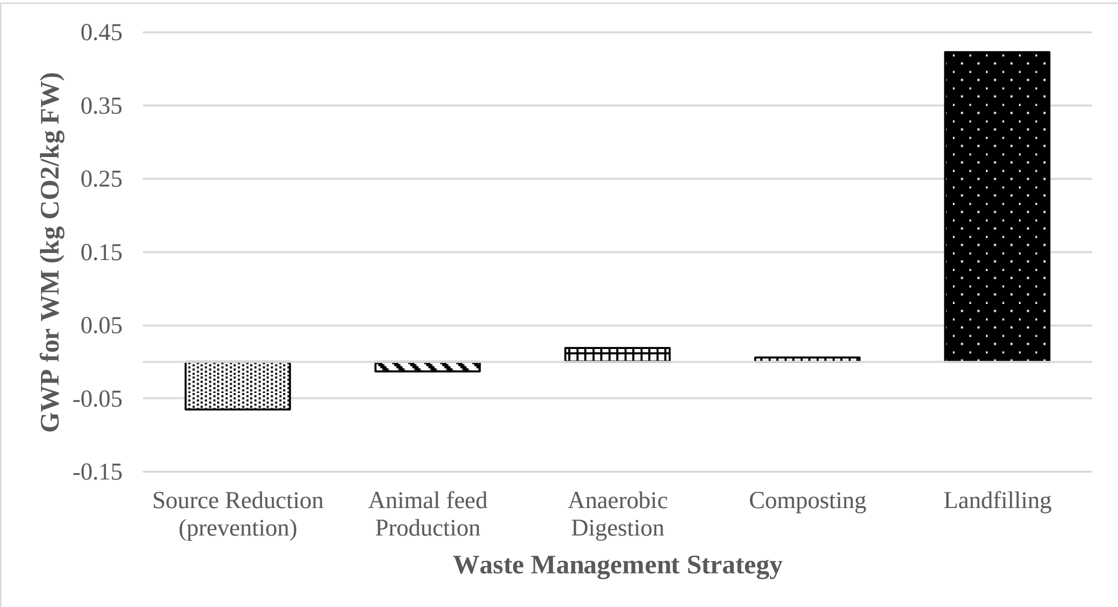

Figure 6. Contribution to Global Warming, in terms of CO2eq, for each Waste Management Strategy.

7.3.1 Environmental impact of the waste management strategies

As expected from the waste management hierarchy, Table 8 shows prevention as the best alternative in the Brazilian context, resulting in the prevention of 0.065 kgCO2eq per kg of lettuce avoided. This emission factor is comparable to the emission factor found in the literature, ranging from 0.02 to 0.50 kg CO2eq/kg of product loss (de Brito Nogueira et al. 2020). When examining the process contribution for this alternative, it is noteworthy that emissions hotspots from lettuce production primarily arise from the avoidance of the use of fertilisers.

Regarding animal feed production, this waste management approach was the most effective for post-production waste. It reduces the demand for industrialised animal feed production, curbing the emission of 0.013 kg CO2eq per kg of lettuce. Manual tasks and minimal transportation contribute to its low carbon footprint. Moreover, this alternative's nutritional value could be enhanced by solar-powered drying tunnels, offering potential benefits like reduced feeding costs and an added revenue stream (Mahgoub, Kadim, Eltahir, Al-Lawatia & Al-Ismaili 2018).

Anaerobic digestion in the case study showed a positive environmental impact, when producing non-upgraded biogas for domestic use. The overall carbon footprint was 0.019 kgCO2eq/kg waste, surpassing Swedish values of -0.047 kg CO2eq/kg for the production of upgraded biogas in a centralised facility (Eriksson, Strid & Hansson 2015). Within the case study context, small-scale biodigesters were considered. Anaerobic digestion, although presenting a waste management alternative to composting or even landfilling, exhibits operational inefficiencies related to the quality of the methane obtained for domestic purposes, with a lower methane content, when compared to upgraded biogas. Although in this context, biogas use for domestic purposes needs refinement, its adoption marks initial progress in decentralised organic waste treatment, offering an economically viable solution for resource recovery for producers.

In the composting scenario, a positive carbon footprint of 0.019 kg CO2eq/kg of lettuce was observed, which is notably lower than the 0.043 kg CO2eq/kg of lettuce reported by Eriksson, Strid and Hansson (2015), which can be attributed to the predominance of manual operations in small-scale farming in the Brazilian context. Therefore, this alternative shows to be as a cost-effective choice for food waste management, operating without the need for electricity.

Transport, heavily reliant on fossil fuels, significantly increased GHG emissions in scenarios involving animal feed, anaerobic digestion, and composting. This discrepancy arises from nutrient and energy recovery calculations considering only 5.1% of lettuce's dry weight, while transportation emissions were based on the wet weight basis of a raw lettuce, with 96% water.

Finally, the landfill scenario was evidently the least favourable option in terms of the overall carbon footprint generation from surplus lettuce disposal for this case study. This outcome primarily stems from the absence of nutrient or energy recovery, leading to the emission of 0.0397 kg of CO2eq/kg of waste. In this scenario, the pivotal factors influencing the alternative's carbon footprint are transportation and the diesel consumption of waste collection vehicles.

7.3.2 Attributional Approach

An attributional approach via system expansion was applied to four waste treatment scenarios: source reduction, animal feed production, anaerobic digestion, and composting. This analysis highlights the positive impact of product substitution in reducing carbon footprints through energy and nutrient recycling.

In the source reduction context, the study found significant emissions reduction by avoiding energy-intensive practices in cultivating and irrigating 1 kg of lettuce. Substantial carbon reduction occurred in animal feed production by partially substituting industrialised feed, which carries higher environmental costs in manufacturing and transportation. The system expansion for anaerobic digestion demonstrated carbon reduction by avoiding fossil fuel production and combustion, especially in household cooking using liquefied petroleum gas (LPG) in Brazil. Finally, in the composting scenario, nutrient recycling, particularly nitrogen and phosphorus, not only lowers carbon footprints but also reduces farmers' reliance on expensive fertilisers.

8. Conclusions – Food Loss and Waste of Leafy Vegetables

The comprehensive literature review on FLW in Latin America revealed various causes of FLW occurring at different stages of the FSC. Inadequate handling, packaging, transportation, and challenges related to adverse weather conditions and strict quality standards were among the key factors contributing to FLW in this context. These studies also highlighted issues with planning, logistics, infrastructure, and technology that played significant roles in food wastage. Interestingly, some causes of FLW were not confined to specific phases of the FSC; for instance, the lack of skilled labour and strict visual quality standards were found to have origins at both the post-harvest and retail levels. This underscores the importance of a multistakeholder approach to addressing FLW effectively. Furthermore, the literature review and case study highlight a crucial finding: a substantial portion of the influence on FLW originates from the retail sector and is subsequently transferred to the producer, challenging the belief that FLW is primarily related to the production phase (Gustavsson et al. 2011).

The structured analysis of risk factors using methods like the "Five Whys," Interrelationship Diagram, and Current Reality Tree established priorities for mitigation measures. Root causes analysed in the case study included take-back agreement conditions and the lack of supportive policies and incentives toward FLW reduction. Major causes, influencing into multiple risk factors simultaneously, comprised the lack of preparation for adverse weather conditions, lack of skilled labour, and strict visual quality standards. Addressing these factors requires policy interventions and collaboration among stakeholders and will effectively tackle the FLW issue in the context of the case study. For this reason, the study proposed specific measures to address the root causes of FLW, encompassing fair trade agreements, policy enhancements, protective measures for producers, skill development, and flexible standards.

Finally, the study evaluated the environmental impact of waste management strategies, whenever food waste is unavoidable. The Life Cycle Assessment provided valuable insights into the environmental consequences of diverse food waste management strategies, particularly in relation to their impact on global warming. The outcomes of the Life Cycle Impact Assessment underscored the positive effects of prioritising source reduction (prevention) and utilising surplus lettuce for animal feed, resulting in the most favourable emissions reductions within the study's scope: -0.065 kg CO2eq and -0.013 kg CO2eq, respectively. Conveniently, animal feed is the most common practice among producers in the case study. The third most favourable option was composting, exhibiting a carbon footprint of 0.006 kg CO2eq. Although frequently employed by local producers, this approach does not strictly adhere to the principles of optimal food composting practices, thereby suggesting potential for enhancing nutrient recycling. Moreover, while anaerobic digestion was still preferable over landfilling, the impact is still positive when discounting the substituted products from the system expansion, resulting in an overall carbon footprint of 0.019 CO2eq/kg. Comparing this anaerobic digestion process with other LCA studies underscores the potential for enhancing environmental performance and creating a viable business opportunity through biogas upgrade. Finally, as expected from the waste management hierarchy, the landfilling scenario was the least preferred alternative for the waste management of surplus lettuce, with a carbon footprint of 0.423 kg CO2eq/kg.

In conclusion, the LCA underscores key implications for enhancing food waste management strategies, whenever source reduction can't be achieved due to external factors. The LCIA outcomes emphasise the priorisation of source reduction and sustainable utilisation pathways, such as animal feed production, for substantial carbon footprint reduction. Moreover, the use of local data is crucial due to the interrelation between waste management methods and environmental outcomes.

References

ABRAS (2022). *Fórum de Eficiência Operacional*. https://static.abras.com.br/pdf/eficiencia-operacional-2022.pdf?a

ABRELPE (2012). Panorama dos resíduos sólidos no Brasil. *São Paulo: Grappa*.

Aliotte, J. T. B., Filassi, M. & Oliveira, A. L. R. d. (2021). Caracterização da logística de distribuição de frutas, legumes e verduras na Central de Abastecimento de Campinas/SP. *Revista de Economia e Sociologia Rural*, 60.

Araujo G. P. de; Lourenço, C. E. A., C. M. L. de; Bastos, A (2018). *Intercâmbio Brasil-União Europeia sobre desperdício de alimentos: relatório final.* (Diálogos Setoriais União Europeia-Brasil. Brasília, DF. https://ainfo.cnptia.embrapa.br/digital/bitstream/item/192093/1/Relatorio-semdesperdicio.pdf

Björklund, A. (1998). *Environmental systems analysis waste management: with emphasis on substance flows and environmental impact.* Diss. KTH.

Brancoli, P., Makishi, F., Lima, P. G. & Rousta, K. (2022). Compositional Analysis of Street Market Food Waste in Brazil. *Sustainability,* 14(12), p. 7014.

Brassard, M. & Ritter, D. (1994). *The memory jogger II: A pocket guide of tools for continuous improvement & effective planning.* Goal/Qpc.

Bustos, C. A. & Moors, E. H. (2018). Reducing post-harvest food losses through innovative collaboration: Insights from the Colombian and Mexican avocado supply chains. *Journal of Cleaner Production,* 199, pp. 1020-1034.

Câmara Municipal da Estância Turística de Tupã (2023). *Dados do Município*. https://www.camaratupa.sp.gov.br/Pagina/Listar/353

Colombo, C., de Oliveira, F. H., Lago, A., da Silva, A., Delai, I. & Pereira, C. R. (2022). Causes and prevention practices of food waste in fruit and vegetable supply chains: How is Brazil dealing with these issues? *Waste Management*, 154, pp. 320-330.

Colombo, C., de Oliveira, F. H., Pereira, C. R., da Silva, A. & Delai, I. (2020). Retail food waste: mapping causes and reduction practices. *Journal of Cleaner Production*, 256, p. 120124.

Cunha, C. F. d., Saes, M. S. M. & Mainville, D. Y. (2015). Transaction and measurement cost in the governance structure chosen between supermarkets and conventional and organic producers in Brazil and in the USA. *Gestão & Produção,* 22, pp. 67-81.

Dal'Magro, G. P. & Talamini, E. (2019). Estimating the magnitude of the food loss and waste generated in Brazil. *Waste Management & Research*, 37(7), pp. 706-716.

de Azevedo, T. R. et al. (2018). SEEG initiative estimates of Brazilian greenhouse gas emissions from 1970 to 2015. *Scientific Data,* 5(1), p. 180045. doi:10.1038/sdata.2018.45

de Brito Nogueira, T. B., da Silva, T. P. M., de Araújo Luiz, D., de Andrade, C. J., de Andrade, L. M., Ferreira, M. S. L. & Fai, A. E. C. (2020). Fruits and vegetable-processing waste: a case study in two markets at Rio de Janeiro, RJ, Brazil. *Environmental Science and Pollution Research*, 27, pp. 18530-18540.

de Moraes, C. C., de Oliveira Costa, F. H., Roberta Pereira, C., da Silva, A. L. & Delai, I. (2020). Retail food waste: mapping causes and reduction practices. *Journal of Cleaner Production*, 256, p. 120124. doi:https://doi.org/10.1016/j.jclepro.2020.120124

de Moraes, C. C. & de Souza, T. A. (2018). Panorama Mundial do Desperdício e Perda de Alimentos no Contexto de Cadeias de Suprimentos Agroalimentares. *Revista em Agronegócio e Meio Ambiente*, 11(3), pp. 901-924.

de Morais, E. A., Rodrigues, C., Gasparoto, M. & Monteiro, M. (2022). Food waste: an exploratory investigation of causes, practices and consequences perceived by Brazilian supermarkets and restaurants. *British Food Journal,* 124(3), pp. 1022-1045. doi:10.1108/BFJ-01-2021-0045

Departamento Nacional de planeación (2016). *Pérdida y desperdicio de alimentos en Colombia* (Estudio de la Dirección de Seguimiento y Evaluación de Políticas Públicas. Bogotá D.C.

Doggett, M. (2006). Root Cause Analysis: A Framework for Tool Selection. *Mark Doggett,* 12. doi:10.1080/10686967.2005.11919269

Dos Santos, S. F., Cardoso, R. d. C. V., Borges, Í. M. P., e Almeida, A. C., Andrade, E. S., Ferreira, I. O. & do Carmo Ramos, L. (2020). Post-harvest losses of fruits and vegetables in supply centers in Salvador, Brazil: Analysis of determinants, volumes and reduction strategies. *Waste Management,* 101, pp. 161-170.

Dubrovskis, V. & Plume, I. (2017). Biogas potential from damaged bread. *Proceedings of International Conference "Engineering for Rural Development*. pp. 437-442.

Eriksson, M. (2012). Retail food wastage. *A Case Study Approach to Quantities and Causes. Available online: http://pub. epsilon. slu. se/9264/1/eriksson_m_121126. pdf (accessed on 22 January 2015).*

Eriksson, M., Ghosh, R., Mattsson, L. & Ismatov, A. (2017). Take-back agreements in the perspective of food waste generation at the supplier-retailer interface. *Resources, Conservation and Recycling,* 122, pp. 83-93.

Eriksson, M., Strid, I. & Hansson, P.-A. (2015). Carbon footprint of food waste management options in the waste hierarchy–a Swedish case study. *Journal of Cleaner Production,* 93, pp. 115-125.

European Commission. *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste.* Official Journal of the European Union.

Fabi, C. & English, A. (2019). *Methodological Proposal for Monitoring SDG Target 12.3. Sub-Indicator 12.3.1.a The Food Loss Index Design, Data Collection Methods and Challenges*. FAO.

FAO (2015a). *Food Losses And Waste in Latin America and The Caribbean* (Bulletin N° 2.

FAO (2015b). *Food Wastage Footprint & Climate Change*. Rome: FAO.

FAO (2019). *The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction*. Rome. Licence: CC BY-NC-SA 3.0 IGO.

Fehr, M. & Romão, D. C. (2001). Measurement of Fruit and Vegetable Losses in Brazil: A Case Study. *Environment, Development and Sustainability,* 3(3), pp. 253-263. doi:10.1023/A:1012773330384

Fei, X., Jia, W., Chen, T. & Ling, Y. (2022). Life cycle assessment of food waste anaerobic digestion with hydrothermal and ionizing radiation pretreatment. *Journal of Cleaner Production,* 338, p. 130611. doi:https://doi.org/10.1016/j.jclepro.2022.130611

Fiol, C. & Huff, A. (2007). Maps for Managers: Where Are We? Where Do We Go from Here? *Journal of Management Studies,* 29, pp. 267-285. doi:10.1111/j.1467-6486.1992.tb00665.x

Flanagan, K., Robertson, K. & Hanson, C. (2019). Reducing food loss and waste. *Setting the Global Action Agenda*.

Flesch, T. K., Desjardins, R. L. & Worth, D. (2011). Fugitive methane emissions from an agricultural biodigester. *Biomass and Bioenergy,* 35(9), pp. 3927-3935. doi:https://doi.org/10.1016/j.biombioe.2011.06.009

Forgiarini, R. & Lamberts, R. (2017). *Relatório: Fatores de conversão de energia elétrica e térmica em energia primária e em emissões de dióxido de carbono a serem usados na etiquetagem de nível de eficiência energética de edificações*. Florianópolis.

French, M. L. & LaForge, R. L. (2006). Closed-loop supply chains in process industries: An empirical study of producer re-use issues. *Journal of Operations Management,* 24(3), pp. 271-286.
Gillman, A., Campbell, D. C. & Spang, E. S. (2019). Does on-farm food loss prevent waste? Insights from California produce growers. *Resources, Conservation and Recycling,* 150, p. 104408.
Guarnieri, P., de Aguiar, R. C., Thomé, K. M. & Watanabe, E. A. d. M. (2021). The Role of Logistics in Food Waste Reduction in Wholesalers and Small Retailers of Fruits and Vegetables: A Multiple Case Study. *Logistics,* 5(4), p. 77.
Guide Jr, V. D. R. & Van Wassenhove, L. N. (2009). OR FORUM—The evolution of closed-loop supply chain research. *Operations research,* 57(1), pp. 10-18.
Gunady, M. G., Biswas, W., Solah, V. A. & James, A. P. (2012). Evaluating the global warming potential of the fresh produce supply chain for strawberries, romaine/cos lettuces (Lactuca sativa), and button mushrooms (Agaricus bisporus) in Western Australia using life cycle assessment (LCA). *Journal of Cleaner Production,* 28, pp. 81-87.
Gustavsson, J., Cederberg, C., Sonesson, U., Van Otterdijk, R. & Meybeck, A. (2011). Global food losses and food waste. In.: FAO Rome.
Gutierrez-Gomez, A. C., Gallego, A. G., Palacios-Bereche, R., Tofano de Campos Leite, J. & Pereira Neto, A. M. (2021). Energy recovery potential from Brazilian municipal solid waste via combustion process based on its thermochemical characterization. *Journal of Cleaner Production,* 293, p. 126145. doi:https://doi.org/10.1016/j.jclepro.2021.126145
Henz, G. P. (2017). Postharvest losses of perishables in Brazil: what do we know so far? *Horticultura Brasileira,* 35, pp. 6-13.
Herrera-Quinteros, G. & Jara-Rojas, R. (2023). Food losses perceived by family farms: Challenges and policy implications from a micro-approach quantification. *Frontiers in Sustainable Food Systems,* 6. doi:10.3389/fsufs.2022.961120
HLPE (2014). *Report Nr. 8. Food Losses and Waste in the Context of Sustainable Food Systems*. Rome: FAO.
Homebiogas (2023). *Homebiogas 6*. https://www.homebiogas.com/product/homebiogas-6/
IBGE (2022). *Tupã*. https://cidades.ibge.gov.br/brasil/sp/tupa
Ismael, R. K. (2023). Quantification of food waste in retail operations: A fruit and vegetable wastage case in Paraguay. *Environmental Challenges,* 10, p. 100665.
ISO (2006). *ISO 40040:2006. Environmental management — Life cycle assessment — Principles and framework.*
Jenkins, M. & Johnson, G. (1997). Entrepreneurial Intentions and Outcomes: a Comparative Causal Mapping Study. *Journal of Management Studies,* 34(6), pp. 895-920. doi:https://doi.org/10.1111/1467-6486.00077
Kummu, M., de Moel, H., Porkka, M., Siebert, S., Varis, O. & Ward, P. J. (2012). Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. *Science of The Total Environment,* 438, pp. 477-489. doi:https://doi.org/10.1016/j.scitotenv.2012.08.092
Lana, M. & Moita, A. (2020). Qualidade visual e perdas pós-colheita de hortaliças folhosas no varejo: dois estudos de caso no Distrito Federal, Brasil.
Lana, M. M. (2020). *Reflexões sobre perdas pós-colheita na cadeia produtiva de hortaliças* Brasília, DF: Embrapa.
Lana, M. M. & Moita, A. W. (2019). Visual quality and waste of fresh vegetables and herbs in a typical retail market in Brazil. *Horticultura Brasileira,* 37, pp. 161-171.

Mahgoub, O., Kadim, I. T., Eltahir, Y., Al-Lawatia, S. & Al-Ismaili, A. M. (2018). Nutritional value of vegetable wastes as livestock feed. *Sultan Qaboos University Journal for Science [SQUJS]*, 23(2), pp. 78-84.

Maps, G. (2023).

Matzembacher, D. E., Vieira, L. M. & de Barcellos, M. D. (2021). An analysis of multi-stakeholder initiatives to reduce food loss and waste in an emerging country–Brazil. *Industrial Marketing Management*, 93, pp. 591-604.

Mena, C., Adenso-Diaz, B. & Yurt, O. (2011). The causes of food waste in the supplier–retailer interface: Evidences from the UK and Spain. *Resources, Conservation and Recycling*, 55(6), pp. 648-658.

Mena, C., Terry, L. A., Williams, A. & Ellram, L. (2014). Causes of waste across multi-tier supply networks: Cases in the UK food sector. *International Journal of Production Economics*, 152, pp. 144-158.

Merriam Webster Dictionary *'Risk Factor'*. https://www.merriam-webster.com/dictionary/risk%20factor

Mustelier, M. R. & Lorenzo, D. R. V. (2021). Pérdidas y desperdicios de alimentos en un mercado de la ciudad de Santiago de Cuba. *Revista Metropolitana de Ciencias Aplicadas*, 4(S1), pp. 43-50.

Nilsson, H. (2013). *Integrating Sustainability in the Food Supply Chain : Two Measures to Reduce the Food Wastage in a Swedish Retail Store.* Diss. http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-194122

Notarnicola, B., Sala, S., Anton, A., McLaren, S. J., Saouter, E. & Sonesson, U. (2017). The role of life cycle assessment in supporting sustainable agri-food systems: A review of the challenges. *Journal of Cleaner Production*, 140, pp. 399-409. doi:https://doi.org/10.1016/j.jclepro.2016.06.071

Our World in Data (2016). *Emissions by sector*. https://ourworldindata.org/emissions-by-sector

Papargyropoulou, E., Lozano, R., K. Steinberger, J., Wright, N. & Ujang, Z. b. (2014). The food waste hierarchy as a framework for the management of food surplus and food waste. *Journal of Cleaner Production*, 76, pp. 106-115. doi:https://doi.org/10.1016/j.jclepro.2014.04.020

Parfitt, J., Barthel, M. & Macnaughton, S. (2010). Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical transactions of the royal society B: biological sciences*, 365(1554), pp. 3065-3081.

Péra, T. G., Gameiro, A. H., Bacchi, D., Rocha, F. V. & Caixeta, J. V. (2015). An overview of the state-of-art of post-harvest losses in Brazil. *First International Congress on Postharvest Loss Prevention*, Rome. ADM Institute for the Prevention of Postharvest Loss. University of Illinois, Urbana-Champaign.

Pimentel, B. F., Misopoulos, F. & Davies, J. (2022). A review of factors reducing waste in the food supply chain: the retailer perspective. *Cleaner Waste Systems*, p. 100028.

Plazzotta, S., Cottes, M., Simeoni, P. & Manzocco, L. (2020). Evaluating the environmental and economic impact of fruit and vegetable waste valorisation: The lettuce waste study-case. *Journal of Cleaner Production*, 262, p. 121435. doi:https://doi.org/10.1016/j.jclepro.2020.121435

Porat, R., Lichter, A., Terry, L. A., Harker, R. & Buzby, J. (2018). Postharvest losses of fruit and vegetables during retail and in consumers' homes: Quantifications, causes, and means of prevention. *Postharvest Biology and Technology*, 139, pp. 135-149. doi:https://doi.org/10.1016/j.postharvbio.2017.11.019

Romero-Gámez, M., Audsley, E. & Suárez-Rey, E. M. (2014). Life cycle assessment of cultivating lettuce and escarole in Spain. *Journal of cleaner production*, 73, pp. 193-203.

Schlag, N. & Zuzarte, F. (2008). *Market Barriers to Clean Cooking Fuels in Sub-Saharan Africa: A Review of Literature*. Sweden.

Secretaria de Estado de Meio Ambiente, D., Ciência, Tecnologia e Inovação - SEMADESC, (2015). *Alimentação para Galinhas – Dicas e Cuidados Importantes*. https://www.semadesc.ms.gov.br/alimentacao-para-galinhas-dicas-e-cuidados-importantes/

Serrat, O. (2017). The Five Whys Technique. *Knowledge Solutions: Tools, Methods, and Approaches to Drive Organizational Performance.* Singapore: Springer Singapore, pp. 307-310. doi:10.1007/978-981-10-0983-9_32

Strid, I. & Eriksson, M. (2014). Losses in the supply chain of Swedish lettuce–wasted amounts and their carbon footprint at primary production, whole sale and retail. *The 9th International Conference on LCA in the Agri-Food Sector, San Francisco*.

Surucu-Balci, E. & Tuna, O. (2021). Investigating logistics-related food loss drivers: A study on fresh fruit and vegetable supply chain. *Journal of Cleaner Production*, 318, p. 128561.

Swedish Gas Technology Centre Ltd - SGC (2012). *Basic Data on Biogas*. Lund.

Tabela Brasileira de Composição de Alimentos - TBCA (2023). *Composição de Alimentos - Alface Americana*. http://www.tbca.net.br/base-dados/int_composicao_alimentos.php?cod_produto=C0063B

Taelman, S. E., Tonini, D., Wandl, A. & Dewulf, J. (2018). A Holistic Sustainability Framework for Waste Management in European Cities: Concept Development. *Sustainability*, 10(7), p. 2184.

Texas Institute for Applied Environmental Research - TIAER Dairy Manure and Effluent as Phosphorus Fertilizer.

Tonini, D., Hamelin, L., Wenzel, H. & Astrup, T. (2012). Bioenergy production from perennial energy crops: a consequential LCA of 12 bioenergy scenarios including land use changes. *Environmental science & technology*, 46(24), pp. 13521-13530.

UN DESA (2021). *Global Population Growth and Sustainable Development*. UN DESA/POP/2021/TR/NO. 2.

UN General Assembly. *Transforming our world: the 2030 Agenda for Sustainable Development, 21 October 2015, A/RES/70/1.* https://www.refworld.org/docid/57b6e3e44.html

UNEP (2021). *Food Waste Index Report 2021 - Appendix.* https://wedocs.unep.org/20.500.11822/35356

Uppsala Vatten (2013). *Environmental report 2013 for the biogas plant at Kungsangens gard*. Uppsala.

Vilela, N. J., Lana, M. M., do Nascimento, E. F. & Makishima, N. (2003). Perdas na comercialização de hortaliças em uma rede varejista do Distrito Federal. *Cadernos de Ciência & Tecnologia*, 20(3), pp. 521-541.

Zhu, Z., Yogev, U., Keesman, K. J. & Gross, A. (2021). Onsite anaerobic treatment of aquaponics lettuce waste: digestion efficiency and nutrient recovery. *Aquaculture International*, 29(1), pp. 57-73. doi:10.1007/s10499-020-00609-x

APPENDIX 1 – Food Loss and Waste Causes Check List – Producers

Retail

Stage of the FSC	Cause	Check	Interviewer's Grade	Observations
Harvest	Unskilled workers take care of the harvest			
	Handling is rough or inadequate			
	There is no use of accessories such as gloves, knives and scissors			
	Harvesting is not done using containers owned by the producer			
	The collection is done in inadequate containers			
	The boxes are not clean			
	Harvesting boxes do not have a uniform surface			
	The containers stack is done incorrectly			
	The harvest is done in the hottest hours of the day (09:00-16:00)			
	At this stage products are trimmed			
Transfering	Handling is rough or improper			
	Measures to prevent sweating and water loss are not taken			
	Internal roads are not in proper condition			
	The internal transfer of the product is done in an outdoor vehicle			
	The transfer is made in a vehicle owned by a third party			
	The transfer is done in a container owned by a third party			
	Transfer boxes are not clean			
	At this stage products are trimmed			
	Handling is not done immediately after harvesting			
Handling	handling is not done in the shade			
	The stacking of the boxes is done improperly during handling			
	Handling is crude or inadequate			
	Handling does not include cleaning/washing with drinking water			
	The handling is done in a place exposed to strong winds			
	Handling includes selection and sorting			
	Product is not refrigerated before deliver (wherever there are long waiting times)			
	At this stage products are trimmed			
	The cold chain procedure is non-existent or not up to date			
Packaging	Handling is rough or improper			
	There is presence of Handling sheds			
	Packaging is done using third-party containers			
	Packing boxes are made of an unsuitable material, such as wood			
	The packaging allows perspiration and water loss			
	Product has low visual quality after packaging			
	The packaging boxes do not have standardised sizes and formats			
	At this stage products are trimmed			
	The transport is done in the vehicle of third parties			
Transportation	Handling is rough or inadequate			
	The transport is not done in a container owned by the producer			
	Transport containers are not clean			
	Transport vehicles are not clean			
	The transport of vegetables is done close to climacteric fruits*			
	There are no adequate cooling systems in transport vehicles			
	At this stage products are trimmed			

Grade	Equivalence	Description
A	Excellent	Does not imply a cause for FLW
B	Outstanding	There is room for improvement
C	Average	Represents a risk of becoming a cause of FLW
D	Below average	Significant changes are needed. May imply a cause of FLW
E	Deficient	It is more likely to be a cause for FLW

* Climacteric products: avocado, apricot, pinecone, plum, kiwi, apple, melon, peach, pear, banana, tomato and watermelon

APPENDIX 2 – Food Loss and Waste Causes Check List – Retailers

Producers

Stage of the FSC	Cause	Check	Interviewer's Grade	Observations
Transport	The transport is done in the vehicle of third parties			
	Handling is rough or improper			
	The transport is done in a container owned by the producer			
	Transport containers are not clean			
	Transport vehicles are not clean			
	There are no adequate cooling systems in transport vehicles			
	At this stage products are trimmed			
Storage	Handling during loading/unloading is rude or improper			
	Temperature is not controlled			
	Relative humidity is not controlled			
	Ventilation is not controlled			
	Storage space is not clean			
	Storage conditions are not controlled			
	Controlled atmosphere is not implemented**			
	The packaging allows perspiration and water loss			
	Storage is done near or near climacteric fruits**			
	There are visual defects in the product related to low temperature			
	Low visual quality is observed during storage			
	There is extended storage time			
	At this stage products are trimmed			
Commercialisation	The treatment of the product by the customer is rough or inadequate			
	The handling of products by workers is rough or inadequate			
	The commercialisation is done by the producer			
	Commercialisation is done by an intermediary			
	Commercialisation is done by the retailer			
	There are no defined functions for receiving, loading, unloading, managing, and			
	There are no set of formal guidelines for returning or rejecting the product upon arrival			
	Good practices of handling techniques are unknown			
	Good practices of handling techniques are not implemented			
	Unsold product returns to producer			
	Unsold product is not paid to the producer			
	Products are arranged in a messy way			
	At this stage products are trimmed			

Grade	Equivalence	Description
A	Excellent	Does not imply a cause for FLW
B	Outstanding	There is room for improvement
C	Average	Represents a risk of becoming a cause of FLW
D	Below average	Significant changes are needed. May imply a cause of FLW
E	Deficient	It is more likely to be a cause for FLW

* Climacteric products: avocado, apricot, pinecone, plum, kiwi, apple, melon, peach, pear, banana, tomato and watermelon

** By decreasing the level of O2 and increase CO2 intentionally

APPENDIX 3 – Food Loss and Waste Questionnaire – Producers

Objective: To estimate the proportion of food losses and waste and identify associated risk factors and limitations for producers.

Stage of the AFSC: Harvest and post-harvest **Location:**

Interviewee's name: **Years of experience in this field:**

Number of fix workers: **Number of seasonal workers:**

Activities performed by the producer (e.g.: harvesting/packaging/storage/etc.):

____

____

____

Vegetables produced.

N°	Product	Commercialised
1	Kale	
2	Lettuce	
3	Parsley	
4	Scallion	
5	Cabbage	
6	Spinach	
7	Mustard	
8	Arugula,	
9	Cress,	
10	Taioba	
11	Other	

Distribution Channels

Distribution Channel*	Product Sold (units)	% Sold per distribution channel

** F: Food Industry, I: intermediary, W: wholesale market, IN: informal channels, R: retail, O: other.*

1. *Sales and management information*

a) Do you keep "production records"? Yes: ____ No: ____

b) Do you keep financial records? Yes: ____ No: ____

c) Do you keep records of food losses? Yes: ____ No: ____

d) Do you train your fixed and seasonal employees in harvesting? Yes: ____ No: ____

e) Select the type of contract(s) with clients

Purchase and sale: ____

Supply contract: ____

Partnership: ____

Take-back Agreement: ____

Other: ____

Describe the type of commercial agreement, if other:

____
____
____

2. *Production information (if marked yes on questions a and b)*

f) Please specify further information about your last month's production. (max. 5)

Month	Product	Production (unit)

3. *Information on Food Loss and Waste**

Food loss and waste: *product surplus, the proportion of harvested product that becomes not suitable for commercialisation, products returned due to retail expectations and requirements.*

g) From the different distribution channels, where do you consider that there is the highest and lowest rate of waste and why?

____
____
____

h) *From your perspective, which of the following are important causes for food loss and waste affecting your business? If there is more than one reason, assign a number from 1 to 3. 1=very important; 2=important; 3=less important)*

Causes	Relevance
Inadequate handling (producers/vendors/consumers)	
Inadequate packaging	
Inadequate transportation/conditions of the vehicles	

Poor planning and accounting	
Inadequate storage (refrigerated conditions)	
Unpreparedness for adverse environmental/weather conditions/plagues	
Quality/cosmetic standards	
Inadequate storage	
Delay between buying and selling / short shelf-life	
Lack of proper training for vendors and staff	
Inadequate conditioning and conservation of the product	
External factors (roads infrastructure)	
Lack of incentives/certifications	
Communication issues	
Inadequate harvesting techniques	
Economic decisions	
Inadequate display or shelving	
Lack of involvement of the producers in the transportation	
Lack of technological resources	
Inefficient marketing strategies	
Labour Shortage	
Water availability	
Other, which one?	

i) What do you do with the part of the production that may be edible, but is not sold for human consumption? (mark with an x, you can select more than one answer)

Sold as animal feed	
It is intended for self-consumption	
Donate it to friends/family	
Leave it on the soil	
Donate it to an NGO	
Other	

j) The reason for managing losses in this way is mainly: (mark with an x, you can select more than one answer)

It is easier	
It is cheaper	
I saw it on the web	
It was recommended by a friend or neighbor	
It was recommended by a producer or an organisation	
It was recommended by an advisor	
Other	

4. Food Losses and Waste Knowledge and awareness

k) Do you have any internal certification? Yes: ____ No: ____

l) Do you have any external certification? Yes: ____ No: ____

Describe briefly:

____
____
____

m) Have you received some training or information about Food Loss and Waste? (Mark with an x)

I have received training about it	
I have received just related information	
I have limited knowledge about some of the concepts	
The topic has come up during a conversation	
I have no knowledge in the topic	

n) Select the motivation to reduce Food Loss and Waste in your business (Mark with an x, you can select more than one answer)

Environmental pollution	
Economic loss	
Waste Management issues	
Yield reduction	
Food security	
Other	

In my opinion, Food Loss and Waste are not an issue for my business _____

o) Mention the good practices that you implement to reduce Food Losses and Waste

____
____
____

p) Mention the good practices that you wish you could implement to reduce Food Losses and Waste

____
____
____

q) In your opinion, what are the main obstacles or barriers to implementing these best practices?

____
____
____

APPENDIX 4 – Food Loss and Waste Questionnaire – Retailers

Objective: To estimate the proportion of food losses and waste and identify associated risk factors and limitations for retailers.

Stage of the AFSC: Commercial distribution. **Location:**

Interviewee's name: **Years of experience in this field:**

Number of fix workers: **Number of seasonal workers:**

Activities performed by the retailer (e.g.: harvesting/ packaging/ transportation/ storage /etc.)

____
____
____

Vegetables commercialised.

N°	Product	Commercialised
1	Kale	
2	Lettuce	
3	Parsley	
4	Scallion	
5	Cabbage	
6	Spinach	
7	Mustard	
8	Arugula,	
9	Cress,	
10	Taioba	
11	Other	

1. Sales and management information

a) Do you keep "sales records" for leafy vegetables? Yes: ____ No: ____

b) Do you train your fix and seasonal employees in food handling. Yes: ____ No: ____

c) Whenever you reject a product from the supplier, is this based on: A guideline: ____
The Manager's experience: ____
The employee's experience: ____
Other: ____

d) Select the type of contract(s) with clients Purchase and sale: ____
Supply contract: ____
Partnership: ____

Take-back Agreement: ____

Other: ____

Describe, if other:

____
____
____

e) Production information (if marked yes on questions a and b)

f) Please specify further information about your last month's sales. (max. 5)

Month	Product	Sales (units)

g) Information on Food Loss and Waste*

***Food loss and waste:** product surplus, the proportion of harvested product that becomes not suitable for commercialisation, products returned due to retail expectations and requirements.*

g) In a normal season, how much of your product (estimate) do you lose during the next stages?

___

___

___

h) From your perspective, which of the following are important causes for food loss and waste affecting your business? If there is more than one reason, assign a number from 1 to 3. 1=very important; 2=important; 3=less important)

Causes	Relevance
Inadequate handling (producers/vendors/consumers)	
Inadequate packaging	
Inadequate transportation/conditions of the vehicles	
Poor planning and accounting	
Inadequate storage (refrigerated conditions)	
Unpreparedness for adverse environmental/weather conditions/plagues	
Quality/cosmetic standards	
Inadequate storage	
Delay between buying and selling / short shelf-life	
Lack of proper training for vendors and staff	
Inadequate conditioning and conservation of the product	
External factors (roads infrastructure)	
Lack of incentives/certifications	
Communication issues	
Inadequate harvesting techniques	
Economic decisions	
Inadequate display or shelving	
Lack of involvement of the producers in the transportation	
Lack of technological resources	
Inefficient marketing strategies	

Labour Shortage	
Water availability	
Other, which one?	

i) What do you do with the part of the production that may be edible, but is not sold for human consumption? (Mark with an x, you can select more than one answer)

Sold as animal feed	
Intended for self-consumption	
Give to friends/family	
Donate to an NGO	
Returned to the producer	
Sold in promotion	
Used in cafeteria or own restaurant	
Sold as processed product	
Other	

j) The reason for managing losses in this way is mainly: (you can select more than one answer)

It is easier	
It is cheaper	
I saw it on the web	
It was recommended by a friend or neighbour	
It was recommended by a producer or an organisation	
It was recommended by an advisor	
Other	

k) Food Losses and Waste Knowledge and awareness
l) Do you have any good practices certification? Yes: ____ No: ____

Describe briefly:

____
____
____

m) Have you received some training or information about Food Loss and Waste?

I have received training about it	
I have received just related information	
I have limited knowledge about some of the concepts	
The topic has come up during a conversation	
I have no knowledge in the topic	

Source of the training:

____

n) Select with an x the motivation to reduce Food Loss and Waste in your business.

Environmental pollution	
Economic loss	
Waste Management issues	
Yield reduction	
Food security	
Other	

In my opinion, Food Loss and Waste are not an issue for my business _____

o) Select the good practices that you implement to reduce Food Losses and Waste

____
____
____

p) Mention the good practices that you wish you could implement to reduce Food Losses and Waste

____
____
____

q) In your opinion, what are the main obstacles or barriers to implementing these best practices?

____
____
____

APPENDIX 5 – Methodology created for the elaboration of a causal mapping with interconnected causes.

Step 1: Collect information from various sources, including interviews and on-site observations.

Step 2: Define the specific problem to be addressed or controlled, such as the loss and waste of LV in the FSC.

Step 3: Create a comprehensive list of all the risk factors related to the identified problem found in the case study. Use concise phrases or sentences to represent each factor.

Step 4: Employ the 5 'Whys' approach for each identified risk factor to determine its underlying causes and the reasons behind those causes until reaching the root cause.

Step 5: Write the title of the problem at the top of a blank document or diagram.

Step 6: In the middle of the diagram, draw boxes to represent the risk factors from Step 3.

Step 7: Draw additional boxes to represent the causes and effects of each risk factor. Place the causes beneath the effects, and the root causes at the bottom of the diagram. Connect the boxes with arrows, starting from the causes and ending with the pointed side at the effects.

Step 8: Assess the logic and clarity of each effect and search for causal relationships between two or more boxes. Add more arrows to indicate additional cause-effect relationships as they are discovered.

Step 9: Iteratively review and refine the diagram to identify and isolate critical elements. Note that critical elements refer to risk factors with a significant number of arrows originating from their respective boxes, representing the causes that have the potential to generate multiple effects.

Step 10: Ensure that the diagram includes all relevant factors that may be contributing to the problem. Exclude intermediate factors that do not directly influence the root causes.

Note: In the elaboration of a causal mapping diagram, connecting lines illustrate the relationship between causes. When multiple causes are required to produce a specific effect, the logical operator "AND" is used (Doggett 2006). As demonstrated by Mena, Adenso-Diaz and Yurt (2011), the "AND" operator can be represented by a circle, indicating that all connected causes must be present for the effect to occur.

APPENDIX 6 – Life Cycle Analysis Calculations

Baseline for lettuce

Table 9. Parameters adopted for the Analysis of Alternatives

Parameter (%)	Value adopted
Water Content	94.9
Dry Matter (DM)	5.1
Volatile Solids (VS)	3.9
Nitrogen (N)	3.86
Phosphorus (P)	0.84

Parameters are based on dry matter, except for DM and VS. Source: (Zhu, Yogev, Keesman & Gross 2021).

Transportation from retail – producer (animal feed, anaerobic digestion, and compost.)

Producer P1

Total distance = 11.8 km

Producer P3

Total distance = 9.4 km

Producer P4

Total distance = 8.1 km

Producer P5

Total distance = 10.2 km

Average distance between retailer and producer = (11.8 + 9.4 + 8.1 + 10.2)/4 = 9.875 km

Waste Managament Scenarios

Anaerobic Digestion (AD)

Firstly, the yield of methane production from lettuce waste was calculated using Eq (2), adapted from Eriksson, Strid and Hansson (2015):

$$m3\ CH4 = VS \times \frac{m3\ CH4}{ton\ VS} \tag{2}$$

Values for VS were obtained from Table 9, which was obtained from experimental data and is assumed to be a percentage of the raw lettuce weight.

Specific Biogas Yield for lettuce = 0.84 m^3 /kg VS (Zhu et al. 2021).

Biogas production = 1 kg x 0.039 x 0.840 m^3 Biogas/kg VS = 0.03276 m3 of CH_4 for each tonne of lettuce. The composition of this biogas is 59% of methane volume and 41% CO_2.

Biogas available: considering losses of 3.5% that turn into digestate, and 3,1% of losses during distribution, the volume of biogas available for use will be:

Biogas Available: 0.03276 m3 of CH_4 – (0.03276*0.035)-(0.03276 x 0.031) = 0.03060 m3 of CH_4 available.

<u>Biogas equivalence to LPG:</u>

Energy content Biogas from AD: 6.5 kWh/m3 (Swedish Gas Technology Centre Ltd - SGC 2012)

Energy content LPG: 12.91 kWh/kg (Forgiarini & Lamberts 2017)

Energy generation from 1 kg of lettuce (after losses) = 0.03060 m3 of CH_4 x 6.5 kWh/m3 = 0.19889 kWh

Therefore, for each 1 kg of lettuce digested through AD, 0.19889 kWh of energy will be produced.

1 kg of LPG → 12.91 kWh

X kg of LPG → 0.19889 kWh

X= 0,015405574 kg of LPG

Therefore, for each kg of lettuce digested, 0,015405574 kg of LPG will be substituted.

<u>Combustion of biogas and LPG</u>

To calculate the emissions from the use stage of LPG and Biogas as cooking fuel, the following assumptions were considered:

- The emission factor for the burning of LPG is 2.932 kg CO2/kg LPG (Forgiarini & Lamberts 2017).
- The emissions from burning biogas are calculated assuming total use of the biogas and complete combustion of the biogas as cooking fuel. Therefore, all the methane contained in the biogas produced will be fully oxidised into carbon dioxide, without the formation of products of incomplete combustion.
- Methane conversion to CO_2 is calculated according to the stoichiometry of the reaction of complete methane combustion, as shown in Equation (2).
- Density of Biogas is 1.15 kg/m^3. Density of CH_4 is 0,668 kg/m^3. Density of CO2 is 1.842 kg/m^3.
- Molar Mass of CH_4 is 0.01604 kg/mol and molar mass of CO_2 is 0.04401 kg/mol.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \qquad (2)$$

Biogas available after losses is 0,03059784 m3 of CH_4, from which 0,01811 m3 are CH_4, and 0,01248 m3 are CO_2.

During the biogas cooking, it is assumed that only the methane reacts, density of methane is 0.668 kg/m^3. Therefore, 0,01811 m^3 of methane are equivalent to 0,01210 kg.

0.01604 kg of CH_4 → 0.04401 kg of CO_2

0,01210 kg of CH_4 → X kg of CO_2

Therefore, 0,01210 kg of CH_4 react to produce 0,03319 kg of CO_2. Moreover, 0,02299 kg of CO_2 remain in the combustion emission.

Emissions from leakages are considered as not reactive and are not treated, therefore it is assumed the biogas is directly released in the atmosphere.

Digestate to compost:

The amount of digestate obtained from the AD process is assumed to be 3.5% dry matter (Uppsala Vatten 2013).

The nitrogen and phosphorus content of lettuce, as a proportion of the DM, are presented in Table 9 and then multiplied by the mass of dry matter.

N = 1 kg x 0.051 x 0.0386 = 0,00197 kg

P = 1 kg x 0.051 x 0.0084 = 0.00043x kg

Therefore, each kg of lettuce contains 0,0019686 kg of nitrogen and 0.0004284 kg of phosphorus available, from which 3.5% will end up as digestate. It is assumed that the nutrient use efficiency potential is 100%

However, on SimaPro the phosphorus content of fertiliser is measured as P2O5. To convert the percent P in organic matter to percent P2O5 multiply the percent P by 2.29. The conversion factor 2.29 is based on the atomic weights of phosphorus and oxygen in P and P2O5 (Texas Institute for Applied Environmental Research - TIAER).

P = 1 kg x 0.051 x 0.0084 x 2.29 x 0.035 = 0.0000012 kg

Compost

Assumptions for the composting process are the following:

- 1 kg of organic waste yields approximately 0.3 kg of compost dirt (Nilsson 2013)
- For the N and P content, the same assumptions are taken from the AD calculations.
- It is assumed that the greenhouse gas (GHG) emissions from the windrow composting process are the ones in Table 10.
- It is considered that 100% of the nutrients available are degraded during windrow composting.
- It is assumed that there are no fugitive emissions of CH_4.

Table 10. Windrow composting GHG emission factors (Fei et al. 2022)

Emissions	Value	Units	Comment	Source
CO2	0.134	kg/kg	Based on dry organic waste basis	(Fei et al. 2022)
CH4	0.000063	kg/kg	Based on dry organic waste basis	(Fei et al. 2022)

N2O	0.000022	kg/kg	Based on dry organic waste basis	(Fei et al. 2022)

Landfill

Transportation Retail – Lanfill (Vicinal São Gonçalo - Estrada Mun. - Tupã, SP, 15700-580, Brazil). Fastest route, not necessary the shortest.

Average Distance from retail to landfill: 4.44 km

Emissions from landfill

To estimate the methane generation from the lettuce in landfill, the same values from the AD process were utilised:

Biogas generation = 1 kg x 0.039 x 0.840 m^3 Biogas/kg VS = 0.03276 m^3 of CH_4 for each tonne of lettuce. The composition of this biogas is 59% of methane volume and 41% CO_2.

Therefore, for each kg of lettuce, 0,01939 m3 of CH_4 and 0,01337 m^3 of CO2 will be generated.

Assumptions are:

- Biogas extraction efficiency factor is 15% (Björklund 1998)
- The treatment method considered for the extracted biogas is flaring, assuming a theoretical flare efficiency of 100%.
- Therefore, it is assumed that 85% of the biogas generated (59% CH4; 41% CO2) is lost in the atmosphere.
- For the fraction of biogas released directly into the atmosphere, values of methane and carbon dioxide per kg of MSW will be utilised.
- To determine volumes for the different substances, a density of 0.668 kg/m3 was considered for methane, and a density of 1.842 kg/m3 was considered for Carbon dioxide.

Biogas emissions from landfill to flaring: 0,03276 m^3 x 0.15 = 0,00491 m^3 of Biogas. Therefore, the volume of CH_4 in the captured biogas for flaring is 0,00291 m^3, and the volume of CO_2 is 0,00201.

Emissions from biogas released in the atmosphere: 0,03276 m^3 x 0.85 = 0,027846 m^3 of Biogas are lost in the atmosphere. Therefore, the volume of CH_4 is 0,01649 m^3, and 0,011361168 m^3 of CO_2.

Biogas generated (m3)	Volume of biogas for flaring (15%)	Volume of biogas released in the atmosphere (85%)
0,03276	0,00491 m3	0,02785 m3

Now, based on the stoichiometry of methane combustion.

Mass of methane for flaring= 0,01649 m^3 x 0.668 kg/m3 = 0,00194 kg of CH_4

0.0160425 kg of CH_4 → 0,04401 kg of CO_2

Then 10,00194 kg of CH_4, with a complete combustion in the flare react to produce 0,005331049 kg of CO_2.