Social Life Cycle Assessment and the Bioeconomy: Methods and Applications for Enhancing Sustainability in Agricultural Value Chains

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December 2023

A thesis submitted to McGill University in partial fulfilment of the requirement for the degree of Master of Science

Dedication:

This thesis is dedicated to my Yia Yia, Denise Georgiou, for whom I am supposed to be making a Christmas gift at the time of writing. Thank you for encouraging me to discover more about the world around me for as long as I can remember.

Abstract

Despite being crucial to achieving global targets in sustainable development, social sustainability is drastically understudied within agrifood systems. Environmental Life Cycle Assessment (E-LCA) is commonly used in this field to assess the environmental impacts of products and processes, and the methodologies and data sources for this assessment tool are well developed. However, E-LCA does not measure social aspects, which are crucial to truly understanding sustainability. Thus, new approaches have been proposed to fill this gap. One of these approaches, Social Life Cycle Assessment (S-LCA), shows great promise. However, it has less developed methodologies and data sources than E-LCA. This thesis presents several related discussions of applying S-LCA to agricultural value chains, as well as a case study in which S-LCA is applied to the value chain of a livestock feed additive. Following the introduction in Chapter 1, Chapter 2 presents a comprehensive literature review of previous applications of S-LCA within the agriculture and agri-food sector and a discussion of the potential benefits and challenges of applying S-LCA in a high-risk agricultural sector such as poultry production. While S-LCA could play a prominent role in the transition to sustainable agriculture, factors such as animal rights, communication to stakeholders, and regional variability are hurdles that must be addressed before S-LCA can realize its potential. Building off of these findings, Chapter 3 presents an argument for a new stakeholder category within S-LCA for animals and their welfare. This argument addressed both philosophical and methodological aspects of the imperative for including animal welfare in S-LCA. Chapter 4 presents a case study in which S-LCA is used to assess the social impacts of a feed additive production value chain, including the production of the additive at the manufacturer, and background system from the production of ingredients to the use at the farm level. The results showed that the production of ingredients contributed over 99% of the social impact of the production of the additive, with the subcategory *social benefits* having the highest impact (76,012 medium risk work hours/ton additive). Within the manufacturing facility, *freedom of association* was the category with the highest impact (11 medium risk work hours/ton). One of the primary challenges of S-LCA comes with integrating it into broader sustainable development concepts. Recognizing the Circular Economy as one of these concepts, Chapter 5 presents a framework for considering the social impacts of circular economy strategies within agriculture. This framework integrates the ReSOLVE circular economy framework with ECOGRAI decision variables and S-LCA indicators to follow the pathways by which the move towards a circular economy might impact stakeholders. Conclusions are then drawn, in which S-LCA was found to be a powerful tool that could play a major role in facilitating the transition to a more sustainable future in agricultural production.

Keywords: Social Life Cycle Assessment, Social sustainability, Sustainable development, Agriculture, Animal welfare, Circular economy

Résumé

Bien qu’elle soit cruciale pour atteindre les objectifs mondiaux en matière de développement durable, la durabilité sociale est considérablement sous-étudiée dans le génie des bioressources. L'évaluation du cycle de vie environnementale (E-LCA) est souvent utilisée dans ce domaine pour évaluer les impacts environnementaux des produits et des procédés de transformation et de production des produits. Les méthodes et les données pour cet outil d'évaluation sont bien développées. Par contre, l’analyse du cycle de vie social (S-LCA) est un protocole plus récent avec des méthodes et des sources de données moins développées. Cette thèse présente plusieurs discussions connexes sur l'application de S-LCA aux chaînes de valeur agricoles, ainsi qu'une étude de cas dans laquelle S-LCA est appliquée à la chaîne de valeur d'un additif alimentaire pour vaches laitières. Après l'introduction dans le chapitre 1, le chapitre 2 présente une revue complète de la littérature sur les applications antérieures de S-LCA dans le secteur agricole et agroalimentaire et une discussion sur les avantages et les défis potentiels de l'application de S-LCA dans un secteur agricole à haut risque, comme la production aviaire. Même si S-LCA pourrait jouer un rôle de premier plan dans la transition vers une agriculture durable, des facteurs tels que les droits des animaux, la communication avec les parties prenantes et la variabilité régionale sont des obstacles qui doivent être surmontés avant que S-LCA puisse combler son potentiel. S'appuyant sur ces résultats, le chapitre 3 présente un argument en faveur d'une nouvelle catégorie de parties prenantes au sein de S-LCA pour les animaux et leur bien-être. Cet argument aborde à la fois les aspects philosophiques et méthodologiques de l’impératif d’inclure le bien-être animal dans la S-LCA. Le chapitre 4 présente une étude de cas dans laquelle S-LCA a été utilisée pour évaluer les impacts sociaux d'une chaîne de valeur de production d'additifs alimentaires, y compris la production de l'additif chez le fabricant, et le système de base depuis la production des ingrédients jusqu'à leur utilisation à la ferme. Les résultats ont montré que la production d'ingrédients contribuait à plus de 99% à l'impact social de la production de l'additif, la souscatégorie des avantages sociaux ayant l'impact le plus élevé (76 012 heures de travail à risque moyen/tonne d'additif). Au sein de l'usine de fabrication, la liberté d'association était la catégorie ayant l'impact le plus élevé (11 heures de travail à risque moyen/tonne). Ensuite, le chapitre 5 présente un cadre pour considérer les impacts sociaux des stratégies d'économie circulaire dans l'agriculture. Ce cadre a intégré le cadre d'économie circulaire ReSOLVE avec les variables de décision ECOGRAI et les indicateurs S-LCA pour suivre les voies par lesquelles la transition vers une économie circulaire, reconnue comme impérative pour le développement durable, pourrait avoir un impact sur les parties prenantes. Des conclusions ont ensuite été tirées, dans lesquelles S-LCA s'est révélée être un outil puissant qui pourrait jouer un rôle majeur pour faciliter la transition vers un avenir plus durable dans la production agricole.

Mots-clés : Analyse du cycle de vie social, Durabilité sociale, Développement durable, Agriculture, Bien-être animal, Économie circulaire

Preface and Author Contribution

Chapter 1 presents an introduction to the field of social sustainability and its applications to agriculture, as well as the context of social life cycle assessment and sustainable development within bioresource engineering and the broader agriculture and agri-food context.

Chapter 2 is a literature review of social life cycle assessment, including its history, methodologies, and applications in agriculture. This review uses the findings of previous works to elucidate challenges and benefits for incorporating S-LCA into a high-risk sector such as poultry production.

Chapter 3 builds on the review of methodologies in Chapter 2 and provides an argument for a new stakeholder category in S-LCA revolving around animal welfare. This chapter includes a discussion of the potential indicators for the new category, as well as the methods for integrating the results with other S-LCA categories.

Chapter 4 presents a case study in which S-LCA was applied for the manufacture of a dairy cow feed additive in Quebec. This chapter follows the value chain from the production of the ingredients through the use of the additive at the farm level. This chapter also discussed different methods of integrating data from various sources, and the implications for future studies.

Chapter 5 looks beyond the current applications of S-LCA to envision a multi-dimensional approach to including aspects of social well-being in circular economy strategies. To achieve this, a new framework was developed based on the ReSOLVE framework created by the Ellen Macarthur Foundation. This framework was then applied to a case study of poultry production.

Chapter 6 presents a general discussion of the findings and implications of this thesis project and concluding remarks.

Aubin Payne was responsible for the conceptualization and methodological development of the project, as well as the writing, visualization, data collection and editing of the manuscripts.

Dr. Ebenezer Miezah Kwofie, the thesis supervisor, assisted with conceptualization, editing, and revision, and provided guidance and supervision during the writing process.

Dr. Elsa Vasseur, the third author of Chapter 3, contributed to the conceptualization and manuscript editing stages of this chapter.

Acknowledgements

I would like to extend a special thanks to my supervisor, Dr. Ebenezer Miezah Kwofie for his patience, wisdom, and unceasing willingness to help; to Prince Agyemang for his mentorship and for being a wonderful friend; and to Dr. Elsa Vasseur for her guidance and patience in helping me to breach the realm of animal welfare.

I would like to thank the Sustainable Food Systems Engineering Lab members and affiliate members, including Derrick, Emma, Ishita, Mariana, Mrs. Mabel, Marie-Anne, Prince, Raphael, Sara, Vincent, Dennis, Patrick, and Trisha. Thank you for your constant support and friendship during my time at McGill.

I would like to thank my mom and dad and all my grandparents, as well as Rayla, Forrest Oliver, Drew, Marguerite, Katie, and Thomas. Thank you for your long-distance love and support, it means more than you could ever know.

I would like to thank all of my friends, but especially Calista, Jimmy, Erny, Cesca, Nick, Josh, Ben, Andrew W., Andrew W., Logan, Will, Seanan, and everyone I lived with in Laird. Despite being spread out over two countries, you always found ways to stay connected.

And to anyone I forgot to mention, thank you too.

Much love,

Aubin

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Chapter 1: General Introduction

1.1 Background

From agriculture to food processing to biomaterials, sustainability and sustainable development are at the heart of agrifood systems. As climate change and land degradation ravage the planet, environmental impacts often take the spotlight in discussions of sustainability. However, focusing solely on the environment undermines the importance of social impacts. Of the 17 United Nations Sustainable Development Goals, 14 directly involve social issues such as poverty, hunger, workers' rights, and animal welfare [1]. Just as climate change and pollution are forcing millions of people into unsafe living conditions, so too are poverty and corruption. So while researchers and decision makers must work to fight environmental damage, they must also work to fight social injustices in order to create a better world in which every person is free to live with dignity and achieve their full potential.

There is a critical need to quantify and dismantle social issues within agriculture worldwide. In 2019, over 2 billion people worldwide were employed in agriculture [2]. Livestock and crops provide food and livelihood to the global population, but there are problems that keep workers and consumers from living with dignity. Unsafe working conditions, insufficient pay, poor animal welfare, and food safety concerns are prevalent across the global agriculture sector [3, 4]. However, before these issues can be addressed, they must first be defined and characterized. Social Life Cycle Assessment (S-LCA) has been proposed as a solution to this gap, as it presents methodologies for defining, characterizing, and measuring social impacts over the life cycle of a product or process. However, unlike its environmental counterpart (E-LCA), the methodologies for S-LCA are underdeveloped, and there is less agreement on aspects such as what indicators to use [5], the role of databases and generic data in S-LCA [6], and to what extent stakeholders should be included in determining scores [7]. The creation and development of S-LCA is a collaborative effort that is still underway, and researchers have called for more case studies and conceptual works in order to formulate and validate assessment strategies.

One major source of disagreement in S-LCA is the inclusion of animal welfare. Many people believe that including animal welfare is a logical imperative, considering the inclusion of external stakeholders such as *Society* and *Children*. However, others believe that equating animals to humans places an undue importance on the lives of nonhuman beings. While there is some subjectivity, a growing international community recognizes the importance of animal welfare's contribution to sustainable development [8]. Movements such as One Welfare [9] aim to create an inclusive paradigm in which animal welfare, human welfare, and environmental preservation are recognized as interwoven goals that can be accomplished together.

Additionally, when other sustainability-enhancing strategies are formulated, they often do not include social aspects. Circular economy is one of the foremost frameworks used to drive sustainable development in policy and business, but it almost entirely neglects social consequences, despite the high potential impact of these strategies on different groups of stakeholders [10]. The ReSOLVE framework for circular economy was developed by the Ellen Macarthur foundation in 2015, and its broad scope of applicability presents a platform from which social impacts can be included in circular economy.

The manuscripts in this thesis are varied in scope, but all address crucial knowledge gaps within the field of S-LCA. The collection begins with a systematic literature review of S-LCA in agriculture, including the challenges and benefits of applying S-LCA to a high-risk agriculture sector (poultry production). Following this, Chapter 3 presents an argument for the creation of a new stakeholder category for animal welfare within the S-LCA framework. This argument includes a discussion of the imperative for the new category and the methodologies necessary for incorporating animal welfare within the existing S-LCA framework. To address the noted lack of S-LCA case studies, Chapter 4 includes a case study of S-LCA applied to a feed additive for dairy cows. The case study examines the social impacts of the production of the feed additive from raw ingredients and the use of the additive at the farm level. Chapter 5 moves to a more holistic sustainability perspective, presenting a framework to integrate social impact assessment into circular bioeconomy strategies. The final chapter discusses the implications of the findings of the manuscripts within the context of S-LCA and sustainable agri-food engineering.

1.2 General Objectives

The overall objective of this thesis was to examine different aspects of S-LCA in agrifood systems and find ways in which the application of S-LCA to the agrifood sector can be improved. This includes evaluating the current state of the methodologies, proposing and testing methods, and developing ways to integrate S-LCA into the broader context of sustainable agrifood system development. To achieve this goal, three objectives are carried out.

Objective 1: Evaluate the status of animal welfare within S-LCA and present methods for incorporating a new animal welfare stakeholder category

Activity 1.1: Evaluate the current state of animal welfare in S-LCA, including proposed strategies for incorporating animal welfare assessment into S-LCA under different philosophical and pragmatic frameworks of welfare.

Activity 1.2: Develop indicators and methods for incorporating animal welfare into existing S-LCA assessment strategies and databases.

Objective 2: Conduct a case study of S-LCA within a sample agricultural value chain and evaluate data collection and calculation methodologies.

Activity 2.1: Collect data on the social impacts of the manufacture of a feed additive from company policies and records, worker opinions, and database records.

Activity 2.2: Evaluate the performance of both the foreground system (the manufacturer) and the background system (the production of ingredients and use on the farm) using S-LCA models.

Activity 2.3: Discuss the impact of worker perception on the impacts and the implications of including stakeholder perspectives in S-LCA calculations.

Activity 2.4: Investigate the impacts of using different data collection methods and the potential issues when attempting to aggregate these results within a holistic S-LCA

Objective 3: Create a framework for the incorporation of S-LCA into circular bioeconomy strategies.

Activity 3.1: Conduct a review of the different circular economy frameworks and the social implications of each.

Activity 3.2: Assess the link between the circular economy and social impacts and develop a framework in which S-LCA methodologies are used to predict and measure social impacts of circular economy practices at each stage of the agrifood system value chain.

Activity 3.3: Explore the potential of this new framework using a case study within the agricultural sector and discuss the results and implications for future use within agriculture and other sectors.

Connecting Text 1

The manuscript in Chapter 2 has is under internal review.

Chapter 1 introduced the thesis and provided the theoretical background for the issues examined in the following manuscripts. However, in order to develop a greater understanding of the current uses and challenges within the realm of S-LCA, a deeper investigation into the literature is required. Chapter 2 provides a review of the existing literature regarding S-LCA in agriculture, including many case studies and several conceptual papers. Following the systematic review, the implications of applying S-LCA to a high-risk agricultural sector (poultry production) were discussed, including the potential benefits and the challenges foreseen based on published literature.

This chapter lays the foundation for understanding S-LCA in agriculture that will be built upon in Chapters 3, 4, and 5. S-LCA occupies a small but growing niche within the field of sustainability assessment, and this review confirms its potential as a tool for sustainable development, although it also identifies several major issues within S-LCA, several of which are addressed in later chapters.

Chapter 2: Social Life Cycle Assessment in Agriculture: Current State and Outlook for Use in the Poultry Industry

Aubin Payne, Ebenezer Miezah Kwofie

Abstract

This paper examines the current state of social life cycle assessment (S-LCA) in the field of agriculture and food production and provides insight into its potential for use in the animal agriculture industry, a growing sector with a high social impact. The benefits and challenges of applying S-LCA to the poultry industry are examined in-depth. First, an overview of S-LCA methodologies was established. Next, a systematic literature review was conducted to understand strategies applied and lessons learned from previous case studies conducted in the agri-food sector. This literature review was used to extract insights into how S-LCA and life cycle sustainability assessment (LCSA) might be used to benefit the poultry industry, an example of a high-risk industry which, despite struggling with a multitude of detrimental social effects, is proliferating worldwide. The potential benefits and challenges of applying S-LCA to the poultry sector are then discussed. The findings suggest that S-LCA has the potential to be a powerful tool to solve many of the social issues within many high-risk sectors in agriculture, but that several issues must be addressed, including (1) the incorporation of better animal welfare metrics, (2) regional variability of data, and (3) issues with the dissemination of information. If these problems are addressed, S-LCA could be used by companies and policymakers to help resolve the harmful social impacts of global animal production.

Keywords: Social Life Cycle Assessment, Agriculture, Poultry, Sustainability, Life Cycle Sustainability Assessment, Animal Welfare

2.1 Introduction

The field of sustainability has proliferated in recent years as international organizations attempt to address complex global problems such as climate change, inequality, and poverty. Most definitions of sustainability involve some discussion of the "three pillars of sustainability," environment, society, and economy, and the United Nations (UN) has published a list of 17 sustainable development goals to address the most critical bottlenecks for sustainable global development [1]. 14 of these 17 goals are directly related to addressing societal problems [11], but academic studies that seek to analyze and address societal problems are few and far between compared to the prolificacy of studies addressing environmental and economic issues. Environmental life cycle analysis (E-LCA) and life cycle costing (LCC) have been used extensively in research. However, for many years, experts in the field of sustainability have expounded upon the need for social life cycle analysis (S-LCA), social-organizational life cycle analysis (SO-LCA) [12], and Life Cycle Sustainability Analysis (LCSA), which combines the social, environmental, and economic life cycle impacts into a holistic sustainability overview.

There is a research bottleneck at the S-LCA analysis stage, preventing life cycle sustainability assessments from becoming more commonplace. Part of the reason for this gap in research is the difficulty of establishing objective metrics for comparison. There are two reasons for this. Firstly, many metrics used to judge human social well-being, such as quality of life and happiness, are difficult to quantify and require adaptation to specific case studies. Attempts have been made to quantify these metrics with units such as quality-adjusted life years [13]. However, these methods are difficult to standardize. Secondly, the amount of data available pales compared to the amount available for E-LCA. Databases like Product Social Impact Life Cycle Assessment (PSILCA) and Social Hotspots Database (SHDB) can help by providing generic data that can indicate social well-being, but such data does not apply to individual case studies. Different studies have included vastly different impact categories [14], and to a certain extent, the selection of impact categories depends mainly on the production system or organization being studied [4, 15]. In addition, S-LCA is distinct in its analysis of both positive and negative effects. Instead of creating alternatives to minimize negative impacts, as in E-LCA, S-LCA has open-ended upper boundaries that can shift as the industry standard becomes increasingly progressive. This open-endedness can be beneficial, as it can encourage progress beyond the status quo; however, it often makes it difficult to establish objective reference scales between different regions (i.e., a company in a developed country can typically be held to a much higher standard of social responsibility than a company in a developing country because of greater resource availability and regulation enforcement in the former)[16].

This review paper begins by providing a background on S-LCA and the path to its development. Next, the current standard (UNEP 2020 Guidelines [11]) are discussed, along with other essential methods discussed in other papers, to provide an overview of the current state of the framework.

Next, a systematic literature review of S-LCA use in various agricultural sectors is conducted. This review aimed to find the unique developments researchers have made to adapt the methodology to the specific needs of each industry sector. Following the sector-by-sector assessment, the similarities and differences in the methods of the studies were compared. Next, the potential of applying S-LCA to a life cycle sustainability assessment (LCSA) framework is discussed. Some challenges were identified, and potential solutions were discussed. Then, using all this information, the potential benefits and challenges of applying S-LCA to sustainability assessment in the poultry sector were discussed, and conclusions were drawn about the current state of S-LCA and its potential for helping the poultry sector achieve true sustainability.

2.2 Methods

This paper begins by analyzing the history of S-LCA, including the different ways researchers and organizations have proposed integrating S-LCA and E-LCA over the years. The review also compiles guidelines for S-LCA and case studies in which S-LCA is applied to agriculture/food production to find the most applicable methods to the poultry sector. The case studies are separated by sector, and the methods and results are compared for studies within the same sector to find similarities and differences between the methods used. Then, the standard methods within each sector are compared to find whether there is any potential for an objective guideline to be set for each sector or the agri-food sector as a whole. The literature search was conducted using SCOPUS and Web of Science. Figure 2.1 details the methodology and outcomes of the literature review. First, a search was done using the terms "S-LCA" OR "Social LCA" OR "SLCA" combined with the terms "Food" OR "Agriculture." This search returned 57 results in SCOPUS and 73 from Web of Science. From there, titles were read to ensure relevance. As a general rule, the only studies included were case studies, although others outside of this scope were included if they presented relevant information. These criteria yielded 32 studies from SCOPUS and 16 additional (not including repeated articles) from Web of Science with perceived relevance to the review. After reading the abstracts, seven of the studies from SCOPUS and four from Web of Science were rejected because they were irrelevant to the study or were unavailable online. Several case studies reviewed food distribution systems. The authors decided not to include these studies in the systematic review, as the primary focus of the review is on production systems. The remaining 37 studies were reviewed. An additional ten articles deemed important were found by following pathways of references. After reading these articles, the number of relevant case studies included in the literature review was 46. These 46 studies and their titles are listed in Table 2.1. Figure 2.2 shows a geographic distribution of countries where these studies were conducted. For studies with multi-country value chains, only the primary country/countries of study were included on the map. This review gives an in-depth overview of many different methodologies of S-LCA and the challenges and benefits of applying the methodology to the agri-food sector so that lessons can be applied to the poultry industry.

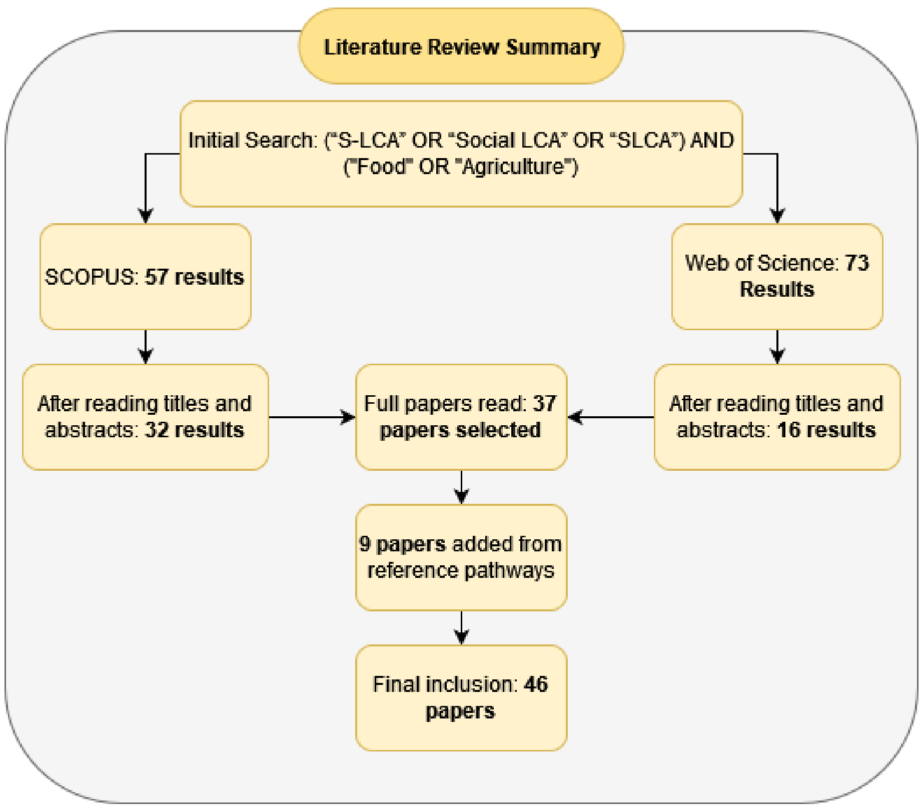

Figure 2.1: Methodological summary of the literature review

Table 2.1: List of case studies included in literature review

Authors	Year	Title
Andrews et al. [17]	2009	Life Cycle Attribute Assessment Case Study of Quebec Greenhouse Tomatoes
Feschet et al. [18]	2013	Social impact assessment in LCA using the Preston pathway: The case of banana industry in Cameroon
Manik et al. [7]	2013	Social life cycle assessment of palm oil biodiesel: a case study in Jambi Province of Indonesia

Martinez-Blanco et al. [19]	2014	Application challenges for the social Life Cycle Assessment of fertilizers within life cycle sustainability assessment
Smith & Barling [20]	2014	Social impacts and life cycle assessment: proposals for methodological development for SMEs in the European food and drink sector
Bouzid & Padilla [21]	2014	Analysis of social performance of the industrial tomatoes food chain in Algeria
Vavra et al. [22]	2015	Assessment of Social Impacts of Chemical and Food Products in the Czech Republic
Revéret et al. [15]	2015	Socioeconomic LCA of milk production in Canada
De Luca et al. [23]	2015	Social life cycle assessment and participatory approaches: A methodological proposal applied to citrus farming in Southern Italy
Tecco et al. [24]	2016	Innovation strategies in a fruit growers association impacts assessment by using combined LCA and s-LCA methodologies
Arcese et al. [25]	2017	Modeling Social Life Cycle Assessment framework for the Italian wine sector
Chen & Holden [26]	2017	Social life cycle assessment of average Irish dairy farm
Prasara-A & Gheewala [27]	2018	Applying Social Life Cycle Assessment in the Thai Sugar Industry: Challenges from the field
D'Eusanio et al. [28]	2018	Assessment of social dimension of a jar of honey: A methodological outline
Cardoso et al. [29]	2018	Economic, environmental, and social impacts of different sugarcane production systems
Pelletier [3]	2018	Social sustainability assessment of Canadian egg production facilities: Methods, analysis, and recommendations
De Luca et al. [30]	2018	Evaluation of sustainable innovations in olive growing systems: A Life Cycle Sustainability Assessment case study in southern Italy
Petti et al. [31]	2018	An Italian tomato “Cuore di Bue” case study: challenges and benefits using subcategory assessment method for social life cycle assessment
Prasara-A et al. [32]	2019	Environmental and social life cycle assessment to enhance sustainability of sugarcane-based products in Thailand
Martucci et al. [33]	2019	Social aspects in the wine sector: Comparison between social life cycle assessment and VIVA Sustainable wine project indicators
Muhammad et al. [34]	2019	Social implications of palm oil production through social life cycle perspectives in Johor, Malaysia
Du et al. [35]	2019	Enriching the results of screening social life cycle assessment using content analysis: a case study of sugarcane in Brazil
Rivera-Huerta et al. [4]	2019	Social sustainability assessment in livestock production: A social life cycle assessment approach

Sureau et al. [36]	2019	Participation in S-LCA: A Methodological Proposal Applied to Belgian Alternative Food Chains (Part 1)
Sureau et al. [37]	2019	How Do Chain Governance and Fair Trade Matter? A S-LCA Methodological Proposal Applied to Food Products from Belgian Alternative Chains (Part 2)
Zira et al. [38]	2020	Social life cycle assessment of Swedish organic and conventional pork production
Iofrida et al. [39]	2020	The socio-economic impacts of organic and conventional olive growing in Italy
Jarosch [40]	2020	A regional socio-economic life cycle assessment of a bioeconomy value chain
Prasara-A & Gheewala [41]	2021	An assessment of social sustainability of sugarcane and cassava cultivation in Thailand
Portner et al. [42]	2021	Sustainability assessment of combined animal fodder and fuel production from microalgal biomass
Brenes-Peralta et al. [43]	2021	Unveiling the social performance of selected agri-food chains in Costa Rica: the case of green coffee, raw milk and leafy vegetables
Furtner et al. [44]	2021	Locating Hotspots for the Social Life Cycle Assessment of Bio-Based Products from Short Rotation Coppice
Phantha et al. [45]	2021	Social sustainability of conventional and organic rice farming in north-eastern Thailand
Toboso-Chavero [46]	2021	Environmental and social life cycle assessment of growing media for urban rooftop farming
Zira et al. [47]	2021	A life cycle sustainability assessment of organic and conventional pork supply chains in Sweden
Maffia et al. [48]	2022	The Olive-Oil Chain of Salerno Province (Southern Italy): A Life Cycle Sustainability Framework
Varela-Ortega et al. [49]	2022	Life cycle assessment of animal-based foods and plant-based protein-rich alternatives: a socio-economic perspective
Kalvani et al. [50]	2022	Social impact and social performance of paddy rice production in Iran and Malaysia
D'Eusanio et al. [51]	2022	From Social Accountability 8000 (SA8000) to Social Organisational Life Cycle Assessment (SO-LCA): An Evaluation of the Working Conditions of an Italian Wine-Producing Supply Chain
Andrade et al. [52]	2022	Assessment of social aspects across Europe resulting from the insertion of technologies for nutrient recovery and recycling in agriculture
Kokemohr et al. [53]	2022	Life Cycle Sustainability Assessment of European beef production systems based on a farm-level optimization model
Wei et al. [54]	2022	Social Life Cycle Assessment of Major Staple Grain Crops in China
Muñoz-Torres et al. [55]	2022	Transitioning the agri-food system. Does closeness mean sustainability? how production and shipping strategies

		impact socially and environmentally. Comparing Spain, South Africa and US citrus fruit productions
Mancini et al. [56]	2023	Social footprint of European food production and consumption
Marting Vidaurre [57]	2023	Social assessment of miscanthus cultivation in Croatia: Assessing farmers' preferences and willingness to cultivate the crop
Tragnone et al. [58]	2023	Contribution of the Product Social Impact Life Cycle Assessment (PSILCA) database in assessing the risks and opportunities of a jar of honey production

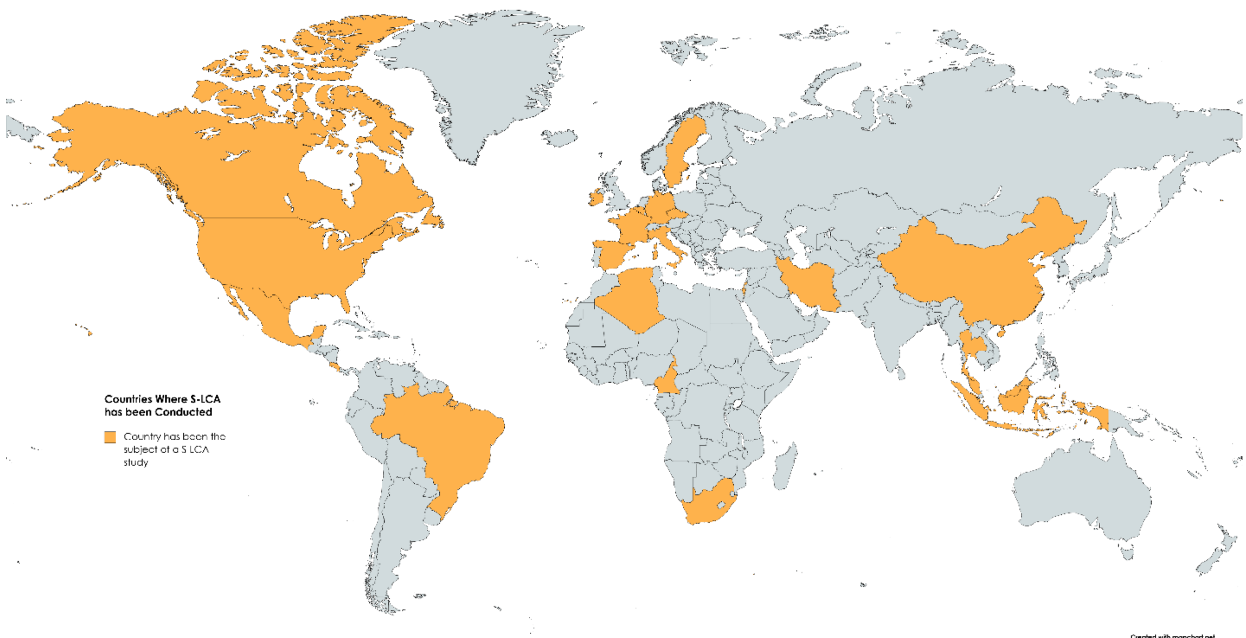

Figure 2.2: Countries in which S-LCA agricultural case studies have been conducted

2.3 Overview and History of S-LCA

Although the need for assessing the social impact of large-scale developments was first recognized by the United States National Environmental Policy Act of 1969 [59] and was first implemented in the environmental impact analysis for the Trans-Alaska pipeline in 1972 [60], it was not until the 1993 publication of the Society of Environmental Toxicology and Chemistry's (SETAC) *Conceptual Framework for Life Cycle Impact Assessment* [61] that S-LCA became a full-fledged concept. This report included social welfare as a suggested impact category but did not outline any guidelines for determining impacts from this category. The first attempt to add a standardized social aspect to this practice came in 1994 when the Interorganizational Committee on Guidelines

Principles for Social Impact Assessment published their *Guidelines and Principles for Social Impact Assessment* [62], which presented the first example of an impact matrix as a means for analyzing the potential social impacts occurring at different stages in the development process. As environmental life cycle analysis became increasingly popular, researchers began to see the potential value of incorporating social wellness indicators into life cycle models to achieve a holistic sustainability model.

S-LCA was developed to objectively measure social impacts resulting from processes and decisions. However, Social LCA naturally relies heavily on principles and paradigms derived from sociology, and specifically from the concept of Corporate Social Responsibility (CSR), as described in ISO 2600. While sociology is subject to the same objective scrutiny as more traditional natural sciences, the natural subjectivity in sociology translates to S-LCA and is one of the primary factors distinguishing S-LCA from its environmental counterpart [63]. While some methodologies attempt to minimize subjectivity in sociological data, it is crucial to recognize that there are instances in social data collection during which the data is based to some extent on the researcher's decisions or the societal context. For example, when interviews or anecdotal evidence are used, the means and extent of incorporating this evidence into the study results is up to the researcher. Using interpretive methods is not a problem so long as researchers acknowledge the potential areas of subjectivity within their research, and appropriately document their decisions.

Throughout the early 2000s, several case studies and reviews were published in an attempt to standardize the practice of S-LCA. This time was referred to by Huarachi et al. as the "first steps towards social life cycle assessment" [6]. A review published in 2008 describes the methodologies used up to that point and attempts to find similarities that could be used as a first step toward standardization [64]. At this time, there was a low volume of studies published during this period, and there were varying opinions on the goals and methods of the assessment. For example, some studies took a comparative approach, seeking to analyze the social impact relative to alternative processes [65, 66], while others attempted to identify hotspots and improvement potentials [67] within product systems. Many stressed that S-LCA could not be reconciled with traditional LCA methods because social effects are often a function of producers' behavior rather than of characteristics of production processes. How to factor in economies of scale and examine organization-driven impacts through a process-driven framework (e.g., an LCA software such as

SimaPro or OpenLCA) remain two of the most significant challenges in the field of S-LCA. However, efforts have been made in more recent guidelines to address them. These studies were foundational to the development and initial acceptance of the field of S-LCA.

In 2009, a group affiliated with UNEP and SETAC published a comprehensive guideline for S-LCA, defining the methods for conducting S-LCA for hotspot identification [68]. This framework laid the foundation for the guidelines published in 2020 by the UNEP [11] and is functionally very similar. The framework was based primarily on international conventions to avoid subjectivity as much as possible and included steps such as defining the goal and scope, inventory analysis, impact assessment, and interpretation [68]. After the publication of these guidelines, there was a relative explosion of case studies in a wide variety of fields, such as urban development [69], materials [70], and agriculture [4, 15, 26].

Since the 2020 UNEP Guidelines are the most recent and most comprehensive set of S-LCA Guidelines, its concepts and methodologies will be discussed in greater detail in the following section. Currently, S-LCA is conducted using the same general outline as Environmental LCA (based on, but not necessarily compliant with, International Standards Organization (ISO) standards 14040 and 14044). However, there are some differences in the basic concept of S-LCA compared to E-LCA; as of 2021, the ISO is working to create a standard for S-LCA (14075). This standard may provide researchers with a more structured basis for conducting S-LCA and help harmonize the methodology for S-LCA across studies.

2.4 S-LCA Methodologies

The most substantial and comprehensive S-LCA document is the United Nations Environmental Programme’s Guidelines for Social Life Cycle Assessment of Products and Organizations, completed in 2020 [11]. This document attempts to set guidelines for conducting S-LCA. While there have been previous efforts to compile and standardize S-LCA guidelines [64], the UNEP document is the most comprehensive and sanctioned by the United Nations. The document parallels the Environmental LCA framework established by ISO 14040, creating a step-by-step outline for conducting S-LCA. The phases include (1) definition of goal and scope, (2) life cycle inventory, (3) impact assessment, (4) interpretation, and (5) communication of results. These operate relatively similarly to their environmental LCA counterparts but are slightly less regimented due to differences in data collection and interpretation methods. Thus, there are multiple possible interpretations of the methods presented, as evidenced by the wide variety of case studies and proposed methods discussed later in this paper.

In addition, a methodological guideline accompanying the 2020 guidelines was published shortly afterwards [71], detailing the best methods for collecting site-specific data for each category of stakeholders who might be affected by the social impacts being measured. Stakeholder categories include workers, local community, value chain actors, consumers, society, and children. These categories are then broken down into related impact categories, such as “freedom of association” for workers or “wealth distribution” for value chain actors.

2.4.1 Additional methods

A method for calculating social risk was employed by [38] to calculate a social risk index score. In this method, a reference point, corresponding to the average risk of an impact in the sector or region under study, is established, and performance is gauged relative to this reference on a scale of 0-1 (the reference point is assigned a value of 0.5). For indicators where a higher score indicates a higher social risk (e.g., hours of unpaid overtime worked), the formula for risk calculation is:

$$SR = 1 - EXP\left(LN(0.5) * \frac{IND}{REF}\right) \cdots (2.1)$$

And for indicators where a lower score indicates a higher risk (e.g., social benefits received), the formula is as follows:

$$SR = EXP(LN(0.5) * \frac{IND}{REF}) \cdots (2.2)$$

Where SR is Social Risk, IND is the indicator value, and REF is the reference value corresponding to a score of 0.5. This formula allows the impact to be normalized based on the average risk present in a sector or region, so that producers can be held to standards that are realistic for their situation. The Social Risk score can be used as a weighting factor in calculations or can be used as a reference scale value.

A proposed method for eliminating bias through comparison to other companies operating within the same sector called RESPONSA (Regional Specific Contextualized Social Life Cycle Assessment) was proposed by Siebert et al. [72]. This method uses the average performance of companies in the sector and the region to normalize the impact score for the process or company being studied. The process is scored within the impact category based on its position relative to the average performance. This method is especially useful in indicators with a "yes/no" dichotomy (i.e., the impact indicator is either present or absent). In such situations, the score for a “no” answer ranges from 0-5, and the score for a “yes” answer ranges from 5-10. The score is calculated based on Equations 2.3 and 2.4:

$$For\ positive\ \text{(yes)}\ answers: r = 10 + (-5 * PRP_{\theta=1}) \cdots (2.3)$$

$$For\ negative\ (no)\ answers: r = 0 + (5 * PRP_{\theta=0}) \cdots (2.4)$$

Thus, regardless of the context, a positive score cannot earn less than a 5 out of 10, and a negative score cannot earn more than a 5 out of 10. The variation within these ranges is determined by the average proportion (PRP) of “yes” (θ=1) or “no” (θ=0) responses within the sector and the region. Therefore, in a sector or country where most companies have a positive indicator response, a positive response will receive a relatively lower score than a company with a positive indicator response in a sector or country where this is less common. This methodology was used in a case study and assessment of German lumber production [40, 73].

Often, indicators are measured and compared to local regulations to reduce the influence of bias from developed countries. A case study of Indonesian palm oil plantations [7] used a metric that initially seems more subjective but may be more reliable in places where regulations are not sufficient or well-enforced. Because a lack of regulations was one of the drivers behind the growth of the palm oil industry, the researchers in the Indonesian study compared workers' experiences to their expectations. The differential between expectations and experience was the basis for scoring social impact. While this may not apply in countries and industries where regulations are well-established, in industries like agriculture where regulations are difficult to enforce, this method may help ensure that workers’ needs are met, which is the primary goal of S-LCA across cultures.

The methods for type 2 (impact pathway) assessment are more standardized through use in databases such as the Social Hotspots Database (SHDB) and Product Social Impact Life Cycle Assessment (PSILCA). However, other impact pathways have been proposed. For example, a relatively early study by Fischer et al. proposed using the Preston pathway, a theoretical model linking GDP contribution to social benefit (life expectancy extension) as an indicator of the social impact of a product [18]. This method carried several restrictive conditions: it must be used in places where the GDP per capita is low and only in industries that carry significant weight; however, the study returned promising results that the Preston pathway could be a valuable model to incorporate into S-LCAs of sectors which fit these conditions.

2.5 Use of S-LCA in agriculture and food production

Food is a necessary part of everyday existence. Since the advent of industrial food processing in the last few centuries, people in the developed world have become increasingly removed from the source of their food [74]. However, consumers are becoming more wary of highly processed foods and demanding more transparent and sustainable food production. These demands extend to the environmental, nutritional, and social aspects of food production [16, 74]. S-LCA can be used in agriculture to help producers and consumers determine the impacts of their choices and the changes they can make to increase social well-being. Stillitano expounded on the need to incorporate S-LCA into circular economy models, assessing a cradle-to-cradle approach instead of a traditional cradle-to-grave approach [75]. The intersection of circular economy thinking and social welfare is understudied; as regulations and methods to increase circularity gain popularity, it is important to consider the social impact that might come as a result [76]. While circularity enhancement and social welfare improvement can often coincide, it is important to consider places where they are at odds.

Whereas the boundaries of study for environmental life cycle analysis are relatively well-defined, the theoretical extent of the social life cycle of products is blurry at best. While this can lead to confusion, it allows for open interpretation of the system boundaries. Impacts on many different stakeholder categories could be included in S-LCAs. In agriculture, aspects ranging from food safety to animal welfare to farmers' job satisfaction can realistically be included in these assessments. In 2009, Jorgensen et al. published a discussion of the validity of S-LCA indicators [5] in which the authors pointed out that subjective well-being indicators, which are often more indicative of happiness and fulfillment, are challenging to measure and that objective indicators like salary and working hours often are only weakly correlated to social well-being, especially once a certain threshold of financial security has been reached. Thus, to use S-LCA in agriculture or food production assessments, it is necessary first to ensure that proper indicators are in place.

2.6 Sector Literature Review and Discussion

This section presents the results of the systematic literature review of agri-food S-LCA case studies, divided by the sector of agriculture, which is the subject of the study. The different studies used different indicators based on the sector, location, and methodology of the study. Most studies relied on some combination of the indicators or indicator categories proposed by either the 2010 [68] or 2020 [11, 71] guideline documents. Indicators and outcomes are discussed for each sector, and similarities and differences are assessed.

2.6.1 Livestock

The livestock sector is critically important worldwide and varies from subsistence farming in developing countries to full-scale factory farms in developed countries. However, there is much disagreement globally over how to find a balance between providing cheap and reliable meat and maintaining worker and animal rights [77]. As an economically important and ethically ambiguous industry, it is only natural that the livestock sector has been the focus of many S-LCA studies. These studies and their implications on social life cycle assessment will be discussed below.

One study was conducted in the states of Veracruz and Yucatan in southern Mexico to determine the social impact of tropical cattle ranching operations [4]. This study utilized the reference scale approach to gauge the social performance of several ranches. Because of the lack of regulatory oversight present in the area of study, the results indicated that most ranch operations fell below compliance levels in the selected categories. This study showcases the importance of adjusting scoring scales for developing regions to account for nuances in sub-compliant performance that would not be captured by simply stating that performance is below compliance levels. A second study was conducted across a broader livestock industry in Canada [15]. Both studies included stakeholder categories of workers, society, community, and value chain actors. The Canadian study used the reference frame approach with a wider variety of indicators (28) than the Mexican study (18) [4]. In addition, the scores for this study were much less lenient than for the Mexican study, with minimum compliance with regulations being awarded a score of 2 rather than 3 out of a possible 4. The differences between these two studies expound on the need to examine further the difference in methodologies between S-LCA studies conducted in developed and developing countries.

A study of the Canadian egg industry used a similar methodology [3], finding that while most of the behaviors of the Canadian egg sector are at least compliant with regulations and accepted practices, some indicators, such as noise and air pollution, workplace equality, and union representation were assessed as “risky,” meaning that they had a high potential to negatively impact the well-being of the workers, community, or value chain actors relative to the baseline established by regulations and standard practices. These findings corroborate other reports regarding risky behaviors in the rest of the poultry industry, which detail similar issues and human rights issues associated with these behaviors [78]. The egg study used worker hours as an activity variable, as recommended by the 2009 UNEP/SETAC guidelines [68].

Chen and Holden [26] used S-LCA methodologies from the 2009 UNEP/SETAC guidelines [68] to examine the social impact of an average Irish dairy farm. The study found that workers' health and safety, safe working conditions, equal opportunity and discrimination, and working hours were the highest risk categories. This outcome corroborates the stereotypical complaints of unsafe working conditions, long working days, and an imbalance of male workers as primary problems in agricultural systems. While issues like this may be familiar to those in the industry, S-LCA studies like this one provide a scientific examination of the damage caused by these issues and an objective justification for addressing them.

Another study by Kohemohr et al. [53] used the FarmDyn software to conduct a life cycle sustainability assessment (LCSA). This software can simulate farm animal production systems and return results based on the different selections made in the model. This software still appears to be relatively new, but in the future could be a powerful tool for analyzing agricultural system performance. The social impacts measured in the study included human-edible calories consumed as animal feed and working hours.

2.6.2 Grains

Grains such as wheat, rice, and maize are the staples of diets worldwide, providing more than 30% of the calories to populations of developing countries [79]. Unfortunately, the social sustainability of the production of these grains, especially in the areas where they are most necessary, is often precarious. Several studies have reviewed the social impacts of grain production in different regions, utilizing different methodologies and scopes.

An S-LCA study of Chinese grain production [54] compared maize, wheat, and rice production in China and did not use a functional unit, instead opting to evaluate the entire value chain of each grain. Indicators were formulated based on the S-LCA guidelines and key issues in Chinese agriculture. The social risk calculations in this study was performed using the social risk equations defined in [38]. Additionally, expert opinions were gauged, and weight was assigned based on their opinions. This was one of the few studies to combine the reference scale and impact pathway approaches by using the expert-assigned weights to translate the calculated social risk factors, to endpoint impacts on the quality of growth in agriculture, quality of life in rural communities, and prosperity of rural people, the three targets of the Chinese government's "Rural Vitalization" policy. The study found that maize had the highest social benefit and lowest negative social impact of the three staple grains.

A study of organic vs. conventional rice farming in Thailand conducted by Phantha et al. [45] used a reference scale methodology with aggregated scores to compare the estimated potential impacts for different categories. This aggregation method presented the data in a way that was simple and easy to understand, although some intra-category nuance was lost. A similar comparative study was conducted by Kalvani et al., comparing rice production in Malaysia and Iran [50]. The results showed that Malaysia's more modern rice farming techniques resulted in much higher social welfare for the affected stakeholders.

2.6.3 Fruits, vegetables, and sweeteners

An LCSA study of sugarcane-based ethanol production in Brazil [29] used S-LCA methodologies within the PROMETHEE-II multicriteria decision framework to assess the benefits and drawbacks of different sugarcane growing and harvesting technologies, finding that manual strategies yielded a higher risk than more mechanized ones. Du et al. [35] used content analysis software to enhance the results of the analysis that the same team had conducted on the Brazilian sugarcane sector using SHDB. The software examined the results of previous studies to identify potential hotspots in the Brazilian sugarcane sector. The study reported a 60% overlap in hotspots identified by SHDB and software-based content analysis. Several studies conducted in Thailand helped illuminate some potential benefits and challenges of S-LCA application to agri-food industries within the country. One study by Prasara-A et al. [32] incorporated E-LCA with firsthand social impact data collected through interviews to reveal the holistic sustainability impact of different sugarcane end products (sugar, electricity, and ethanol) in Thailand. This study concentrated on workers and farm owners, who were found to be the most affected. A different study [27] analyzed the challenges in conducting S-LCA in the Thai sugar industry, noting a limited potential for application due to the limited experience of interviewees with many essential indicators and the need for a standard interpretation approach. A third study compared sugarcane production with cassava production [41], finding that cassava production is slightly more socially sustainable when all metrics were aggregated for workers, farm owners, machine owners, and the local community. Studies like these prove that S-LCA could help farmers decide which crops to grow in situations with multiple options.

An S-LCA case study of a jar of honey was performed by researchers in Italy [28]. One of the goals of this study was to incorporate the different positive impacts of the honey production process (e.g., biodiversity, cultural preservation, and food production). The Subcategory Assessment Method (SAM) developed by [80] was used, so the assessment was conducted using organizations as unit processes. A reference scale was used to account for these positive impacts in which the highest score was only attainable to processes that provided measurable social benefit. The study, like many others, noted a difficulty in collecting primary data.

An assessment of citrus fruit production in southern Italy [23] used the Analytic Hierarchy Process (AHP) as a multicriteria decision-making framework to incorporate the preferences and priorities of the three stakeholder groups considered (workers, local community, and society). A study of the social and environmental impacts and tradeoffs of innovations in the Italian raspberry industry [24] showed that mulching and covering raspberry plants increased stakeholder outcomes. While the study expertly incorporated environmental and social indicators, many of the indicators included as social benefits were more related to the successful harvest performance (financial welfare) and less to the direct welfare of the workers. These results emphasize the question of which indicators have effects that can be translated to welfare outcomes and how this translation occurs. Another Italian study of the "Cuore di Bue" variety of tomatoes [31] included the action plan of the company to address the problems indicated by the S-LCA, confirming that S-LCA results can be translated into real-world actions. Other studies on tomatoes were conducted relatively early, demonstrating the potential of the S-LCA framework in Quebec [17] and Algeria [21], respectively.

2.6.4 Oil crops

A comparison study of conventional and organic olive farming in Italy confirmed the overall social benefit of organic production strategies on farmers and workers [81]. One of the only studies to include a non-commercial (hobbyist) production process was a study of olive oil production in southern Italy [48]. This study notably included unique indicators such as “respecting delivery times” and "philanthropic activities of the farm" that were specific to the studied production process.

A study concerning the palm oil industry in Indonesia presented a questionnaire to affected communities gauging the difference between their expectations and perceived reality for different social indicators within the industry. This method offers no objectivity but provides valuable insight into different stakeholders' expectations for the industry in the region [7]. Instead of comparing practices to regulations or standard practices, this method offers insight into what workers see as both ideal and realistic. Studies like this can guide policymakers to target areas of impact where stakeholders' expectations differ most from their experiences. A separate study of Malaysian palm oil found that while there were negative impacts on the categories of cultural heritage and community, the overall social benefits from the presence of palm oil plantations outweighed the negatives [34].

2.6.5 Food and Beverages

An assessment of the social impacts of chemical and food production in the Czech Republic [22] reported that social impacts of food production were largely dependent on communication with consumers and demanded a higher standard of health and safety precautions than the chemical industry. Therefore, researchers should be careful to consider the context of the industry when assessing performance. The selection of regulations used to establish scoring systems usually accounts for this consideration. However, the context could be neglected where regulations are insufficient or where disruptions have occurred. Similarly, Mancini et al. [56] found that many of the social hotspots in the European food sector are in processes occurring outside of the EU.

In Costa Rica, following the COVID-19 pandemic, a study examined three products in the food production sector: leafy vegetables, coffee, and milk [43]. The impacts were assessed for farmers, workers, and local communities. The study discussed that while these production sectors allowed farmers to meet their needs, the COVID-19 pandemic may have increased rural food insecurity.

Three studies have reviewed the social impact of wine production in Italy. First, Arcese et al. [25] expounded on the need to consider positive social impacts as well as negative ones and the need for a complete life cycle approach in S-LCA, noting the lack of cradle-to-grave studies in the available literature. Another study by Martucci et al. [33] assessed the social sustainability implications of the VIVA sustainable wine production standards compared with the S-LCA methodologies. The study demonstrated that S-LCA can be used for assessing and potentially certifying companies over a wide variety of social sustainability impacts. Finally, D'Eusanio et al. [51] explored SO-LCA from the experience-based Pathway 1 defined in the 2020 UNEP guidelines [11]. This pathway allows researchers to conduct SO-LCA based on existing organizational assessment methodologies (in this case, SA8000 [82]). The study found that reports generated for SA8000 compliance provided much information that could be applied to SO-LCA but needed more information in categories such as Equal Opportunities and Discrimination.

2.6.6 General agriculture

One of the first studies to incorporate a robust S-LCA methodology into a comprehensive life cycle sustainability assessment (LCSA) was a comparative study of three different fertilizers produced in Spain and Israel by Martinez-Blanco et al. [19]. In the study, the social impact indicators from databases such as SHDB were assessed for quality based on whether they were quantitative or qualitative. The processes were then compared on three geographical scales (country, sector, and company) based on various qualitative and quantitative metrics derived from the 2009 UNEP/SETAC guidelines. The incorporation of S-LCA into LCSA will be discussed further in the next section. Another LCSA study discussed the production of fuel and fodder from algal biomass [42]. While their results indicated that fuel and fodder production systems would be environmentally and socially sustainable, the authors indicated that the results were limited to the country (Spain) where the study was conducted. An assessment of novel agricultural technologies by Andrade et al. [52] noted that social benefit might be tangentially derived from environmental benefit and that this possibility is not accounted for in the current literature.

2.6.7 Similarities and differences

The methods used in these papers varied widely but generally revolved around the same principle in which indicators were used to measure social impacts within a specified goal and scope. The studies followed the guidelines of either the 2009 UNEP/SETAC guidelines or the 2020 UNEP guidelines, whichever was the most recent available during the study. Many studies noted a need for more consistent or available data as a hindrance to the completion or future applicability of the study [27, 28, 42, 52]. Data would likely be more accessible if companies played a more prominent role in the process, but there is a noted lack of motivation for them to do so [28]. Some studies used databases [19, 35, 42, 58], while others used firsthand data such as interviews, surveys, and audits [21, 28, 32, 34, 39, 41], and some used both [27, 43, 52]. Some studies were comparative, assessing and weighing impacts from different processes or production strategies to determine which performed better [24, 29, 41-43]. Others were assessing the impact of a product or industry on a community [28, 34]. Several studies were primarily focused on ways to better engage stakeholders in the S-LCA process [7, 57, 83], with many other studies noting the need for more stakeholder engagement.

There are countries where S-LCA has been used more frequently than others, often with overlapping research personnel. Such is the case in Italy [25, 28, 48, 51, 81] and Thailand [27, 32, 41, 45]. Meanwhile, large agricultural producers like the United States and India are significantly underrepresented in the literature. This trend corroborates the observations of [84]. The data gap is concerning but also promising, as the location-specific requirements of S-LCA mean that future researchers will have many opportunities to test out and improve the S-LCA framework in regional-specific contexts. This potential is especially strong in the case of the poultry industry, for which the United States is the leading producer.

2.7. Implication for Life Cycle Sustainability Analysis (LCSA)

Life cycle sustainability assessment is a framework that combines the economic, social, and environmental aspects of life cycle assessment into one comprehensive study. Typically, the method involves combining the results of environmental life cycle assessment (E-LCA), life cycle costing (LCC), and S-LCA [85]. As this is a relatively new concept, few published studies attempt to conduct a full LCSA in the agriculture sector, and the methods used, including inventory and aggregation methods, are varied. A study by Martinez-Blanco et al. [19] recognized that the different components of an LCSA (S-LCA, E-LCA, and Life Cycle Costing (LCC)) should be conducted with the same functional unit, and the scope should be similar. However, the authors present a convincing argument that it is acceptable— and even encouraged—to mold the exact system boundaries for each component assessment to include only the processes with the greatest impact on that component. For example, waste production should be included in the E-LCA and LCC, but it is not necessary to include it in the S-LCA unless the waste is affecting communities or workers via improper handling. Recent studies have discussed the potential of LCSA in complex agri-food contexts. For example, Allotey et al. [86] detailed the outlook for implementing LCSA in the plant-based meat sector, incorporating the socio-economic perspective previously examined by Verela-Ortega et al. [49]. Within the poultry industry, LCSA could provide the necessary evidence to inspire changes that support workers, animals, and the environment, including financial justification.

Many scientific disciplines consider themselves objective and strive to conduct research separately from ethical or value-based judgements, but conducting a social assessment necessarily involves the inclusion of ethics. These ethical metrics can be taken from international concerning human rights. However, ethics are (1) constantly evolving, (2) not consistent across cultural boundaries, and (3) do not carry the enforceability of laws and regulations [87]. While metrics concerning personal and emotional well-being (i.e., from anecdotal survey results) are very important for a holistic assessment of social welfare, there is great difficulty in aggregating these with other indicators. Therefore, if these indicators are used in the S-LCA study, it may be advisable that they are not considered when incorporating S-LCA results into LCSA.

2.8. Potential benefits of applying S-LCA to the poultry industry

The poultry industry is historically very socially destructive [78]. Contract systems keep farmers indebted and tied in exploitative relationships to large corporations, and animal welfare is disregarded in pursuit of high production efficiency [78]. S-LCA could help identify hotspots for social impacts and exploitation along the value chain. However, some challenges come along with this, mostly related to the extent to which companies that control production care to change their practices. There has been much activism surrounding the modern practices of livestock farming. However, more must be done to change these practices, as they are built to minimize expenses and maximize output, often at the expense of animals and workers. If a holistic and reliable social life cycle model could be created and presented to consumers, they could use their purchasing power to swing the hand of the market to favor more sustainable practices. Additionally, S-LCA results could provide data-based evidence to convince policymakers to create laws and protections for workers in high-risk industries (a category in which the poultry industry appears to be included).

The poultry industry, specifically large, vertically integrated poultry producers, has generated much backlash following numerous accusations of animal cruelty and worker rights violations in recent years. As is the case when any problem becomes sensationalized, it is difficult to separate the real problems from the ones that receive the most attention. It also becomes difficult for companies to rectify their reputation, even if they implement positive changes. The thorough and mostly unbiased methods of S-LCA may provide the path for companies who wish to implement better practices and may prove that their changes have benefitted their workers, value chain actors, consumers, and local communities.

2.9. Challenges of applying S-LCA to the poultry industry: limitations and improvement potential

Many of the challenges regarding the implementation of S-LCA in the poultry industry have to do with the prevailing market trade terms, which make it difficult to justify increasing social welfare financially. Businesses seeking to invest in social infrastructure must invest large quantities of money, either directly or indirectly (through opportunity cost). No self-serving corporation will agree to invest in these changes when they are subsisting perfectly well on the current abusive production tactics. Additionally, many subjugation tactics, such as competitive contract-based growing systems, are implicit rather than explicit. These do not count as forced labor or sub-standard wage payment but may equate to such in practice [78]. Knowledge of these practices from external experts is necessary to determine the difference between what is measured and what is observed concerning socially harmful practices.

2.9.1 Animal rights

Another challenge in analyzing the social impacts of animal production is choosing how or whether to incorporate animal welfare in the calculation. In recent decades, there has been much debate about the ethical position of modern livestock farming methods. In developed countries, where these "factory farming" methods are most prevalent, there is little regulation of animal rights beyond the bare minimum required to keep animals from constant pain [88]. In his book *The Case* *for Animal Rights* [89], philosopher Tom Regan delineates his argument for why anyone who values human rights should place equal value on the rights of animals. While this is categorially unachievable for anyone working in the livestock industry, there is a convincing argument for prioritizing the welfare of animals to a much greater extent than is typical in current practice. To do so, it may be necessary to create better metrics for including animal welfare in S-LCA.

Additionally, for developed countries, having some form of animal welfare standards, however low they may be, is a common practice. In developing countries, however, regulations are scarce and often unable to be enforced [90]. David Fraser posited that good animal welfare strategies must (1) provide for good health and biological functioning, (2) provide opportunities for animals to live consistent with their evolutionary history, and (3) minimize the occurrence of negative psychological states and encourage positive psychological states when possible [91]. Unfortunately, even the most robust animal welfare standards rarely venture beyond providing for biological health and minimizing psychological distress. Enrichment activities for animals are also few and far between, especially in these confined production systems. Since the sector average or legal compliance baseline is typically the platform from which actions are judged. If there are no regulations, or if the regulations do not sufficiently address ethical violations, it is difficult to objectively call out ethically questionable actions that fall within the legal status. This is also true for the highly variable local regulations concerning worker safety and rights.

2.9.2 Regional Variability

A 2017 review found that there was very little overlap in the indicators included between different S-LCA studies [92], it is unclear why, but a likely culprit is a difference in priorities between the various regions of the world. The UNEP guidelines discuss incorporating interregional variability of local norms and regulations into the framework [11]. This strategy allows for a better understanding of how the subject process or company operates within the context of its region and helps to level the playing field for operations in developing countries, but it makes objectivity difficult. For example, the studies comparing livestock operations in Mexico and Canada [4, 15] showed considerable variation in what an operation needed to receive a good score. In the study of Mexican cattle ranchers, a score of 3 out of a possible 4 was given to operations meeting the bare minimum of compliance with regulations. In the Canadian study, conversely, compliant-only operations scored 2 out of a possible 4. Even though these two studies draw valid conclusions about their respective subjects, the scores of the operations in the two studies are not comparable.

Additionally, values are often very different between cultures. Even within the same country, impacts such as long working hours may be viewed as abusive by some and laudable by others. An early S-LCA study recommended splitting S-LCA categories into "obligatory" and "optional" categories based on whether they relate to globally accepted welfare metrics like forced labor or discrimination or more value-dependent ones like working hours and conditions [93].

The potential regional variation of S-LCA indicators is a major problem that could have implications on the adoption potential of S-LCA. Significant work towards improving cross-cultural data normalization is needed before S-LCA can be used as a globally comparative tool. Alternatively, a level of cultural subjectivity could be welcomed in S-LCA, so long as values and assumptions are recorded and justified. In any case, the task of defining the methods and acceptable uses of S-LCA will require international and interdisciplinary collaboration.

There is also concern that by relying on Western scientific knowledge to set standards, local knowledge or stakeholder values could be lost or deemed unimportant [94]. Additionally, social certification programs (which are popular among socially conscious producers) can affect social patterns in places where production occurs, causing resentment or discontent among different value chain actors based on the programs' exclusivity and the benefits program members enjoy [95]. These lessons can be extended to S-LCA as well, and while standardization must play a key role in the future of S-LCA, there must also be strategies in place to incorporate local nuance. This could involve practices such as consulting stakeholders during the weighting or data inventory process.

2.9.3 Dissemination of information

As with many concepts in sustainability, one of the primary challenges in achieving social sustainability is the sharing of information between researchers and those who can implement changes [30]. This challenge is especially prevalent in the social-organizational realm, as the decision-makers in the most damaging sectors are often the ones who care the least about social betterment practices (i.e., if you are a farmer, you may not be aware that you are contributing to eutrophication or ecotoxicity, but you almost certainly would be aware that you were using forced labor). Additionally, it is often the case that people making decisions are not experienced in interpreting scientific data. Conducting research and publishing papers is only helpful if it can be translated into tangible and meaningful change.

The other issue in translating data to action, which also ties into the previous limitation (regional variability), is that results can only sometimes be extrapolated between studies. For example, the cattle farming study in Ireland [26] and the cattle study in Mexico [4] show that the impact from place to place will vary significantly even within the same industry. The same is true between industries in the same place. The implication is that practically every application of S-LCA must be conducted on a case-by-case basis. However, this inconvenience can be partially avoided by the raw power of aggregation, creating a collection of data gathered from previous studies, which is general enough to apply to other studies. The availability of such collections would make it much easier to conduct a thorough assessment with limited site-specific data. This strategy is at the heart of databases such as PSILCA and SHDB.

2.10. Discussion

In conducting S-LCA in the agri-food sector, the primary difficulty is not in collecting data but determining whether the data collected is a good enough indicator of the impact being studied. This is especially true when utilizing the impact pathway (Type II) analysis approach, in which the researcher must draw cause-and-effect relationships between indicators and impact categories. However, there is much to be gained from applying S-LCA in agriculture. Agricultural workers are often overburdened and underpaid for arduous tasks. This pattern is especially true for workers in developing countries. The concept of S-LCA encourages companies to look at all the impacts aggregated over the course of the production process. Because of this, companies sourcing materials from developing countries are encouraged to be wary of the potential social impacts they are incurring. However, since reducing poverty is also a primary sustainability goal of the United Nations [1], it is necessary from a social sustainability perspective that citizens of developing countries have access to jobs, which are often tied to production chains based in more developed countries. This conundrum also leads to several conflicts of interest when it comes to issues such as deforestation. An environmental perspective might wholly condemn deforestation for palm oil production, but what if palm oil provides value that boosts developing economies and provides local workers with well-paying jobs [34]? These kinds of conflicting perspectives are a significant barrier to developing universally accepted regulations based on S-LCA results.

The lack of safe and well-paid agricultural jobs in developing countries works against citizens of these countries in multiple ways. It is a direct detriment in that it reduces their standards of living, but the citizens also suffer indirect harm when companies searching for social sustainability certifications move their operations out of the country to places where production systems meet defined welfare metrics. For the case of the poultry industry, as the demand for poultry products in developing countries grows exponentially, animals and humans could suffer due to low welfare standards. This threat can be combatted by active participation by stakeholders and workers in encouraging the development and enforcement of socially progressive regulations, but whether this will happen or not is as of yet uncertain. S-LCA could potentially play a role in encouraging policymakers to focus on social welfare improvements within agricultural production systems. However, before this can happen, S-LCA ideally must reach a point where it carries the power of standardization. While there are many case studies in which S-LCAs are conducted, very few of them are in complete agreement with regard to which indicators to use, how to measure those indicators, and how those indicators should be interpreted. Standardization efforts in the form of databases or guidelines ones formulated by SETAC and the United Nations Environment Programme are crucial in making S-LCA a tool that can be used globally in the poultry industry to measure social sustainability and the welfare of people and animals.

2.11. Conclusion

Based on its past applications, S-LCA has a high potential to be applied in the poultry industry and other high-risk industries. While the methodological principles of S-LCA are robust, some improvements could be made. For example, where animal welfare metrics are included in S-LCA studies, they are often based on insufficient regulations. Better metrics for animal welfare could improve the lives of animals and the reliability of the assessment method in delivering results that can help systems improve. Additional concerns include regional variability and how to properly communicate results.

There are also concerns about the tool’s ability to present objective judgment. It is practically guaranteed that any S-LCA conducted will retain some subjectivity based on the culture and values of those conducting it. While the present guidelines attempt to remove subjectivity from the calculations in a very admirable standardization effort, the inherent subjectivity of social assessment makes it challenging to use as a comparative tool, although this does not mean that subjectivity is not also present in E-LCA and LCC. A paradigm shift in which subjectivity is accepted as a natural input of life cycle assessment would remove the demand for objectivity inherent in scientific thought and decrease the skepticism surrounding the efficacy of S-LCA. So long as value judgements and personal decisions are recorded and justified, replicability and scientific integrity are preserved.

The least controversial application of S-LCA is a decision-making tool to help companies determine their actions' potential impacts or compare different production strategy choices. For example, a poultry company wishing to better its social impact, whether for altruistic or market-driven motives, can use S-LCA to examine the potential impacts of different betterment strategies or to examine hotspots along its associated value chain . Additionally, governments or regulatory agencies can use S-LCA to justify enforcing policies to mitigate some of the more detrimental effects of the poultry industry's current operations.

Acknowledgements

The authors would like to thank Sara Russo Garrido for reviewing and editing the original draft of the manuscript. Funding for this study was provided by Mitacs Accelerate grant number IT32990.

Connecting Text 2

The manuscript in Chapter 3 has been submitted for publication in the International Journal of Life Cycle Assessment.

Chapter 2 provided a review of relevant literature within the field of S-LCA. This review examined 46 unique studies and found that, while the potential of S-LCA in agriculture is great, there are several major challenges that researchers face when using S-LCA in the assessment of agricultural value chains. One of the primary challenges was the issue of animal welfare. There is much disagreement within the community of S-LCA researchers regarding how—or even if— animal welfare should be included in S-LCA. While this is still open for debate, there are several reasons why animal welfare should be included in S-LCA in order to achieve a holistic view of the social impacts of a system. Indeed, many researchers and policymakers have noted the link between protecting animal welfare and achieving global sustainable development goals.

Thus, Chapter 3 presents an argument for the inclusion of animal welfare as a separate stakeholder category within S-LCA. This chapter details the justification for this new category, and also proposes the methods by which this new category can be incorporated into existing methodological frameworks and databases. The creation of a new stakeholder category will ensure representation of all affected stakeholders in the system, and thus will help improve the quality and accuracy of S-LCA studies within agricultural value chains.

Chapter 3: Integrating Animal Welfare into Social LCA: The Argument for a New Stakeholder Category

Aubin Payne, Ebenezer Miezah Kwofie, Elsa Vasseur

Abstract

Recently, the global community has developed an increased awareness of the social impacts of products and processes and has started demanding more accountability from producers and policymakers. In response, Social Life Cycle Assessment (S-LCA) has been developed as a tool to assess the social impact of products and processes on a variety of social groups, including workers, local communities, value chain actors, and children. The results from these assessments can be used to guide corrective action in both policy and practice. Animal welfare is increasingly recognized as an important social impact with strong ties to the United Nations' sustainable development goals, but it is yet to be included in a meaningful way in S-LCA frameworks. This study presents the argument for the creation of a stakeholder category for animal welfare in S-LCA, including a discussion of the subcategories and assessment methodologies that would be necessary to make this possible. To ensure that metrics are based on internationally recognized goals, subcategories of the new animal welfare stakeholder category were developed from the Five Domains/Freedoms model and the 3 "R"s of welfare in research. Example indicators were developed from the available welfare science literature but should be amended based on case studies and expert opinion. Additionally, methods are presented for integrating these indicators into the Type I (reference scale) and Type II (impact pathway) assessment methodologies defined in the United Nations Environment Programme's current S-LCA guidelines. An animal welfare subcategory could be added to the current S-LCA framework with very little modification of existing methodologies, and recognizing the importance of animal welfare would greatly benefit both animals and people and is a crucial step toward achieving sustainable development.

3.1. Introduction

In recent decades, there has been an increased recognition of the importance of animal welfare in production systems. Philosophers like Ruth Harrison [96], Tom Regan [97], and Peter Singer [98] pioneered discussions of the ethical dilemmas that arise due to current industrial farming methods. As a result, the global population is developing an increased awareness of the mistreatment of animals in agriculture. This is evidenced by the increased rate of choice-based activism such as veganism around the world, especially in Europe and North America [99]. As farmers seek to address these concerns, simply not harming animals is no longer sufficient. There are many enrichments that farmers can provide to go beyond the minimum effort required to keep animals safe and healthy and create positive experiences for the animals under their care.

In the traditional "three pillars" model of sustainable development, comprehensive sustainability rests on environmental preservation, economic prosperity, and social well-being. However, in modern academic discussions of sustainability, there is a noted lack of attention given to social impacts [11, 100]. Social Life Cycle Assessment (S-LCA) is a proposed tool that seeks to measure the social impacts of processes and organizations along the value chain of a given product. The assessment uses indicators to measure the impact of activities on different groups of stakeholders. Current stakeholder groups include workers, local communities, value chain actors, consumers, society, and children [11]. While only a small discourse exists on the topic, some authors have argued that animal welfare should be included as a subcategory under one of these existing categories [101], while others have studied animal welfare through its association with consumers or other interested stakeholders [102, 103]. This reflects the current practice in S-LCA, as "Ethical treatment of animals" is a subcategory in the "Society" stakeholder category in the 2020 version of the United Nations Environment Programme (UNEP) S-LCA guidelines [11]. Others have noted the possibility that animals could be considered their own stakeholder category [38, 77, 101]. Although equating animal rights with those of humans has historically been controversial [97], concepts like the One Welfare framework [9] have been proposed to integrate the metrics of animal health and welfare with human health and environmental conservation. Incorporating animal welfare into S-LCA could be a way to help decisionmakers quantify and realize the goals of One Welfare.

While the inclusion of "ethical treatment of animals" as a subcategory in the most recent S-LCA guidelines is an inspiring confirmation that animal welfare is a social impact worth including in S-LCA, this inclusion is not yet sufficient to capture the full range of animal welfare [11]. Where animal welfare is included, indicators typically are based on regulations or reports of negative impacts, which are insufficient in most countries [104]. The result is that, whereas S-LCA allows for positive social handprints for categories like worker welfare and local community, the best measurable outcome for animal welfare is that negative impacts are minimized. This contradicts the modern tenets of animal welfare science, which recognize that good welfare comes from increasing positive experiences as well as decreasing negative experiences [105, 106]. Another indicator used in these guidelines is the presence of an independent welfare certification [11]. While welfare certifications are important in regulating the global market, there is wide variation in the trustworthiness of independent certifications [16]. In order to provide a comprehensive assessment of animal welfare, it is necessary to create a new stakeholder category for animals within the S-LCA framework that relies on direct measurements when possible. This study presents the argument for this new stakeholder category, and then presents the methods by which this new category could be added to the S-LCA framework with minimal modification of the present guidelines. The creation of this new category will expand the S-LCA methodologies to capture a crucial aspect of social sustainability which is currently understudied.

3.2. Theoretical Background

It has been noted by previous works that the comprehensive measurement of animal welfare contains a non-negotiable degree of subjectivity. This is explained well by Fraser in [107], who states that:

> *"In assessing welfare at the farm and group level, we should attempt not the impossible goal of eliminating value assumptions from animal welfare assessment, but the achievable goal of making value assumptions more explicit." [107]*

This presents a difficult task for researchers wishing to measure welfare objectively, because it implies that opinions and perspectives on welfare—which vary widely from place to place—have a place in the social assessment of animal product systems. Thus, before proposing a framework for measuring welfare, it is necessary to make explicit the values on which the framework was based. The following section details the process by which these values were selected for this study. While animal welfare values and definitions are dependent on social context and may not be agreed upon by all actors, care was taken to ensure that these values represented global perspectives by using internationally recognized guidelines and frameworks as the basis for this study.

In conventional LCA terminology, "indicators" describes measurable metrics which are used to gauge "impacts," which are the categories in which the system being studied impacts animal welfare. In measuring animal welfare, indicators can be separated into those measuring animal-based impacts (i.e., effects on animal well-being) and environment-based impacts (i.e., risk factors that may lead to animal-based impacts). Both are necessary to understand the full scope of animal welfare. For the duration of this paper, "impacts" refers to both animal-based and environmental-based impacts, unless otherwise specified. It is also important to note that in all cases, Life Cycle Assessment is an oversimplification of the real world, and there are many factors and synergistic relationships between variables which are not controlled for. For example, appropriate environmental management can counteract negative effects from overcrowding [108]. Although these factors are not typically accounted for in the LCA models, they can be noted when discussing results.

3.2.1. Values as basis for the framework

Modern discussions of animal welfare often recognize both positive and negative animal welfare. Negative welfare typically involves pain or suffering, whether that be physical (such as pain, sickness, or discomfort), or emotional (such as loneliness, boredom, frustration of natural behaviors). In the animal production industry, welfare improvement strategies are often targeted at minimizing negative welfare. Proponents of positive animal welfare (PAW), on the other hand, recognize that more than a lack of suffering is needed to create positive experiences and emotions. A review by Lawrence, et al. found that the effects of positive welfare could be classified into four categories: positive emotions, positive affective engagement (from goal-directed behaviors), quality of life, and happiness [106]. Methods for developing and evaluating positive welfare are still being investigated, but these four categories provide a foundation for PAW improvement strategies [106].

A balance of biological functioning, comfort and lack of suffering, and expression of natural behavior is necessary for good animal welfare in production systems. The relative importance of each of these is up for debate, as mentioned by Fraser [107]. In the context of S-LCA, however, the ideal balance for each research project can be achieved through different weighting strategies. It is recommended, however, that each factor be accounted for, and that none are entirely overshadowed by the others.

The values used as a basis for this framework largely mirror the utilitarian school of animal welfare philosophy, championed by Peter Singer [98]. This is based on the apparent general global consensus that raising animals for food is acceptable, so long as a minimum standard of respect for the animals is met. There is much contention to the legitimacy of this school of thought; some argue that utilitarianism overreaches in conflating the interests of animals with those of humans, while others argue that it does not go far enough to protect the inalienable rights of sentient beings. However, utilitarianism is the school of thought most representative of the approaches taken by modern animal welfare legislation and sustainability assessments. Regulations, including those set by independent certification programs and stakeholder initiatives, typically designate standards that producers must meet in order to achieve an acceptable level of animal welfare [109]. Even if these standards are high, critics point out that animals are still treated as a means to an end [110]. While utilitarianism seems to be the prevailing global mindset, it leaves much room for interpretation, including the standards that are set and how those standards should be implemented. These, then, must also be evaluated based on some ethical framework. Luckily, there are several frameworks and guidelines which can be translated into indicators and have support from governments and agencies around the globe [111-114]. Additionally, a large number of guidelines and scientific opinions come from the European Union [115-118]. Furthermore, there has been much academic research into measuring and improving animal welfare around the world [104, 106, 119]. These various sources can be combined to create a comprehensive understanding of the state of global animal welfare and what can be done to protect it.

3.2.2 Previous Frameworks

Previous studies have attempted to incorporate animal welfare into S-LCA; however, the metrics that they include are measures of exclusively poor animal welfare, such as prevalence of mortality and morbidity [101]. Other studies which have incorporated animal welfare do so by comparing practices to local regulations [15]. As consumer demand for welfare improvements increases and becomes more concerned with increasing positive welfare rather than mitigating negative welfare, these frameworks do not include a broad enough range of categories and indicators to measure the full spectrum of both negative and positive animal welfare impacts. The Five Freedoms framework, developed in the United Kingdom as a result of the Brambell Report of 1965 [120, 121], is internationally recognized due to its incorporation of a wide range of factors affecting different aspects of welfare. These freedoms have been interpolated into a more in-depth framework called the Five Domains, which more thoroughly incorporated positive aspects of welfare [111]. As noted in a review by Lanzoni et al [122], no studies as of 2023 had incorporated aspects of all five domains into their social sustainability assessment strategies. The Five Domains, as described by the Mellor et al. [111], are presented in Figure 3.1.

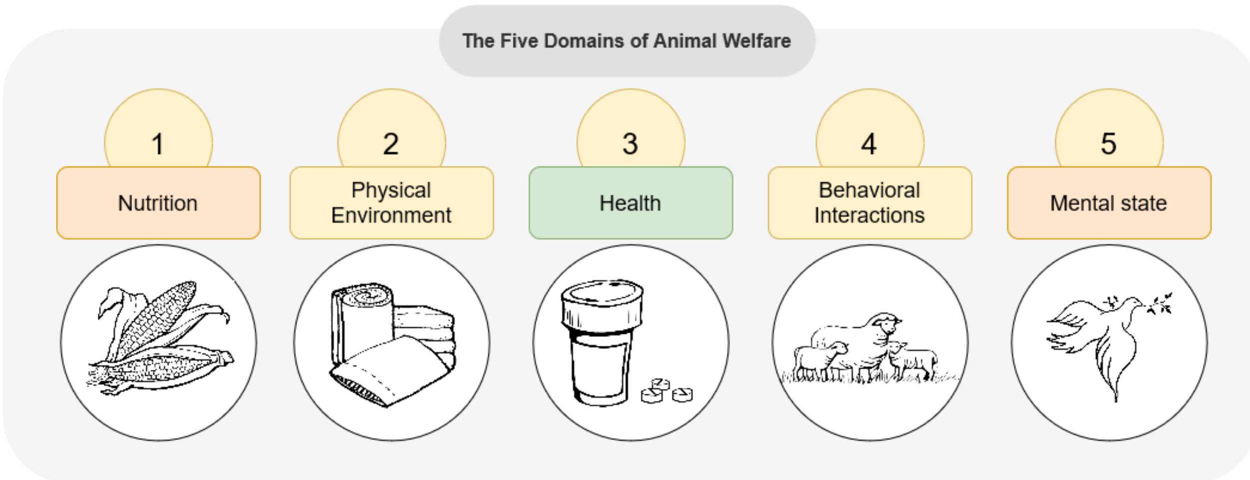

Figure 3.1: The Five Domains of Animal Welfare [111]

The Five Freedoms have been used to formulate international guidelines and regulations [123]. The Five Domains, which follow the general outline of the Five Freedoms, include "survival-critical" categories (1, 2, and 3), and "situation-related" effects (4). The combined results of these impacts are then used to gauge the impact in the fifth category (mental state). Thus, a framework for measuring social impacts based around these five domains would encompass all important aspects of animal welfare. The Five Domains model for measuring animal welfare is loosely based on this Five Freedoms concept, and presents an in-depth guideline for measuring positive and negative impacts of environment, healthcare, and management strategies on animal welfare [111]. However, as noted in another study, it is incredibly time-consuming and difficult to measure a comprehensive range of both animal-based and environment-based welfare indicators [101]. This same study attempted to create a standard model for integrating animal welfare indicators into social LCA using the Five Freedoms as the basis for the model [101], but this model did not encompass all of the Five Freedoms in its calculations. This was noted by the authors of the study, who justified the exclusion based on the difficulty of measuring positive impacts but recommended that a means for including these impacts should be developed. Indicators of positive welfare could include the presence of environmental enrichment (such as outdoor time allowance), dietary palatability and enrichment, or the level of engagement with the environment, handlers, and other conspecifics.

In scientific research, the demand for increased welfare of laboratory animals has led to the development of another framework, called the 3 "R"s (replacement, refinement, and reduction). This framework encourages researchers to find alternatives for animal use in research, or if animal use is necessary, to reduce the number of sentient animals used to obtain results, and refine the experimental procedures so that harmful practices are removed as much as possible [124]. This ensures that the number of animals being used in traumatic and harmful procedure is minimized. The 3 Rs and the 5 domains/freedoms have both been mentioned in international legislation or guidelines, indicating widespread support for the concepts presented in these frameworks [114, 125]. While the goals of the One Welfare framework [9] are often less tangible and measurable than those of the Five Domains and 3 "R"s, the concept can be used to drive action and policy and to frame the discussion surrounding animal welfare in S-LCA. The available literature shows that, while there has been significant research towards measuring welfare in animals (for example, the Welfare Quality Assessment Protocol [126]), there is still much work to be done to bridge the gap between the welfare assessment and S-LCA [122].

Additionally, previous studies that have focused on outcomes of poor welfare have not traced the pathways to find the root causes of welfare issues. For other S-LCA indicators, the indicators are based on both the causes and results of poor welfare. For example, one indicator of workplace health and safety is the number of fatal accidents that occur within a worker population [71]. This could be considered an "effect" of poor working conditions because unsafe working conditions would cause a higher rate of fatal accidents. However, there is also an indicator related to whether or not safety training is given and whether proper safety measures are enforced in the workplace. This indicator acknowledges the causal pathway between safety training and enforcement and worker safety [71]. Thus, to create a comprehensive stakeholder category or subcategory for animal welfare, it is necessary to acknowledge not just the outcomes of animal welfare but also the causes.

While there have been international agreements regarding the importance of animal welfare, perceptions of the importance of animal welfare still vary significantly from place to place, especially in developing countries [104, 127]. Regulations from place to place therefore vary significantly, and enforcement is often not prioritized. Additionally, an increasing portion of the population, especially in the developed world, do not interact with animal production systems in their daily lives [123], leading to much confusion and disagreement about the place of animals in the modern world. Thus, unlike most human-related S-LCA impacts, animal welfare can have very high "highs" as well as very low "lows" without exceeding the boundaries of social acceptance. This makes creating a scale to objectively (or semi-objectively) measure animal welfare difficult.

3.3. A New Stakeholder Category for Animals

Given the deficiencies in the current methods proposed to incorporate animal welfare impacts into S-LCA, a new methodology is required to address the following issues:

1. Frameworks do not account for positive impacts as well as negative ones.
2. Foundational frameworks such as the Five Domains are not included completely.
3. Cause and effect pathways for animal welfare are rarely explored (e.g. genetic susceptibility to disease, effect of human-animal interactions on mental well-being).

Thus, the indicators presented in Table 3.1 were compiled. These indicators are not meant to be final, simply the beginning of a discourse. In fact, the indicators will likely be changed from species to species and even application to application depending on what is applicable and measurable (e.g., cattle may be transported by truck in some places and by foot in others, this difference would need to be accounted for). Table 3.1 provides a set of example subcategories and indicators based on literature to indicate an appropriate level of detail that an animal welfare stakeholder category should provide and to provide a starting point for discourse on a holistic animal welfare S-LCA stakeholder category. The different aspects of this new framework are justified in depth in the following section. The main arguments which require justification are (1) formation of a new S-LCA stakeholder category for animals, (2) the use of the Five Domains/3Rs in conjunction with resources such as the Welfare Quality Assessment Protocol [126] as the bases for welfare assessment, and (3) the proposed indicators and reference scale. The sixth category (research) will only be applicable in assessments of animals used for testing and research but was included because this group represents a significant portion of the population of animals used by humans. Where possible, animal-based indicators should be used over environmental-based indicators, but these are often more difficult to measure and may require veterinary professionals to take part in assessments. The example indicators in Table 3.1 were suggested to facilitate both accuracy and ease of measurement.

Table 3.1: Proposed impact categories and subcategories with example indicators

Impact categories	Subcategories	Example Indicators	References
1. Nutrition	Hunger	Body condition score	[126]
	Thirst	Access to water at all times	[126]
	Quality of food	Optimal feed formulation	[111]
		Presence of dietary enrichment	[111]
2. Physical environment	Climate	Temperature control for indoor facilities	[128, 129]
	Comfort	Stocking density	[129-131]
		Presence of comfortable flooring/bedding	[126]
		Transport time with no stops	[132]
	Light, odor, and noise	Light levels	[133-135]
		Noise levels	[136]
		Air quality	[135, 137, 138]
3. Health	Genetic-associated health effects	Genetic susceptibility of the breed to disease or disability	[139]
	Pain	Access to veterinary care and pain management	[111]
		Use of painful procedures	[126]
	Disease and disability	Rates of lameness and disease	[140]
		Carcass condemnation rates	[101]
		Dead on arrival (DOA) rates	[101]
4. Behavioral interactions	Interactions with humans	Stockperson perceptions and attitudes	[141]
		Farm policies regarding animal handling	[126]
		Instances of injury from humans	[126]
	Interactions with conspecifics	Instances of injury from conspecifics	[126]
		Number of animals housed together	[105, 142]

5. Mental state	Anger/frustration	Rates of injury from conspecifics	[38, 126]
	Loneliness/boredom	Frequency of affiliative contact compared to social requirements for species	[111]
	Fear	Flight distance from stockpeople	[111, 141]
	Happiness/engagement	Time spent inactive/engaging with environment	[111, 143]
6. Research	Number of animals used	Number compared with similar experiments	[124]
	Justification for use	Presence of justification	[124]
	Type of animal used	Feasibility of an *in silico* or less sentient animal model	[124]

3.3.1 The Argument for a New Stakeholder Category for Animals

This framework defines animal welfare as a unique stakeholder category when conducting S-LCA. The presence or absence of a category does not necessarily imply that it takes precedence over other categories. Placing animal welfare as a subcategory of another category necessarily links animal welfare to its benefit to humans. This contractarian viewpoint is summarized as follows: *Animals are not conscious and cannot have rights, but people care about animals. Since people care about animals, harming animals indirectly harms people, and harming people is bad because people are conscious and have rights.* Beyond the mounting evidence to support that animals can indeed be the subjects of conscious lived experiences, this viewpoint has still been denounced by many critics, who argue that animal welfare is necessary regardless of public perception [97, 144]. Since animal welfare is an internationally recognized goal [125], it is the responsibility of researchers to include it as a category in social assessments.

Critics may object that the creation of a new stakeholder category for animals would undermine the importance of human welfare in the assessment of social impacts. This criticism echoes concerns of many politicians around the world who feel that developed countries are prioritizing animals over people [145]. However, in LCA, the addition of a new impact category is not meant to diminish the importance of the other categories, but to fill the gaps and create a more holistic methodology that captures all impacts. This can be seen in the extensive list of Environmental

LCA impact categories which do not detract from each other, but rather work together to provide a comprehensive review of the impacts of a process on the environment. Many studies have noted that, although they are not directly mentioned, animals play an important role in the context of the sustainable development goals (SDGs), and their welfare is inextricably linked with the welfare of humans [1, 8]. Additionally, weighting can be used to influence the contribution that any individual category has towards an aggregated final impact score. The absence of a separate category for animal welfare is a likely cause of the current uncertainty surrounding the inclusion of animal welfare impacts in current S-LCA practice.

Former objections to the creation of a separate category for animals [77] cited the fact that, in the 2009 S-LCA guidelines, children were not included as a unique stakeholder category, but rather as a subcategory [68]. However, in the updated 2020 guidelines, children are included as a unique stakeholder category [11], lending credibility to the argument for a new category for animals.

3.3.2 The Five Domains as the Basis for the Framework

It is common practice for S-LCA researchers to develop indicators based on international agreements and publications. A policy brief by the Food and Agriculture Organization includes the following recommendation: "Improve animal welfare delivering on the Five Freedoms and related OIE [now WOAH, [146]] standards and principles, including through capacity building programmes, and supporting voluntary actions in the livestock sector to improve animal welfare [125]." Additionally, all European Union member states have passed stronger legislation in an international effort to protect animal welfare [123], with updated legislation currently under review. Similarly, the Universal Declaration of Animal Rights was declared by UNESCO in 1978. The Universal Declaration of Animal Welfare was introduced to the UN in 2009 [114] and currently has full support from 46 members and partial support from 17. While this is nowhere near a majority, there are supporters from all continents, representing strong if not unanimous support among members of the international community. This declaration recognizes the Five Freedoms and 3 "R"s as fundamental to protecting the welfare of animals. Since the Five Freedoms (which have been expanded into the Five Domains framework) and 3 Rs are the foundation for most international documentation, it follows that they should be the basis for a new framework to integrate animal welfare into S-LCA.

3.3.3 Proposed Indicators

The indicators proposed in Table 3.1 were mostly aggregated from literature, either on animal welfare or on S-LCA. Studies and references used to develop indicators are included in Table 3.1. The goal of these subcategories and example indicators is to find a balance between completeness and ease of measurement. The subcategories and example indicators presented were selected because (1) they provide a comprehensive assessment of welfare based on the Five Domains/3Rs framework, and (2) they are relatively simple to measure (i.e., could be measured with relatively simple tools during a farm visit). For example, while mental state may be better measured using a preference study, this would take much time and effort to set up and complete. Similarly, pain and distress are measured using reported rates of painful procedures and availability of veterinary care rather than blood cortisol measurement, which requires laboratory work. A measurement of time spent engaging with environmental enrichment tools could be done in a single farm visit without any environmental manipulation. While this list of indicators was developed as an example of a comprehensive S-LCA stakeholder category for animals, it is intended to be modified through case studies and expert opinions. Many other indicators have been used in the past, and these differ depending on the goal and scope of the research. A comprehensive summary of indicators used by previous S-LCA studies was compiled in [122]. Just as regional and sectorial nuances should be considered in other S-LCA categories [5, 11], adjustments in indicators and methods will be needed for the animal welfare stakeholder category based on the species and the context in which production occurs.

As noted in a study by Tallentire et al, S-LCA indicators are most effective if the data required is objective and easily available [101]. That study argued for the use of "iceberg indicators," or indicators for which data is easily accessible that are likely indicative of deeper issues [101]. The principle of maximizing the ease and simplicity of data collection is important; however, to ensure completeness, a sufficient number of indicators are required to cover the full scope of the Five Domains and 3 "R"s. Thus, the example indicators in Table 3.1 are proposed. If measurement of a certain impact subcategory is unavailable or excessively difficult to measure, it may be left out of the assessment, but as many subcategories as possible should be included. Subcategory 6 (Research) only needs to be included if the animals are being used for research purposes. Similarly, if the study is conducted for animals in research, several of the indicators in other categories may not apply.

One of the dangers of aggregating results within S-LCA categories is that enough good scores can outweigh the presence of some bad scores. This is especially true in the context of animal welfare, where very harmful elements can be present in systems which would otherwise perform well. For this reason, aggregation of indicator scores is not recommended. The following section will discuss presentation methods for each of the two S-LCA impact assessment approaches.

3.3.4 Impact Assessment

As described in the 2020 updated UNEP guidelines [11], there are two approaches to conducting S-LCA. The Type I (reference scale) approach to S-LCA is conducted by measuring values for each indicator relative to a reference value, usually the average value for the indicator for the region or sector. The Type II approach, on the other hand, attempts to link indicator measurements with final impacts via cause-and-effect pathways, often making use of activity variables (which will be described in detail later). The Type I approach is much simpler and easier to conduct than Type II, as it does not involve the translation of impacts from their original units.

Reference scales are usually developed based on local regulations or norms. In order to present results objectively, S-LCA needs an objective or semi-objective basis for its scoring system. It is here that a significant standardization problem arises. An objective reference scale must be created, but animal welfare laws are insufficient to serve as the basis for this scale, since they rarely regulate beyond the bare minimum of ensuring that animals are not suffering. While farmers should not necessarily be punished for complying with laws, laws are often not specific or enforceable enough to ensure positive animal welfare. Thus, a more robust baseline is needed. This can be achieved through expert opinions or values from literature. Veterinarians, animal scientists, farmers and other experts who regularly work with animals could be surveyed to determine their perceptions of animal welfare. Welfare standards created for independent certifications can also play a role in forming a baseline for good welfare. Labels like Red Tractor in the UK and FARM in the US [147] can provide the basis for good welfare standards. Even though they exceed legal standards, cooperatives and processors often require farmers to participate in these programs [119].

Additionally, much research on measuring animal welfare has been performed. Best practices and impact evaluations from literature could be used to establish a baseline to which indicators could be compared. Some impact categories can be optimized by meeting a standard (e.g., temperature control). Others, however, can be optimized to a virtually unlimited extent to provide positive impacts (e.g., level of environmental enrichment). Accounting for both of these on a reference scale is difficult, but it can be done through relative referencing in which a sliding scale is used. For example, on a scale from 0 to 10, the baseline at which basic animal welfare standards are met but not exceeded is assigned to a score of 5. Any reference points above this are scored via Equation 3.1.

$$S_i = 5 + \left(\frac{5i}{n_{rh}}\right) \cdots (3.1)$$

Where S_i is the score of the i^{th} ordered reference point above the baseline, and n_{rh} is the total number of reference points above the baseline. Similarly, scores below the baseline can be calculated from Equation 3.2

$$S_j = 5 - \left(\frac{5j}{n_{rl}}\right) \cdots (3.2)$$

Where S_j is the score of the j^{th} ordered reference point above the baseline and n_{rl} is the total number of reference points below the baseline. In either case, the determination of the baseline should consider aspects of each of the three areas of welfare as defined by Fraser: biological functioning, comfort and lack of suffering, and expression of natural behavior [107]. An example could be created for the feed formulation, as shown in Figure 3.2. In this scenario, n_{rh} is 2 and n_{rl} is 3. An equation presented by Zira et al. [38] was developed to assess risk levels (and is discussed further in the Type II section below), but can also be used to calculate reference scale scores relative to a baseline or sector average.

A score of 5 represents systems that meet the basic requirements for animal welfare. Higher scores are only allocated to systems that go above and beyond meeting these minimum requirements. In many categories, it is not possible to go above and beyond the minimum requirements, in which case a score of 5 represents the best-case scenarios. It is important to acknowledge this when scores are aggregated or presented graphically.

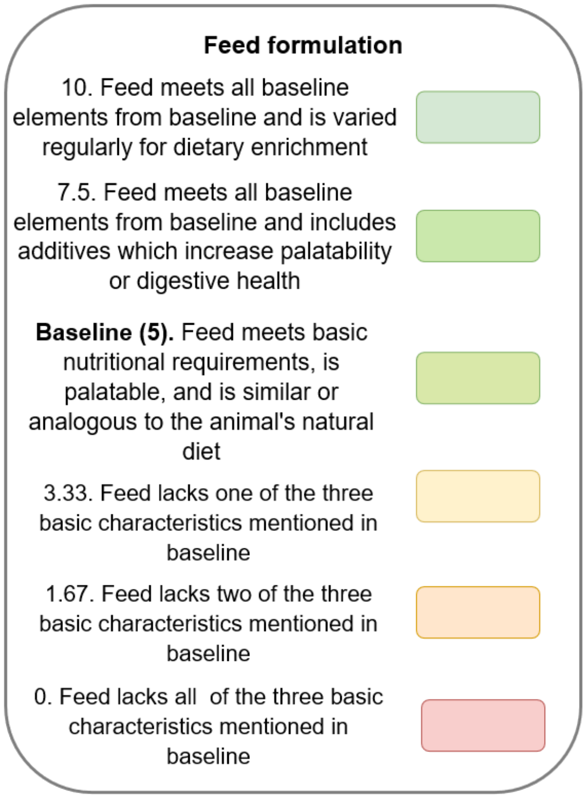

Figure 3.2: Example reference scale for animal feed formulation, based on those presented in [11].

For numeric indicators such as mortality rate and rate of disease, the values may be compared to data from industry and literature, where available, about averages for these numbers. The reference scale can then be created using the standard deviations of this data (e.g., a farm with a mortality rate of three or more standard deviations above the average for the sector in the region will score a “0”, one operating three or more standard deviations below the average would score a “10”) . Ideally, in the future, these data sets will be incorporated into databases like Product Social Impact Life Cycle Assessment (PSILCA) or Social Hotspots Database (SHDB)—the two databases currently available for social impact assessment—to ensure access and consistency for researchers and other users and interested stakeholders like farmers and policymakers. The Type 1 (reference scale) approach may be difficult to implement in practice, and it would be difficult to maintain consistency between studies. The methodologies presented in this paper are consistent with options presented in the 2020 UNEP Guidelines for S-LCA [11], but they are simply suggestions to guide future research efforts.

To present the data, it is recommended in S-LCA guidelines that the indicator scores are not aggregated, but rather are presented together [11]. This will allow researchers and decision-makers to determine where improvements can be made. Aggregation can lead to masking of negative effects by positive ones. An example with placeholder data is shown in Figure 3.3. Data are presented as being below, at, or above the minimum acceptable standard of welfare.

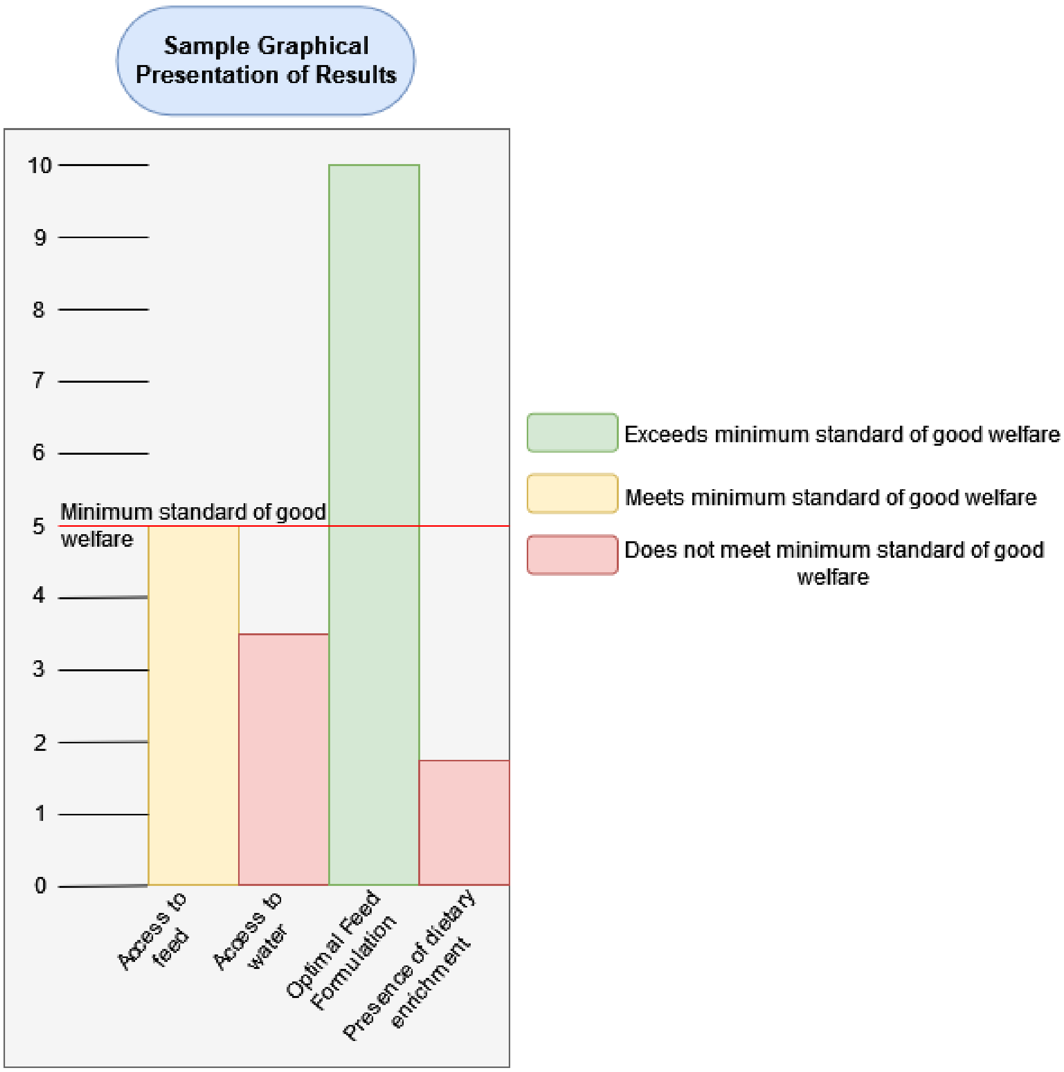

Figure 3.3: Sample graphical presentation of Type I assessment results

The Type II impact pathway approach to S-LCA involves translating impacts from their respective units of measurement to a single unit via an impact pathway. This often involves the use of an activity variable. The activity variable is defined in S-LCA as "… a measure of process activity which can be related to process output" [11]. Examples of activity variables include worker hours and value added. Each process in a value chain is tied to an activity variable (e.g., how many worker hours does this process take to complete? How much value is added by this process?). Since these can be measured across all processes, they can be used to aggregate scores across all processes in the value chain.

While many studies conduct S-LCA studies using only collected data, generic data from databases are also used in many studies where data collection on entire processes might be difficult, or where the goal is to identify hotspots along the value chain where social impacts are the highest. In the Social Hotspots Database (SHDB) and PSILCA database, results are presented in terms of worker hours and the risk associated with those hours. The worker hours activity variable examines the number of hours worked in each sector to yield one functional unit of the final product (the unit used to normalize quantities across the value chain, e.g., 1 kg milk produced). Risk in S-LCA is typically assessed on an ordinal scale with five options (very low, low, medium, high, or very high risk), which are defined relative to reference data, typically an average or minimum acceptable value determined from national or international databases. The risk score is used to weigh the aggregated final score for an impact pathway. In the work of Zira et al., a new method is proposed in which risk is calculated on a sliding scale using equation 3.3 if the value is higher than the reference value, and equation 3.4 if the value is lower than the reference value. This presents the risk on a scale of 0-1, with 1 representing the highest possible risk (both equations are taken from [38]).

$$\mathrm{SR}_i = 1 - \mathrm{EXP}\left(\mathrm{LN}(0.5) \times \frac{\mathrm{IND}_i}{\mathrm{REF}_i}\right) \cdots (3.3)$$

$$\mathrm{SR}_i = \mathrm{EXP}\left(\mathrm{LN}(0.5) \times \frac{\mathrm{IND}_i}{\mathrm{REF}_i}\right) \cdots (3.4)$$

Where SR is social risk for indicator i, IND is the indicator value (measured onsite or estimated using published data), and REF is the reference value (average or minimum acceptable value). This allows risk to be gauged on a sliding scale rather than in incremental values, which can result in the same score being assigned to a wide range of indicator values. From here, the impact score for each indicator is calculated using Equation 3.5.

$$Impact_i = AV_i * SR * W \cdots (3.5)$$

Where AV_i is the measured or estimated value of the activity variable (e.g., worker hours or collective animal work hours) associated with the process in question (i), SR is the risk level assessed using Equations 3.3 & 3.4, and W is a weighting factor that may be applied [38, 101]. Often, the weight will be kept at 1 for all categories, but some researchers use stakeholder priorities and expert opinions to weight indicators differently. Since SR and W are unitless, this will yield an impact in terms of the unit of the AV, which can then be aggregated with other impacts using the same AV.

Tallentire et al [101] proposed a strategy for directly assessing animals' welfare using "collective animal work hours" as an activity variable rather than worker hours. Using collective animal work hours as the activity variable is beneficial because it removes the link between animal life hours and human work hours while still maintaining the time-based activity variable. This method also develops a score relative to the worst-case scenario for animals on the farm in order to avoid misattributing welfare impact changes to lifespan, farm size, or other confounding factors [101]. A similar methodology was employed by [38]. However, while the creation of a metric that detaches human work from animal work is admirable, there are two issues that must be resolved.

The first issue is how work is defined for an animal. The simplest solution may be to consider animals as workers, and their lives as working hours. This is the strategy employed by Tallentire et al. The logic of this strategy is easy to follow; animals raised for products like meat or leather spend their whole lives "creating product," simply through biological function. However, this strategy becomes more uncertain when considering lab animals, work animals like horses, or animals like dairy cows which are only economically productive at certain times. For these animals, there is a clearer definition of time associated with their work. Additionally, counting animal life hours as working hours might lead to overrepresentation if results are aggregated, since other stakeholders for whom the effects of impacts are not time-dependent (children, communities, society) are still represented with worker hours rather than life hours.

The second issue is that there is currently no option in the PSILCA or SHDB databases for including activity variables other than worker hours. While this may be resolved in future updates, for now, data must adhere to this format to facilitate aggregation. Therefore, it is necessary to attach animal welfare to worker hours in a way that can be incorporated into the current version of the databases until more activity variables are included. This means translating animal welfare metrics to levels of risk and attaching them to worker hours, as described in the PSILCA v.3 documentation [148].

One of the primary features of the proposed "collective animal work hours" methodology is that animals are given more recognition as individuals who experience positive and negative effects. Thus, a possible alternative strategy would be to measure the number of hours worked by each worker on the farm. Then, in order to count animals as individuals, the number of hours worked could be multiplied by some ratio expressing the number of animals that are in each worker's care, as represented by Equations 3.6 and 3.7.

$$R = \frac{Number\ of\ animals\ on\ the\ farm}{Number\ of\ workers\ on\ the\ farm} \cdots (3.6)$$

$$AV = R * (Total\ farm\ worker\ hours\ per\ functional\ unit) \cdots (3.7)$$

where AV = animal-adjusted worker hours (which would then be used in the impact calculation). This would allow the impact of animal welfare to be assessed on the basis of human worker hours while recognizing the importance of the welfare of individual animals. If necessary, H could then be multiplied by a weighting factor that is representative of the perceived importance of animal welfare for the given study.

The benefits of this method would address both issues identified within the collective animal work hours concept while maintaining the benefits. For animals raised for meat, the input of labor will be fairly constant across the animals' lifespans. For animals like dairy cows and work horses, work hours would be tied to the amount of time that workers spend attending to them or utilizing their skills. These values will be higher while the animal is producing, and lower (but not zero) when the animal is resting, meaning that the work accounted for will be proportional to the work done by the animal. As for the issue of the single AV present in databases, this method would translate the results to worker hours in a way that maintains the individuality of the animals while not overstating the impacts associated with their labor by associating it to their entire lifespans.

The risk level for the indicators presented must be developed on a species-to-species basis, as different animal species (and even members of the same species at different life stages) have different needs. For example, housing systems for broiler chickens are much different from those for pigs, and even for layer hens. Comparing these based on physical properties should be secondary to comparing them based on the impact that they have on the welfare of the animal. Physical properties such as space allowance may be good "iceberg indicators," as called for by [101], but it is important to adjust indicators and their associated risk factors based on the species and application. The risk levels may also be adjusted to a sliding scale rather than four levels, as proposed by Zira et al. [38]. However, current databases use ordinal levels of risk assessment, so it is worthwhile to provide an example. Additionally, there are interactions between the indicators so that an increase in one may affect the impacts of another. Nevertheless, a brief example is presented here for several of the example indicators from the physical environment subcategory for broiler chickens. To translate these to a regional or national level, the average value for the region could be found and compared to these metrics. These risk levels are simply examples adapted from literature and should be modified based on expert opinion in the context of a case study. Table 3.2 presents an example of this for the subcategory "physical environment" for broiler chickens.

Table 3.2: Risk level assignment for indicators in the "physical environment" subcategory for broiler chickens

Indicator	**Very low risk**	**Low risk**	**Medium risk**	**High risk**	**Very high risk**
Stocking density [149-151]	$D \leq 11$ kg/m^2	$11<D<25$ kg/m^2	$25<D<39$ kg/m^2	$39<D<56$ kg/m^2	$D \geq 56$ kg/m^2
Temperature control for indoor facilities [152, 153]	20°C<T<24°C	15°C <T<20 °C OR 24°C <T<28°C	10°C <T<15°C OR 28°C <T<32°C	0°C <T<10°C OR 32°C <T<35°C	Temp reaches ≥35°C or ≤0°C
Ventilation (ammonia levels) [154]	Ventilation present, peak ammonia ppm <25	Peak ammonia ppm <30	Peak ammonia ppm <50	Peak ammonia ppm <100	Confined system w/o ventilation system OR peak

					ammonia ppm ≥100
Light levels [133]	-Daylight OR -Intensity 10-100 Lux	-Intensity 7.5-10 lux OR -Intensity 100-200 Lux	-Intensity 5-7.5 lux OR -Intensity 200-500 Lux	-Intensity 2-5 lux OR Intensity above 500 lux	-light below 2 lux
Consecutive time spent in transport[155, 156]	No transport, slaughter on-site	<1 hour	1-4 hours	4-8 hours	>8 hours

As a visual summary, the complete methodology for incorporating animal welfare as a stakeholder category in S-LCA is presented in Figure 3.4. This is based on the ISO 14040 and 14044 standards as interpreted in the 2020 UNEP S-LCA guidelines [11], and adapted for the animal welfare stakeholder category. It is emphasized in [11] that S-LCA is an iterative process, and the goal and scope can be changed based on data availability and hotspot identification.

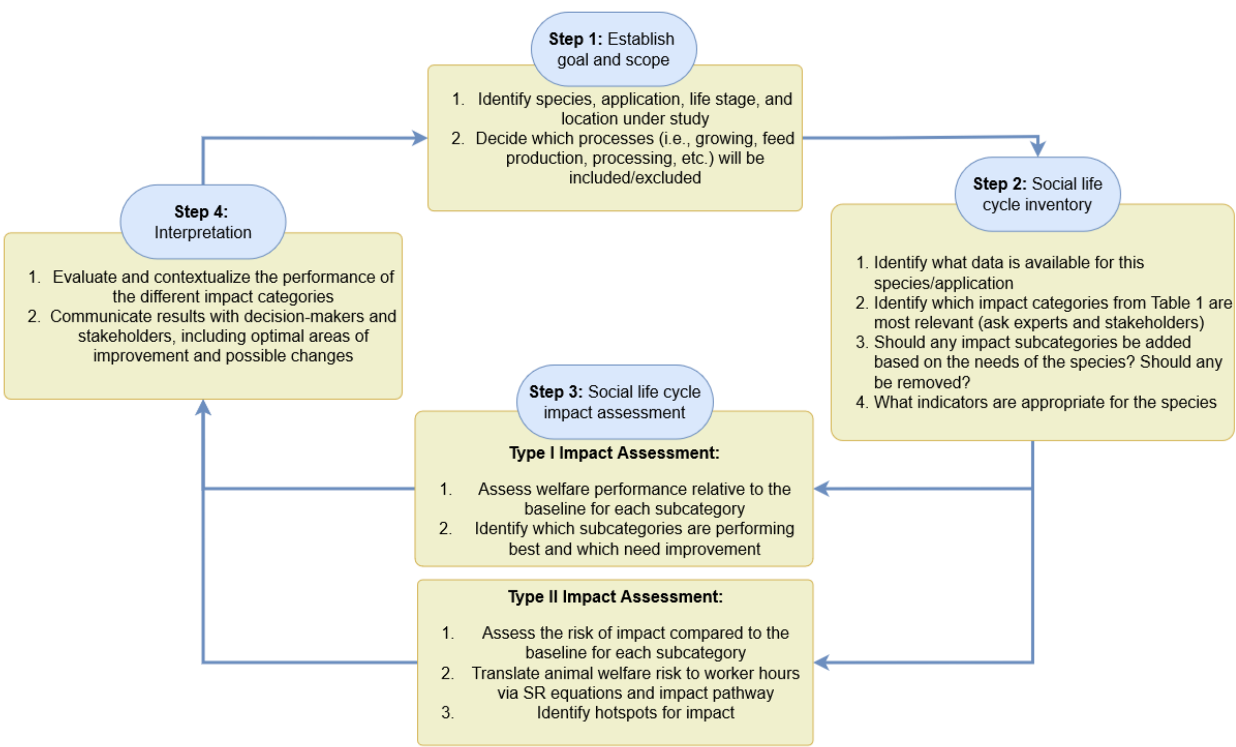

Figure 3.4: Iterative process view of incorporating animal welfare in S-LCA

3.4. Discussion

Animal welfare is of vital importance and consequence in food production systems. While much literature in the field of animal welfare studies is devoted to developing indicators for animal welfare assessment, little effort has been devoted to incorporating this impact category directly in a standardized way into S-LCA methodologies. Many researchers have noted the need for a consensus on the inclusion of animal welfare in S-LCA [8, 101, 122]. However, this poses a great difficulty given the wide variation in perceptions and legislation regarding animal welfare around the world. Despite this variation, there is a large and growing number of independent certifications acting both locally and globally which help to standardize welfare goals [157], indicating that demand among consumers and other stakeholders for the fundamental principles of animal welfare is growing worldwide. While it was once thought to be enough to simply maintain the physical health of animals, there is mounting evidence for the importance that the mental states and natural behaviors of animals are equally important [111].

Much animal science research is devoted to developing indicators of animal health and welfare. However, while indicators exist for a wide variety of animal welfare issues, there is work to be done to translate these metrics to a S-LCA context. A small but important collection of studies have laid the foundation for the inclusion of animal welfare in S-LCA [38, 101, 122]. Thus, the critical issue is not a lack of research on animal welfare, but rather fitting welfare measurement strategies into the existing framework for S-LCA, which uses indicators from site-specific and generic sources to holistically assess the social impacts of a given system. The subcategories and example indicators proposed in this paper are compatible with both Type I (reference scale) and Type II (impact pathway) impact assessment approaches, although significant development will be needed in order to craft risk assessment scales and appropriate indicators for different species in different applications. Similar to other S-LCA categories, there are some overlaps and cause-and-effect relationships between the indicators that are not accounted for when constructing impact pathways in the S-LCA framework. As this set of indicators is amended and expanded, double counting (using the same or similar indicators in multiple categories) should be avoided [11]. The complete methodology for including the animal welfare stakeholder category in S-LCA was presented in Figure 3.4. This figure shows how the animal welfare category is incorporated into S-LCA methods, which in turn satisfy the requirements laid out in ISO 14040 and 14044.

3.5. Conclusions

S-LCA has shown great promise and is currently one of the foremost tools for evaluating social sustainability, but it lacks a consistent methodology for incorporating animal welfare into assessments. Animal welfare is an important aspect of social welfare that is crucial in reaching the United Nations' Sustainable Development Goals [8]. However, while it is well researched from an animal science perspective, it is understudied and undervalued in the current S-LCA guidelines defined by the UNEP in [11]. This study presented an argument for why animals should be included as a unique stakeholder category in S-LCA and presented a set of subcategories and example indicators based on the Five Domains and 3"R"s, (two globally accepted animal welfare guidelines). The proposed framework could be used to assess animal welfare in production and research systems, and can help researchers and decision-makers move towards achieving the goals of One Welfare [9]. While the indicators themselves are simply examples derived from literature and previous measurement frameworks such as the Welfare Quality Assessment Protocol [126] which are open to revision and reformulation, it is important to include all aspects of the Five Domains/3"R"s to ensure a complete and comprehensive assessment of welfare.

Methodologies were then presented for incorporating the animal welfare stakeholder category into a full S-LCA using the two methods (Type I, Reference Scale and Type II, Impact Pathway). For Type I studies, a reference scale can be created using values from animal welfare science literature or expert opinions. Measured or estimated site-specific values can be compared to these reference values to estimate the level of impact for each indicator. These impacts can be presented individually in a chart like the example shown in Figure 3.3.

For Type II (impact pathway) studies, there are two steps. The first is to establish an activity variable. In this study, a method was developed to translate the "collective animal work hours" metric defined by Tallentire et al. [101] to worker hours using the number of animals under a worker's care. This activity variable maintains the benefits of the collective animal work hours metric while still utilizing the standard activity variable for commonly used databases. The second step is to establish a risk factor. For this, one may use the methodology presented by Zira et al. [38], in which a sliding scale of risk is used to translate activity variables to social risk (see Equations 3.3 & 3.4). This method is ideal when fully relying on site-specific data. The second option is to use an ordinal risk scale similar to that presented in the SHDB and PSILCA databases.

An example of how this could be established is presented in Table 3.2. More work must be done to reformulate the indicators and risk assignments and apply them to different species and other industries outside of production and research (such as zoos or pet breeders), but the frameworks presented in this study are a crucial step towards the inclusion of a holistic and consistent animal welfare category in S-LCA.

Acknowledgements: The authors would like to thank Thaina Landim de Barros and Daniela Haager for reviewing the manuscript and providing feedback

Connecting Text 3

The manuscript in Chapter 4 is under internal review.

Chapter 3 detailed the proposition for a new stakeholder category for animals and animal welfare in the agriculture industry. Billions of animals worldwide are impacted by agriculture practices and can suffer greatly if welfare is not an explicit goal. The proposed addition to the S-LCA methodologies seeks to include aspects of welfare above and beyond simple health and functioning indicators. The addition of a new category for animal welfare aligns with internationally recognized welfare frameworks like One Welfare [9] and the Universal Declaration on Animal Welfare [114], and can be accomplished without altering the current frameworks and databases. The methodological improvements proposed in Chapter 3 are crucial to improving the accuracy of S-LCA in the agriculture and agri-food sector.

However, there are other gaps besides animal welfare which must be addressed in applying S-LCA in agriculture, such as data variability and a lack of case studies. Many researchers have noted that case studies are recognized as necessary for the evaluation and validation of methodologies. Thus, the purpose of the case study in Chapter 4 is twofold: first, it seeks to assess social impacts in an agricultural value chain (a feed additive for dairy cattle), and second, it seeks to evaluate the reliability and comparability of data collected from different sources. To complete the assessment, data was collected from databases, company policies and records, and a survey of worker opinions. These various data sources provided a solid foundation for discussing data variability and the effects it can have on S-LCA results.

Chapter 4: Social Life Cycle Assessment in Animal Agriculture: A Feed Additive Case Study and Methodological Assessment

Aubin Payne, Ebenezer Miezah Kwofie

Abstract:

A case study of social life cycle assessment (S-LCA) was conducted at a feed additive production company in Quebec, Canada. This study included both the foreground and background systems, including the use at the farm level in Canada and Brazil. This study was conducted using data from a variety of sources including company policies and records, worker opinions, and the Product Social Impact Life Cycle Assessment (PSILCA) database. First, the assessment was conducted for the production of the feed additive at the company. The results indicated that the category with the worst performance was *freedom of association and collective bargaining*, which scored a 0.346/1. However, worker perceptions indicated that this category was of low importance to the effects of their work on their well-being, indicating instead that *discrimination and equal opportunities* was the most important category. The assessment of the background system indicated that the production of medical and pharmaceutical products in China was the ingredient system with the highest social impact, and that the use at the farm level in Brazil yielded higher social impacts than in Canada for all impact categories except *social benefits*. The pathways of integrating data from different sources were evaluated. Although the impact pathway method can be used to convert primary data to risk-adjusted worker hours for the purpose of aggregation, the primary benefit of collecting data from multiple sources may be the ability to validate results, which is highly important as S-LCA becomes an increasingly powerful tool for assessing social impacts and informing policy decisions in the agri-food industry.

4.1. Introduction:

The growth and proliferation of industrial production over the past centuries has led to the innovation of many products, and the more recent globalization of world trade has made high-quality products accessible to remote corners of the world. However, there has been a growing understanding of the potential negative impacts of global-scale production and trade on sustainability parameters—economic stability, environmental preservation, and social well-being. Agriculture, and specifically livestock production, is a major contributor to these negative impacts. Environmentally, the production of animal products consumes more land and contributes more greenhouse gases than their plant-based counterparts [158, 159]. For example, beef contributes 5.9 times more emissions than dairy milk and 71.1 times more emissions than soybeans per gram of edible protein [160]. Social and economic issues are also common in agriculture, including gender discrimination [161], poor animal welfare [127], unfair contracts [78], and unequal wealth distribution [162]. In order to address these issues, much effort has been dedicated to quantifying these impacts and identifying areas where improvement potential is high. These are the major goals of sustainability assessment tools such as Life Cycle Assessment (LCA).

Sustainability assessment such as LCA has grown in popularity in recent years as a tool for researchers to identify pathways towards sustainable development in different sectors [163, 164]. LCA allows for standardized assessment of the sustainability impacts along a product or process' life cycle (i.e., from when it is produced to the end of its life when it is thrown away or repurposed). Businesses can use these results to assess their practices to improve performance in each area of sustainability while maintaining economic stability [165]. However, while environmental and economic assessment have become prolific in research and industry, the methodology for the assessment of social parameters has struggled to gain universal consensus [6]. One of the most promising social impact assessment strategies is social life cycle assessment (S-LCA). This methodology was formulated as complementary to environmental life cycle assessment (E-LCA), but it was developed much later than E-LCA, and from its conception, it was held back by the perceived subjectivity of its indicators and calculation pathways. This has been addressed in recent years through the formulation of the UNEP/SETAC Guidelines for the Social Life Cycle Assessment of Products in 2009 [68] and the updated Guidelines for the Social Life Cycle Assessment of Products and Organizations in 2020 [11].

Additionally, a growing number of S-LCA case studies are available, and several of these case studies have evaluated agricultural production systems. These studies have revealed problems associated with insufficient pay, poor animal welfare, and poor working conditions [4, 38, 50]. There is also a noted discrepancy between social conditions in different countries [4], which highlights one of the major difficulties in conducting S-LCA. For example, countries with different levels of governmental stability and law enforcement power cannot be held to the same standard when it comes to the provision of services and the enforcement of laws. Several studies attempt to address this issue through methodological improvements, either contrasting or expanding upon the

UNEP guideline methodology. For example, Siebert et al. [72] developed the RESPONSA method for scoring social performance relative to average conditions in the region/sector being assessed. In a case study of palm oil production in Indonesia, Manik et al. [7] advocated for using stakeholder opinions as the primary basis for evaluating the social impact of systems (comparing perceptions to expectations).

In Canada, S-LCA case studies have been conducted for milk [15] and egg [3] sectors. These studies demonstrated that, while a high level of development affords Canada a high standard of worker protections and regulations, the agriculture sector in Canada is not immune to many of the sector's globally prevalent challenges such as low wages and unsafe working conditions [3]. In Brazil, several studies have been conducted on products such as sugarcane [35] and biofuel feedstocks [166]. Several comparative S-LCA studies have been conducted, with some comparing different industries within the same country [41] and others comparing the same industry in different countries [19, 50, 55]. However, there is a lack of S-LCA studies which compare agriculture sectors in countries at different development levels [55]. Additionally, very few studies have assessed the variability and validity between assessment methodologies and the potential to integrate site-specific data with generic data to conduct a holistic life cycle assessment. This study fills this knowledge gap by considering site-specific policy data, generic data, and worker perspectives, and presents results using both Type I (reference scale) and Type II (impact pathway) methods.

Agricultural research has shown increasing support for the use of feed additives in animal production, with benefits including increased feed conversion rate, animal health improvements, and even reduction of harmful pollutants in waste [167]. This study assessed the life cycle social impact of the production of a feed additive for dairy cattle at a company in Quebec, a province in eastern Canada, and also assessed the benefit of using feed additives to increase feed conversion efficiency by comparing farm-level scenarios of feed additive use in two different representative countries (Canada and Brazil). It should be noted that, while social impacts can be both positive and negative, in this study, "social impacts" refers to negative social impacts unless otherwise stated.

Thus, the goals of the study were twofold. Firstly, the study conducted a holistic social life cycle assessment of a feed additive manufacturer and the associated value chain in order to evaluate the impacts associated with different processes and identify hotspots. Second, the pathways of integrating and validating data from various sources (worker perceptions, company policy, and databases) were explored. These explorations attempt to fill the current research gap by revealing the benefits and drawbacks of the different data collection methods and exploring how the data can be used to build a comprehensive and reliable picture of social welfare along the product value chain.

4.2. Methods:

This study followed the general outline of LCA presented in the ISO 14040 and 14044 standards for Life Cycle Assessment [168]. However, the study was split into two phases (the feed additive manufacturing system and the farm-level feed production and feeding system). The first phase of the study was split into two separate assessments: one for the foreground study (the processes for which site-specific data is available) and one for the background study (the processes for which generic database data will be used). The foreground and background processes were assessed separately and using different methods that allowed for more comprehensive data analysis. The foreground system (the production of the feed additive at the company) was assessed using worker and HR questionnaires. The questions included in these questionnaires (listed in Appendices A&B) were selected based on the UNEP's 2020 S-LCA guidelines [11] and the accompanying methodological sheets [71], and were assessed using methods proposed by Zira et al [38] and Siebert et al. [72]. The background system was assessed using the PSILCA database. A representative dataset for the foreground system was added to the PSILCA database in order to create a complete representation of the system, however, it was noted that there were likely some differences between the data collected and the representative data in the database which could influence the results. Guidelines recommend that direct comparisons only be conducted when processes use similar data collection and assessment methodologies [11].

4.2.1: Methodological Framework

This study was split into the two phases of assessment mentioned above, followed by a comparison and evaluation. The methodological framework for the study is shown in Figure 4.1.

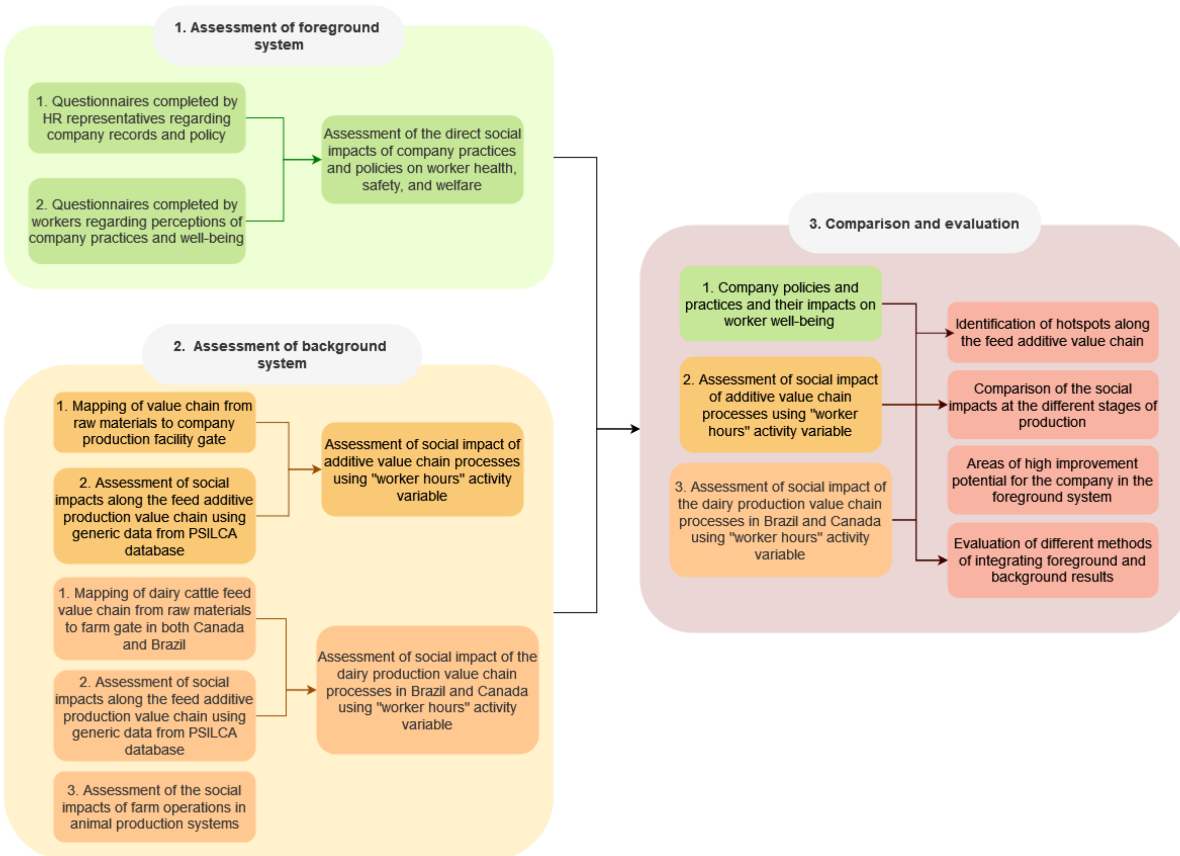

Figure 4.1: Methodological framework for the study showing the major components of assessment

4.2.2: Goal and Scope

This project aims to determine the social impact of the production of a feed additive for dairy cattle at a company in Quebec, Canada and to compare the production of milk from cows fed with and without this feed additive. This will be accomplished in two phases. The first phase will consist of the assessment of both the foreground and background processes for the feed additive manufacturer. The second phase will consist of the assessment of the value chain of feed production and on-farm feeding for an average dairy cattle production operation in Canada and Brazil. Canada was chosen because it is the location of the additive manufacturer, and Brazil was chosen because it is a quickly developing country with large and growing dairy sector. Impacts like animal welfare which primarily relate to on-farm practices will not be considered due to lack of data, although they are very important for holistic S-LCA and should be included in future studies. The waste management was similarly not included, making the scope a cradle-to-gate approach, with the final gate being the production of milk at the farm. Effects were not examined at the consumer or waste management level or beyond because the primary goal of the study is to examine the social impact of feed additives, and while additives can have farm-level effects by improving feed conversion rate and other health factors, they do not have a notable effect on the social aspects of on-farm practices and waste management.

Thus, the scope of the first assessment is all the processes performed at the Quebec production facility and the production of all ingredients used in the production facility. Figure 4.2 shows a visual representation of the scope of this assessment.

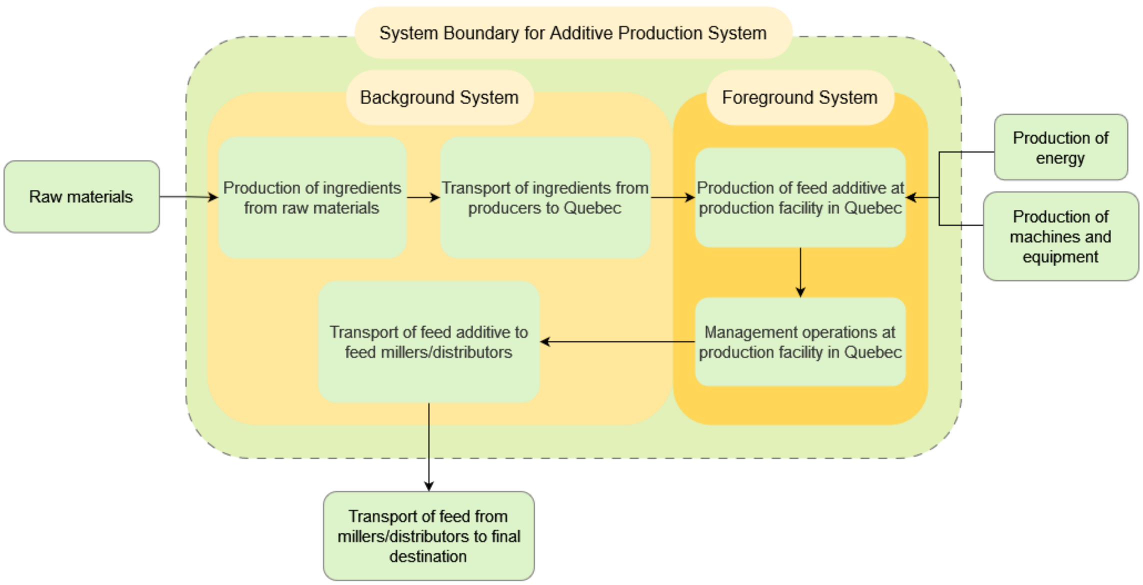

Figure 4.2: System boundary for first assessment (feed additive production)

For the foreground assessment, the subcategories "Smallholders Including Farmers," "Respect of Indigenous Rights," "Delocalization and Migration," and "Secure Living Conditions" were excluded because they were not affected measurably by the foreground study. "Community Engagement" was also dropped because there was overlap between the indicators for this and those used to assess the "Cultural Heritage" and "Access to Material"/"Immaterial Resources" subcategories. Additionally, the "Consumer," "Society," and "Children" stakeholder categories were excluded because the pathways by which the foreground system affects these stakeholders is difficult to delineate.

The scope of the second assessment includes the feed production and dairy production systems in Canada and Brazil. Social impacts were measured for the production of the feed additive from raw ingredients up to the use of the product in complete feed at the farm level in Canada and Brazil. Comparing these two countries illuminated the comparative benefit of using feed additives in dairy production in countries with different levels of development and regulation in the animal production sector. The system boundary includes the production of the raw feed ingredients, the transport of the feed ingredients to the respective countries, and the activities of the dairy farm. This system boundary is shown in Figure 4.3.

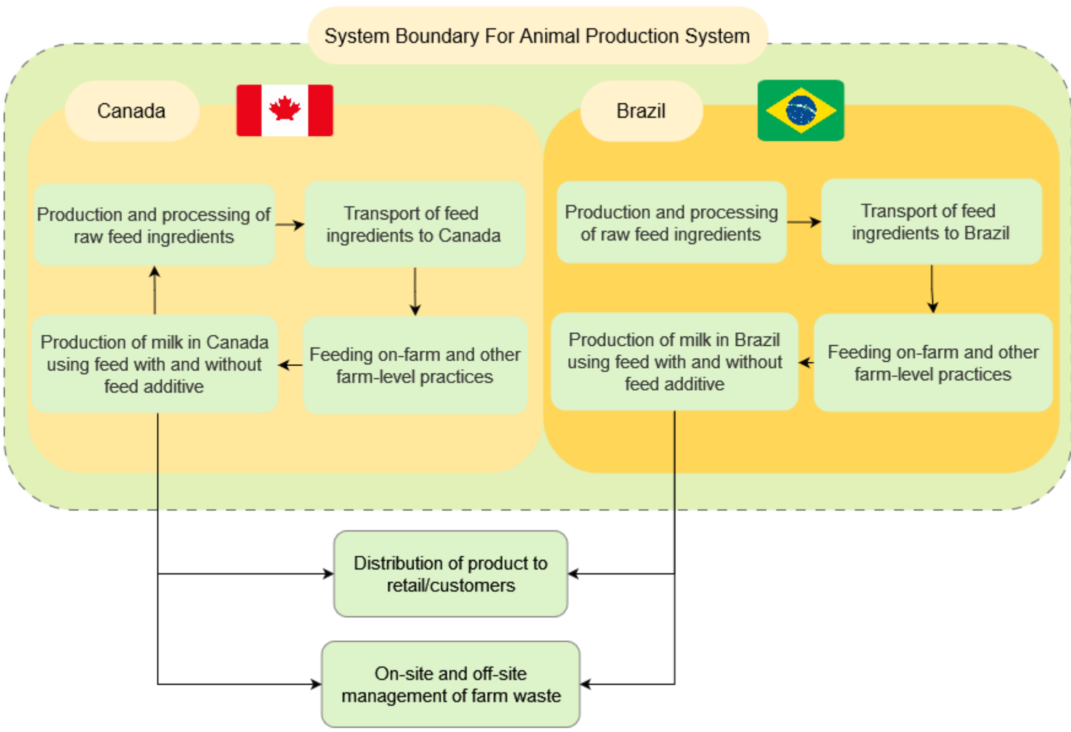

Figure 4.3: System boundary for second assessment (feed production and farm activities in Canada and Brazil)

4.2.3: Inventory

For the foreground system in the first assessment, the data was collected from site-specific sources. Company HR representatives were asked specific questions about operations and the policies and practices of the company. These questions can be found in Appendix A. The company's workers were asked two different sets of questions (Appendix B). The first set of questions was a weighting questionnaire in which workers were asked to rate different aspects of social welfare in the workplace based on personal priorities. Then, workers were asked a set of questions regarding their perceptions of company policies and practices. Both the HR and worker surveys were conducted in order to (1) identify any discrepancy between policy and practice in the workplace, and (2) gauge how the workers viewed these policies with regard to their well-being. To facilitate the latter, several questions were asked using more subjective terminology such as “how does your job impact your quality of life?” While subjectivity is discouraged in scientific assessment, it was decided that gauging worker perception would be helpful in determining the social impact of company policies on different stakeholders, even if such responses cannot be translated to purely objective results. Other S-LCA research has supported this, calling for stakeholder engagement and positing that a certain level of subjectivity is necessary to find accurate results [5, 7, 57, 83]. The results from the HR survey, on the other hand, can be translated to more objective results through comparison with national and sectoral averages found in regional databases, PSILCA, and other sources. These sources are listed in the Supplementary Document (Inventory). For many of the indicators in the “local communities” and “value chain actors” stakeholder categories there was a lack of inventory data for average sector performance in these categories. Thus, indicators were assessed binary scores based on presence or absence of the indicator, following the strategy of [3].

The background assessment was conducted using generic data from the PSILCA database. For ingredients, data was used for the exact production sector in the exact country where the ingredient was produced where possible. Otherwise, data was taken from a country or sector with perceived similar production conditions (i.e., pharmaceuticals production in China was used as a substitute for vitamin production in China). For many commodities, the PSILCA database requires the user to express the amount of product in terms of USD. Where data on average product market costs were unknown, webpages for distributors and manufacturers were consulted to find an estimate of the market price in the given country.

For the second assessment (the production of ingredients and farm-level impacts in Brazil and Canada), the data was also taken from the PSILCA database based on the location of production of the feed ingredients. The ingredients and the location of their production was taken from various sources, including [169] for Canada and [170, 171] for Brazil. The Canadian study [169] listed the ratios for feed ingredients. For the Brazilian simulation, a forage-concentrate ratio of 55/45 was used based on approximations from [170].

4.2.4: Assessment

The assessment was performed in two stages. For the background system (the value chain of the ingredients used in feed additive production), the impact was assessed using the PSILCA database, which uses the impact pathway assessment approach. In this approach, the database uses unit costs for ingredients to calculate how many worker hours are used to create one functional unit of the product. These worker hours are used as an activity variable so that results can all be expressed in terms of the same unit. The worker hours are then associated with the level of risk of each social impact occurring within the country or sector being studied, yielding a final unit of medium risk worker hours, which is how the results are presented within the PSILCA database.

For the assessment of milk production systems in Brazil and Canada, the PSILCA database was also used. Four scenarios were simulated: (1) production of milk in Canada with the additive, (2) production of milk in Canada without the additive, (3) production of milk in Brazil with the additive, and (4) production of milk in Brazil without the additive. For each scenario, the inventory was gathered from the PSILCA database. For calculations, a scaling factor cutoff of 1E-5 was used.

For the foreground system (the company and the processes directly under its control), responses from HR representatives and workers at the company were collected and compared to averages for the sector/region of production. These averages were gathered from the PSILCA database and other sources. For numeric indicators, scores were assigned based on comparison with the mean values for the country or sector using Equation 4.1 for indicators where a lower indicator score indicates a higher risk, and Equation 4.2 for indicators where a higher indicator value indicates a higher risk, as proposed by Zira et al [38].

$$R = 1 - EXP\left(LN(0.5) * \frac{IND}{REF}\right) \cdots (4.1)$$

$$R = EXP\left(LN(0.5) * \frac{IND}{REF}\right) \cdots (4.2)$$

Where R is the social risk score on a scale of 0-1, IND is the indicator value, and REF is the reference value (typically the sector or regional average).

For non-numeric values, the RESPONSA method, first proposed by [72], was used as a defuzzification method to assign a score to impact categories depending on their performance relative to the average for the sector/region. For binary options (i.e., either the factor is present or not in the system), the RESPONSA method involves using Equations 4.3 and 4.4, taken from [72]:

$$R\ for\ best\ option = (-0.5 * PRP_{\theta=1}) + 1 \cdots (4.3)$$

$$R\ for\ worst\ option = (0.5 * PRP_{\theta=0}) \cdots (4.4)$$

Where $PRP_{\theta=1}$ is the sector average proportion of positive (i.e., best option is present) responses, and $PRP_{\theta=0}$ is the sector average for negative (i.e., worst option is present) responses. For example, if the indicator is measuring presence of a health and safety policy, $PRP_{\theta=1}$ would represent the percentage of companies in the sector or region with a health and safety policy. For both assessment methods, a 1 represents the best possible performance while a 0 represents the worst possible performance. These initial results, representative of Type I (reference scale) assessment will be presented via a color scale following [3, 15] in which the company's performance is assessed as "risky," "compliant," "proactive," or "committed" based on the impact score for each subcategory. These designations represent the level of potential harm or benefit that the company's performance could have on stakeholder well-being and social sustainability in the sector or community.

Following this, these scores were translated to a 4-point ordinal scale corresponding to risk levels in the PSILCA database. This translation was performed using the formula in Table 4.1. This scale was chosen based on the organization of ordinal scales for other indicators (e.g, right of association, trade union density) with the slight modification that "compliant" performance was associated with "medium risk" rather than "high risk" because the "risky" designation encapsulates both "very high risk" and "high risk" performance. From here, the results were translated to worker hours using the characterization factors presented in the PSILCA documentation [148]. The reference scale, colors, and corresponding risk values are presented in Table 4.1.

Table 4.1: Four-point reference scale for data assessment and corresponding risk levels, adapted from [3, 15]

Designation	**Performance score**	**Color**	**Corresponding risk level**

Risky	0-0.3		Very high risk
Compliant	0.3-0.6		Medium risk
Proactive	0.6-0.8		Low risk
Committed	0.8-1.0		Very low risk

In addition to the traditional calculation, another assessment was conducted based on worker perceptions of category importance and well-being. In a survey, workers were asked to gauge the importance of several different subcategories affecting different stakeholders. These weights were calculated and assigned using Equation 4.5, where AR is the adjusted reference value for subcategory i, and S is the score assigned by the workers. 4.94 was the maximum score received by any one category, so this category will receive a weight of 1.

$$AR_i = 0.5 + [\left(\frac{S_i}{4.94}\right) * (R_i - 0.5)] \cdots (4.5)$$

This equation was formulated so that the impact (positive or negative, measured by deviation from the average score of 0.5) is muted in categories which workers deemed less important to their well-being in the workplace. This additional assessment will revolve around the perceived well-being of the *workers* stakeholder group, and whether or not the perceived well-being could be correctly assessed from the S-LCA data collected. The goal of this assessment is to validate the methods of S-LCA as a means to predict worker happiness and subjective well-being.

4.2.5: Interpretation

The interpretation of the results of the assessment will begin with the four meta-assessments recommended by the 2020 UNEP Guidelines [11]. These are:

Completeness check: The activities of the study are reviewed to confirm that the data collected reflects the goal and scope, and that the data provides sufficient justification for drawing the conclusions which are drawn.

Consistency check: The methods are reviewed to ensure that assessment strategies were applied consistently for each impact category. This is especially important where results are compared or aggregated, as it ensures that the comparison or aggregation is valid.

Uncertainty and data quality check: As inventory data is collected, data quality should also be assessed. As part of the uncertainty check, these risk assessments measured in this study were compared with several comparable sectors from the PSILCA database. These sectors were, "Manufacturing of Food Products and Beverages; Manufacturing of Tobacco Products – Canada" and "Other Animal Food Manufacturing – United States." Comparing the risks assessed based on the measured data in this study with the risks assessed by the PSILCA database may help elucidate whether or not— and if so, to what extent— the results of the real-world data can be integrated with data from the PSILCA database, and how much reliability might be sacrificed in this endeavor.

Materiality check: This check is used to assess the impacts that are the most relevant or important. This can be done via a hotspot assessment, or an influence analysis, where impacts are assessed based on the level of control that the company has over the process. These checks influence the conclusions that can be drawn and the recommendations that can be developed based on those conclusions.

Following these checks, implications were discussed, and conclusions were drawn based on the results of the study. Based on these conclusions, recommendations were developed for stakeholders and decision-makers. These recommendations were developed based on the level of impact, as well as the level of control that the company has over the process in question, in accordance with the materiality check.

4.3. Results

4.3.1 Foreground system

4.3.1.1 Policies and records

Based on questionnaires completed by HR representatives at the feed additive production company regarding company policy and records, the following risk levels were assessed for the applicable impact categories. These were based on values from regional and sectorial databases and other sources, and were assessed using the RESPONSA framework equation (4.3 and 4.4) from [72], and social risk equation (4.1 and 4.2) from [38], where applicable. The inventory reference data used to calculate these scores can be found in the Supplementary Document (Inventory). Figure 4.4a presents the measured impacts (based on company policy and records) for the *workers* stakeholder group. None of the categories were assessed as "risky;" the category with the lowest score was *freedom of association and bargaining* with a score of 0.346. This was due to the absence of union access for workers at the company (although unionization is allowed by policy). Of the other categories, *child labor* (0.5), *forced labor* (0.5), *working hours* (0.49), *health and safety* (0.6), and *employment relationship* (0.565) were gauged as “compliant.” The company’s performance in the categories of *fair salary* (0.641) and *social benefits and social security* were gauged as “proactive,” while *equal opportunities and discrimination* and *sexual harassment* were gauged as “committed.”

For the “Local Community” and “Value Chain Actors” stakeholder categories, it was more difficult to find inventory data from the sector/region to compare with the company’s performance. Therefore, most were rated as “compliant” based on their compliance with laws and regulations, while several were rated as “proactive” or “committed” due to the company providing social benefit in excess of legal requirements. Figures 4.4b and 4.4c show these impacts.

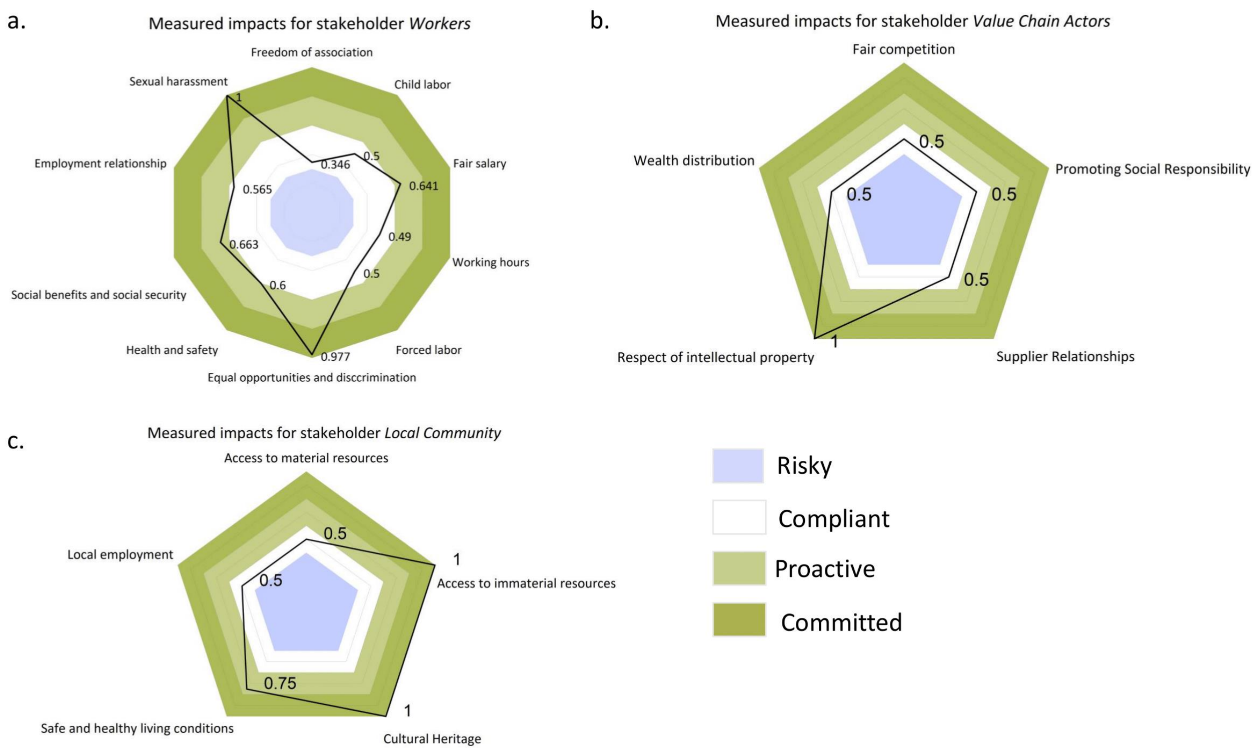

Figure 4.4: Impacts for different stakeholder categories (a) workers, (b) value chain actors, and (c) local community

4.3.1.2 Worker Perceptions

The perception of the workers at the feed additive manufacturer regarding the social impacts of the company's policies and practices was measured via a survey (for survey questions, see Appendices). 66 workers participated in the survey, and their perceptions and any implications will be discussed. The first set of questions dealt with weighing nine different S-LCA subcategories by rating their relative importance to stakeholder safety and well-being. Figure 4.5 shows the results of this section. Although all options were rated as important (all averaged >3/5), the highest ranked subcategory was *health and safety* (avg. score 4.94/5), while the lowest was *freedom of association and collective bargaining* (avg. score 3.02/5). This implies that, although the *freedom of association* was the lowest-performing category in the foreground system assessment, it may not be as important in shaping the workers' perception of well-being. To determine the effect of the workers' perceptions, the scores were recalculated using weights prescribed by workers following Equation 4.5, with the results shown below in Figure 4.6.

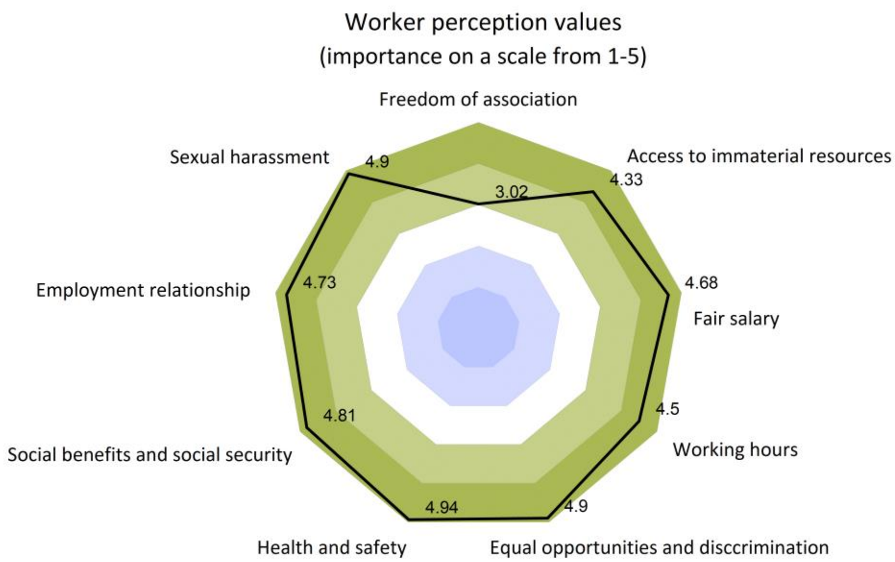

Figure 4.5: Chart showing worker perceptions of the importance of different impact subcategories

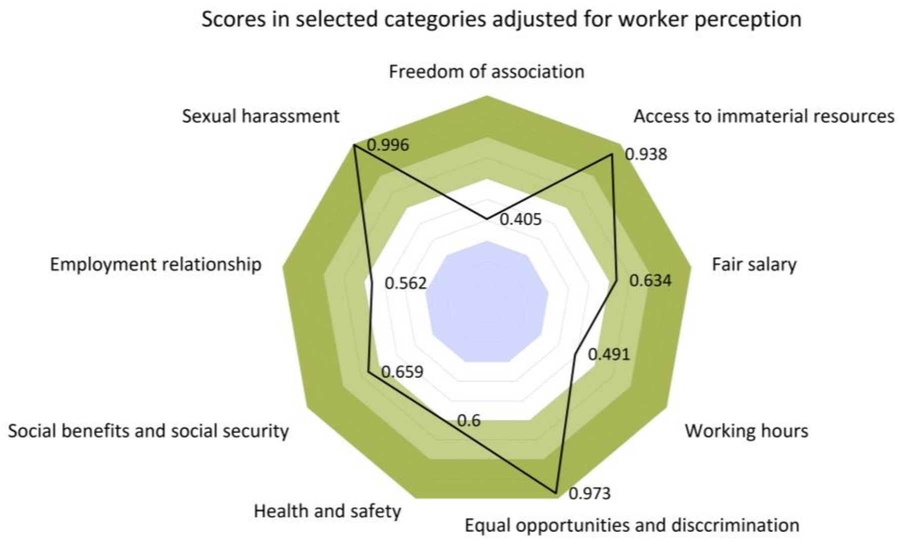

Figure 4.6: Scores in select categories adjusted based on workers' perceptions of their importance.

Workers also rated their perception of several aspects of the company's performance. When asked about their understanding of company policy with questions like, "are you aware of any violations of laws or policies regarding worker benefits?" or "does the company have a flexible policy regarding vacation days and overtime work?", the answers were usually unanimous (89% "no" for awareness of violations of benefits laws question and 85% "yes" for the company's vacation policy question). However, in some instances, it was clear that workers were unsure about the policies, for instance, 34% answered "no" to "are you familiar with the workplace discrimination policy?" This may indicate a need for additional training in these areas.

Additionally, in categories which relied more heavily on worker perception, the answers were more divided. For example, for the question, "do you feel that you are earning a fair wage for your work?" the answers were split (58% "yes", 42% "no"), and for the question, "do you feel that worker opinions and interests are taken into consideration when planning large changes at the company, 75% answered "yes," while 25% answered "no."

Finally, workers were asked two simple questions: "Please rate your overall satisfaction with your job," and "how does your job contribute to your quality of life?" Despite the inconsistency present in the responses to many of the questions above, only six workers in total chose the most negative options (one chose "I would change most aspects of my job," and five chose "my job negatively impacts my quality of life"). Rather, for the first question, a majority (66%) selected "some things could be better, but overall, I am satisfied with my job," and for the second question, 68% selected "my job improves my quality of life." This indicates that, despite some issues, most workers at the feed additive company view their job and its impact on their lives positively.

4.3.2 Background system

The background system, including the production of the ingredients used in the feed additive, was conducted using the PSILCA database. The background system was found to have a high social impact. The results for the *Workers* stakeholder category are shown in Figure 4.7 using a functional unit of 1 metric ton (1000 kg) of feed additive produced.

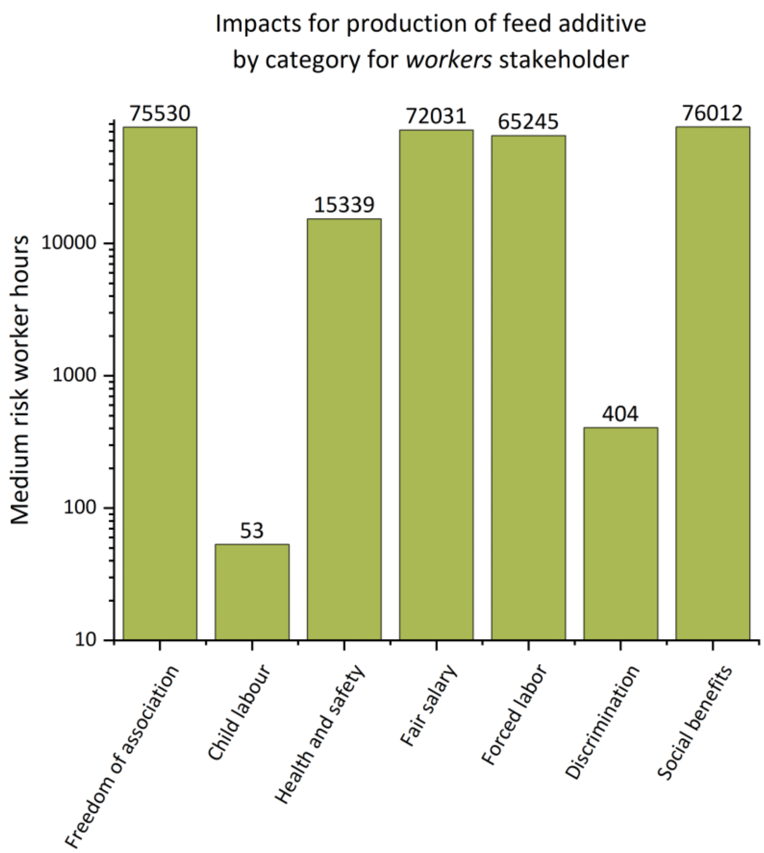

Figure 4.7: Impact results for the production of the feed additive.*

*Note the log scale on the Y axis, which was chosen due to the large discrepancy between the values.

The subcategories with the highest social impact in the feed additive production background system were (1) *fair salary,* (2) *social benefits,* and (3) *freedom of association and collective bargaining.* Hotspots were identified using the impact assessment results within the PSILCA database in OpenLCA. The main hotspots along the value chain occurred at different points for different subcategories. For the subcategory of *fair salary,* the primary industries of impact contribution were all in China, including “production of medical and pharmaceutical products” (27.4% of total risk-adjusted worker hours), “crop cultivation” (10.8%), and “wholesale and retail trade” (5.5%). Outside of China, the largest contributors to *fair salary* risk were the USA (5.9%), followed by Malaysia (2.4%). In the *social benefits* subcategory, the highest risks came from “production of medical and pharmaceutical products” in China (22.8%) and “oil palm primary products” in Malaysia (17.6%). For *freedom of association and collective bargaining,* the primary contributors were “production of medical and pharmaceutical products” in China (84.3%), “lime and gypsum product manufacturing” in the USA (2.8%), and “oil palm products” in Malaysia (2.3%). These results indicate that the production of medical and pharmaceutical products in China contributes much of the risk present in the system. This is logical, as vitamin and pharmaceutical production is a labor-intensive sector, and products sourced from this sector contribute nearly 23% of the product formula by mass.

4.3.3 Farm-level production in Brazil and Canada

The impact of the feed additive was interpolated out from production to include the impact at the farm level using OpenLCA software. The results indicated that for almost all social impacts along the animal feed value chain, Brazilian production systems have a higher impact than their Canadian counterparts. However, Canadian systems had a higher negative impact in categories such as *social benefits***,** *promoting social responsibility,* and *migration.* These results likely reflect the laws and standard practices in the two countries that are corroborated in literature. Additionally, as many ingredients in Canadian feed were assumed to be sourced from the USA, some impacts in the Canadian results were reflective of American agricultural conditions. Whereas Brazilian agricultural workers are more likely to be exploited and underpaid than Canadian workers [35], Canadian and American companies often do not provide sufficient benefits and pay to meet the much higher cost of living, and have a higher average immigration flux. Additionally, Brazilian companies are more likely, on average, to promote social responsibility through membership in responsibility-promoting organizations the USA and Canada, which is reflective of the relatively high commitment of Brazilian citizens to environmental and social justice relative to other countries [104, 172]. The results for the Worker stakeholder category are shown in Figure 4.8 for a functional unit of 1 metric ton of milk produced at the farm gate.

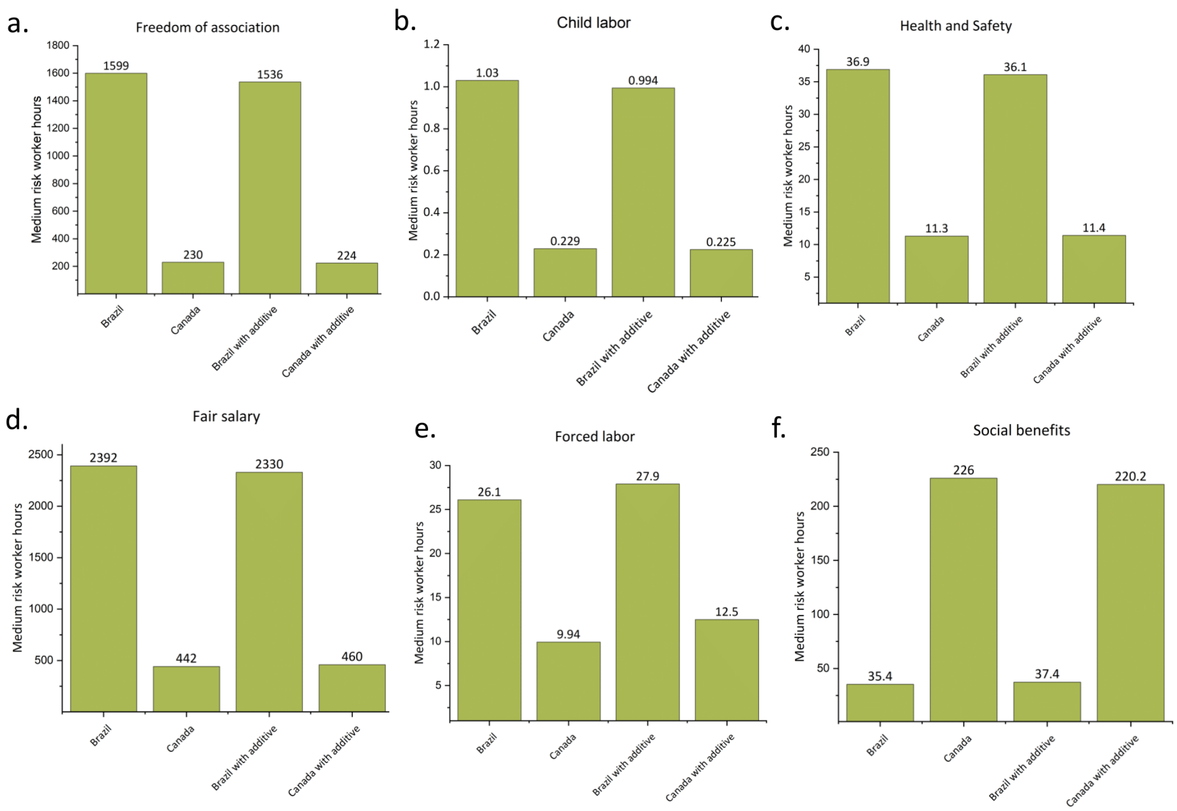

Figure 4.8: Comparison of worker social impacts of 1kg milk production in Brazil and Canada with and without feed additive for (a) freedom of association, (b) child labor, (c) health and safety, (d) fair salary, (e) forced labor, and (f) social benefits

Interestingly, the social impact within the *Forced Labor* category increased when the feed additive was used, implying a significant driver of forced labor somewhere in the value chain of the feed additive. This corroborates the results shown in Figure 4.7, which demonstrate significant contributions of forced labor in the ingredient production value chain.

While animal welfare was not included in this study due to lack of data, it is a crucial component of sustainable development strategies [8] and S-LCA in particular. The feed additive company has collected data which indicates that animal welfare parameters such as rumen health may be improved by the inclusion of the feed additive, and other studies have shown that additives may increase health as well as palatability of feed [167]. In future studies, it would be beneficial to measure a wide array of animal welfare metrics, including handling practices and indicators of animals' mental and emotional well-being, in the different production systems to identify regional variations and to identify any impacts from the inclusion of feed additives.

4.3.4 Integration and comparison

To integrate the site-specific results with the background system, the results must be translated to a unit of medium-risk worker hours (the standard unit for impact pathway calculation approach). To translate the site-specific foreground system results presented in Figure 4.4 to risk levels, a functional unit of 1 metric ton of feed additive at the production facility was used. It was estimated that producing 1 ton of feed additive requires 0.11 worker hours at the facility based on employee records. The risk levels assessed for each subcategory are presented in Table 4.2, following the risk designations proposed in Table 4.1. It should be noted that two subcategories, *child labor* and *forced labor,* were reassessed during the risk assessment. Both were assessed as "compliant" in the reference scale assessment (because these phenomena are both illegal and uncommon in Canada, companies do not receive "extra points" for compliance). However, as they were fully absent in the system, the risk level was adjusted to "very low risk" for the impact pathway assessment.

Using the characterization factors from the PSILCA database, the estimated worker hours (0.11 worker hours/ton feed additive produced) were adjusted for the risk level, yielding the final results in terms of medium risk equivalent worker hours.

Table 4.2: Assessed risk for social impact subcategories for the stakeholder categories of workers, value chain actors, and local community

Impact Subcategory	**Assessed risk**	**Medium-risk eq. worker hours/ton**
Workers		
Freedom of association and collective bargaining	Very high risk	11
Child labor	Very low risk	0.0011
Fair salary	Low risk	0.011
Working hours	Medium risk	0.11
Forced labor	Very low risk	0.0011

Equal opportunities and discrimination	Very low risk	0.0011
Health and safety	Low risk	0.011
Social benefits and social security	Low risk	0.011
Employment relationship	Medium risk	0.11
Sexual Harassment	Very low risk	0.0011
Value chain actors		
Fair competition	Medium risk	0.011
Promoting social responsibility	Medium risk	0.011
Supplier relationships	Medium risk	0.011
Respect of intellectual property rights	Very low risk	0.0011
Wealth distribution	Medium risk	0.011
Local community		
Access to material resources	Medium risk	0.11
Access to immaterial resources	Very low risk	0.0011
Cultural heritage	Very low risk	0.0011
Safe and healthy living conditions	Low risk	0.011
Local employment	Medium risk	0.11

This process was integrated into the PSILCA database by creating a new process connected to the background system value chain. When added to the background system, these impacts have a very small impact on the system. Table 4.3 presents a comparison of the total impacts for the *worker* stakeholder subcategories before and after the addition of the risk-translated on-site data.

Table 4.3: Comparison of results before and after translated foreground system results were added for the subcategories in the worker stakeholder group. Where numbers are rounded for consistency, percent change for the unrounded results is still indicated.

Subcategory	**Background system impact pathway results (med. risk worker hours)**	**Background+foreground system impact pathway results in med. risk worker hours (% change)**
Freedom of association	75530.5	75541.5 (+0.015%)
Child labor	53.3	53.3 (+0.002%)

Health and safety	15339.0	15339.0 (0%)
Fair salary	72031.2	72031.2 (0%)
Forced labor	65244.7	65244.7 (0%)
Discrimination	404.4	404.4 (+0.0002%)
Social benefits	70613.0	70613.1 (0.0001%)

As evidenced by Table 4.3, there is minimal additional social impact from integrating the results of the study with the background system. This could be because of the relatively large impact of certain ingredient value chains, such as the production of medical and pharmaceutical products in China, or it could be due to the sheer volume of sectors included in the background system within the 1E-5 scaling factor cutoff. The largest impact additions came in the subcategories of "freedom of association" (+0.015%) and "child labor" (+0.002%). While the former is due to the high risk within the foreground system, the latter is likely due to the relatively low overall impact for the "child labor" subcategory, which makes the change more pronounced.

4.3.5 Interpretation and Data Checks

Following this comparison, the four data meta-assessments were performed as recommended by the UNEP guidelines [11].

Completeness check: The life cycle of the system was evaluated from the production of the ingredients from raw materials to the use of the feed additive on the farm. While the life cycle could be extended beyond this to consider effects such as the potential impacts on manure composition, this was decided against due to a lack of reliable data. The assessment of the foreground system left out several stakeholder categories and subcategories, however, this was done in the interest of not extrapolating impacts from unrelated indicators.

Consistency check: The methods used in this study were applied consistently for the most part, although part of the goal of this study was to evaluate different methods of data collection and integration. Some issues arose during the data inventory process. Because the questionnaires collected site-specific data and the databases often rely solely on national data, different indicators were used for impacts between the database and the survey. For example, for the "local employment" category, the PSILCA database uses the level of unemployment in the country, whereas the questionnaires used percent of spending on local materials and services in order to better gauge the individual impact of the company. Similarly, for "discrimination and equal opportunities," the questionnaires measured the number of discrimination complaints received by the company, whereas the database used gender wage gap and gender ratio in the workforce. While these indicators are different, the indicators chosen for the questionnaires were more accurate in a site-specific context, whereas the indicators in the database were likely easier to inventory in a sectorial or regional context. While true consistency is ideal, it was decided that the most accurate indicators for the category—rather than the most consistent— should be used where there is a discrepancy between the two.

Uncertainty check: The data collected in the inventory was gathered primarily from reliable national databases within the country (most from Statistics Canada, for a full list see Supplementary Document (Inventory)). However, there was little data available for stakeholder categories other than *workers*. For the *local community* and *value chain actors* subcategories, reference scale and risk levels were formulated primarily on a binary basis (i.e., was this indicator present or not?). This may yield some uncertainty in the final results, as potential nuances are not captured in a binary scale as well as in the four-point scale used for the *worker* subcategories.

The comparison of the risks assessed based on the site-specific measurements was compared with risk levels prescribed for similar sectors by the PSILCA database ("manufacture of food products and beverages" – Canada, and "other animal food manufacturing" – US). The risk levels for the measured system were assessed at the same level as both of the database categories for *child labor* and *forced labor*, and for one category for *working hours, health and safety,* and *employment relationship*. For the *sexual harassment* category, there was not an equivalent in the PSILCA database, so it was not included in the comparison. The risk levels for the different representative sectors are compared in Figure 4.9. This comparison indicated that relying on database data from comparable sectors as a replacement for unavailable data may greatly increase the ease of data collection but may result in misestimations which may potentially sway the final results. Where site-specific data is available, it is highly preferable to generic data collected from databases, as it will be much more representative of the system in question. However, as databases become more robust and complete, this uncertainty will likely decrease.

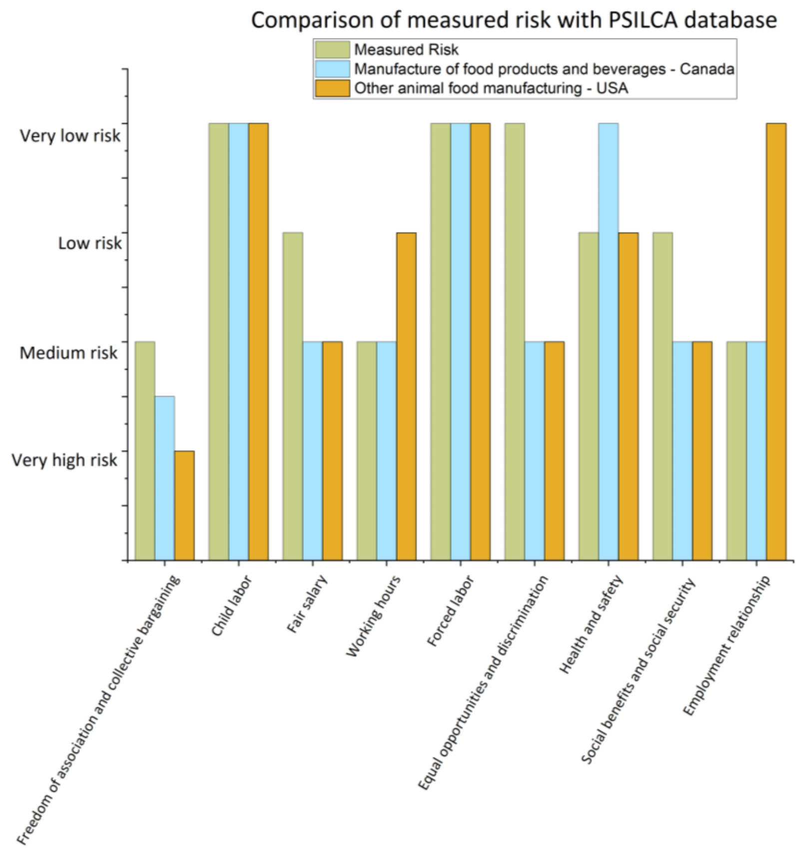

Figure 4.9: Comparison of the site-specific risk with values from the PSILCA database for different comparable sectors

Materiality check: Table 4.3 indicates the relatively low impact of the company's activities against the backdrop of the entire value chain. As indicated in the "background system" section, the major hotspot in the ingredient value chain was "production of medical and pharmaceutical products" in China. Stakeholders in China, the United States, and Malaysia were at the highest risks for impacts overall, likely because the majority of ingredients are sourced from these countries. Despite being the country of production, Canada's negative social impact was comparatively low.

When considering the level of influence of the company, it is clear that the processes over which the company has the greatest influence will be the ones that occur within the company. Within this, the policies on workplace health and safety, discrimination, hiring practices, and social benefits are directly changeable and enforceable by company management. The company also has the ability to financially support education and cultural heritage. *Fair salary* (relative to living wage) and *freedom of association* are within the realm of company influence, but also depend on economic and political factors outside of the company's control.

4.4. Discussion

4.4.1 Results and implications

For S-LCA, it is ideal to have as much primary data as possible, but for the general purpose of life cycle assessment, it is necessary to be able to link the primary data collected with other sectors along the value chain. A promising way to do this is using a database such as PSILCA or the Social Hotspots Database (SHDB) [6]. Data collected on-site and generic (database) data can be integrated with each other, but the methods for performing this integration and gauging the reliability of the results are still uncertain. While generic data (data gathered from databases) is much more standardized and consistent than data from other sources, it is ultimately a high-level overview of the potential risk in a system from a sectorial or regional perspective. Surveys, despite being more subjective and contradictory at times, capture the real picture of the social impacts caused by a process or organization as experienced by the affected stakeholders. Company policies and records can bridge the gap by offering a way to validate claims made by workers and also to provide numerical data that can be compared to database values.

The social impact of dairy feed additives varied between impact categories and between the countries studied, but in general has the ability to improve the social well-being of stakeholders along the value chain. Within the feed additive value chain, the primary impact comes from the production of ingredients rather than the on-site manufacturing. At the manufacturing site, the highest risk was in the *freedom of association and collective bargaining* subcategory, in which performance was rated as a 0.346/1 (still designated as "compliant"). This is not unexpected, as private sector trade union density in Canada is low [173], but it should still be considered as a pathway to improving worker well-being. The company performance was also rated as "compliant" in the categories *worker hours, wealth distribution,* and *promoting social responsibility.* This is likely due in part to prevailing attitudes towards work in North America, which place more emphasis on the value of hard work and less emphasis on companies' responsibilities to ensure income equality and social responsibility. However, as these prevailing attitudes shift, companies may improve performance in these categories. While the company could take proactive steps to enact policies above and beyond the requirements in these categories, their current practices appear to be fully compliant with local regulations and industry standards. With regard to positive impacts, *equal opportunities and discrimination*, *sexual harassment*, *respect of intellectual property rights*, *access to immaterial resources*, and *cultural heritage* all receiving the highest possible score of 1/1, indicating that the company is proactive in these categories.

While compliance with standards and regulations is a valid threshold by which to gauge performance, it is beneficial to also assess the perspective of the workers at the company. While these perspectives are more unreliable and prone to contradiction than generic data, they are ultimately the most reliable measure of worker well-being and happiness, which is one of the primary target metrics of a S-LCA study. The fact that most workers indicated that their work positively impacted their life corroborates the assessment of the company's policies and records, which yielded mostly favorable results with some minor flaws. These results imply promising potential for S-LCA as a tool for measuring stakeholder well-being, however, additional studies are needed to confirm the correlation (and the extent of correlation) between objective system performance and subjective worker experience. Additionally, more work is needed to validate the correlation between well-being as measured by indicators and experienced happiness, as the latter is more intangible and can be perceived in different ways [174].

As discussed in the consistency check, the indicators for each impact category varied depending on the data collection method. Databases rely more on general statistics, whereas onsite data collection can include more situation-appropriate indicators. Using impact pathways, these indicator values can be translated to risk levels or risk-adjusted work hours and can be compared, as in Figure 4.9. While this comparison may elucidate inconsistencies, it also presents an opportunity for validating results and methods. Ultimately, the more data collected for a S-LCA assessment, the better. However, when using data from different sources, researchers must be judicious in their interpretation of results.

4.4.2 Recommendations

For the feed additive company, the authors recommend ensuring responsible sourcing, as the upstream value chain contributed much more impact than the production process itself. Within the production process, the highest risk came from the *freedom of association and collective bargaining*. However, worker opinions indicated that the freedom to unionize was a relatively unimportant factor in how their work impacted their well-being. The survey results also indicated that, while most workers were familiar with company policies regarding health and safety, many workers were unsure of policies such as discrimination and sexual harassment. Providing company-wide training or educational sessions on these policies may help workers to feel safe and well in the workplace, especially because *discrimination and equal opportunities* was indicated by workers as the most important factor in their workplace well-being.

For researchers, the authors recommend using a wide variety of data sources. This data may be used for validation in addition to aggregation, as conflicts or inconsistencies in data can spark thoughtful questions which can help practitioners improve the ever-developing S-LCA methodologies. Based on the results of the study, the authors also recommend diving deeper into the feed additive value chain and gathering site-specific data from different points along the chain. In particular, the production of ingredients and on-farm practices are two major sectors where more data is needed. On-farm practices can be examined in different countries to assess different feeding regimens and handling practices. It is recommended that any on-farm studies include components of animal welfare, which is recognized as a major component of socially sustainable development.

4.5. Conclusion

Within agriculture, S-LCA has demonstrated high potential to help stakeholders, researchers, and policymakers assess and improve the welfare of workers in agricultural value chains. This study employed several different data collection methods (databases, HR questionnaires, and worker surveys) to examine the life cycle of a feed additive for dairy cows as it is produced from raw materials and used at the farm level. Following this, several methods for integrating and presenting the data collected through the various assessment methods were assessed.

The data obtained indicated that within the value chain for the ingredients of the feed additive (data collected from database), there were high social impacts in the categories of *freedom of association and collective bargaining, social benefits,* and *fair salary.* For the production of the feed additive at the manufacturer (data collected from surveys and questionnaires), *freedom of association and collective bargaining* was the only category of poor performance, while *working hours, forced labor, child labor,* and *employment relationship* were evaluated as compliant with local norms and regulations, and all other categories performed better. Worker opinions were also surveyed to gauge perceived importance of the different impact categories. Workers placed the lowest importance on *freedom of association* and the highest on *discrimination and equal opportunities.*

When these opinions were used to adjust the foreground system results, the impacts of several categories were muted because they were perceived as less important by workers.

Following this, the study simulated the use of the feed additive at the farm level in Brazil and Canada (data collected from database). The results found that the dairy sector in Brazil often has a much higher negative social impact than its Canadian counterpart, with *social benefits* being the only category in which the latter had a higher social impact. For most subcategories in Brazil, the use of the feed additive reduced the social impact of the system, whereas the results were more mixed in Canada because of the low initial impacts from the baseline feed production value chain.

In the uncertainty check, it was found that, while comparable sectors from the PSILCA database may provide a decent estimate for the risk present in a given system, there are significant deviations between measured risk and the generic risk data measured for comparable sectors, and relying on database data exclusively may present an unacceptable level of uncertainty, depending on the system under study and the data which is used to approximate this system. While integrating data from multiple sources is possible, the primary benefit of diversifying data sources is for validation. Data can be compared, and any inconsistencies can inspire further examinations into the reliability of the data source, which will ultimately help improve S-LCA methods. S-LCA is a powerful tool which can help improve awareness of and response to social issues in agricultural value chains. The various methods of data collection for S-LCA can inform and validate one another, but researchers should use caution, as the pathways by which this data can be integrated may result in inconsistent or misleading conclusions.

Acknowledgements: The authors would like to thank Prince Agyemang and Marie-Anne Dessureault for their help in the data collection process. The ethical approval for the worker survey was granted by the McGill University Research Ethics Board (file no. 23-04-010).

Connecting Text 4

The manuscript in Chapter 5 has been submitted for publication in Sustainable Development

In Chapter 4, S-LCA was used in a case study of the value chain for a feed additive for dairy cows. The results showed that the production of ingredients contributed the largest portion of the social impact within the system, however, this may have been due to the number of processes included within the scaling factor cutoff within the PSILCA database. The category with the highest impact in the ingredient value chain was *social benefits*, and the highest impact at the manufacturing stage came from *freedom of association and collective bargaining*. However, according to workers' opinions, *freedom of association* was perceived as having the lowest importance. These results demonstrate how S-LCA can be used to evaluate social impacts, and the potential challenges and opportunities presented by data collection and interpretation.

But where is social life cycle assessment in agriculture most helpful, and how can it be used to support decision-making in the bioeconomy? Chapter 5 builds on the findings of the previous chapters and looks to the future of social impact assessment to consider how it might be integrated into circular economy thinking to provide guidance to sustainability-driven decision makers in business and policy. Using the ReSOLVE circular economy framework as a foundation, this study proposes an updated framework which includes social impact assessment. As circular economy thinking gains popularity in the bioeconomy, it is important for decision-makers consider not only environmental and economic impacts, but also social ones. The new framework and subsequent discussion in this chapter presents a hopeful look at the future of S-LCA in agriculture and how its use can yield benefits beyond measurement alone.

Chapter 5: Unleashing Circular Economy Potential in the Poultry Sector: Integrating Social Impact Assessment with the ReSOLVE Framework as a Tool for Sustainable Transformation

Aubin Payne, Ebenezer Miezah Kwofie

5.1. Introduction

The earth is experiencing an anthropogenic environmental crisis, causing changes in global climate patterns, mass extinction, and deforestation, among other things [175]. By 2050, agricultural yields will decrease, and prices will increase due to the detrimental effects of climate change [176]. One of the primary issues fueling global destruction is how we produce and consume products under the current market conditions. The current use model in the global economy is take-make-dispose, where products are created from raw materials, serve a purpose, and are disposed of, often reaching the end of their life cycle without being recycled or reused in any capacity. The circular economy concept aims to transform this model to include reuse, recycling, and repurposing at the end of the product’s life cycle [177]. This model has significant application in the agricultural sector, where resource recovery potential is often overlooked [178].

The circular economy model has grown in popularity in recent years as a means to repurpose waste streams, find opportunities to create co-products, and reduce the wasteful overuse of raw materials. Although the concept is sound, proponents of circular economy initially lacked precise methods to realize the concept [179]. Thus, since the conception of CE, Several frameworks have been proposed [180]. The Business Models approach provides guidance on circular business policies and the resulting profits that might be gained but the proposed methods are formatted specifically for business practices and are minimally applicable to public policy [181]. The ReSOLVE framework (an acronym for **Re**generate, **S**hare, **O**ptimize, **L**oop, **V**irtualize, and **E**xchange) was developed in 2015 by the Ellen MacArthur Foundation to provide guidelines for implementing circular economy principles. This framework also primarily targets business strategies, but it is versatile enough to be applied to many sectors and can also be used by other stakeholder groups like communities and public policy makers.

Many case studies have examined the potential and concrete application of these principles to different industries, from housing to food production. Still, thus far, there is a lack of research in applying the ReSOLVE framework to the agricultural sector. Additionally, the social implications of implementing this framework are highly understudied. The motives behind circular economy initiatives are almost always environmental and economic, but many include aspects which carry some benefit to various social stakeholder groups. Because of the interconnections and interdependencies between the different aspects of sustainability, examining the social impacts of circular economy is critical for sustainable development and the realization of the Sustainable Development Goals [182]. Because social impact assessment must consider many different stakeholder perspectives [11], the ReSOLVE framework is an excellent framework to guide the discussion of social impacts in the circular economy.

Although the ReSOLVE framework has been applied infrequently in the agriculture sector, its application is of particular interest from a food sustainability perspective. Technology is rapidly making its way into the agriculture sector with the advent of Agriculture 4.0, and many of these technologies are targeted at reducing waste and improving efficiency [183]. Of these, many can help improve the welfare of farmers and smallholders [184]. However, the increase in production due to the rising global population is straining resource supplies and creating problems for the environment. For example, the rise in soybean and beef cattle farming in Brazil (including their associated indirect impacts) has been linked to deforestation in the Amazon rainforest [185]. In the present work, the poultry industry is used as a case study because many of the positive and negative aspects of the agriculture industry are compounded in the poultry sector. Millions of people rely on poultry meat and eggs for survival, and the global poultry sector is growing faster than any other livestock production sector [186]. Other livestock sectors may present similar or worse environmental impacts, but the high social impact [78] and increasing global prevalence [187] of the poultry industry makes it an ideal representative case study for the development of the updated ReSOLVE framework formulated in this study. While poultry was used as a case study, the framework can easily be applied to other agricultural sectors.

The well-being of animals and agricultural stakeholders is drastically impacted by environmental change. For example, in the poultry sector, researchers have noted detrimental effects on bird welfare and production costs as a result of climate change [188]. These effects will likely be most damaging for stakeholders in already-vulnerable developing regions where poultry meat is an important source of financial and nutritional security. This could create social detriments such as poverty, malnutrition, and conflict over resources. While implementing circular economy principles could help attack these issues at the source by working against climate change, there are also more direct social benefits of circularity improvements that could more quickly improve the lives of people in developing places. These direct benefits will be examined in this study.

The objectives of the study are (a) to define the current state of the circular economy in agriculture and identify processes and methods that have potential for circularity based on the principles of the ReSOLVE framework based on literature, (b) to develop a framework to analyze the social implications of optimizing waste streams for circularity based on the ReSOLVE principles, and (c) to apply this updated ReSOLVE framework to the poultry industry as a case study to evaluate the practicality of the framework. These goals are achieved through a discussion of the theoretical background of circular economy in agriculture, the creation of the updated ReSOLVE framework in which ECOGRAI decision variables are infused with social life cycle assessment (S-LCA) indicators to predict and measure social impacts of circular economy principles. Finally, this updated framework was applied to a real-world case study in the poultry industry. The study takes a multifaceted approach towards improving the potential of the ReSOLVE framework in the agricultural industry for a more sustainable future of food.

5.2. Materials and Methods

5.2.1 Theoretical Background

5.2.1.1 Circular Economy

The term "circular economy" was first mentioned in 1988 [189], after being developed over decades as a response to the excessive waste caused by the linear consumption model in which goods are produced from raw materials, used, and disposed of in landfills. This model is especially problematic for non-biodegradable products such as plastics, which accumulate in landfills and cause issues if released into fragile ecosystems [190]. In theory, circular economy proposes mechanisms by which waste streams can be reincorporated into either the input stream of the original product or another product. In recent years, researchers and policymakers have increased focus on circular economy [191, 192]. Studies have indicated that policy implementation of circular economy principles is critical, and that the successful implementation of circular economy principles depends more on government action and policies than on consumer choices or producer action [193]. However, that does not mean that consumers and producers are free from responsibility. Consumer demand for sustainability is one of the main drivers of sustainable production in agriculture in places where regulations are insufficient [194]. Businesses and corporations can help to drive circularization strategies with high social innovation through Corporate Social Responsibility, but relying on this puts stakeholders at risk of changes in company policy [195].

In agriculture, there is a focus on transitioning away from high-output low-efficiency operations towards processes that recycle nutrients within the system [196]. Examples of this include feeding low-value food scraps to animals (although this has the potential to cause outbreaks such as foot-and-mouth disease) [197] or using crop residues as fertilizers. However, the path to widespread adoption of circular economy principles remains unclear. Despite the popularity of circular economy thinking in Europe, only 5% of raw material value was recovered by recycling and reusing as of 2016 [198].

5.2.1.2 The ReSOLVE Framework Principles in Agriculture

The ReSOLVE framework was introduced in 2015 by the Ellen MacArthur Foundation as a standardized framework that provides entrepreneurs with concepts to follow when incorporating circularity into their business models. The definitions of these principles, paraphrased from the Ellen Macarthur Foundation document [177], are detailed in Table 5.1, along with discussions from published literature of the challenges and benefits of applying these principles.

Table 5.1: Summary of ReSOLVE principles that have been applied in literature on agriculture.

ReSOLVE principle	Definition [177]	Discussions from previous work
Regenerate	Maintain and repair the health of natural ecosystems through active recovery, use of green technology, or preservation of already-existing natural spaces.	• Regenerative agriculture can help farmers transition away from monocultures and combine different operations (e.g. crops and livestock) [199] • Incorporating indigenous knowledge can help farmers understand how to extract value while preserving biodiversity [200] • Socially regenerative practices should be included in circular economy considerations [10]
Share	Establish product-sharing systems to minimize the demand for individual products	• Cost-sharing programs can help convince stakeholders to take action. [201] • Circular economy thinking encourages farmers to share or pool resources with their communities [202].

		• Many consumers reject resource sharing because they do not trust shared items and prefer individual ownership, despite high idleness rates [203-205]. • Vertical and horizontal integration can be beneficial as supply chains are condensed and companies pool resources. Idleness of tools and transportation decreases and efficiency increases. However, integration can negatively affect individual stakeholders' ethical decision-making capacity and can create monopoly-like conditions, which hurts consumers [206, 207].
Optimize	Increase efficiency in the production process. Optimization does not require changing the product, just cutting unnecessary waste	• Improving technologies for alternative energy production (like algae) can help make these pathways feasible and affordable [208]. • Increased use of technology like biofilters and air scrubbers in on-farm applications can help to significantly reduce greenhouse gas emissions [209] • Feed additives can greatly improve the feed conversion efficiency of animals in production, leading to decreased feed requirements per unit of output. These additives can often be sourced from waste streams (e.g. grape pomace), which adds a further level of circularity as it diverts waste back into production [210, 211]. • Genetics can play a factor in animal production efficiency, and farmers can use genetic resources to improve their yields without any farm-level change. There are some ethical issues with overbreeding [97], but in general it can improve circularity [212].
Loop	Recognize and encourage opportunities for end-of-life reuse and upcycling of waste products	• Waste streams from other processes can be reincorporated as inputs in agriculture/animal production. These new inputs, which can include feed additives and ingredients, can increase cost efficiency and reduce waste [210]. • Manure from agricultural processes can be recycled in many different ways. It can be used as a fertilizer, or anaerobically digested to yield biofuel [178]. • Phosphorus is one of the major wastes from poultry production, but its value as a fertilizer

		is very high in places where it is unavailable. Is there a way to move some of the excess phosphorus to somewhere where it would be more useful? [213, 214]
Virtualize	When possible, create virtual technologies that replace wasteful processes	• Virtualization can serve one of two goals: decreasing cost or improving productivity [198]. • Pixel farming trades monoculture for a mixed planting pattern, which can be optimized based on soil conditions. The planting, care, and harvesting are performed by a robot, which can be controlled remotely [215]. • Despite claims that increased technology in animal production systems necessarily correlates to decreased welfare, many technologies are developed specifically with the intent to increase or monitor animal welfare. Animal welfare could be considered a socially regenerative benefit, and should be taken into account in circular decision-making [216].
Exchange	Purchase more sustainable and longer-lasting products as replacements for products at the end of their life.	• In agriculture, tools, machines, monitoring, and remote sensing mechanisms, etc., are all being updated as the market favor shifts towards more intelligent and sustainable technologies [217]. • Government subsidies or cost-sharing programs could help poultry farmers adopt environmentally friendly technologies [201].

The ReSOLVE framework can serve a dual purpose- functioning as both a guide for business owners and a tool for researchers to analyze business practices. The Materials Circularity Indicator, also developed by the Ellen MacArthur Foundation, gives a quantifiable metric that companies can use to gauge their commitment to enacting circular economy principles. This metric is helpful but does not provide substantial information on its own about the impact of a product [218]. Thus, there is still a pressing need for better circularity accounting metrics.

Few case studies utilize the ReSOLVE framework, but they present valuable information on the difficulties of translating these principles to the real world. For example, a case study of the planted tree industry in Brazil found that of the companies who adopted ReSOLVE/circular economy concepts, 37.1% applied them superficially, and only 14.3% applied them comprehensively to all organizational levels [219]. Additionally, this study found that of the ReSOLVE principles, Virtualize and Share were the least likely to be implemented. These findings contrasts with a study of European textile manufacturers, which found that the Exchange principle was the least likely to be implemented [220]. Part of this discrepancy could be due to the lack of an objective categorization technique and the potential overlap between the principles. For example, upgrading old technologies with new, more advanced ones that digitalize processes could be counted under Virtualization, Exchange, or both, potentially leading to disagreement between studies. Similarly, Regeneration and Looping have overlapping definitions that could be easily confused in many cases. Future efforts to implement the ReSOLVE framework should be clear in establishing the distinction between these categories to increase consistency, at least case by case or at a sector level.

5.2.2. Methods

For this study, a framework for analyzing the incorporation of social indicators into the ReSOLVE framework was developed based on the ECOGRAI method [221]. The ECOGRAI method is a separate framework developed for business decisions which uses decision variables (categories of decisions that lead to certain stakeholder outcomes) to more easily assess the impacts that a decision might have. Rukundo et al. used this method to examine the circularity of the egg production sector in Canada [222]. This study expands on this framework and examines the potential social value added to the poultry value chain from circularization strategies by using decision variables to incorporate social indicators into the ReSOLVE framework. The poultry industry was selected as a case study due to its high social and environmental impact and its high potential for incorporating circular economy strategies.

First, following the ECOGRAI method [221] and Rukundo et al study [222], a set of decision variables were created for the poultry sector based on hotspots identified from literature where potential for increasing circularity via the ReSOLVE framework concepts is high. Next, the decision variables were narrowed down based on perceived relevance and importance. Then, social value addition for each decision variable was discussed based on similar applications from literature, and measurable indicators were developed for each variable. The implications of this updated framework for S-LCA and life cycle sustainability assessment (LCSA) were then discussed. Figure 5.1 presents the methodological framework for the study.

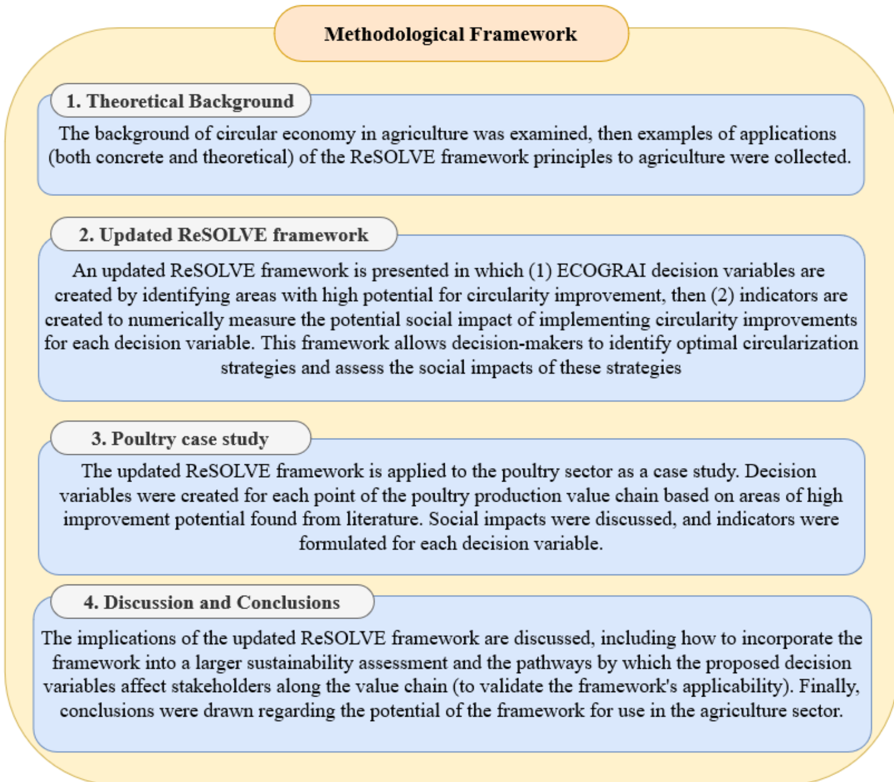

Figure 5.1: Methodological framework for the study presenting the four major steps of the study, including the theoretical background, the updated ReSOLVE framework, the poultry case study, and finally discussion and conclusions.

5.2.2.1 The Updated ReSOLVE Framework

There is high potential for applying ReSOLVE circular economy principles into agriculture, but there is currently insufficient discussion of the social benefits derived from the application of circular economy principles. Nevertheless, there are some immediate social benefits: for example, renewable energy ventures can create new high-paying jobs. Regeneration and Looping can have positive impacts by creating new products or reducing the input costs of raw materials, which helps with accessibility among low-income farmers. This benefit depends on the upcycling potential of the waste stream and transitional costs. A flowchart showing a sample poultry production process is shown in Figure 5.2. In this figure, processes with improvement potential and choice-dependent inputs are shown. From this figure, it is clear that there are many decisions which actors at many points along the value chain could make to optimize the system. This section will outline and analyze these decisions for social value increase potential, and the decisions with the highest potential will be identified.

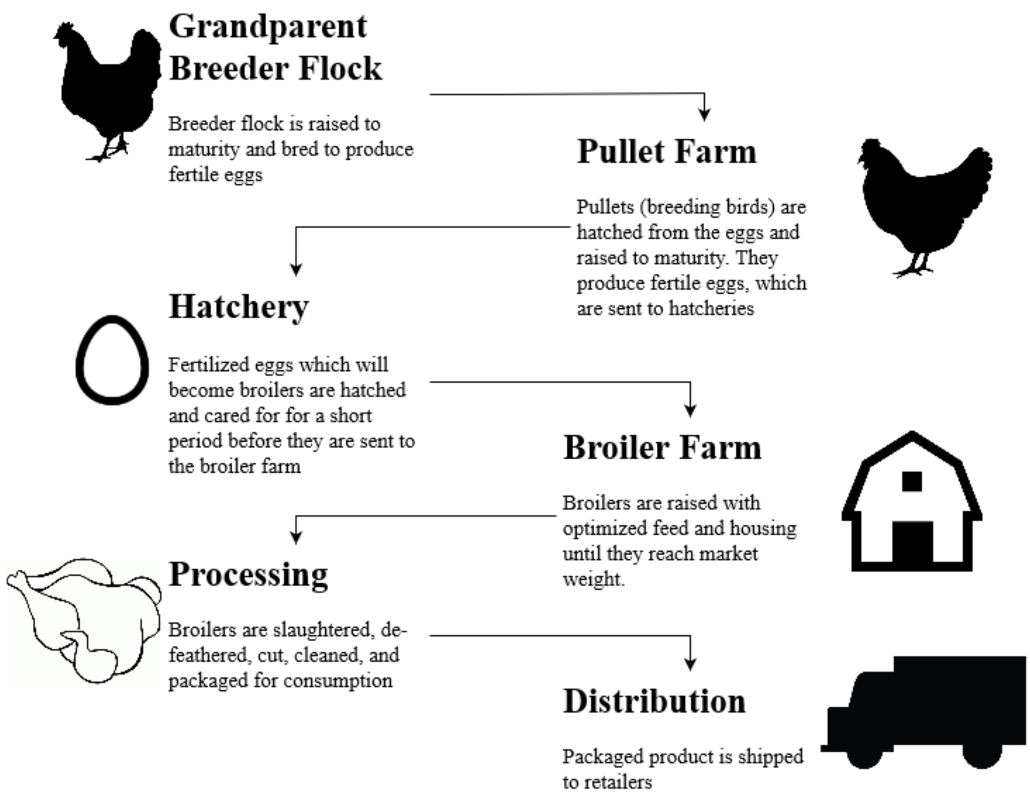

Figure 5.2: Process flow diagram of the industrial poultry production process from the grandparent breeder flock to distribution of the final poultry product to retailers. [223]

5.2.2.2 Inventory of areas of focus based on of ReSOLVE principles

The ReSOLVE framework is currently underutilized in agricultural research, but several examples of applications from literature were discussed in Table 5.1. The present study seeks to adapt the framework to include social impacts as well as the environmental and economic impacts traditionally considered in discussions of circular economy. Figure 5.3 presents a collection of more traditional environmental/economic circularization strategies posed alongside social circularization strategies under the different principles of the ReSOLVE framework. This proposed addition could function as a simple addition of social considerations to the ReSOLVE framework as it stands, or a separate level could be added to each principle to indicate whether the proposed improvement is social or environmental/economic (e.g., Regenerate-S, Optimize-E). Traditional circular economy implements often combine environmental and economic benefits, so these are difficult to separate.

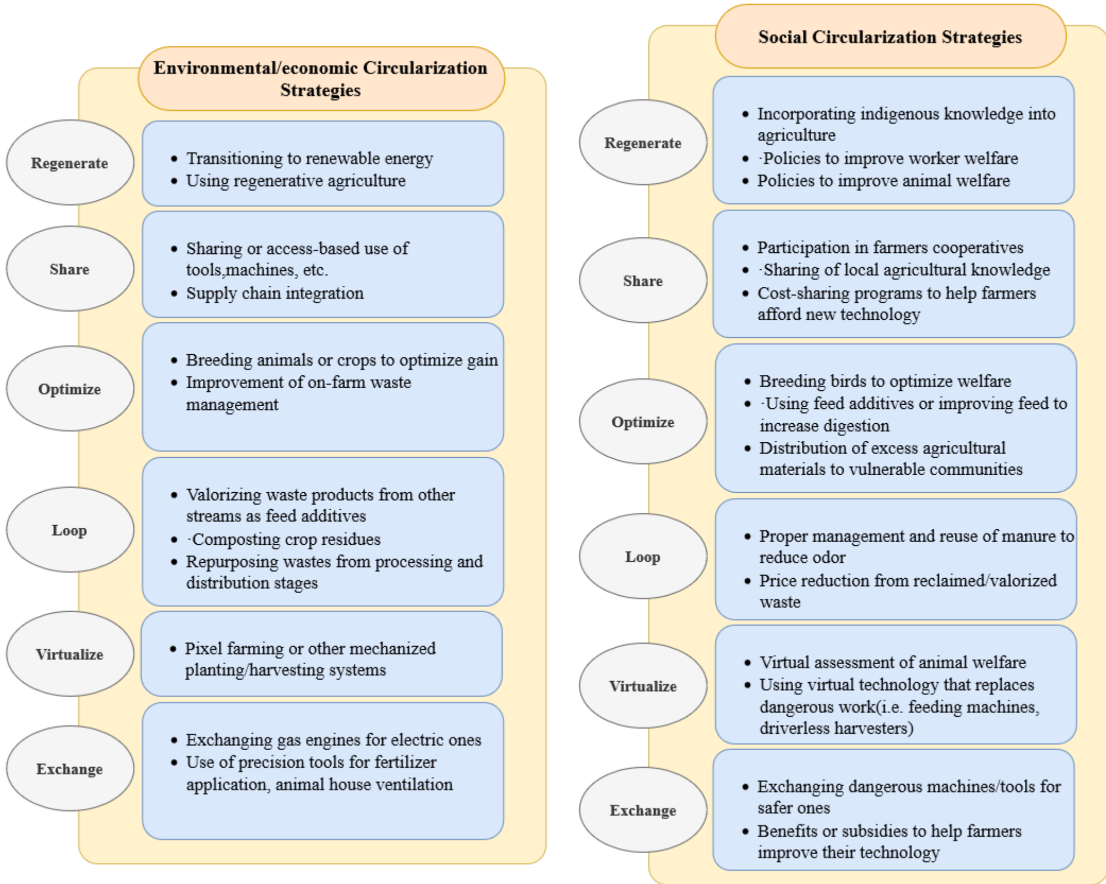

Figure 5.3: Examples of traditional and social applications of ReSOLVE principles within agriculture based on theoretical background review.

5.2.2.3: Decision variables

In order to facilitate the integration of social aspects into the ReSOLVE framework, some translation is required. The ECOGRAI method provides a way to facilitate this translation through the use of decision variables (DVs). A study by Rukundo et al. [222] analyzed economic circularity potential in the Canadian egg production sector. This study identified the leading DVs (areas in which decisions could lead to improvement) that could increase circularity potential based on a variety of factors.

The framework developed in the Rukundo et al. paper developed a collection of performance indicator DVs, which were then whetted through interviews with farmers and site visits. The finalized performance indicators are used to locate hotspots and areas with a high potential for circularity improvement [222]. For the present study, the decision variables are formulated using the areas of interest developed using the ReSOLVE framework method, as described in section 5.4.1. While the general areas of interest indicated in Figure 5.3 can be included in most agricultural value chains, some will need to be removed/added depending on the specific sector under study.

5.2.2.4: Indicators

Measuring the social value of a system can be difficult to gauge on anything but a theoretical basis due to the subjectivity of many social impacts and the high uncertainty of links between causes and effects [5]. Performance indicators can be used to gauge the increased circularity of the system when social values are unavailable or unmeasurable. The benefits derived from changes in these indicators can be calculated via a sliding reference scale in which the identified benefit can range from low to high depending on the performance of the indicator relative to the highest possible value. This method is used often in S-LCA to assess the performance of processes and organizations relative to expected or regulated levels [11]. These objective numeric indicators can be supplemented by stakeholder interviews to get a holistic reading of the circularity potential and to identify hotspots for potential improvement. Hotspots (and therefore DVs) should be identified based on potential value addition to the ReSOLVE framework principles, as described in sections 4.1 and 4.2.

5.3. Results: Poultry Production Case Study

5.3.1 Poultry Production and its Problems

5.3.1.1 Poultry Production

The definition of poultry production usually includes the production of chicken, duck, goose, and turkey meat and eggs; however, some studies limit or expand this definition as needed. In the present study, “poultry” refers to chickens produced for meat, unless otherwise specified. The poultry sector is one of the most industrialized sectors in meat production, meaning high efficiency but also high environmental and social impact. While poultry farming is essential to smallholder food security, especially in low resource setting communities, industrial broiler production provides livelihood to millions of people globally [186, 187] and has been increasing dramatically in popularity over the past 50 years, especially in Asia and South America [224]. Given the scale, relative homogeneity, and focus on efficiency and economic returns in these systems [78, 186], they will be the basis for examining the ReSOLVE framework application in the remainder of the paper.

Industrial broiler production typically follows the process shown in Figure 5.2, which details an industrial poultry production process adapted from the process described by Tyson Foods [223]. First, pullets are bred from a grandparent breeder flock and then lay eggs, which are then sent to hatcheries. The chicks hatched at the hatcheries are the broilers, which are grown, slaughtered, processed, and distributed to retailers and consumers. In many cases, especially in developed countries, these processes are vertically integrated so that one company hatches the chicks, and controls the slaughter, processing, and distribution.

5.3.1.2 Waste Generated by Poultry Production

Waste generated by poultry production consists primarily of litter or manure, dissolved air flotation (DAF) sludge and waste like blood and feathers from production and processing, and dead birds [225]. Litter often has very high concentrations of nitrogen and phosphorus which, if improperly managed, can enter water bodies and create major eutrophication problems [201]. DAF sludge can accumulate and cause blockages in pipes and wastewater treatment equipment, causing infrastructural damage that is expensive to remediate [226]. Dead birds are a major issue in production, especially as concentrated production operations can amplify the spread of diseases, so they are typically incinerated, or sent to landfills offsite to avoid contamination. Fortunately, all of these waste streams have the potential to be effectively circularized and repurposed, but circularization strategies must be properly implemented to avoid further damage to ecosystems and workers.

5.3.1.3 Social Detriments of Poultry Production

The poultry industry is vulnerable to detrimental social impacts on both animal and human stakeholders, especially considering the recent shift in global climate patterns. Excessive heat, which can result from climate change, can have negative impacts on the health and welfare of birds such as chickens and Japanese quails [227]. Exposing birds to excess heat can decrease egg production, reproductive performance [227], and meat quantity and quality [228]. Additionally, breeding birds to increase growth rate and feed conversion efficiency can increase the susceptibility of birds to adverse responses to heat stress, leading to increased mortality. An increased mortality rate often negates any decrease in feed conversion rate. From a human standpoint, poultry production is one of the most socially destructive industries in the developed world, as the “southern model” for growing poultry uses contracts and debts to trap farmers in the production system, while discouraging unionization and providing low wages for workers and farmers [78]. This disregard for workers’ rights is contrary to the foundational principles of sustainability and contrasts the socially regenerative principles of circular economy [10]. Farmers’ cooperatives could help in giving contract farmers a platform for negotiating higher wages [229], but as of now unions do not appear to be common in the industry; most decisions regarding production are made by the corporations who oversee the operations.

5.3.2 Decision Variables for the Poultry Case Study

Figure 5.4 shows a typical poultry production value chain. The processes that have high improvement potential based on ReSOLVE principles are indicated in red, and these processes became the basis for the formulation of DVs. Other studies have identified feed use efficiency and manure production and management as the most critical means by which the livestock sector can increase circularity. The decision variables are expressed in Table 5.2 below, and their applications to the ReSOLVE principles in each stage of the poultry production value chain are presented in

Table 5.3. Some DVs are generalized and used multiple times, although the actual application strategy may differ.

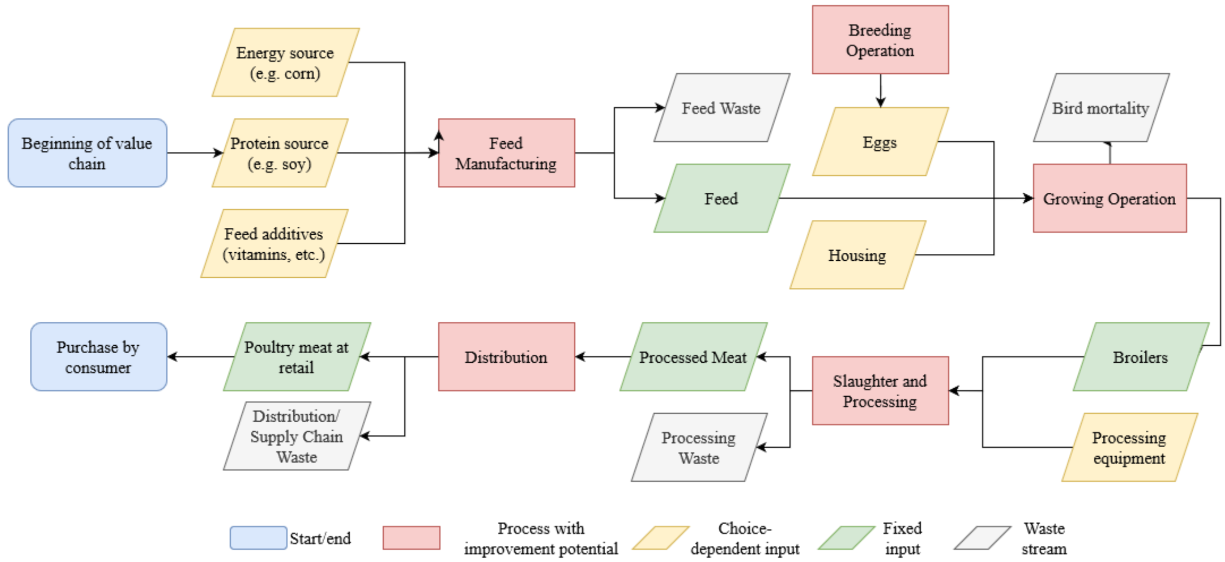

Figure 5.4: Example broiler production process with potential hotspot processes indicated with red rectangles.

Table 5.2: List of decision variables

Symbol	Decision variable
DV1	Use of renewable energy (solar, wind, etc.)
DV2	Regenerative agriculture practices
DV3	Membership in a union or farmer's cooperative
DV4	Use of advanced/specialized breeds
DV5	Composition of feed (ingredients, ratios, etc.)
DV6	Level of technology used in production
DV7	Tool replacement rate
DV8	Housing infrastructure
DV9	Manure management
DV10	Use of electric/high-efficiency vehicles for transportation
DV11	Bird feed conversion efficiency
DV12	Mortality rate
DV13	Level of vertical integration
DV14	Level of technology used in monitoring
DV15	Minimization and reuse of waste from processing and distribution
DV16	Welfare and comfort of animals
DV17	Welfare and safety of workers

Table 5.3: Matrix showing which DVs apply to each ReSOLVE principle in each value chain link

	Feed Production	**Poultry Breeding**	**Poultry Growing**	**Processing**	**Distribution**
Regenerate	DV1, DV2, DV17	DV1, DV16, DV17	DV1, DV16	DV1, DV17	DV1, DV10, DV17
Share	DV3, DV13	DV3, DV13	DV3, DV13	DV3, DV13	DV13
Optimize	DV4, DV5	DV4, DV8, DV11	DV8, DV11	DV15	DV10
Loop	DV2	DV9	DV9	DV15	DV15
Virtualize	DV6	DV6, DV8	DV8, DV14	DV6	DV10, DV
Exchange	DV2, DV7	DV7	DV7	DV7	DV7

Of these variables, 12 with the highest potential for improvement based on the literature were selected: DV1, DV2, DV3, DV4, DV5, DV6, DV9, DV11, DV14, DV15, DV16, and DV17. Of the remaining variables, DV7, while it applies directly to the Exchange principle, can be encompassed by DV6 and DV14. DV8 can similarly be encompassed under DV6. DV10 is a decision made by transporters rather than poultry producers, except in the most vertically integrated businesses. DV12, although essential to measure, is encompassed by DV11 for most practical purposes. Finally, the conflicting ethical implications of DV13 make it unhelpful in gauging sustainability. Several variables were included in this table but do not directly contribute to increasing economic/environmental circularity (DV3, DV16, DV17). Still, they are important to consider in the calculation because of their high social impact. These categories, including membership in farmers' cooperatives and animal and worker welfare, can theoretically be designated as regenerative, as they contribute to increasing sustainability and social resiliency.

5.3.3 Indicators for the Poultry Case Study

The use of renewable energy is essential in the transition to a circular economy and is one of the foundational examples mentioned in the ReSOLVE framework. Using anaerobic digestion to turn agricultural waste products into fuel is particularly promising from a circularity perspective, as it reduces waste flows while simultaneously decreasing the amount of fossil fuels consumed. Currently, only 18.9% of Canada's energy comes from renewable sources, with biomass accounting for only 1.4% of electricity generation [230]. The theoretical cost of transitioning to farm-scale anaerobic digestion can be very high. However, some countries are taking steps to help farmers make the transition [231]. Although the cost may still be prohibitive, this program may help encourage more farmers to switch to renewable energy. Although the benefit to the social sphere is less apparent, it is still present [232]. The social benefit from renewable energy transition comes primarily from pollution reduction but may also occur through the creation of lower-risk jobs compared to sectors like oil and coal. Additionally, the benefit to farmers of having energy produced on-site rather than purchased from the grid can help give them more agency over their operations. Surrounding communities may benefit from odor reduction if manure is removed from storage and digested into biofuel.

The growth of feed is a crucial factor in determining the circularity and sustainability of livestock production. Much has been published on regenerative agriculture [199, 233-235], but the general basis is that agriculture should regenerate soil mass and soil nutrients at a rate greater than or equal to the rate of degradation and plant uptake, respectively. This regeneration can be accomplished by retaining soil on the land using practices such as no-till agriculture or cover cropping or by returning mass to the soil using organic matter application or retaining crop residues. These methods are relatively easy to implement and, in the long run, are an environmental and economic imperative, as they protect and preserve non-renewable soil resources and decrease fossil fuel use. This is important from a social perspective, as it preserves resources for future generations and ensures access to arable land, likely preventing future conflicts. Additionally, food security can be increased due to increased crop and land use diversification associated with regenerative practices.

Animal welfare, worker welfare, and membership in unions or cooperatives can be reviewed together, as they all involve purely social benefits, as opposed to the other more economically driven circularization techniques. It is important to consider these variables, as they contribute significantly to the resiliency of the production system and improve the subjective lived experience of animals and the farmers that raise them. A large portion of farming technology developed recently is in the interest of increasing animal welfare [216], but there is still a high level of concern that industrial agriculture is inherently harmful to animal welfare. Farmer’s cooperatives are a popular method to collectivize members' interests, either politically or financially. Cooperatives and unions can be powerful tools in fighting the social detriments of vertically integrated corporate farming practices. Social benefits derived from increasing performance in these categories are not explicitly mentioned in the ReSOLVE guidelines, but positive impacts on the social economy are a necessary part of a circular economy [10]. Therefore, it seems appropriate to consider these as regenerative effects with positive impacts on employment and worker well-being.

Chicken growth rate and feed conversion efficiency can be linked to breeding and feed composition. Genetic resource efficiency has caused birds to grow more quickly and with less feed than before [236] which may be linked to mitochondrial function [237]. Much of the population in the world's developing rural areas relies on backyard poultry farming, in which the feedstock comes partly from scavenging and partly from local feed, often not specially formulated. Industrial feeds, on the other hand, are extensively formulated with additives for maximum growth and minimum cost [186]. The availability of specialty formulated feed additives and chicken breeds to producers in developing countries could have a high potential social benefit by increasing meat availability and reducing labor costs. However, while efficiency may increase, the transportation impact of the feedstocks and additives can be highly damaging [238]. Feed composition also affects the environmental impact of the birds themselves by changing the nitrogen and methane content in poultry manure and may have negative impacts on animal welfare. Using additives such as protease and adjusting the macronutrient ratios in the feed can help decrease the methane emissions from birds and the nitrogen content in the manure. Additionally, what happens to the manure after it is collected can also impact the circularity of the system; recycling the manure can create additional income for farmers and can support regenerative agriculture practices.

The infrastructure and technology used in poultry production allow farmers and other workers along the value chain to monitor and control more aspects of production. In the grow houses, farmers use precision livestock technology (PLT) to monitor both external factors, like temperature or relative humidity in the grow house, and internal ones, such as bird movement and body temperature. Monitoring these factors helps ensure the animals' welfare and that they are in optimal conditions for growth, as heat stress can disrupt birds. One study estimates that the economic loss due to heat stress in the poultry industry ranges from $128-165 million USD per year due to increased mortality and decreased meat quality [239]. Most poultry production in the United States occurs in the South, where the warm climate puts the birds at risk of heat stress for much of the year without proper ventilation. Ventilation systems require energy, often in the form of fossil fuels. Different mechanisms for cooling have been explored, and some, such as the dew point indirect evaporative cooling system (DPIEC), are more efficient than the standard methods [240], which could improve bird welfare. Technology like sensors, cameras, microphones, and IoT applications can decrease the amount of active oversight required from farmers and help them identify problems more quickly when they arise to keep yields high. Such technology brings the social benefit of increasing animal welfare and decreasing manual labor requirements by transitioning to more virtual tools.

Waste streams from processing and distribution can be reused in other feeds or lower-value products or composted and used as fertilizer for feed crop production. They can also be transformed through bioprocessing into more valuable products. This practice is another example of looping in which value is added to waste products that previously had no value. This can deliver significant economic benefits, provided that the cost of recovering, transporting, and processing the waste is lower than the revenue that can be earned from the upcycled product. The reduction of waste also has an inherent social value. Reducing the exposure of communities to dangerous and toxic materials and decreasing visible pollution and odors in natural environments like oceans, rivers, and parks which have emotional value for the public are two examples of indirect social value that could be added from waste reduction.

Table 5.4 presents indicators that can be used to gauge circularity and social performance in each of the 12 selected variables.

Table 5.4: List of indicators for the selected decision variables

Decision Variable	**Potential Social Indicators**
1: Use of renewable energy	• Cost savings and accessibility increase after energy transition • High risk work hours averted due to energy transition
2: Regenerative agriculture practices	• Effect of regenerative methods on animal welfare • Value of soil health preserved in at-risk areas
3: Membership of farmers in cooperatives or unions	• Presence and accessibility of local farmers' cooperatives • Level of sharing/cost-sharing practices between farmers in cooperatives
4: Use of specialized/advanced breeds	• Decrease in mortality or increase in feed conversion rate due to breeding (poultry) • Price reduction and availability of meat
5: Composition of feed ingredients	• Social welfare of producers along the value chain • Cost for farmers to purchase feed
6: Level of technology used in production	• High risk work hours saved by technology improvement. • Effect of this technology on bird welfare

9: Manure management	• Runoff and eutrophication damage in public water systems • Complaints of odor or water pollution by neighbors or agencies
11: Bird feed conversion efficiency	• Cost for farmers to purchase feed. • Effects of efficiency improvement strategies on animal welfare
14: Level of technology used in monitoring	• Ease of use and rate of adoption of technology by farmers • Improvement in animal welfare from using technology
15: Reuse of waste from processing and distribution	• Reduction in waste generated. • Reduction in cost of materials due to recycling
16: Welfare and comfort of animals	• Compliance of production system with regulations • Presence of best management practices
17: Welfare and safety of workers	• Accidents per year • Human health damage in QALYs • Right to collectivization and union/Co-op participation rate • Wage compared to minimum/living wage

In order to properly link the indicators to their corresponding social impacts, the affected stakeholder group must be identified. Figure 5.5 presents these pathways for the poultry case study. As indicated in the figure, some indicators can impact multiple stakeholders. If a quantitative social assessment is being conducted in which impacts are translated to endpoint values (such as type II impact pathway S-LCA), these impacts can be allocated based on relative importance or other characterization factors, but users of this framework in such contexts should be careful to avoid double counting (i.e., counting results from the same indicator in multiple stakeholder categories).

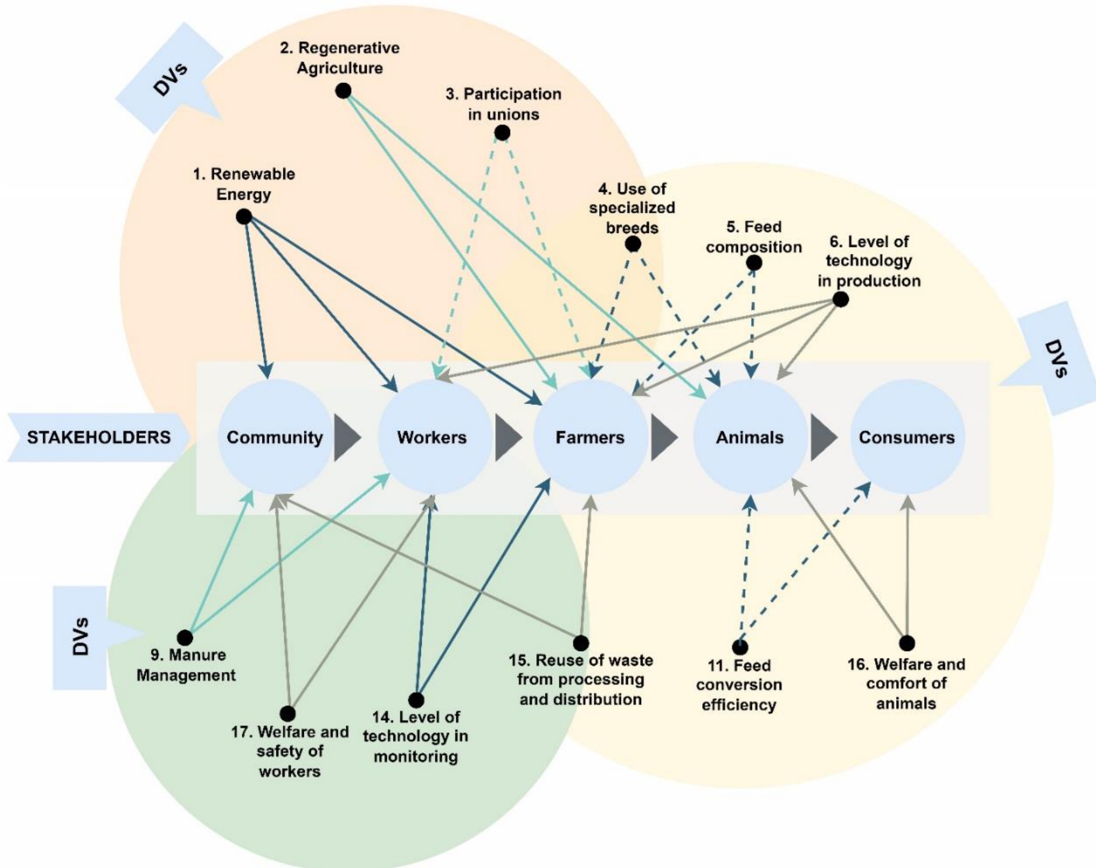

Figure 5.5: Pathways by which decision variables may affect stakeholders for the poultry industry case study.

This framework can be applied in S-LCA in the inventory and impact stages, as it can help researchers find hotspots in a potential circular production system and assess those impacts using decision variables and indicators, respectively. These results can then be translated to final results via Type I or Type II S-LCA methods. Figure 5.6 illustrates the pathway by which social value analysis can be conducted following the methods presented in this study and expanding to combine the results with other assessments such as E-LCA and Life Cycle Costing (LCC). Analyzing the tradeoffs between environmental, social, and economic metrics is one of the most critical components of a holistic sustainability assessment. For example, suppose the decision is to switch to a new type of feed that increases conversion efficiency. In that case, the environmental impact of the different feedstocks must be analyzed to determine whether making the switch will cause an increase in environmental damage, and the social impact must be analyzed to determine the effect on animal welfare, food safety, etc. Additionally, practices like regenerative agriculture can provide just as much social good as environmental good, as it increases the productivity and lifespan of soil, allowing farmers to continue using the soil for many years without excessive fertilization, which can have detrimental impacts on human health and wellness metrics. This paper presents the methodology to predict and assess the social impacts of the circular economy, which, until now, have been seen as secondary to the environmental and economic impacts. This methodology facilitates the secondary combined tradeoff analysis, which can be accomplished using a multi-criteria decision-making framework such as TOPSIS, which will present the optimal choice based on proximity to the ideal combination of environmental, social, and economic impacts.

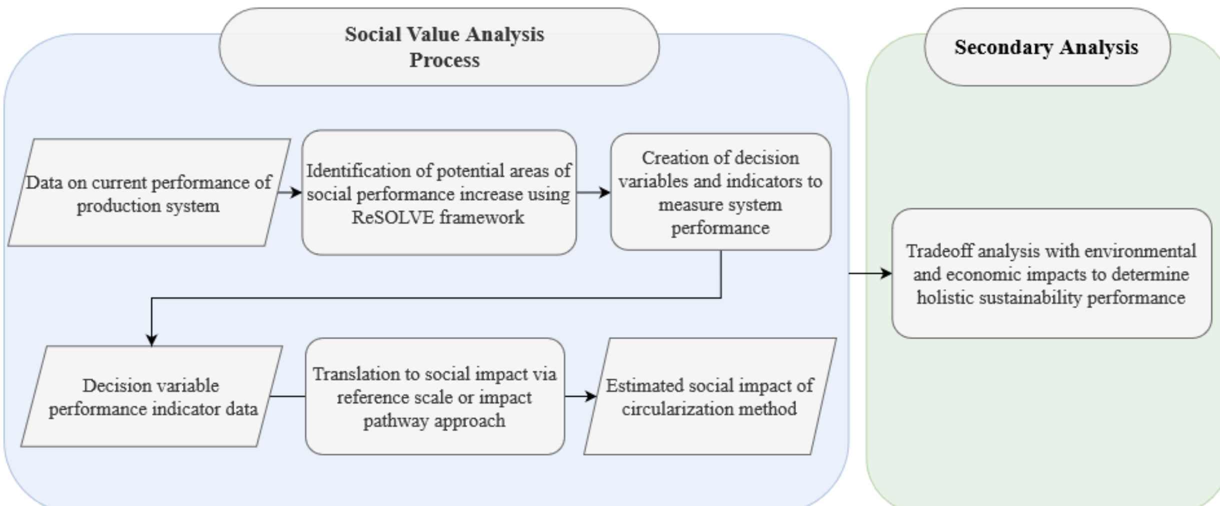

Figure 5.6: Framework for total sustainability analysis including social value creation for circular economy decision variables.

5.4. Discussion

When investigating the consequences of increasing circularity in the poultry sector via the ReSOLVE framework methodology, a concerning trend was noted in which several practices that increase circularity/efficiency in the agricultural sector based on the ReSOLVE framework principles have damaging social impacts. For example, farmers' decision-making rights are negatively impacted by vertical integration. Similarly, aggregating small-scale farms into large-scale industrial agriculture operations increases efficiency but often negatively affects animal and worker welfare. This study highlights the unfortunate necessity of fighting a two-front battle. On the one hand, efficiency must increase, and resource use must decrease to find a sustainable balance within the poultry production sector. However, on the other hand, farmers' rights and animal welfare must be protected, goals often at odds with mechanization and streamlining of agriculture based on the current methods [78].

Despite this concerning duality, there is promising evidence that innovations in agricultural technology are being used to ensure animal welfare rather than simply increasing profit at the expense of the animals [216]. Additionally, many of the principles of ReSOLVE framework have been shown here to have positive social impacts beyond those present in economic value creation and environmental preservation. Despite the noted harmful social and environmental impacts of the poultry sector, the modified ReSOLVE framework presented in this study can assist decision makers along the poultry value chain in maximizing the welfare of the stakeholders affected by their decisions.

The ReSOLVE framework was initially created to help guide business and policy decisions, so any modification to the framework must also help in this regard. The proposed addition of social sustainability indicators presented in the present study fits these criteria. There has been an increasing demand among consumers and policymakers for social sustainability in recent years, and in response, new frameworks and guidelines have been presented to assess and improve social welfare of stakeholders across the value chain. By incorporating indicators to assess circularity and sustainability, the modified ReSOLVE framework could become a tool not only to brainstorm circularization strategies for businesses, but also to assess the implications of these strategies. This modified framework carries a benefit to researchers as well. The standard template of the ReSOLVE framework is easy to apply to many different sectors and situations, meaning that researchers wishing to conduct assessments of circularity, or its impacts have an easy starting point. The ReSOLVE framework's greatest strength is its versatility, and the incorporation of the social aspect only adds to the capacity of the framework.

Although the framework presents a wide range of benefits, it has some critical limitations. It provides guidance for policy and business, but whether and to what extent it will be used is entirely dependent on decision makers. There is also no formula yet for assessing the tradeoffs between the different aspects of the ReSOLVE framework (i.e., how to weigh the positive and negative outcomes of a potential decision). This study seeks to introduce the concept of objective social welfare indicators into the discussion of circular economy, but there is much that still needs to be understood about the reliability of the pathways connecting circular economy strategies to social impacts. Additionally, more behavioral research is needed about how to encourage stakeholders to choose beneficial strategies, as this can present a significant challenge. Despite these limitations, the modified ReSOLVE framework still presents much promise as a tool for motivated researchers and decision makers. The framework presented may help stakeholders brainstorm ideas that fit the ReSOLVE framework and analyze them for social impacts. Following this methodology could simplify the transition to circular economy without incurring any potential social damage that follows some strategies.

5.4.1. Recommendation for Future Research

A more objective analysis of values added is necessary to address the tradeoffs between economic, social, and environmental effects in which one often comes at the expense of another. In future research, a multi-criteria decision matrix could be created to determine the optimal activity choice based on the priorities of the producer. This matrix would use results from environmental and social LCA and life cycle costing analysis to determine the economic, environmental, and social benefits or detriments of implementing each activity. This would be most easily accomplished using a case study where data can be collected, and estimates can be made based on actual measured input and output quantities. Further studies are needed to test the proposed indicators and create new ones for similar or different applications.

5.5. Conclusions

The transition to a circular economy model from the current wasteful linear economic model has been advocated by scientists, activists, and consumers worldwide. As a result, several programs and paradigms have been developed to help economies transition towards circular economies on a local, regional, national, or international scale. One of the most holistic frameworks introduced is the ReSOLVE framework, developed by the Ellen MacArthur Foundation in 2015. This framework identifies six core principles of circularity (Regenerate, Share, Optimize, Loop, Virtualize, and Exchange), which function as guidelines for stakeholders to follow to increase circularity in their operations. This study found that the ReSOLVE framework is a valuable tool for brainstorming new circularity improvement techniques, as it identifies six standard means by which value chain actors can increase circularity. However, there is some issue with the ambiguity of the framework, which makes it difficult to use the framework as an objective metric for study.

To analyze system performance through the lens of the ReSOLVE framework, researchers must incorporate other decision-making strategies like environmental and social LCA methodologies.

The agriculture sector is one of the largest consumers of energy and resources and is a massive contributor to waste and social welfare issues worldwide. The potential to add economic and social value by increasing circularity within the agricultural value chain is immense. This paper examined the potential means by which circularity could be increased in a case sector (poultry) based on historical applications in agriculture, and the social benefits derived from implementing these practices.

The study found that the most established methods for increasing circularity in agriculture were:

(a) Increasing renewable energy use
(b) Utilizing regenerative agriculture practices for feedstock growth
(c) Properly managing manure and recycling it for fertilizer or biofuel when possible
(d) Genetic modification and feed improvement to improve feed conversion rate in birds

Other methods used were less commonly researched but fell within the ReSOLVE framework guidelines and were also found to contribute potential value, whether economically or socio-environmentally. These methods include:

(a) Protecting animal comfort and welfare
(b) Protecting worker safety and welfare, including encouraging membership in farmers' cooperatives or unions
(c) Adopting improved technology in production monitoring and processing
(d) Repurposing waste from production and distribution

The benefits derived from these identified methods show strong potential to add social value to the agriculture sector and help it grow within environmental, social, and economic boundaries as demand for sustainable food grows worldwide.

Following the analysis of methods and applications, a framework was developed based on a previous study by Rukundo et al [222], the ECOGRAI framework [221], and social LCA methodologies [11] to assist researchers in analyzing the social impact of implementing circularization strategies. Combing the brainstorming power of the ReSOLVE framework, the characterization methods proposed by ECOGRAI and the Rukundo study, and the analysis methods of social LCA, there is immense potential for improving the social welfare of workers, communities, animals, and many other stakeholders within global agricultural systems.

Chapter 6: Discussion and concluding remarks

Social sustainability is an integral component of sustainable development, and the imperative for the transition to more socially sustainable practices is especially high in the agriculture and agri-food sector, where environmental and social impacts are causing damage to stakeholders and their communities worldwide. While their subjects, methods, and approaches may differ, the chapters of this thesis are unified by a common goal: evaluating and improving the outlook of S-LCA as a tool to facilitate this transition in the agriculture and agri-food sector. After the introduction in Chapter 1, in which the project was justified and the objectives are defined, the rest of the chapters address these objectives while laying out a map of the past, present, and future use of S-LCA in agriculture and agri-food.

Chapter 2 presents a literature review detailing the past uses of S-LCA in agriculture and agri-food and examines the potential challenges and benefits of using S-LCA in high-risk agricultural sectors like poultry production based on this historical context. Thus, Chapter 2 demonstrates that, while agricultural and sustainability researchers seem increasingly inclined to include social impacts and S-LCA in their work, regional variability, animal welfare, and communication with stakeholders are major barriers to widespread adoption and acceptance of these methods. Additionally, many researchers are concerned with the subjectivity of S-LCA indicators and pathways compared to E-LCA and other assessments. However, science is rarely as "value-free" as it claims to be, and researchers' personal decisions (so long as they are documented and justified) are common throughout all forms of LCA. With time and effort from dedicated researchers, S-LCA has practically endless potential within the bioeconomy, and can is an important piece in the creation of a sustainable future.

One of the more contentious issues within S-LCA is animal welfare. While there is much debate as to whether it should be included in social assessments, Chapter 3 presents the stance that if the goal of S-LCA is to help quantify and direct action to maintain the welfare of stakeholders, it is imperative that animals be included in the framework. Doing so does not seek to undermine the importance of humans who are suffering as a result of poor agricultural management systems, rather to guide decisions that will lift both animals and humans out of suffering together. This echoes one of the foundational goals of the One Welfare project, which seeks to promote research with "mutual benefit between animal welfare, human wellbeing and/or the environment" [9]. As of 2014, over 26 billion livestock animals are under human care [241]. As we apply S-LCA to learn to better care for ourselves and our communities, we must not forget to care for the other beings whose lives are intertwined with our own. Chapter 3 addresses Thesis Objective 1 by evaluating the current state of animal welfare in S-LCA and proposing methods by which a new stakeholder category for animals can be created and integrated with current methodologies.

While methodological and conceptual studies can help improve S-LCA and standardize practices, case studies are necessary to explore the validity and practicality of these methods. Chapter 4 presents a case study of S-LCA applied to the value chain of a feed additive for dairy cattle produced in Quebec, Canada. The study includes both the foreground (production of the additive at the manufacturer) and background (raw ingredient manufacturing and use at farm level) systems. The findings showed that the highest impacts came from *freedom of association and bargaining* for the manufacturer, and *social benefits* for the ingredient production system. However, the data collected from various sources was often conflicting or contradictory. An uncertainty assessment found that there were significant differences between impacts for comparable categories in the database and the impacts evaluated for the product system under study. This underscores the importance of using data from multiple data sources as a tool for validation. While databases and on-site collection methods each have their strengths and weaknesses, they can be compared to fill in each other's gaps and ensure that the results paint a complete picture of performance and potential risk within the system. Through the activities conducted during the course of the study, Chapter 4 represents the completion of Objective 2.

Objective 3, meanwhile, is fulfilled by the study in Chapter 5, which presents a discussion of applying social indicators within an updated ReSOLVE circular economy framework. This study was an insightful look into the path forward for sustainable development. The movements of circular economy and S-LCA are similar in that their acceptance is contingent on a changing mindset within both the sustainability research community and the business world. Current wasteful practices must be phased out in order to achieve a circular economy that is able to meet the demands of the worlds' population without compromising our shared resources. Similarly, practices which subjugate workers, communities, animals, and other stakeholders and deprive them of dignity must be phased out in favor of those which allow all beings the freedom to seek happiness and achieve their potential. Overcoming these barriers to sustainability will take the tireless effort of interdisciplinary actors, united under the banner of care and compassion for future generations.

S-LCA is a tool for not only quantifying impacts, but also for designing and building a sustainable future. In the context of sustainable engineering practice, it can provide a fresh perspective on an understudied component of sustainability. As engineers and other practitioners work with stakeholders from farmers to corporate decision-makers to promote sustainable practices in all aspects of agriculture, S-LCA can be interwoven with many other frameworks and concepts such as Circular Economy and One Welfare to make more informed decisions. While at its heart, social sustainability relies upon changes to current oppressive paradigms, the power of S-LCA as a tool to help realize this change cannot be understated. Although the primary focus of the studies included in this thesis was on agricultural value chains, methods have been proposed, evaluated, and tested which can help guide future engineers and practitioners in their studies as they apply S-LCA within their respective fields.

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Appendices:

Appendix A: Questionnaire for HR

1. What is the current number of workers that the the company HR office oversees?
2. Are workers restricted (by policy or in practice) from joining unions or practicing collective bargaining?
3. (conditional) if unions exist, are they adequately supported by company policy (facilities may be used for meetings, notices may be posted, etc.)?
4. Are collective bargaining agreements kept on file and available for viewing?
5. Do workers have access to an independent, neutral, and binding dispute resolution procedure?
6. Are children under the age of 14 employed at the company? If so, in what regard and what protections do they have?
7. What is the lowest wage paid by the company? How many workers are earning this wage?
8. Are workers paid full wages on a regular schedule and is pay recorded?
9. Is there a policy mandating the maximum number of hours worked per week?
10. What is the company policy regarding compensation for overtime work?
11. Are workers free to terminate their employment at will? Does any contractual obligation prevent this?
12. Are there formal policies promoting equal opportunities/diversity and discouraging discrimination?
13. Are job openings posted directly to the public?
14. Is there a formal company-wide system for reporting and addressing discrimination complaints?
15. Have there been any recorded reports of wage discrimination (pay inequality based on gender, ethnicity, sexual orientation, etc.) in the past three years?
16. Are male and female employees in similar positions paid equally?
17. How many accidents resulting in injury have occurred in the last three years?
18. How many accidents resulting in death have occurred in the last three years?
19. Is there a formal safety policy that workers are trained in before beginning work?
20. Is there an emergency protocol for workplace accidents?
21. Is there an emergency protocol for chemical hazard exposure?
22. Are workers required to wear protective gear when in potentially dangerous situations?
23. How many occupational health and safety violations have occurred in the past three years? What is the current status of these violations (open, resolved, etc.)?
24. Please list and describe benefits provided to workers (health insurance, pension plan, child care, paternity leave, etc.)
25. Have there been any reports of violations to social security or labor laws in the past three years?
26. What percentage of full-time workers receive paid vacation time and how much vacation time do they receive? Does this amount vary with experience, department, position, etc.?
27. Does each worker have a written employment contract that they can view a copy of at any time?
28. Is there a policy regarding sexual harassment reporting and what to do if it's reported?
29. How many incidents of sexual harassment have been reported in the past three years?

Community

30. Has the company created any infrastructure with community access?
31. Does the company have a certified environmental management system?
32. Does the company have any community education initiatives?
33. Have the practices of the company ever forced any local residents to resettle or move (through land acquisition, loud or obtrusive activities, etc.)?
34. Does the company have any official procedure for helping integrate migrant workers into the community?

35. Is there an internal review commission for ensuring the structural integrity of buildings and infrastructure?
36. Does the company have any community health infrastructure that is publicly available or contributes in a meaningful way to public health?
37. Does the company make a conscious effort to minimize the use of harmful chemicals in their products/processes?
38. Does the company have any policies promoting engagement with indigenous groups?
39. Does the company have any written policies concerning community engagement (volunteering, community outreach, etc.)
40. What groups, if any, from the local community does the company interact with? If these groups exist, how often does the company meet with them?
41. Approximately what percent of the company's workers are hired from the region where they work?
42. Approximately what percent of the company's supplies are sourced locally (percent of money spent on ingredients, services, equipment, etc.)
43. Does the company have hiring practices which favor local candidates (eg. From Quebec, or Canada)

Value Chain Actors

44. Has the company ever been the defendant in legal action regarding anti-competitive behavior?
45. Is the company a part of any business alliances?
46. Does the company have any official policy regarding avoiding anti-competitive behavior?
47. Does the company have any policies regarding the protection of human rights of workers in supplier companies?
48. Does the company ever conduct audits on suppliers to determine human rights violations?
49. Does the company have a purchasing or distribution policy which establishes criteria for social responsibility for suppliers or distributors?
50. Does the company offer support to suppliers for raising awareness for social issues?
51. Do the company's supplier trade agreements maintain standard policy for ordering products (volumes, lead times, etc.)?
52. Does the company have any policies regarding the use of intellectual property (internal or external source)?
53. Are there any contracts in the company's supply chain ensuring equitable value distribution?
54. Does the company interact with any professional organizations which represent specific actors in the value chain?
55. Does the company work with suppliers to agree on a fair price based on social responsibility to workers in the supply chain?

Appendix B: Questionnaire for Workers

*Please note that the name of the company has been replaced with "Company A"

There are 37 questions in this survey.

Participant Consent Form

Submitting your survey responses indicates your consent to participate in the study described below. You do not waive any rights by continuing with this study. Please read this form carefully, and keep a copy for your reference. If you would like to request a copy of this form, contact Aubin Payne (contact information at the end of this page).

Primary Researcher: Aubin Payne (MSc Student, McGill University)

Supervisor: Dr. Ebenezer Miezah Kwofie, McGill University Faculty of Agriculture and Environmental Science, 514-398-7776 ebenezer.kwofie@mcgill.ca

Title of Project: Survey of Workers at an Animal Feed Additive Manufacturer for a Social Life Cycle Assessment Case Study

Sponsor(s): Mitacs Accelerate Program, Fund # 261065

Purpose of the Study: The purpose of this study is to capture workers' perceptions of how the policies and practices of Company A affect worker welfare, health, and safety. This survey is part of a holistic Social Life Cycle Assessment of the company, in which company practices are assessed and the quantitative impact of the practices on worker health, safety, and welfare is estimated.

Study Procedures: This study consists of a questionnaire regarding your experiences with Company A's policies and practices and your perception of well-being at work. The questionnaire will be filled out and submitted online. Completion of the survey will take approximately 15 minutes, but this may vary depending on the length of responses to open-ended questions.

Voluntary Participation: Participation in this study is entirely voluntary, and you may decline to answer any of the questions (a "prefer not to answer" option will be given). If, during the survey, you decide that you no longer wish to participate, you may close the survey and your responses will not be recorded. Choosing to withdraw from this survey will have no consequences. Since your responses will not include your name or personal information (except for your affiliation with Company A and your department), it will not be possible to withdraw your responses after you have submitted the survey. Your responses will remain confidential, and any publication of data will not include any information from individual responses. You do not waive any personal or legal rights in the participation of this study.

Potential Risks: There are no anticipated risks to you by participating in this study.

Potential Benefits: Participating in this study will help advance research methods that assess worker welfare. A summary of the data (NOT individual responses) may be shared with decision-makers at Company A in order to address welfare issues identified in the study that may need attention. This may allow the company to make changes that will increase your perceived welfare and safety in the workplace.

Confidentiality: This survey will ask for personal information, but no information linking you to your individual response will be collected, and the research team has taken care to remove any questions that would directly identify you. In rare cases, it may be possible to identify you through your answers to demographic questions. In any such case, this data will never be shared outside of the research team. Although any specific information from your individual response will never be shared or published outside of the research group, you may choose not to answer any question that you feel may compromise your anonymity. Survey results will be kept on a password-protected account for the length of time required by the McGill ethics committee.

Dissemination of Results: The results of this study will be aggregated and assessed as part of a Social Life Cycle Assessment of Company A and its associated value chain. These aggregated results may be published in a peer-reviewed journal and may be shared with decision-makers at Company A. However, only processed and aggregated data will be shared. Your individual response will remain confidential, and no information that could possibly link you to your response (including general demographic data) will be shared or published.

Questions: If you have any questions, please contact Aubin Payne

Email: aubin.payne@mail.mcgill.ca

If you have any ethical concerns or complaints about your participation in this study, and want to speak with someone not on the research team, please contact the Associate Director, Research Ethics at 514-398-6831 or lynda.mcneil@mcgill.ca citing REB file number 23-04-010

Thank you for your participation. Please remember that your responses are confidential and will never be published in association with any personal information. If you do not wish to fill out an open-ended question, you may leave it blank.

1. Please indicate the department in which you work.

Please write your answer here:

Questions for Weighting

Please rank the following items on a scale from 1-5 based on how important they are to fostering social well-being in the workplace (1 is slightly important and 5 is crucial):

Q1. A company should provide all its workers with a wage that allows them to live comfortably, regardless of the local minimum wage

☐ 1
☐ 2
☐ 3
☐ 4
☐ 5

Q2. A company must allow workers to unionize or bargain collectively.

☐ 1
☐ 2
☐ 3
☐ 4
☐ 5

Q3. Workers should have sufficient opportunity to work, but they should not feel pressured to work more than 40 to 45 hours per week.

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5

Q4. Companies should provide fair conditions of employment and these conditions should be made easy for employees to understand.

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5

Q5. Companies should take active steps to prevent discrimination in the workplace.

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5

Q6. Companies should take active steps to ensure the safety of their workers, especially those working in potentially unsafe conditions.

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5

Q7. Companies should provide social benefits such as insurance, pension plans, paid time off, etc. to permanent workers.

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5

Q8. Companies should take active steps to prevent sexual harassment in the workplace.

- ☐ 1
- ☐ 2
- ☐ 3

- ☐ 4
- ☐ 5

Q9. A company should provide resources and an environment for its workers which allows workers to feel a sense of community at work.

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5

Q10. Companies should contribute social value to the city and community in which they operate.

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5

Survey Questions

Please answer the following questions. If you do not wish to answer a question, you may skip it. If you would like to provide a comment, space is available for you to do so, but it is not obligatory.

QS1. Do you feel that worker opinions and interests are taken into consideration when planning large changes in the company?

- ☐ Yes
- ☐ No

QS2. Do you have access to an independent, neutral, and binding service or procedure for resolving labor disputes?

- ☐ Yes
- ☐ No

QS3. Do you feel that you are earning a fair wage for your work?

- ☐ Yes
- ☐ No

QS4. Have you ever noticed any suspicious or unexplained pay deductions (other than usual taxes and withholdings)

- ☐ Yes
- ☐ No

QS5. Are you aware of any violations of laws or policies regarding worker benefits?

- ☐ Yes
- ☐ No

QS6. Approximately how many hours do you work per week, on average?

- ☐ Less than 30
- ☐ 30-35
- ☐ 35-40
- ☐ 40-45
- ☐ 45-50
- ☐ More than 50

QS7. Approximately how many weeks per year do you work more than 48 hours per week?

- ☐ Never
- ☐ 1-5
- ☐ 5-10
- ☐ 10-20
- ☐ More than 20

QS8. What are the company policies for overtime compensation (extra time off, extra pay, etc.) as you understand them? Are these policies strictly followed by management?
Please write your response here :

QS9. How many vacation days per year do you have available?

QS10. Approximately how many vacation days did you use in 2022?

QS11. Does the company have a flexible policy regarding vacation days and overtime work?

- ☐ Yes
- ☐ No

QS12. Do any of your conditions of employment prevent you from terminating your employment at will, if you wanted to?

- ☐ Yes
- ☐ No

QS13. Are you familiar with the company workplace health and safety policy?

- ☐ Yes
- ☐ No

QS14. Do you feel that the company workplace health and safety policy would keep you safe in the event of an emergency?

- ☐ Yes
- ☐ No

QS15. Do you feel that you are at high risk for physical injury in the workplace?

- ☐ Yes
- ☐ No

QS16. Are you familiar with the emergency accident response protocol for physical injuries?

- ☐ Yes
- ☐ No

QS17. Do you feel that you are at high risk for dangerous chemical exposure in the workplace?

- ☐ Yes
- ☐ No

QS18. Are you familiar with the emergency chemical exposure response protocol?

- ☐ Yes
- ☐ No

QS19. Are requirements for wearing personal protective gear followed as prescribed?

- ☐ Yes
- ☐ No

QS20. Are you familiar with the workplace sexual harassment policy?

- ☐ Yes
- ☐ No

QS21. Do you know how to properly report an incident of sexual harassment, and would you feel comfortable doing so?

- ☐ Yes
- ☐ No

QS22. Are you familiar with the workplace discrimination policy?

- ☐ Yes
- ☐ No

QS23. Do you know how to properly report an incident of discrimination, and would you feel comfortable doing so?

- ☐ Yes
- ☐ No

QS24. Please rate your overall satisfaction with your job.

- ☐ I am very satisfied with my current job
- ☐ Some things could be better, but overall I am satisfied with my job
- ☐ I would change most aspects of my job if I could

QS25. How does your job contribute to your quality of life?

- ☐ My job improves my quality of life
- ☐ My job has no impact on my quality of life
- ☐ My job negatively impacts my quality of life

Thank you for completing this survey.