Environmental Justice and Governance Dynamics of Supply Chains in the Livestock Sector

by

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To

My parents

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Table of Contents

Acknowledgements iii

List of Figures viii

List of Tables x

List of Acronyms xi

Glossary of Terms xiii

List of Appendices xx

Abstract xxi

CHAPTERS 1

Chapter 1: Introdction 2

1.1 State of knowledge and research need 5

1.1.1 Environmental justice and localized impacts of supply chains 6

1.1.2 Supply chain governance, power asymmetry, and environmental performance 10

1.1.3 Industrial ecology, justice, and supply chain governance 14

1.2 Research design 16

1.2.1 Case study 18

1.3 Dissertation structure 18

1.4 Intellectual merit and broader impacts 21

Chapter 2: Environmental Justice Impacts of Concentrated Animal Feeding Operations (CAFOs) 23

2.1 Abstract 23

2.2 Introduction 24

2.3 Materials and methods 27

2.3.1 Generating the dataset 27

2.3.2 Data used in the analyses 29

2.3.3 Statistical analysis 30

2.4 Results 31
2.4.1 Location and Size of CAFOs 31
2.4.2 National analysis of $PM_{2.5}$ and local communities near CAFOs 33
2.4.3 Communities living near CAFOs 34
2.4.4 Spatial concentrations of CAFOs' injustice issues 35
2.5 Discussion 39
Chapter 3: Where's the Beef? Costco's Meat Supply Chain and Environmental Justice in California 44
3.1 Abstract 44
3.2 Introduction 45
3.3 Materials and methods 50
3.3.1 Define study scope 51
3.3.2 Collect data 51
3.3.3 Identify and validate linkages 52
3.3.4 Evaluate environmental and socioeconomic hotspots 53
3.4 Results 54
3.4.1 Harris Ranch — Costco beef supply chain 54
3.4.2 Hotspots of particulate matter in California beef production 59
3.4.3 Environmental injustices around CAFOs 62
3.5 Discussion 65
3.5.1 Harris Ranch: reducing particulate matter at the CAFO 65
3.5.2 Implications for Costco 67
3.5.3 Policy recommendations 70
3.5.4 Methodological reflections 71
3.6 Conclusions 73
Chapter 4: Power Asymmetries in Supply Chains and Implications for Environmental Governance: A study of the beef industry 75
4.1 Abstract 75
4.2 Introduction 76
4.3 Literature review: power asymmetries and supply chain governance 82
4.4 Materials and methods 86
4.4.1 Data collection 87

4.4.2 Data analysis 89
4.5 Results 91
4.5.1 Power asymmetry in the beef supply chain 92
4.5.2 Power across the supply chain 93
4.5.3 Challenges facing the beef supply chain 97
4.6 Discussion 99
4.6.1 Power asymmetry in the beef industry 100
4.6.2 The advantages of measuring power across the supply chain 102
4.6.3 Policy implications and future work 105
4.7 Conclusion 107
Chapter 5: Conclusion 109
5.1 Major findings 109
5.2 Future research 114
5.2.1 A broad range of supply chains 115
5.2.2 Quantify governance dynamics of supply chains 117
5.3 Intellectual merit 118
APPENDICES 121
REFERENCES 141

List of Figures

Figure 1. Tracking Corporations Across Space and Time (TRACAST) methodology 7

Figure 2. Overall view of the methodological approach in the dissertation 17

Figure 3. Examples of cattle and pigs CAFOs 29

Figure 4. Location of cattle and pigs CAFOs 33

Figure 5. Local Indicators of Spatial Autocorrelation in the 10km buffer around the CAFOs ... 38

Figure 6. Poverty and income variation in block groups around select CAFOs.......................... 40

Figure 7. Costco beef supply chain in California...................................... ……………………58

Figure 8. Physical flow of beef in Harris Ranch supply chain 58

Figure 9. (A) $PM_{2.5}$ daily average (mg/m^3) in California. (B) $PM_{2.5}$ annual value across different industries 60

Figure 10. (A) $PM_{2.5}$ annual value (Tons) in CA regions. (B) $PM_{2.5}$ average (mg/m^3) in US, CA, and San Joaquin valley.. 61

Figure 11. $PM_{2.5}$ concentration (mg/m^3) and proximity to the feedlots. 62

Figure 12. Environmental justice and cattle feedlots in California's Central Valley. Box plots of health outcomes (A), ethnicity and race (B), and poverty rate (C) of census block-groups less than 1 km from a feedlot and more than 1 km from a feedlot. 63

Figure 13. Beef supply chain nodes across the internal and external actor-groups. 87

Figure 14. Power scores for each actor-group in the beef supply chain 91

Figure 15. Power scores show an unequal distribution of power between internal and external actor-groups with respect to environmental indicators 92

Figure 16. Power scores for all actor-groups in areas of environmental concern........................ 97

Figure 17. Actor-group perceptions of power... 99

Figure 18. Beef supply chain environmental impact (color) AND hypothesized power structure (color) and reputation vulnerability (shadow) in the supply chain case studies. 118

Figure 19. Correlation of CAFOs digitized and EPA estimated number of CAFOs 123

Figure 20. Integrated plots of distance to the CAFOs by (1) ethnicity and color fill to represent poverty in Ca, (2) ethnicity and color fill to represent education in CA (3) ethnicity and color fill to represent no high school education in TX, and (4) No high school education and color fill to represent black communities... 125
Figure 21. Correlation of elevation and $PM_{2.5}$ concentrations across the U.S. 130
Figure 22. Detailed structure of Harris Ranch supply chain... 132
Figure 23. Detailed structure of the active stakeholders in the California beef supply chain ... 133
Figure 24. Detailed structure of Harris Ranch supply chain retailers in California.................. 134
Figure 25. A simple sketch of beef supply chain... 135

List of Tables

Table 1. Number of CAFOs (cattle and pigs) per state 34

Table 2. Results of predicted $PM_{2.5}$ concentrations at each distance by race, ethnicity, and socio-economic variables.. 35

Table 3. Environmental Justice studies of livestock supply chains 47

Table 4. Attributes of census block-groups within 1 km of feedlot in California's San Joaquin Valley. 64

Table 5. Power asymmetry score between producers (all phases of production) and retailers.... 93

Table 6. Regression analysis of relative coefficient of the top three actors................................. 94

Table 7. Descriptive statistics of the communities living near the CAFOs 125

Table 8. Descriptive statistics of the communities living near the CAFOs in the most cattle producing states. 126

Table 9. Descriptive statistics of the communities living near the CAFOs in the most pigs producing states. 128

Table 10. Descriptive statistics of the communities living near the CAFOs. (i) Top 10, (ii) Top 50 dirtiest counties. 129

Table 11. Harris Ranch supply chain references... 131

List of Acronyms

AFO	Animal feeding Operations
CAFO	Concentrated Animal feeding Operations
CARB	California Air Resources Board
CAA	Clean Air Act
CSR	Corporate Social Responsibility
CWA	Clean Water Act
EJ	Environmental Justice
EPA	Environmental Protection Agency
e-LCA	Environmental Life Cycle Assessment
FAQSD	Fused Air Quality Surface Downscaling
GIS	Geographic Information Systems
GVC	Global Value Chain
GPN	Global Production Network
LCA	Life Cycle Assessment
NAICS	North American Industry Classification System
NAAQS	National Ambient Air Quality Standards
NEI	National Emissions Inventory
OEHHA	Office of Environmental Health Hazard Assessment
PM	Particulate Matter
s-LCA	Social Life Cycle Assessment
SCC	Source Classification Code
SCM	Supply Chain Management

SNA	Social Network Analysis
SSCM	Sustainable Supply Chain Management
SSCG	Sustainable Supply Chain Governance
SWRCB	California State Water Resources Control Board
TRACAST	TRAcking Corporations Across Space and Time
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USRSB	U.S. Roundtable for Sustainable Beef

Glossary of Terms

Animal feeding operation (AFO)- The U.S. Environmental Protection Agency defines "feedlot", "feedyard" or AFOs as agricultural enterprises where animals are kept and raised in confined situations. AFOs congregate animals, feed, manure and urine, dead animals, and production operations on a small land area. Feed is brought to the animals rather than the animals grazing or otherwise seeking feed in pastures, fields, or on rangeland.

Buyer-driven supply chains- Buyer-driven chains are those in which large retailers, marketers and branded manufacturers play the pivotal roles in setting up supply chains. Buyer-driven chains are characteristic of labor-intensive sectors such as agricultural commodities, footwear, clothing and furniture. These are chains where the final retailers are the lead parties.

Concentrated animal feeding operation (CAFO)- EPA defines a CAFO as an AFO with more than 1000 animal units (an animal unit is defined as an animal equivalent of 1000 pounds live weight and equates to 1000 head of beef cattle, 700 dairy cows, 2500 swine weighing more than 55 lbs, 125 thousand broiler chickens, or 82 thousand laying hens or pullets) confined on site for more than 45 days during the year. Any size AFO that discharges manure or wastewater into a natural or man-made ditch, stream or other waterway is defined as a CAFO, regardless of size.

Clean air act (CAA)- The Clean Air Act (CAA) is a comprehensive federal law that regulates air emissions from stationary and mobile sources. This law authorizes EPA to establish National

Ambient Air Quality Standards (NAAQS) to protect public health and public welfare and to regulate emissions of hazardous air pollutants.

Clean water act (CWA)- The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters.

Corporate social responsibility (CSR)- Corporate social responsibility is a business model in which companies make a concerted effort to operate in ways that enhance society and the environment.

Disproportionate effects- EPA defines disproportionate effects as situations of concern where there exists significantly higher and more adverse health and environmental effects on minority populations, low-income populations or indigenous peoples.

Environmental and social sustainability- Environmental and social sustainability is the adaption and integration of precautionary environmental and social principles and considerations into decision making processes.

Environmental justice (EJ)- EPA defines environmental justice as the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.

Environmental life cycle assessment (e-LCA)- A life cycle assessment is a systematic gate-to-gate, cradle-to-gate, and cradle-to-grave process that evaluates the environmental impacts of products, processes, and services.

Fair treatment- The principle that no group of people, including a racial, ethnic or a socioeconomic group, should bear a disproportionate share of the negative environmental impacts from industrial, municipal and commercial operations or the execution of federal, state, local and tribal programs and policies. In implementing its programs, EPA has expanded the concept of fair treatment to include not only consideration of how burdens are distributed across all populations, but the distribution of benefits as well.

Green procurement- Green procurement refers to the purchase of products and services that cause minimal adverse environmental impact. In green procurement, an enterprise is concerned more about the environmental impact of its purchasing decision than the cost of products and services.

Graph theory- Graph theory is the study of graphs, which are mathematical structures used to model pairwise relations between objects. A graph is made up of vertices (also called nodes or points) which are connected by edges (also called links or lines).

Green supply chain- A green supply chain or sustainable supply chain is the management method and optimization approach to reduce the environmental impacts along the life cycle of a product, from the raw material to the end product.

Global production networks (GPN)- Global production networks are diffuse and interconnected networks of actors, functions, operations and transactions through the life cycle of a product or service. GPN theory renounces the linearity of value chains.

Hotspot analysis- The analysis of a range of information sources, including life cycle based studies, scientific research, expert opinion and stakeholder concerns in order to identify and prioritize potential actions around the most significant economic, environmental and social sustainability impacts or benefits associated with a specific geography, industry sector, organization, product or service. Hotspot analysis is often used as a pre-cursor to developing more detailed or granular sustainability information.

Internal linkages and external linkages- The relationships between actors in the supply chain are "linkages". These can be "internal linkages", the consecutive links between companies across the supply chain. These can also be "external linkages" with influential actors outside the supply chain (e.g. governments, unions, third-party assessors, banks, NGOs, and even the media) that affect a chain's structure, geography, and governance.

Life cycle- Life cycle is the consecutive and interlinked stages of a product or service, from the extraction of natural resources to the final disposal.

Life cycle thinking- Life cycle thinking is going beyond the traditional focus on production site and manufacturing processes to include environmental, social and economic impacts of a product over its entire life cycle.

Producer-driven supply chains- In producer-driven chains, large, usually transnational, manufacturers play the central roles in coordinating supply chains (including their backward and forward linkages). This is typical of capital- and technology-intensive industries such as automobiles, aircraft, computers, semiconductors and heavy machinery. Here producers take responsibility for assisting the efficiency of both their suppliers and their customers.

Power- power is one party's ability to enforce its will on another party even against resistance. In supply chain relationships, power might be used to demand a higher share of value (economic, social, etc.) that exists in the supply chain.

Power asymmetry- Power emerges from the dependencies, and control over certain resources within and between companies. If one organization obtains a larger share of benefits resulting from a given relationship, then power asymmetry emerges in the supply chain.

Social life cycle assessment (s-LCA)- A social life cycle assessment is a method that can be used to assess the social and sociological aspects of products, their actual and potential positive as well as negative impacts along the life cycle.

Supply chain- A supply chain is the network of individuals, companies, resources, activities, and technologies used to make and sell a product or service. A supply chain starts with the delivery of raw materials from a supplier to a manufacturer and ends with the delivery of the finished product or service to the end consumer.

Supply chain management (SCM)- Supply chain management encompasses the planning and management of all activities involved in a product life cycle. It also includes coordination and collaboration with internal and external linkages, which can be suppliers, intermediaries, third party service providers, and customers.

Supply chain governance (SCG)- Supply chain governance constitutes the rules, structures, and institutions that guide supply chains towards various objectives, including environmental and social responsibility.

Supply chain nodes- Key nodes of a supply chain are the critical points of supply chain governance, and therefore, represents opportunities to affect change across the supply chain. In related literature, key nodes are akin to the “lead firms”, “chain drivers”, and “movers and shapers” in the chain.

Supply chain sustainability- Supply chain sustainability refers to companies’ efforts to consider the environmental and social impact of their products’ journey through the supply chain, from raw materials sourcing to production, storage, delivery and every transportation link in between. The goal is to minimize environmental and social impacts from factors like energy usage, water consumption and waste production while having a positive impact on the people and communities in and around their operations.

Supply chain power structure- Power dynamics in a chain is the potential to control a particular outcome and create change in the supply chain, which is an important aspect of supply chain governance and plays an important role in shaping supply chain sustainability.

Stakeholders- The term stakeholders covers anyone who has a direct or indirect interest in the project or organization in question as they can affect or are affected by the activities that take place. Stakeholders include, amongst others, employees, customers, suppliers, shareholders, governmental and non-governmental organizations.

Social network analysis (SNA)- Social network analysis is a collection of methods and tools from graph theory that could be used to study the relationships, interactions and communications among individuals, groups and/or organizations.

Transparency- Transparency refers to the disclosure of information to trading partners, shareholders, customers, consumers, and regulatory bodies. Transparent supply chain means that a business knows exactly what is happening at every node of its supply chain and communicates clearly about its supply chain operations internally and externally.

Value chain- The value chain or commodity chain comprises all business activities which increase the value of a product or service in the eyes of the customer. The value chain flows from the customer, back through the supply chain to the production/creation/extraction of raw materials, but also includes activities such as product development and marketing.

List of Appendices

Appendix A. CAFOs' Representativeness across The U.S……………………………………122

Appendix B. Descriptive Statistics of the Communities Living Near the CAFOs…………….124

Appendix C. Correlation of Elevation and $PM_{2.5}$ Concentrations across The U.S…………….130

Appendix D. Costco-Harris Ranch Suppy Chain References and Structures……………..……131

Appendix E. Beef Supply Chain Stakeholder Survey…….......……………………………..……135

Abstract

In 2006, the United Nations published *Livestock's Long Shadow*, a landmark study that documented the global environmental impacts associated with livestock production (Steinfeld et al., 2006). Since then, academic studies, popular publications, and Hollywood documentaries (e.g., Cowspiracy, Before the Flood, What the Health) have conveyed the heavy burden unsustainable livestock consumption levels have on the environment and society. Despite this notable attention, there has been little effort to understand the distributive local environmental impacts, especially where burdens follow familiar lines of vulnerability. This dissertation contributes to both research and practice by addressing this critical challenge. Through five chapters prepared as journal articles, this dissertation 1) Identify and measure the location and size of ~15,700 pig and cattle CAFOs across the U.S. using high resolution remote sensing techniques, and systematically clarify their relationship to local air quality measures and the socio-demographic characteristics of adjacent communities; 2) Map a specific beef supply chain, and construct linkages with beef suppliers and sub-suppliers at high geographic specificity, and clarify supply chain's relationship to California's hotspot of $PM_{2.5}$ and the environmental and health cost of living across the production phases of supply chains for nearby communities; and 3) Develop a new approach to quantify power structure across an entire supply chain, considering both internal and external nodes for strengthening the relationships in the chain in order to induce change to the environmental and social outcomes of the supply chain. ***Intellectual Merit:*** This dissertation represents a sustained effort to combine fields exploring Environmental Justice (EJ) with those exploring Supply Chain Governance in pursuit of a deeper knowledge of social and environmental

impacts that need change. It seeks to explore avenues to reshape the future of supply chain governance by first advancing a quantitative methodology to explore gaps and inefficiencies in the governance mechanism of supply chains and then by giving compelling empirical evidence for impact reduction and improvement of environmental and social outcomes through environmental governance. ***Broader Impacts:*** This dissertation provides rigorous, evidence-based decision support to the growing number of supply chains to build a more effective governance mechanism, one that will improve the environmental and social outcomes associated with the supply chain structure. The study also contributes to the public awareness of disproportionate localized environmental burdens, and it empowers marginalized communities affected by the supply chains.

CHAPTERS

Chapter 1

Introduction

The livestock supply chain drives environmental and social challenges, although consumption of the final products does not expose the negative impacts of the production processes (Von Essen, & Auvermann, 2005; Heederik et al., 2006; Wing et al., 2008). Globally, meat consumption is expected to triple by 2050 (Hocquette& Chatellier, 2011; Gerber et al., 2015). Not generally considered in the sustainability metrics are the distributive local environmental impacts of livestock supply chains. livestock production has been linked to elevated levels of particulate matter and ozone in the air (Morello-Frosch et al., 2002; Pastor et al., 2005; Fiala, 2008; Nicole, 2013; Mallin et al., 2015; Mallin et al., 2019; White & Hall, 2017). The livestock sector contributes around 40% to global nitrate emissions (Hou et al., 2016), and about 80% to ammonia emissions (Ogneva-Himmelberger et al., 2015). In the livestock sector, beef is generally considered the most intensive meat in terms of greenhouse gases, resource demand, and local pollution (Ogneva-Himmelberger et al., 2015). Many studies have shown the effect of beef production on greenhouse gas (GHG) emissions and climate change while underrepresenting the impact of air pollution on local communities (Lynch & Pierrehumbert, 2019; Lynch, 2019).

Vulnerable communities often reside close to the production sites and bear the worst air quality (O'Neill et al., 2003; Morello-Frosch & Jesdale, 2006; Scanlan, 2017; Purdy, 2018). Studies have indicated the unequal distribution of negative impacts across the supply chain may contribute to health disparities in these communities, such as cancer, cardiovascular disease, or asthma (Adler & Rehkopf, 2008; Haribar, 2010; Wing & Johnston, 2014; Eshel et al., 2016; Shonkwiler & Ham, 2018). Sensitive populations have shown rising susceptibility to the health effects of air pollution (Bell et al., 2013; Bind et al., 2016). However, Environmental Justice (EJ) studies have focused on regional analysis of one phase in the supply chain without linking the impacted communities to end consumers (Wing et al., 2000; Emel & Neo, 2015). Environmental justice entails "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (EPA, 2021). I identify environmental injustice as the disproportionate exposure and burden of pollution on vulnerable communities. Environmental justice provides the foundation of environmental and social sustainability in the supply chains.

Nonetheless, many scholars consider the failure of environmental and social sustainability in supply chains as mainly a crisis of governance and its associated power structure (Van Zeijl-Rozema et al., 2008; Adger & Jordan, 2009). Supply chain environmental and social sustainability refers to the adaptation and integration of precautionary environmental and social principles and considerations into decision making processes. A corporation's supply chain consists of horizontal and vertical linkages among suppliers and customers as well as stakeholders (Croxton et al., 2001; Héritier & Rhodes, 2011; Lim & Phillips, 2008). By governance dynamics, I refer to policies, regulations, standards, certifications, and financial incentives that different organizations in the supply chain use to promote environmental and social sustainability in the chain (Vurro et al., 2009; Park-Poaps & Rees, 2010; Gimenez & Sierra, 2013; Dallas et al., 2017). Scholars argue that the power structure of supply chains- the potential to control a particular outcome and create change in the chain- must become reoriented towards environmental and social sustainability in order to induce change in the supply chains (Lange et al., 2013). However, present literature includes only a few studies of real-life supply chains due to the difficulties in tracking the supply chains (Goldstein & Newell, 2019).

In this study, I emphasize on the air quality ($PM_{2.5}$) concentrations from livestock production at the (1) national level, and (2) at the supply chain level alongside socio-economic variables such as (i) race, (ii) ethnicity, and (iii) educational attainment, (iv) poverty/income as social justice indicators and (i) number of people with asthma, (ii) number with cardiovascular diseases, and (iii) low-weight birth as sensitive population indicators. This selection of indicators illustrates a comprehensive analysis of the localized impacts of livestock production and highlights the health outcomes of exposure to production sites. Therefore, this dissertation after a comprehensive national analysis of the EJ associated with livestock production builds on an in-depth corporate-specific case study to address this EJ gap by quantifying the distribution of environmental impacts across a beef supply chain as the most resource intensive livestock; And to analyze the underlying governance dynamics that enforces these impacts. I will then interpret the research findings through the lens of an interdisciplinary perspective to identify supply chain governance capacity to engage in collaborative action and complex problem-solving with the aim of limiting the local impacts across the chain. The objective of the dissertation is to (i) understand the underlying structure that enforces environmental and social burdens and (ii) to reveal the challenges and opportunities to remove these burdens and promote more environmentally stable communities.

1.1 State of knowledge and research need

The livestock industry has changed dramatically over the past half-century (Hoover, 2013). While the number of small, family-owned livestock farms decreased, the number of industrial farms has increased (Hoover, 2013). The communities living near industrial farms are usually comprised of small family farms, seasonal farmworkers, and neighboring rural and town residents (Donham et al., 2007). Numerous studies documented that these communities are mostly low-income or less-educated communities (e.g., Jacques et al., 2012; Ogneva-Himmelberger & Huang 2015; Chamanara et al., 2021; Son et al., 2021). This disproportionate burden has led to calls for EJ studies. However, the geographic disparity of supply chains creates an unfelt public ignorance of the environmental and social impacts from the production phases of supply chains. On the other hand, supply chain governance scholarship has mainly focused on global environmental impacts with less attention to localized impacts. Localized impacts of production processes are difficult to quantify, and perception of these impacts is highly variable (Jørgensen et al., 2008).

Moreover, analyses have commonly associated supply chain environmental and social sustainability with each sector's encompassing governance and power structure (Van Zeijl-Rozema et al., 2008; Adger & Jordan, 2009; Lange et al., 2013). Power, with roots in social and political science, is a foundational concept in supply chain, value chain and production network studies (Cook & Emerson, 1978; Lawler, 1992), which is closely related to governance. If power refers to the ability of specific actors that can bring change in the chain, governance refers to the actual mechanics of that change, including regulations, certifications, and policy (Gereffi, 1994).

Although power is at the heart of Supply Chain Governance (SCG), Global Value Chains (GVC) and Global Production Networks (GPN) literature, and studies have confirmed power's link to supply chain efficiency, supply chain performance, and improved trust and collaboration (Cox, 2004; Vachon & Klassen, 2008; Meehan & Wright, 2012; Brito & Miguel, 2017; Gold et al., 2020), many scholars agree that power is often a missing element in sustainable supply chain studies due to its complexity and the difficulties of measuring it (Zelbst et al., 2009).

With growing concerns over the environmental and social sustainability of business practices, supply chain relationships have become even more critical. Companies are challenged to mitigate the reputational and operational risks that emerge from unsustainable practices (Krause et al., 2009; Chamanara et al., 2021). Surprisingly, there are very few studies that characterize EJ across the chain to analyze how the power structure of a supply chain impacts environmental and social sustainability. We need a methodology that combines the strengths of multiple disciplines to holistically understand and mitigate the environmental and social outcomes of supply chains. The following sections summarize relevant research in the present study's integrated fields, noting strengths and shortcomings.

1.1.1 Environmental justice and localized impacts of supply chains

Environmental justice (EJ) emerged in various disciplines under the umbrella of social justice (Bullard, 2018). In the last thirty-five years, EJ has become an integral part of environmental governance (Ringquist, 2005; Taylor, 2014; Mohai & Saha, 2015). EJ concerns might arise across all the supply chain (Greenpeace, 2008; 2010; 2015), but EJ studies by focusing on one phase of the production practices, dissociating impacted communities across the supply chains, and also disconnecting them from producers, retailers, and end consumers. In fact, although the unsustainability of global trends is clear, it remains difficult to link consumers and producers to the localized impact of the products. This approach has brought public ignorance towards the disparate injustices across the supply chains. A supply chain perspective in EJ studies connects producers' practices and consumers' choices to the injustices across the chain. Therefore, despite the rich and influential body of literature on EJ, its shortcomings have been noted, from privileging one phase of production to the dominance of simplified quantitative approaches.

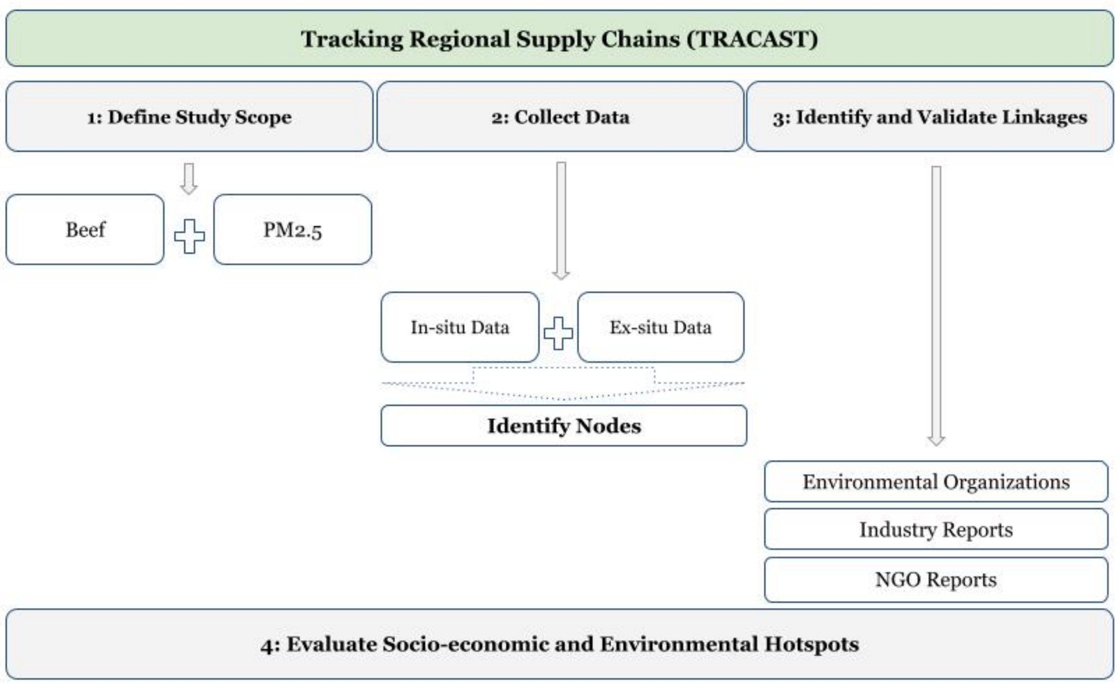

Figure 1. Tracking Corporations Across Space and Time (TRACAST) methodology

1. Lack of a national analysis of EJ associated with livestock production. Environmental injustices associated with industrial farms are a longstanding issue. Several studies documented disparity of race, and socio-economic variables of the people living near these farms at the regional scale. Different studies in Illinois (Gómez & Zhang, 2000), Iowa (Durrenberger & Thu, 1996), Michigan

(Abeles-Allison & Connor, 1990), and Wisconsin (Foltz & Chang, 2002) have documented that communities near large industrial farms tend to have less economic well-being. Several studies have shown that a disproportionate number of pig operations in North Carolina are located in low-income and nonwhite areas (Wing et al., 2000; Wilson et al., 2002; Ladd, & Edwards, 2002) and near low-income and non-white schools (Mirabelli et al., 2006a; Mirabelli et al., 2006b). A few studies in North Carolina found that industrial farms are located disproportionately in communities with higher percentages of minorities and in low-income communities (Edwards & Ladd, 2001; Nicole, 2013; Kravchenko et al., 2018; Son et al., 2021). In Ohio, higher proportions of children and Latinx populations live in regions with high densities of dairy and pig farms (Lenhardt & Ogneva-Himmelberger, 2013).

To date, the vast majority of EJ studies related to industrial farms were conducted at the regional or state level. More recently, Domingo et al. (2021) linked 43% of deaths from the agriculture sector to air pollution (primary and secondary $PM_{2.5}$) (Domingo et al., 2021) while Tessum et al. (2021) linked the $PM_{2.5}$ exposure from the agriculture sector to the Black and Hispanic minorities. Despite these efforts, knowledge on these issues is still obscured due to the lack of a comprehensive and reliable dataset, regardless of the calls for more research on the topic to address the challenges (Miller, & Muren, 2019). Although industrial farms are the biggest contributor to air pollution from livestock production (Chamanara et al., 2021), there is not a single national analysis across the United States (U.S.) (Gilbert & Chakraborty, 2011). EJ studies of the livestock industry have been constrained by the data available, as well as the time, labor, and high costs associated with obtaining the data (Maantay, 2002). The current legal landscape in the United States also prevents environmental agencies to know where industrial farms are located, which has led to a huge gap in the studies of livestock production at the national level. Therefore, in this study by using GIS and remote sensing techniques I develop a comprehensive dataset of industrial farms across the U.S. to perform an EJ national analysis on these farms.

2. Environmental justice of beef supply chains and privileging one phase of production. Despite the influential work on industrial farming, EJ studies have focused mostly on a single phase of the production, without connecting impacted communities to the other nodes of a supply chain such as producers and end consumers. Supply chains are complex webs that include multiple nodes from production to consumption. Dissociating impacted communities from other nodes of the chain has led to an unfelt public ignorance towards these communities. In fact, concrete empirical modeling of EJ associated with every phase of the supply chain is absent. For example, some studies examine the interrelationships between industrial farms and the disproportionate impact on low-income and people of color communities (Fiala, 2008; Cambra-Lopez et al., 2010; Hadlocon, et al., 2015) but don't draw any link to other phases of the beef supply chain, and also to the producers and consumers. EJ scholars are not unaware of the supply chain impacts, but the impacts have not been specifically linked across the chain to further investigate the underlying governance structure to improve the outcomes. To overcome the present shortcomings, I incorporate a supply chain approach to explore the environmental burdens on local communities from every phase of the supply chain and to delineate the processes that have shaped the impacts.

3. Simplified quantitative assessments of EJ. Concerns regarding inequalities in the distribution of environmental burdens have led to considerable EJ scholarship utilizing quantitative assessments at the state, watershed, or metropolitan area level (Pastor et al., 2005; Baden et al., 2007; Gilbert & Chakraborty, 2011; Hou et al., 2016). While several analyses have been employed and study areas examined, most studies used a simplistic approach by examining the relationship between point sources of pollution, such as industrial farms, and socio-economic status (Baden et al., 2007; Gilbert & Chakraborty, 2011). A growing number of EJ studies have applied GIS to assess disproportionate impacts of environmental burdens at census tract levels (e.g., county) (Perhac, 2000). The analyses revealed that different spatial scales and resolutions produce different levels of correlation between environmental burdens and social impacts (Higgs& Langford, 2009; Raddatz & Mennis, 2013), and finer scales (e.g., census block group) is important to adequately measure a supply chain's localized impact (Higgs& Langford, 2009; Raddatz & Mennis, 2013).

This study aims to advance quantitative approaches in EJ scholarship through several methodological improvements, which allows us to spatially reveal the hotspots of environmental injustice and livestock production across the United States. Therefore, in this study I investigate air quality ($PM_{2.5}$ level) as the environmental indicator and race/ethnicity and socio-economic demographics as social indicators (i) to develop a national analysis of livestock production and the injustices associated with it, and (ii) to identify the EJ hotspots across one specific supply chain in California for further power and governance analysis.

1.1.2 Supply chain governance, power asymmetry, and environmental performance

Sustainable Supply Chain literature "Sustainable Supply Chain Governance (Park-Poaps & Rees, 2010), Sustainable Supply Chain Management (Wang & Ran, 2018), Green Supply Chain (Sirvastava, 2007), Green Procurement (Beer & Lemmer, 2011)" mainly focuses on how a supply chain can reduce environmental impacts throughout its life cycle without considering the distributive impacts of environmental burdens on local communities (Andersen & Skjoett-Larsen, 2009; Ageron et al., 2013). Localized impacts of supply chains have no relation to supply chain processes, but rather to the conduct and values of corporations performing the processes

(Jørgensen et al., 2008). Accordingly, research has shown that two products with the same environmental impacts can have totally different social impacts (Jørgensen et al., 2008). Scholars broadly agree that supply chain governance is necessary for transformation toward environmental and social sustainability (Ayre & Callway, 2005; Lange et al., 2013; Formentini & Taticchi, 2016). Long-term sustainability depends on our willingness to explore underlying governance dynamics and its respective power structure (Sirvastava, 2007; Wang & Ran, 2018). An empirical study by Nepstad et al. (2014) found that change in a beef supply chain's governance dimensions led to a 70% decline in deforestation outcomes in the Brazilian Amazon (Nepstad et al., 2014). Thus, the interplay between power structures along the chain and the context in which they are embedded is worth investigating. Three interrelated trends illustrate the shortcomings in supply chain governance studies.

1. Limits on the use of power. Much of the literature on supply chain governance suggest that an unequal power structure in the chain works in favor of the powerful actors through influencing the decisions (Donaldson, 1995; Pfeffer, 1997, chap 3; Muthusamy and White, 2006). While an equal relationship among the nodes of a supply chain brings collaboration and trust to the chain (Muthusamy and White, 2006), unequal power structure results in exploitation rather than cooperation (He et al., 2013). However, developing long-term relationships in supply chains is inherently time consuming (Newbert & Tornikoski, 2013), and as a consequence, an unequal power exists across the supply chain. Equal distribution of power in a supply chain might be hard to achieve due to the unequal value capture and profit maximization. Larger political-economic considerations lead to an inherently uneven playing field, which puts some nodes of a supply chain at a disadvantage. These inequalities in the power dynamics might influence environmental and social outcomes. However, power doesn't have to have a negative meaning; it depends on the governance dynamics of the chain (Gereffi et al., 2005). In fact, who has the power and how do they choose to use it? We need empirical studies to see the distribution of power in a specific supply chain, especially in the environmental and social arena to understand how this distribution can benefit all the actors in the chain.

Furthermore, most studies on power in supply chains are concerned only with buyer-supplier relationships in terms of profitability. To account for the environmental and social sustainability of a supply chain, there is a need to expand the analysis beyond the immediate buyer-supplier relationship. All the suppliers downstream as well as retailers and consumers affect the decisions in the chain. Therefore, an isolated view on power dynamics in a single relationship might fall short of capturing the complex interrelationships in supply chains. Moreover, very few studies considered the role of stakeholders in the power structure. Governmental and regulatory agencies, NGOs, and trade associations are three stakeholders with power that are usually dismissed in the supply chain studies (Neville & Mengue, 2006). Governmental policies represent the greatest opportunities to constrain or enable environmental and social sustainability in a supply chain through codes of conduct, auditing procedures, policies, penalties, guidelines, and education (Mayer & Gereffi, 2010). Environmental problems are complex and their solutions require the involvement of all these actors (Rodriguez et al., 2016). Therefore, this study considers all of the actors across the supply chain (internally and externally) in realizing the power structure of the supply chain. This is an important step toward a more holistic view of power distribution across the supply chain.

2. Qualitative assessments of supply chain power structure. Power in supply chains is shown to be a context-dependent concept (Ponte, 2019), and the governance dynamics in a supply chain cannot be fully understood without simultaneously understanding power in each node (Huo, 2017). However, the empirical work in the supply chain literature is mostly qualitative rather than quantitative (Ponte, 2019). Although qualitative research has its own value, it is bound by the rationality of the researcher, and data collection is usually time- and energy-intensive; and due to the limited sample, generalizability is a problem.

Power plays a significant role in supply chain sustainability (Meloni & Benton, 2000), therefore, there needs to be clarity regarding who holds power in the supply chain. A methodology that combines the strengths of previous research to holistically understand the power in supply chains is needed. Therefore, in the current study, I see opportunities to use different methods to shed new light on how power operates within supply chains. I will analyze the power structure of a specific supply chain using a formal, quantitative approach of systematic survey along with Social Network Analysis (SNA) (Grover & Malhotra, 2003; Borgatti & Li, 2009; Galaskiewicz, 2011; Burt, 2017; Hamilton et al., 2019). SNA has been used in sociology and environmental studies to quantify and visualize structural conditions of supply chains for better communication, cooperation, and joint problem solving among supply chain nodes (Bodin & Crona, 2009; Berardo & Scholz, 2010; Newig et al., 2010; Lubell et al., 2014; Fischer & Jasny, 2017). I use this method to measure perceived power amongst internal and external linkages in supply chains of the beef sector in the United States. However, success in analyzing supply chains and the power structure depends on detailed mapping of the supply chain structure.

3. Geographic disparity of supply chains and network structure. Because of the complexity of supply chains and tracking them, studies in this area usually use a conceptual model to estimate power in supply chains. Reliable, comprehensive, credible information is necessary to construct the network structure of the supply chain to improve environmental and social impacts through governance dynamics. A shift in focus from direct relationships to a systematic view of network structure will deepen understanding of environmental and social sustainability within a supply chain and illuminate the scope of contextual factors influencing the connection between governance dynamics and sustainability (Provan& Kenis, 2008; Wilding 2012; Boström et al., 2015). Mapping the network structure of supply chains requires an elaborate, detail-oriented approach due to the lack of transparency in the food supply chains. Transparency allows access to product-related information (Wognum et al., 2011), and influences consumers' willingness to pay for products (Napolitano et al., 2009). Tracking food supply chains is compulsory in the EU (General Food Law – 178/2002/EC) but still a challenge in the United States. For this project, I use a method known as TRACAST "TRAcking Corporate Actors across Space and Time" (Goldstein & Newell, 2019), a systematic approach that delineates the input-output structure, linkages, and key nodes of governance of a corporate-specific supply chain through in-situ and ex-situ datasets. This approach will lead to a better understanding of the justice outcomes of supply chains by developing a clear idea of the geographic scope of analysis and a time period to capture the chain dynamics. The illuminated structure will then act as input in the survey to investigate the governance dynamics of the supply chain and to advance supply chain governance scholarship by offering real-world evidence.

1.1.3 Industrial ecology, justice, and supply chain governance

In industrial ecology, supply chain modeling via Life Cycle Assessment (LCA) has emerged as the primary means to quantify the flows of material and their environmental impacts (e-LCA). Environmental burdens have been prioritized over social impacts, which have typically been given a simplified treatment (s-LCA) or not considered at all (Jørgensen et al., 2008). While e-LCA studies have been measured across years with significant methodological advances that enable more accurate quantification of environmental impacts, s-LCA work has been less successful due to sensitivity to location and the difficulty of obtaining information (Benoît et al., 2010). Also, e-LCA studies have assumed linear relationships in supply chain structures; however, linear relationships fail to capture justice impacts associated with supply chains (Burt, 2017). Industrial ecology studies lack location-based evidence, due to the major costs associated with obtaining granular and accurate data, to assess the impacts of supply chains on communities. An EJ concern is that despite the intrinsic relevance of industrial ecology, it is rarely a voice for the local population (Emel & Neo, 2015). Scholars also have been critical of LCA for paying scarce attention to the underlying processes that drive impacts (Broto et al., 2012; Swyngedouw, 2006; Angelo & Wachsmuth, 2015).

e-LCA's lack of spatial differentiation has also been criticized among industrial ecology scholars (Geyer et al., 2010). It is frequently suggested that GIS should be implemented with LCA studies (Geyer et al., 2010; Geyer et al., 2013); however, because LCA does not normally focus on the local impacts of a supply chain, the implementation has been rare (Geyer et al., 2013). LCA studies are usually conducted in a site-generic scale (Mutel, 2012; Liu et al., 2014). It is important to disaggregate the results into smaller spatial units to capture the localized impacts of supply chains (Geyer et al., 2013). To address these shortcomings, I will choose a case study, couple LCA with tools from spatial science such as GIS to allow sensitivity of s-LCA to the study locations (Pincetl & Newell, 2017). Therefore, this dissertation extends this scholarship by quantifying environmental burdens with respect to their local vulnerabilities, to construct EJ impacts along the supply chains. I seek to go beyond integrative justice to reveal the underlying governance dynamics that make environmental and social sustainability a factor in the formation of supply chains.

In conclusion, Industrial Ecology provides a method to understand how meat is produced and its environmental and resource intensity, but it does not address where impacts occur and who is affected. Conversely, EJ studies show where meat is produced and who is impacted, but without connecting impacts to consumers and producers. Supply chain governance studies show which companies are producing the meat and link all the nodes.

1.2 Research design

This project attempts to address gaps in current literature by focusing on two interrelated research questions: (1) *How are environmental costs of beef supply chains distributed among local communities in terms of air quality ($PM_{2.5}$) (i) across the U.S. and (ii) in California? Approach:* A comprehensive analysis of $PM_{2.5}$ from livestock production across the U.S., finding the hotspots. Map the network structure of a specific supply chain through a novel hybrid methodology in the hotspot and analyze $PM_{2.5}$ emissions associated with each phase of production. *Key hypotheses:* livestock consumption shapes EJ challenges in production geographies, with impacts distributed unevenly across space and time. These burdens are largely borne by communities that live near the production sites. (2) *Which nodes in the beef supply chain have the power over the environmental and social outcomes? Approach:* Quantify the governance dynamics and underlying power structure in the US beef industry. *Key hypotheses:* Interactions of power structure underlying supply chain governance shape the associated environmental and social outcomes, (*Figure 2)*.

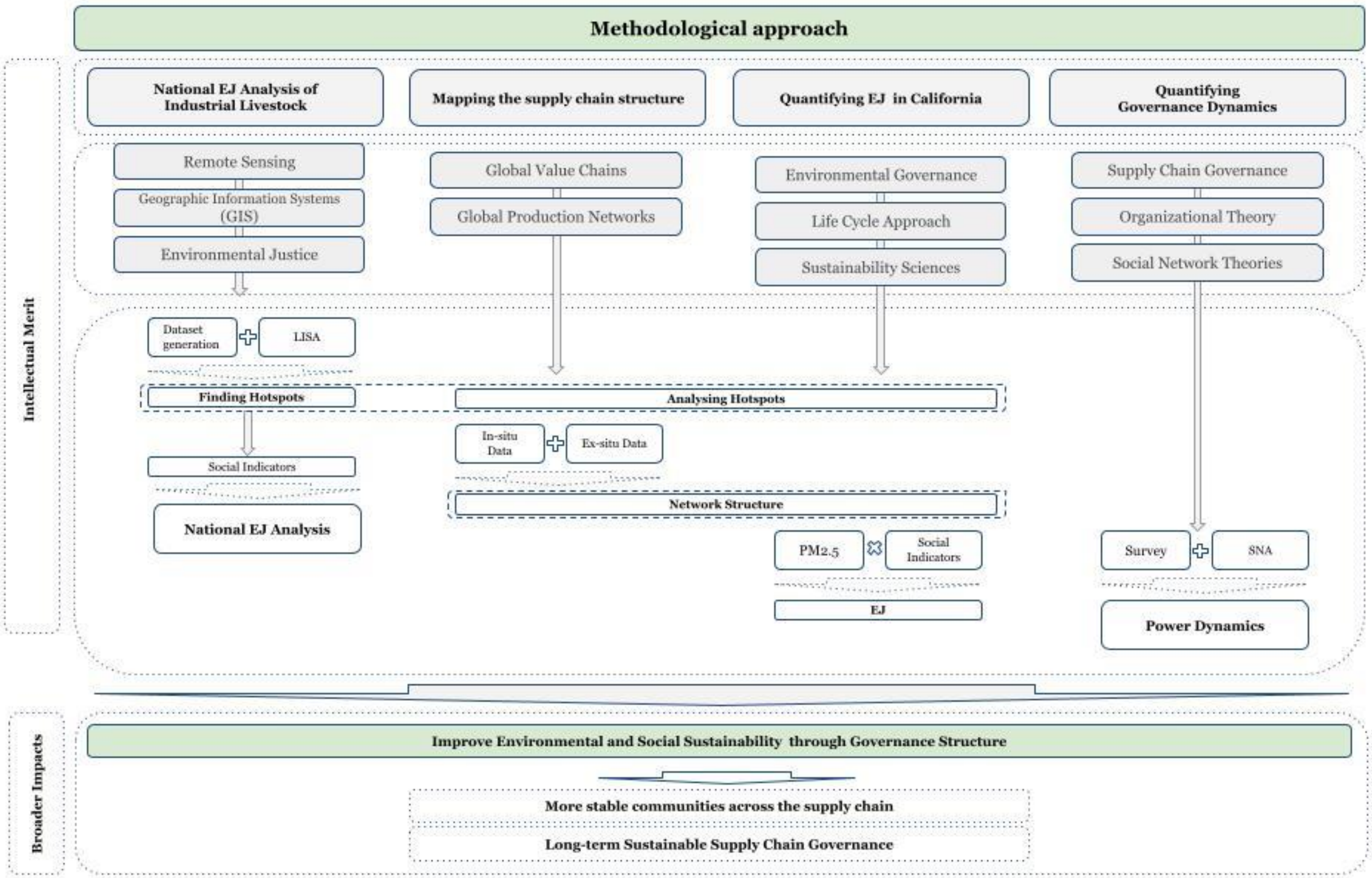

Figure 2. Overall view of the methodological approach in the dissertation

1.2.1 Case study

In this study, as a case study, I focus on one of the most prominent beef supply chains in California to understand the local impacts of livestock production. I chose California as a case study because California is awash in air pollution due to big agricultural supply chains such as beef cattle. Moreover, studies show that communities of color and low-income communities in California experience higher levels of health problems from air contaminants (Pastor et al., 2005). According to the American Lung Association (ALA), in Kern County, home for more than 100 CAFOs (USDA, 2019) particulate pollution registers in the unhealthy air range 40 days per year (ALA, 2019). In the San Joaquin Valley, one in six children suffers from asthma (Plummer et al., 2015). California is among the top five states for beef production (USDA, 2019) and has been deemed especially vulnerable to air pollution (Anderson et al., 2018). Beef cattle are raised in every county except San Francisco. Tulare is the leading county in cattle production (20.9%), followed by Fresno (12.3%), Imperial (10%), and Merced and Kern (both 7.9%) (USDA, 2019). The supply chain is Harris Ranch Beef, California's largest beef producer and the largest ranch in the Western United States. With a feedlot covering 800 acres in the San Joaquin Valley, Harris Feeding Company has a capacity to process 250,000 heads of cattle annually. Harris Ranch is a supplier of Costco in California- the second largest beef retailer-, and a U.S. Roundtable for Sustainable Beef (USRSB) member. USRSB is a multi-stakeholder initiative developed to advance, support and communicate continuous improvement in the sustainability of the U.S. beef value chain.

1.3 Dissertation structure

In chapter 2, My co-authors and I start with a comprehensive EJ analysis of industrial farming at the national level. Concentrated Animal Feeding Operations (CAFOs)-- the third phase of livestock production after breeding and backgrounding-- are agricultural enterprises where animals are kept and raised in confined situations for more than 45 days during the year. CAFOs congregate animals, feed, manure, and production operations on a small land area, and therefore emit immense volumes of particulate matter and particulate matter precursors. These emissions produce numerous health issues for communities that live near these facilities. However, information on the exact locations, spatial distributions, and sizes of CAFOs is still unclear in the U.S., hampering the ability to measure their impact on a national scale, increase the transparency of meat supply chains, and identify who is most impacted. This study generates the first national dataset of ~15,700 CAFOs (pigs and cattle) using high resolution remote sensing techniques, and systematically clarifies their relationship to local air quality measures and the socio-demographic characteristics of adjacent communities. This study explores the correlation between proximity to the CAFOs and $PM_{2.5}$ concentrations and reveals the demographics of communities that have been disproportionately exposed to CAFO-induced air pollution.

In Chapter 3, My co-authors and I scale down the analysis to one of the hotspots of beef and dairy production in California. Although the environmental and social burdens associated with the production of beef are well-understood, due to supply chain complexities, we rarely know precisely where these impacts occur or who is affected. This limitation is a barrier to more sustainable production and consumption of animal products. In this chapter, we combine life cycle thinking with an environmental justice approach to map Costco-Harris Ranch's beef supply chain in California and to explore the environmental burden of air pollution ($PM_{2.5}$) due to beef production in the San Joaquin Valley, a region that has some of the worst air quality in the United States. We then model $PM_{2.5}$ emissions across the beef supply chain to find the hotspot node of beef production to further EJ analysis and to reveal who is affected by the beef production in California.

Chapter 4 explores the underlying governance dynamics of the U.S. beef industry. Supply chain governance consists of rules, structures, and institutions that shape supply chains towards various objectives, including environmental and social sustainability. Although previous supply chain studies have provided insight into the relationship between governance and environmental sustainability, they have generally overlooked two crucial dimensions: power relations and outside nodes' influence. Power relations among companies within a supply chain can foster sustainable outcomes or sow mistrust and conflict. Key outside nodes (such as NGOs, regulatory agencies, unions) can influence supply chain sustainability. This chapter addresses these two gaps by introducing an approach to measure differential power among actors across the entire supply chain, including key external nodes. We develop a structured survey in which supply chain participants rank their peer's ability to affect environmental and social sustainability in the chain and apply this method to the beef production sector in the United States. This study provides a replicable approach for scholars broadly interested in measuring and mapping perceptions of power (and related governance) in supply chains. In addition, this quantitative assessment of power provides the basis for testing multiple supply chains to generate a generalized framework for power dynamics in supply chains.

Chapter 5 summarizes the key findings and theoretical and practical implications of each of the chapters. I suggest that the three most important outcomes of this dissertation are: 1) Identify and measure the location and size of ~15,700 pig and cattle CAFOs across the U.S., and systematically clarify their relationship to local air quality measures and the socio-demographic characteristics of adjacent communities; 2) Map the network structure of a specific supply chain at high geographic specificity, and clarify supply chain's relationship to California's hotspot of $PM_{2.5}$ and the environmental and health cost of living across the production phases of supply chains for nearby communities; and 3) Develop a new approach to quantify power structure across an entire supply chain, considering both internal and external linkages in order to induce change to the environmental and social outcomes of the supply chain. I conclude by identifying a number of potential avenues for future research that would build on the foundation developed in this dissertation.

1.4 Intellectual merit and broader impacts

The *significance* of this dissertation lies in its ability to advance quantitative methodologies for reliable, comprehensive EJ analysis of supply chain structure and to characterize where power lies in supply chains to identify who is culpable for environmental and social degradation— potentially indicating broader trends influencing changes in supply chain governance. The corporate-specific case study has implications for supply chain governance worldwide that are shaped/reshaped by ongoing environmental degradation. Understanding the perceptions of environmental and social sustainability among both internal and external linkages through a comprehensive survey analysis will provide policymakers with critical information and insights on how to improve environmental and social sustainability outcomes of a chain through policy and regulations.

This dissertation provides society with the knowledge and tools necessary to make changes that can mitigate the EJ impacts across the supply chains. Beyond the short-term goals, this project will impact society through three interrelated primary long-term goals: First, this project is a voice for communities of color and low-income communities that have been affected by disparate siting of production phases of supply chains. Second, developing a comprehensive open dataset of CAFOs across the U.S. and analysis of their EJ impacts informs consumers of the unfelt and unseen negative impacts of livestock production. This dataset improves transparency and can be used by activists, NGOs, and even regulators to monitor CAFO expansion, see who is impacted, and lobby for voluntary change or command and control regulation. This information, along with the current studies, publications, and documentaries about other negative impacts of beef consumption, can have a huge impact on consumers' diet choices. Finally, this dissertation argues that the transformation of supply chain structure represents a new form of political action on every geographic scale to promote more sustainable outcomes. In the process, both the society and the supply chain itself will benefit from this transformation.

Chapter 2

Environmental Justice Impacts of Concentrated Animal Feeding Operations (CAFOs)

This chapter is prepared as a journal article as

Chamanara, S., Gounaridis, D., Goldstein, B., & Newell, J. P. (2022). Environmental justice impacts of concentrated animal feeding operations (CAFOs).

2.1 Abstract

Concentrated Animal Feeding Operations (CAFOs) emit immense volumes of particulate matter and particulate matter precursors. These emissions produce numerous health issues in neighboring communities. Yet, the lack of information describing CAFO location, their spatial distribution, and the size of the facilities hampers our ability to measure the impact and environmental justice implications of CAFOs on a national scale. In this study, we address this gap by identifying ~15,700 pig and cattle CAFOs using high resolution remote sensing techniques and then systematically clarifying their relationship to both local air quality measures ($PM_{2.5}$ concentrations) and socio-demographic characteristics of CAFO-adjacent communities. Our analysis showed that particulate concentrations are consistently higher in areas close to

CAFOs and that the larger the CAFO the higher the concentration of nearby particulates. We also found that Latinx, People of Color (POC), and less-educated communities (no high school degree) are more likely to live near CAFOs than their White counterparts and as such are more exposed to higher $PM_{2.5}$ concentrations. Geographic analysis of the results revealed significant clustering of CAFOs in a small number of counties-- we found more than 3,200 CAFOs concentrated in just 19 counties in California, the Upper Midwest, and North Carolina. This spatial concentration of CAFOs contributes to high pollution burdens and environmental inequities in these areas. This study is the first step toward a national systematic analysis of $PM_{2.5}$ inequalities of industrial farming across the U.S.

2.2 Introduction

Concentrated Animal Feeding Operations (CAFOs) are the biggest contributor to air pollution from livestock production in the United States (Chamanara et al., 2021) which in turn leads to thousands of deaths each year (Domingo et al., 2021). The U.S. livestock industry has changed dramatically over the past half-century as the number of small, family-owned livestock farms has decreased due to growing numbers of industrial farms (Hoover, 2013). This has ushered in a new phase of feedlot or CAFO based-production. Whereas smaller-scale family farms typically fatten livestock by grazing the animals on open rangeland or pasture, industrial-size feedlot operations instead pen livestock and feed the animals grain to promote rapid weight gain. Most feedlots are classified as "animal feeding operations" (AFOs), meaning that the animals are confined for more than 45 days in a season and that the area imports feed rather than growing vegetation onsite. The term "concentrated animal feeding operation" (CAFO) applies to AFOs housing over 1,000 animal units.

Dusty conditions, high stocking densities, and massive amounts of manure contribute to many air pollution problems in and around CAFOs (Wing et al., 2008). The most problematic pollutants for local air quality are particulate matter under 2.5 microns in diameter ($PM_{2.5}$) and its precursors, such as sulfur dioxide, oxides of nitrogen, volatile organic carbon, and ammonia. The U.S. Environmental Protection Agency (EPA) estimates that CAFOs produce 1.2–1.37 billion tons of manure annually (Rogers & Haines, 2005). Regardless of how this manure is managed (e.g., contained or spread as fertilizer), it can release up to 400 noxious gases, including ammonia, methane, and particulate matter (O'Shaughnessy & Altmaier, 2011). Air pollution, while just one of the many public health issues associated with these facilities--e.g., foodborne illness, antibiotic resistance, chronic diseases, eutrophication, and water pollution (Gilbert, 2020)--is among the most serious.

Dosman et al., (2004) documented that at least 25% of CAFO laborers suffer from respiratory diseases (Dosman et al., 2004). $PM_{2.5}$ concentrations from CAFOs have been linked to persistent respiratory symptoms, a progressive decline in lung function, cardiac health, cancer, and even death for residents near these industrial farms (Heederik et al., 2007). Such negative health impacts can extend to residents living up to 10 miles away (Wing & Wolf, 2000; Bullers, 2005). Moreover, multiple studies have documented disproportionate exposure of air pollution from CAFOs to low-income, less educated, and non-white (e.g., Black, Asian, Hispanic, Native American, and Native Hawaiian) communities in West Michigan (Jacques et al., 2012), California (Chamanara et al., 2021), North Carolina (Ogneva-Himmelberger & Huang, 2015; Son et al., 2021), Ohio (Lenhardt & Ogneva-Himmelberger, 2013), and Mississippi (Wilson et al., 2002). This disproportionate burden is the poster child of environmental (in)justice. Environmental justice entails "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (EPA, 2021b). We, therefore, identify environmental injustice as the disproportionate exposure and burden of pollution on vulnerable communities.

Environmental injustices associated with CAFOs are a longstanding issue (Goldschmidt, 1978). To date, the vast majority of environmental justice studies related to CAFOs have been conducted at the regional or state level using census-based units of analysis (county, census tract, or block group) and variables (socio-economic data). As such, the studies lack the scope to clarify whether inequities are localized or expansive (i.e., persist across a large, diverse, and geographically varied area). How and whom CAFOs impact across the U.S., therefore, remains to be known. Recent work by Domingo et al. (2021) linked 43% of deaths from the agriculture sector to air pollution (primary and secondary $PM_{2.5}$). Tessum et al. (2021) documented disproportionate $PM_{2.5}$ exposure from the agriculture sector to Black and Hispanic minorities. Yet, as these studies focus on the agricultural sector writ large, the state of environmental injustices associated with CAFOs specifically is still unknown. Even though there have been calls for transparency and more research on the topic, the lack of a comprehensive and reliable dataset of the location of the CAFOs has impeded work in this area to date (Miller, & Muren, 2019).

Despite the urgency of this issue, the current legal landscape in the U.S. precludes researchers and environmental agencies from knowing where CAFOs are located. CAFOs are protected by various bills that designate them as confidential "superfund" sites (EPA, 2021). No federal agency collects consistent and reliable information on the number, size, and location of CAFOs at the national level either (Gilbert, 2020). Although the EPA, various NGOs, and multiple research entities have tried to locate these farms, the lack of a reliable national dataset makes it impossible to systematically monitor CAFOs and their impact on people living nearby. This data gap prevents the creation of a critically needed system for monitoring CAFOs and their impacts on a national scale and limits our ability to craft effective policies to curb CAFO pollution and related injustices. Therefore, this study generates the first high resolution dataset of CAFOs across the U.S. to perform the most comprehensive study of CAFO-generated $PM_{2.5}$ emissions to date. In doing so, we can answer: (1) Where are cattle and pig CAFOs located in the U.S.?; (2) Who is disproportionately exposed to lower air quality in areas nearby a CAFO?; and, (3) Where exactly are the hotspots of high $PM_{2.5}$ concentrations and disadvantaged communities? We specifically leveraged high resolution remote sensing techniques to produce a dataset of 15,738 cattle (beef and dairy) and pig CAFOs across the U.S. This dataset not only includes the precise location of individual CAFOs but also documents their size. Moreover, we use the resulting dataset to examine the ramification of living in close proximity to a CAFO and highlight where certain communities across the country are disproportionately exposed to and bear the costs of higher $PM_{2.5}$ concentration. This study marks the first effort to systematically analyze the geographies of CAFOs in relation to 15-year averages of $PM_{2.5}$ concentrations.

2.3 Materials and methods

2.3.1 Generating the dataset

To develop a comprehensive dataset of cattle and pigs CAFOs across the U.S. for our analysis, we used three existing but incomplete datasets as a reference combined with an extended survey on high resolution satellite imagery and systematic visual inspection. We used the data available from EPA (Thereafter EPA Dataset) which includes 7,058 cattle and 2,378 Pigs CAFOs. The data come with coordinates so we systematically evaluated each entry against high resolution Google satellite imagery (nominal years 2017-2019) in QGIS. One shortcoming of this dataset is that it is not geographically representative of the CAFOs across the US. Each EPA region has its own rules and some states underreport their CAFOs. We paired the EPA data with data derived from a USA Business database from Data Axle (formerly known as InfoGroup). We extracted entries that refer to livestock farming and CAFOs based on the NAICS code for both Cattle (dairy and meat) and Pigs. This process yielded 5,138 Cattle and 317 pigs CAFOs locations with coordinates which we evaluated against the Google satellite imagery. The Data Axle dataset still has systematic underrepresentation and missingness especially for smaller CAFOs, while we also found many false entries (e.g. company headquarters, slaughter houses, warehouses instead of a CAFO). Finally, we used the newly developed crowd-sourced dataset created by CounterGlow, which has 10,299 cattle and 7,800 Pigs CAFOs (CounterGlow, 2021), and performed the same evaluation steps to remove all the duplicates and false positives. CAFOs have distinct characteristics-- land patches without vegetation, with manure piles and cattle and pigs present-- that allowed us to delete the false positives and capture new ones that have been missed in all the datasets. Finally, all three datasets were collated in one single layer of both cattle and pigs CAFOs. Preliminary tests of representativeness indicated the need to extend this dataset to include smaller CAFOs which were omitted. To do so, we created a nationwide 10x10km grid and visually inspected each grid cell against the Google satellite imagery. The objective of this endeavor was to include as many CAFOs as possible to increase the representation of all meat-producing regions and to calculate the size of CAFOs since it is a key factor of their capacity and environmental costs. We cross-checked each identified CAFO for their accuracy using digital ground truth audits via the *go2streetview* plugin in QGIS (nominal years 2017-2019). *Go2streetview* plugin gives a street view or bird's eye view of the location. We marked a land patch as a CAFO when there was: 1) clear evidence of cattle or pigs and 2) clear evidence of manure piles, *Figure 3*. We visually identified 3,754 cattle and 2,800 pig CAFOs with this process and digitized the boundaries of 15,738 CAFOs in total in order to calculate their size.

Figure 3. Examples of cattle and pigs CAFOs

2.3.2 Data used in the analyses

To understand disparities associated with the $PM_{2.5}$ concentration around the CAFOs, we used census block group level data (American Community Survey, 2019). Following literature findings, we selected race/ethnicity, education, poverty, and income along with the physical distance to CAFO weighted by its size, to examine whether these attributes can explain the variation of $PM_{2.5}$ concentration in varying distances (3km, 5km, 10km) from CAFOs literature. All data were joined to census block group boundary files and were normalized and projected to a common metric reference system. For categorical variables (e.g., educational level, race), we divided the number of people in each category by the total population of each block group and used the percentage in our model. For numeric variables (e.g., income) we calculated the mean for each census block group. We also calculated the physical (euclidean) distance of each CAFO to the centroid of each census block group and weighted it by the size of the CAFO.

For the $PM_{2.5}$ emission, we used time-series data (2002-2017) from the EPA Fused Air Quality Surface Downscaling (FAQSD) (EPA, 2017). To estimate annual average $PM_{2.5}$ concentrations for the conterminous U.S., we interpolated the data for each year using multilevel b-splines at 100-m spatial resolution (threshold error = 0.001) (Lee et al., 1997). Next, we calculated the mean of the resulting raster files and the result was spatially joined to the census block group polygon layer. The final dataset included $PM_{2.5}$ concentration, distance from a CAFO weighted by its size—as a key factor of the CAFOs' capacity and environmental cost--, and socio-economic variables for each census block group. We extracted six datasets from this dataset: 1) Census block group polygons that are within 3km distance from cattle CAFOs; 2) Census block group polygons that are within 5km distance from cattle CAFOs; 3) Census block group polygons that are within 10km distance from cattle CAFOs; 4) Census block group polygons that are within 3km distance from pigs CAFOs; 5) Census block group polygons that are within 5km distance from pigs CAFOs; 6) Census block group polygons that are within 10km distance from pigs CAFOs.

2.3.3 Statistical analysis

We fitted generalized linear models (GLM) for the six datasets (3km, 5km, 10 km) for both cattle and pigs. Each model was checked for collinearity with the variance inflation factor (VIF) and variables with VIF > 5 were eliminated from the models. On the basis of the GLM models, we calculated the Moran's I statistic which indicated there was significant spatial autocorrelation of fitted variables and model residuals (Dormann et al., 2007). We ran a Lagrange multiplier test which indicated the Spatial LagModel as the most appropriate for all six models (Anselin, 2010). We fitted the spatial regression models on the basis of first-order Queen's rule of adjacency for all six models. The rules of adjacency are used to determine neighbors, and their spatial weights, as they weigh more than distant entities. The Queens rule defines census block groups as neighbors when they have shared borders or vertices. To complement the spatial regression results with spatial clusters of $PM_{2.5}$ concentrations and disadvantaged communities across the U.S., we used the Local Spatial Autocorrelation (LISA) (Anselin, 2010). LISA allows the identification of bivariate clusters of $PM_{2.5}$ concentration and each independent variable color-coded by the type of spatial relationship. We considered p-values less than 0.005 as significant, and the queen contiguity was set as 5. High-High and Low-Low are the hotspots and coldspots respectively which indicate that a cluster of high or low $PM_{2.5}$ concentrations is found in areas with high or low rates of Latinx, POC, below poverty, or no high school degree communities at the census block group level.

2.4 Results

2.4.1 Location and Size of CAFOs

Location and Size of CAFOs: We identified, mapped, and measured the dimensions of 15,738 CAFOs across the contiguous U.S. *(Fig 4)*. We mapped 8,772 cattle (98% accuracy) and 6,966 pig CAFOs (99% accuracy) across the U.S., with 90% correlation with EPA-reported numbers of CAFOs per county (For accuracy numbers see *Appendix A*). Although no authoritative count exists, our dataset accounts for more than 91% of total estimated CAFOs by the EPA in the contiguous U.S. The average CAFO in the U.S. covers 16.9 hectares (ha). We did not differentiate between CAFOs raising cattle for beef or for dairy. The average cattle CAFO covered 24.5 ha, and the average pig CAFOs covered 7.7 ha.

Analyzing the spatial distribution of the CAFOs, we found that CAFOs are clustered both across and within states. Cattle CAFOs are mostly in the central part of the U.S. (e.g., Nebraska, Oklahoma) but also extend to the West (e.g., California). Pig CAFOs are mostly in the Northern part of the U.S. (e.g., Minnesota, Iowa) but also extend to the Southeast (e.g., North Carolina). Iowa, North Carolina, California, Minnesota, and Nebraska rank the highest in terms of number of CAFOs per state *(Table 1)*. Narrowing our focus to the county level, we found that only 59 (of 3,140) counties have more than 50 CAFOs. These 59 counties contain a third of all U.S. CAFOs (5,992). More than half of these (3,260) are concentrated in just 18 counties in California, the Upper Midwest (Iowa, Minnesota), and North Carolina. Eight counties in California, Minnesota, Oklahoma, and Nebraska stand out as hotspots of cattle CAFOs while ten counties in Iowa, North Carolina, and Minnesota stand out as hotspots of pig CAFOs. Among the most noteworthy of these, Californian counties of Tulare, Stanislaus, Merced, Kings, and San Joaquin contain more than 1000 cattle CAFOs while the North Carolina counties of Duplin, Sampson, and Bladen counties contain approximately 1000 pig CAFOs.

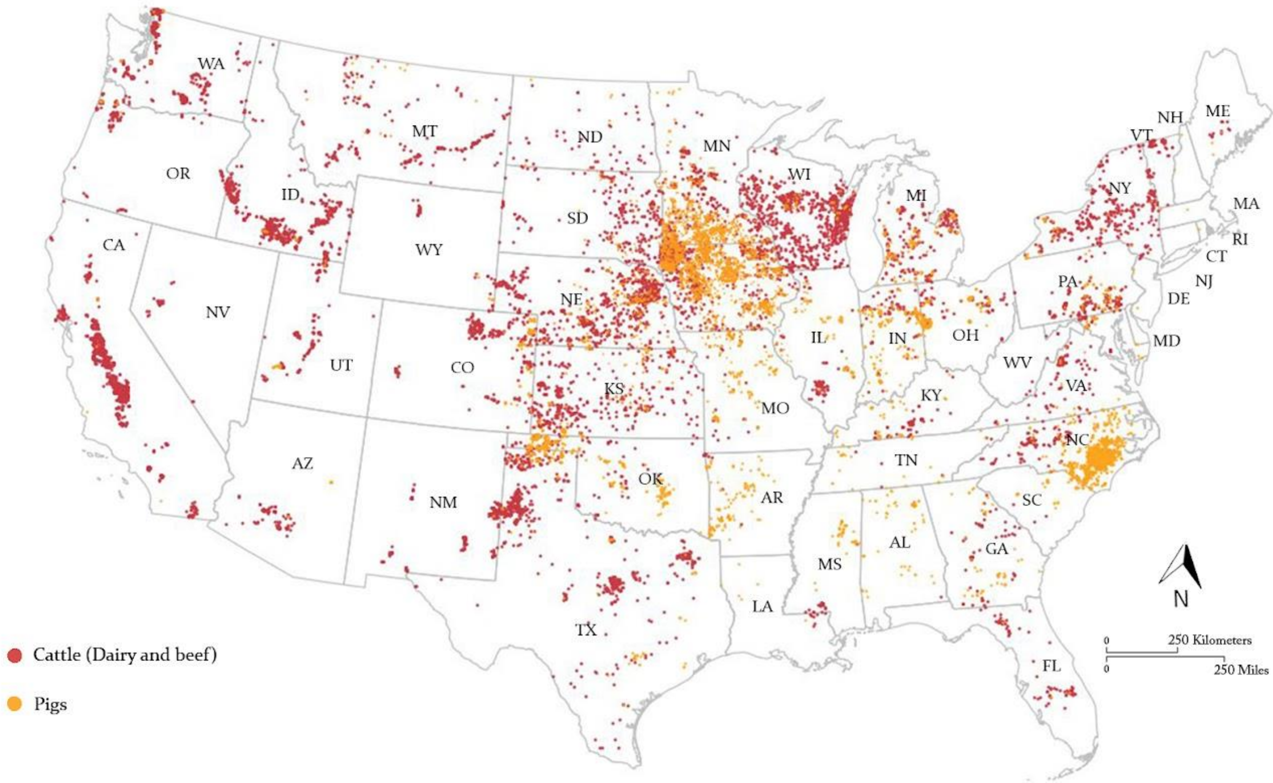

Figure 4. Location of cattle and pigs CAFOs

2.4.2 National analysis of $PM_{2.5}$ and local communities near CAFOs

We quantified the disparities associated with the $PM_{2.5}$ concentrations around the CAFOs, by measuring the distance from each census block group in the U.S. to the CAFOs and then weighted it by the size of the CAFOs. We then created three models per CAFO type (e.g., cattle versus pig) varying the distance for each (e.g., 3km, 5km, and 10km). Our model results pointed to a consistent connection between the physical distance to the CAFOs and the $PM_{2.5}$ concentration for both cattle and pig CAFOs *(Table 2)*. *Distance weighted by Size* from the CAFOs is significantly associated with higher $PM_{2.5}$ concentrations in all models. In terms of the *size of the CAFOs*, our results showed significantly higher $PM_{2.5}$ concentrations closer to larger CAFOs (both cattle and pigs) which highlights the air pollution burden CAFO-based livestock production exacts on proximate communities.

Table 1. Number of CAFOs (cattle and pigs) per state

State	CAFOs	State	CAFOs	State	CAFOs	State	CAFOs
Iowa	2723	Michigan	305	Georgia	99	Louisiana	14
North Carolina	1616	South Dakota	283	Kentucky	93	Maine	14
California	1391	Missouri	276	Arizona	88	West Virginia	7
Minnesota	1292	Indiana	225	Florida	76	New Jersey	4
Nebraska	981	Ohio	224	Mississippi	68	Delaware	2
Wisconsin	924	Montana	217	Vermont	63	Massachusetts	2
Texas	712	Pennsylvania	208	Alabama	62	New Hampshire	2
Idaho	626	Virginia	201	Maryland	54	Rhode Island	1
Kansas	481	Illinois	175	North Dakota	50	Connecticut	0
Washington	413	New Mexico	167	Wyoming	45	District of Columbia	0
Oklahoma	384	Utah	163	South Carolina	42		
Colorado	324	Arkansas	128	Nevada	32		
New York	315	Oregon	124	Tennessee	30		

2.4.3 Communities living near CAFOs

We quantified the exposure of communities near CAFOs to $PM_{2.5}$ concentrations using spatial lag regression models defined by CAFO type (cattle or pig) and distance between a given community and a CAFO (3km, 5km, 10km). Model results revealed that race and ethnicity are strong predictors of $PM_{2.5}$ exposure. Black individuals in particular are predicted to be exposed to high $PM_{2.5}$ concentrations at all distances for either type of CAFO. The models similarly showed that Asian individuals are more likely to experience high $PM_{2.5}$ concentrations at all distances--but only around cattle CAFOs. Latinx communities are exposed to high $PM_{2.5}$ concentrations across all distances from cattle and pig CAFOs but experience worse $PM_{2.5}$ conditions near cattle CAFOs than pig CAFOs. While White individuals are less likely than other racial/ethnic groups to be exposed to high $PM_{2.5}$ concentrations close to cattle CAFOs, they do experience pollution burdens near pig CAFOs *(Table 2)*.

All six models suggested that people living close to the CAFOs tend to have lower educational attainment. Our analysis showed that block groups with high $PM_{2.5}$ concentration near both cattle and pigs CAFOs have a markedly higher percentage of people without a high school degree. Finally looking at the economic characteristics, we found that the percentage of people living below poverty rates are consistently lower in areas with high $PM_{2.5}$ concentration in the vicinity of cattle CAFOs *(Table 2)*, *(Appendices B and C).*

Table 2. Results of predicted $PM_{2.5}$ concentrations at each distance by race, ethnicity, and socio-economic variables

	Cattle			**Pigs**		
	3km	**5km**	**10km**	**3km**	**5km**	**10km**
Constant	**11.238*** **	**9.824*** **	**8.231*** **	**9.238*** **	**9.563*** **	**9.481*** **
Distance W Size	**-5.3e-007*** **	**-2.9e-007*** **	**-1.2e-007*** **	**-5.4e-007*** **	**-6.5e-007*** **	**-1.2e-007*** **
% Latinx	-0.119	**0.334***	**0.387*** **	**-2.724*** **	**-2.95*** **	**-1.911*** **
% Whites	**-2.1579*** **	**-0.938*** **	0.004	**1.061** **	**0.980** **	**0.653** **
% Blacks	**1.934*** **	**2.318*** **	**3.170*** **	**1.459** **	**1.352*** **	**0.613** **
% Asians	**7.222*** **	**4.891*** **	**2.891*** **	0.209	0.089	0.230
% No High School Degree	**2.423*** **	**2.433*** **	**2.562*** **	**3.875*** **	**3.498*** **	**3.302*** **
% Below Poverty	**-1.595*** **	**-0.626** **	**-0.268** **	-0.049	-0.279	-0.146
R-Squared	0.247	0.271	0.284	0.126	0.116	0.068
Lag Coefficient	0.186	0.171	0.183	-0.048	-0.046	0.041

2.4.4 Spatial concentrations of CAFOs' injustice issues

Our regression analyses suggested that systemic disparities associated with livestock production in the United States exist. However, they did not reveal where the disparities are happening. We, therefore, created a geographic representation of our (10km) model-based findings using Local Indicators for Spatial Association (LISA) which classifies areas into four groups: high values near high values (High-High), low values near low values (Low-Low), and low values with high values (Low-High; High-Low) (see Methods). This allowed us to identify spatial clusters of where high or low $PM_{2.5}$ coincides with high or low counts of economically disadvantaged, less educated, POC and Latinx communities (*Figure 3)*.

The results revealed two major clusters of high $PM_{2.5}$ concentration coinciding with high counts of economically disadvantaged, less educated, POC, and Latinx communities (High-High zones in Figure 3). These clusters exist around known CAFO hubs: one cluster sits in the Central Valley of California where cattle CAFOs are concentrated, and the other in North Carolina where pig CAFOs are concentrated. Other smaller clusters of High-High sit in Georgia, eastern Texas, eastern Missouri, and southern Illinois. These High-High hotspots highlight areas where marginalized communities experience systemic exposure to low-quality air as a result of CAFOs. High sea-level pressure contributes to the concentration of $PM_{2.5}$ in North Carolina and other coastal regions while weak winds, a lack of precipitation, and high temperatures contribute to higher $PM_{2.5}$ levels in California's Central Valley (Tai et al., 2010).

The inverse pattern, Low-Low, characterizes much of the Midwest (Iowa, Wisconsin, eastern South Dakota, eastern Nebraska, central Michigan, and central Kansas) as well as a swath of New England (New York and Vermont). In these areas, low $PM_{2.5}$ concentrations coincide with lower counts of economically disadvantaged, less educated, POC and Latinx communities. The low $PM_{2.5}$ concentration in the Midwest region is a reflection of the area's geomorphology, climate, lower population density, and lack of heavy industrial activity (Tai et al., 2010). Higher elevations across the Northeast, West, and Appalachia similarly lead to lower $PM_{2.5}$ levels (Tai et al., 2010, Austin et al., 2013). The demographics in these Low-Low areas trend more White, which explains the lower incidences of Latinx and Black communities. In terms of poverty and no high school education in these areas, these remain also low due to the differences in the land ownership in these regions (Brown et al., 2000). Differences in land ownership in the U.S. contribute to high poverty rates and low educational attainment (Brown et al., 2000). While residents of central California and eastern North Carolina tend to be laborers on industrial farms, Midwesterners tend to hold management jobs, own land, and have a higher level of education (Brown et al., 2000).

Large extents of southern Michigan, northern Illinois, Indiana, Ohio, and eastern Pennsylvania exhibit High-Low patterns meaning they have high $PM_{2.5}$ concentrations but lower counts of economically disadvantaged, less educated, POC and Latinx communities. The higher $PM_{2.5}$ concentrations can be partly attributed to relatively high industrial activity and population density (Tai et al., 2010). Northern Texas, southern Kansas, and parts of Oklahoma exhibit the inverse, a Low-High pattern with regards to $PM_{2.5}$ concentrations and counts of less educated and Latinx communities, respectively. A sliver of northern Texas exhibits a Low-High pattern for $PM_{2.5}$ concentrations and counts of economically disadvantaged and POC communities.

Spatial analysis of model results reveals two primary areas where high $PM_{2.5}$ coincides with economically disadvantaged, less educated, POC and Latinx communities. These High-High hotspots are in California's Central Valley and eastern North Carolina. Detailed data available at the state-level in California allowed us to conduct finer scale analysis of $PM_{2.5}$ emission sources across eight counties (Fresno, Madera, Kern, Merced, Stanislaus, San Joaquin, Tulare, and Kings) in the Central Valley in 2017. These eight counties have more than 1000 CAFOs and are intensely used for beef and dairy production. We found that over 70% of $PM_{2.5}$ emissions stem from livestock production, followed by industrial processes (15%), and fuel combustion (5%) (California Air Resources Board, 2017).

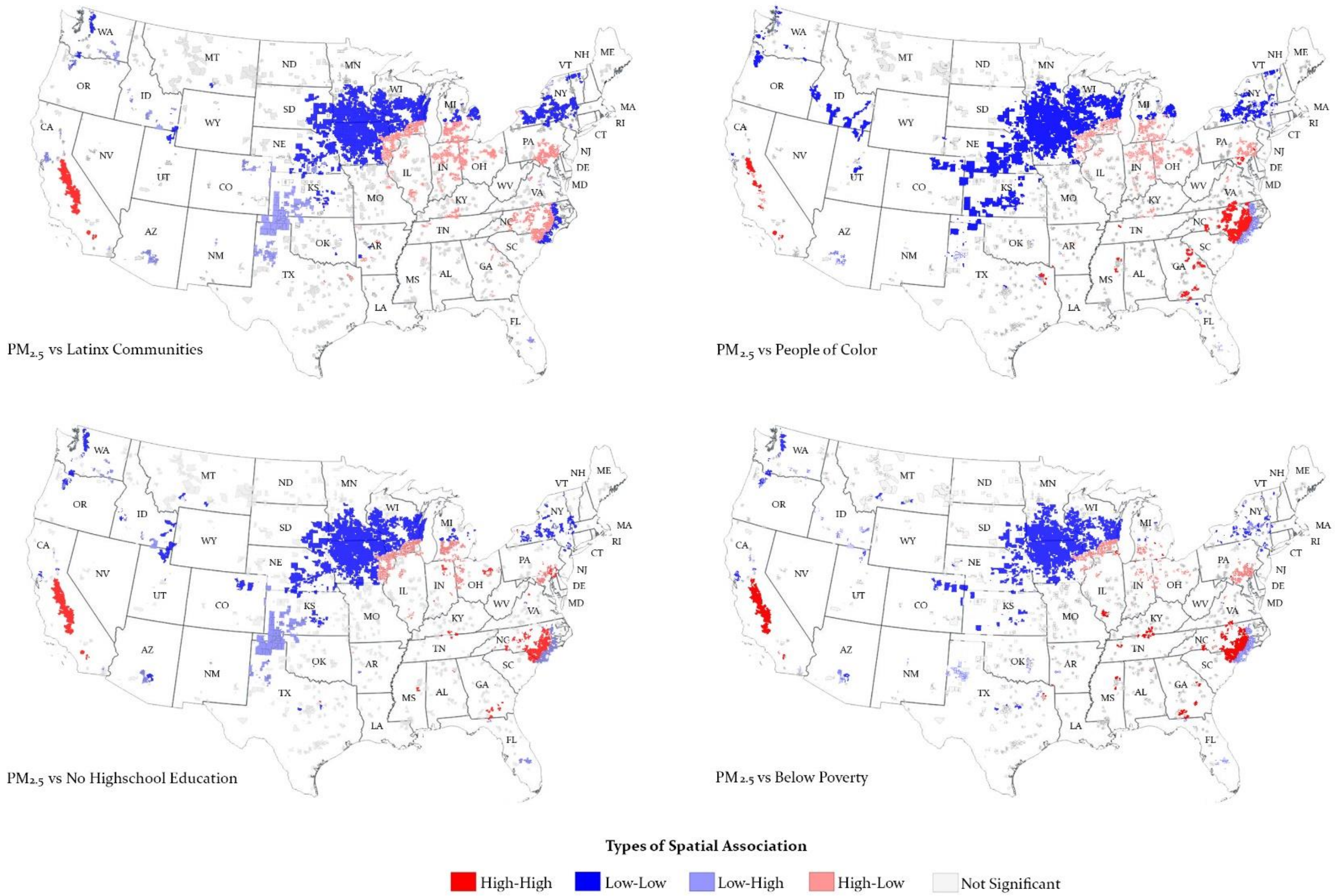

Figure 5. Local Indicators of Spatial Autocorrelation in the 10km buffer around the CAFOs (cattle and pigs). High-High means high $PM_{2.5}$, high demographic variables. Low-Low means low $PM_{2.5}$ and low demographic variables.

2.5 Discussion

Our study provides the first national assessment of the relationship between CAFOs, $PM_{2.5}$ concentrations, and community demographics. We demonstrated how the location distribution and size of cattle and pig CAFOs are consistently correlated with higher $PM_{2.5}$ concentrations at varying distances from such facilities. We unveiled how certain communities across the country are disproportionately exposed to the impacts of CAFOs and therefore bear the costs of higher $PM_{2.5}$ concentrations. Estimates of exposure impacts of $PM_{2.5}$ across race/ethnicity and socio-economic variables showed that Latinx, POC, and less educated communities are disproportionately affected by $PM_{2.5}$ emissions from CAFOs. Our census block group level results confirmed previous findings from other studies at the state and substate levels (Edwards & Ladd, 2001; Nicole, 2013; Carrel et al., 2016; Son et al., 2021; Chamanara et al., 2021). Our study also disclosed the Central Valley of California and eastern North Carolina as the two major hotspots of high $PM_{2.5}$ concentration coinciding with high rates of disadvantaged communities. A recent study has shown that most deaths from agriculture sector have happened in these two regions (Domingo et al., 2021).

In contrast to prior state-specific studies of Illinois (Gómez & Zhang, 2000), Michigan (Abeles-Allison & Connor, 1990), Wisconsin (Foltz & Chang, 2002), and North Carolina (Wing et al., 2000; Wilson et al., 2002) that report that communities near large CAFOs tend to have less economic well-being, our national-scale study found significantly lower poverty levels around cattle CAFOs. This finding is consistent with other research that has found that the relationship between CAFOs and income or poverty varies by region (Edwards & Ladd, 2001; Lenhardt & Ogneva-Himmelberger, 2013). Our scaled-down analysis of representative block groups in California, North Carolina, and the upper Midwest revealed substantial variations in both mean incomes and poverty rates. Across the selected block grounds in California, mean income ranged from $29,000 to more than $90,000. Although most CAFOs in North Carolina are clustered in low-income counties, one of the selected block groups is characterized by a mean income of over $90,000. We found that block groups with higher incomes have a higher number of people with college degrees and in management positions. The same trend has been observed in Illinois, (*Figure 6).*

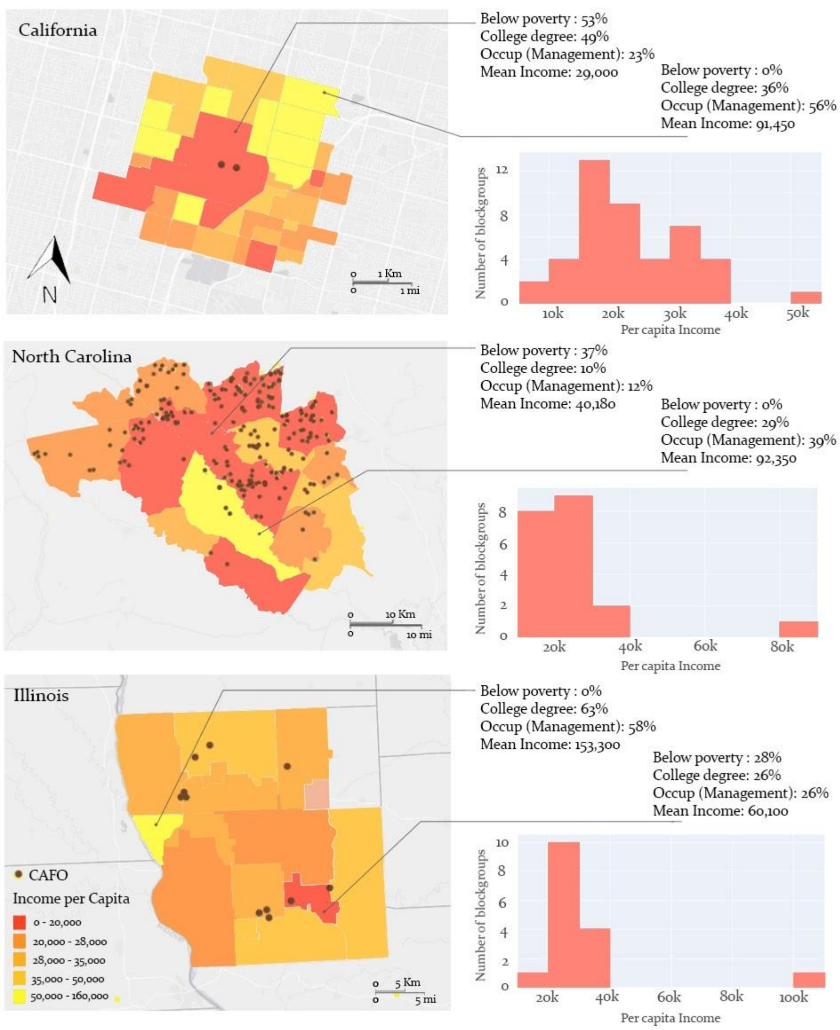

Figure 6. A few examples of poverty and income variation in block groups around select CAFOs in California, North Carolina, and Illinois.

Our study notably generates a comprehensive national dataset of CAFO location and size that will allow scholars to quantify nationwide injustices associated with industrial farming. However, the analysis is accompanied by a few caveats. Advocates of industrial agriculture argue that the cause and effect relationships of CAFOs and air quality in the surrounding areas are not fully scientifically established (Merchant et al., 2002). While causality may be difficult to establish, the analysis of CAFO location and size in relation to surrounding air quality can be a first step towards addressing the impacts of these operations. Moreover, such analysis makes critical inroads towards documenting who bears the cost of these impacts. Our clustering model revealed that variables such as geomorphology, meteorology, and the presence of other industrial activities should be considered alongside $PM_{2.5}$ concentrations to establish causality. This national-scale study complements a number of previous studies conducted at the state and regional level; collectively this body of literature represents much needed efforts towards manifesting the causality between CAFOs and air pollution.

Despite their highly localized impacts, CAFOs are largely unregulated due to the rapidity of their arrival. The shift from local farms to CAFOs happened so fast that the policy protecting human health and the environment has not been able to keep up. Only a few states have passed laws prohibiting the expansion of existing CAFOs or instituting temporary moratoria on new CAFOs (Fry et al., 2013). There are no existing laws related to regulating CAFO emissions. Existing policy *shields* industrial farms from having to take responsibility for their environmental harms (Gilbert, 2020). For example, the “Farm Regulatory Certainty Act” removed manure from the definition of waste thus exempting CAFOs from having to manage excrement (Congress, 2018a). Two companion bills, the “Agricultural Certainty for Reporting Emission Act" and the

“Fair Agricultural Reporting Method Act” exempted agricultural air pollution from the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act, which gives the federal government the power to tax corporations found responsible for hazardous waste (Congress, 2018b; Congress, 2018c). Such exemptions are made possible by the concentration of power in the hands of a few processors that own all of the CAFOs nationwide. Their market dominance gives them the means to dictate terms and grants them significant political influence.

Moreover, as governmental institutions enact policies that subsidize both feed and technological fixes for pollution and fail to hold corporations accountable for their environmental impacts, they continue to support industrial farming behemoths. In recent years, significant EPA attention has gone towards the design of technological fixes for reducing nitrogen and phosphorus in manure. Although these “fixes” may alleviate problems in the short term, they are only band-aids that fail to address the systemic, bigger picture problem of CAFOs. Meaningful reduction of air pollution from industrial farming requires systemic change to production practices that simultaneously address livestock concentration and waste management (Domingo et al., 2021). It also requires societal dietary changes to reduce the demand for meat and thus the “need” for industrial-scale production. Although consumer education is essential, changing dietary habits is not easy because the food system is inherently embedded within a deeper cultural, economic, and political system that is hard to change.

To foster societal shift towards more sustainable diets, policymakers should enact bills that tax animal products and subsidize foods that meet environmental and human rights criteria. Policymakers also have a role in reviewing existing bills that favor and shield CAFOs from being systematically analyzed or having to take responsibility for their environmental impacts. CAFOs need to be held financially responsible for the environmental harm they cause. Finally, policymakers can use their position to lobby for alternative production methods that avoid the problems associated with CAFOs. The EPA has an important role to rise to--it needs to implement better air quality monitoring programs around CAFOs and extend regulations like the Clean Air Act (CAA) to livestock production. The EPA must strictly and rigorously enforce CAA regulations on CAFOs, while supporting alternative livestock farming methods that can mitigate, and even reverse, the damage of industrial agriculture, on local farmers, communities, and the environment.

This study is the first step toward documenting the environmental injustice of $PM_{2.5}$ exposure due to industrial farming. The comprehensive, national dataset of CAFOs can be used in future research to explore other environmental inequalities related to industrial farming at the national level. Our public dataset can also provide a starting point for improving the accountability of industrial farming to CAA regulations. We recommend future studies analyze the governance of industrial agriculture to further understand who has the ability to induce change in the livestock supply chain.

Chapter 3

Where's the Beef? Costco's Meat Supply Chain and Environmental Justice in California

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3.1 Abstract

Although the environmental and social burdens associated with the production of beef are well-understood, due to supply chain complexities, we rarely know precisely *where* these impacts occur or *who* is affected. This limitation is a barrier to more sustainable production and consumption of animal products. In this study, we combine life cycle thinking with an environmental justice approach to map Costco's beef supply chain in California and to explore the environmental burden of air pollution ($PM_{2.5}$) due to beef production in the San Joaquin Valley, a region that has some of the worst air quality in the United States. To map the supply chain of one of Costco's primary suppliers, Harris Ranch, and the feedlots they operate, the study uses a methodological framework

known as Tracking Corporations Across Space and Time (TRACAST). Our modeling revealed that feedlots produce ~95% of total $PM_{2.5}$ emissions across the beef supply chain, and they alone account for approximately 1/3 of total anthropogenic $PM_{2.5}$ emissions in the Valley. $PM_{2.5}$ concentrations are markedly higher around these facilities. The spatial analysis revealed that communities living near feedlots are often poor, predominantly Latinx, and have increased $PM_{2.5}$ related disease burdens, including asthma, heart disease, and low weight birth. Based on company documents and news reports, neither Costco nor Harris Ranch are addressing this environmental injustice. Documenting the geographically specific impacts of livestock production opens up opportunities for corporations to address environmental injustices in their supply chains through more sustainable sourcing and production practices, and for consumers to rethink their consumption of meat.

3.2 Introduction

Have you ever found yourself at a restaurant, grocery store, or your local butcher wondering about the origins of the meat you can buy? Who produced it? And where? And how? In what situations? These are puzzling questions for consumers, scholars and, even, those selling the beef. Livestock supply chains often span thousands of miles and involve multiple transactions (Weber and Matthews, 2008; Smith et al., 2017). This opacity hinders our ability to ascertain the environmental and social costs of producing the meat that retailers sell, and people consume, a hurdle towards more sustainable production and consumption of animal products. Recent research shows shifts are urgently needed. Global livestock production produces roughly one-fifth of global greenhouse gases (GHGs) (IPCC, 2014), commandeers one-third of global arable land (Foley et al., 2011), and disrupts global flows of critical nutrients (Steffen et al., 2015). Land expansion for pastures and feed crops continues to fell primary forests and negatively impacts local communities (Vale et al., 2019; Rausch et al., 2019). Addressing these impacts will be challenging given a predicted 73% increase in global meat consumption by 2050 (Alexandratos and Bruinsma, 2012), with no easy technological fixes in sight (Goldstein et al., 2017). Although the unsustainability of global trends is clear, it remains difficult to concretely link consumers and producers to negative social and environmental change along the meat supply chains that feed them. Life cycle assessments (LCAs) have shown that animal protein sources generally produce more pollution and use more resources than vegetal alternatives, with beef being particularly burdensome (Eshel et al., 2014; De Vries et al., 2015). However, LCAs have focused on conceptual production systems (e.g. beef in the Upper Midwestern United States) rather than specific supply chains. When communicating impacts, studies have often pinpointed ‘hotspots’ in production systems that drive the majority of impacts, but here the focus has been on identifying the processes (e.g. feed production, calving, ranching, etc.) rather than the specific locations where impacts are greatest (Smith et al., 2017). By largely sidestepping the spatiality of livestock production, LCA practitioners often fail to convey how that production concentrates at specific locations and impacts proximate communities (Goldstein and Newell, 2019).

Table 3. Environmental Justice studies of livestock supply chains

AUTHORS, (YEAR)	LOCATION	LIVESTOCK	ENVIRONMENTAL INDICATOR	SOCIAL INDICATORS	HEALTH INDICATORS	SUPPLY CHAIN STAGE COVERED
WING, S., GRANT, G., GREEN, M., & STEWART, C. (1996).	North Carolina	Pig operations		Race/ Income		Feedlot
WING, S., & WOLF, S. (2000).	North Carolina	Pig operations		Quality of Life	Health symptoms	Feedlot
NICOLE, W. (2013).	North Carolina	Pig operations		Poverty/ Non-white		Feedlot
OGNEVA-HIMMELBERGER, Y., HUANG, L., & XIN, H. (2015).	North Carolina	Pig operations	Air Pollution (Ammonia)	Children, Elderly/ Whites, and Minorities		Feedlot
CARREL, M., YOUNG, S. G., & TATE, E. (2016).	Iowa	Pig operations	Water quality (Antibiotics)	Income/ Race, Ethnicity		Feedlot
WILSON, S. M., HOWELL, F., WING, S., & SOBSEY, M. (2002).	Mississippi	Pig operations		Income/ Race, Ethnicity		Feedlot
HARUN, S. M., & OGNEVA-HIMMELBERGER, Y. (2013).	United States	Pig, cattle, and chicken operations		poverty/ Race, Ethnicity	Health and environmental characteristics	Feedlot
LOWMAN, A., MCDONALD, M. A., WING, S., & MUHAMMAD, N. (2013).	North Carolina/ South Carolina/ Virginia	Land application of manure from CAFOs		Quality of life	Health impact/ Physical well-being	Feedlot
TAQUINO, M., PARISI, D., & GILL, D. A. (2002).	Mississippi	Pig operations		Race/ Education/ Household income		Feedlot
EDWARDS, B., & LADD, A. E. (2000).	North Carolina	Swine operations	Farm loss	Homeownership/ Education		Feedlot
STINGONE, J. A., & WING, S. (2011).	North Carolina	Poultry litter		Race/ Age/ Poverty	Asthma, Cardiovascular Disease and Diabetes hospitalization	Feedlot
MACMULLAN, C. N. (2007).	California	Dairy CAFOs	Air Pollution/ Water Pollution	Income/ Race/ Age/ poverty		Feedlot
JACQUES, M. L., GIBBS, C., RIVERS, L., & DOBSON, T. (2012).	Michigan	Pig, cattle, and chicken operations		Gender/ Race, Ethnicity		Feedlot
LENHARDT, J., & OGNEVA-HIMMELBERGER, Y. (2013).	Ohio	Pig, cattle, and chicken operations		Income/ Race, Ethnicity / Age		Feedlot

Empirical work by Environmental Justice (EJ) scholars has revealed elevated levels of particulate matter and ozone in communities near large animal production facilities (Morello-Frosch et al., 2002; Nicole, 2013). Sensitive populations, such as young children and the elderly, show heightened susceptibility to health burdens from this pollution (Morello-Frosch et al., 2002; Shumake et al., 2013; Bell et al., 2013; Bind et al., 2016), including increased prevalence of cardiovascular disease and asthma (Stingone and Wing, 2011). These facilities are often situated in socioeconomically depressed areas or minority communities (Fiala, 2008; Cambra-Lopez et al., 2010; Hadlocon, 2015; Purdy, 2018). Although meat supply chains consist of multiple, geographically dispersed processes (e.g. breeding, pasture, feedlot), EJ scholarship has prioritized the feedlot, dissociating impacted communities from end consumers *(Table 3).*

Thus, LCA provides a method to understand how meat is produced and its environmental and resource intensity, but it does not address where impacts occur and who is affected. Conversely, EJ studies show where meat is produced and who is impacted, but without connecting impacts to consumers and producers. Often absent from both research streams is which companies are producing the meat. Academic research on the specific companies that drive supply chains, including livestock supply chains, is scarce, with most work prioritizing generic production conditions or anonymizing producer identities (Goldstein and Newell, 2019). This is a missed opportunity. The companies that grow livestock feed, raise, and slaughter animals and that sell meat are often multibillion dollar corporations (Stull, 2017). In many countries, this industry is concentrated in the hands of a few large players with varying degrees of vertical integration along their supply chains. For instance, in the United States, four corporations of Tyson Food, Cargill, JBS SA, and National Beef control over 80% of America’s beef supply (Emel and Neo, 2015).

This market power and concentration makes these companies potent levers of change towards more sustainable livestock production.

This paper addresses these challenges through a case study of beef supply chains in California. This case study has two goals. First, we map the beef supply chain of one of America's largest beef retailers (Galber, 2016), Costco Wholesale Corporation (herein "Costco"), using a method called TRAcking Corporations Across Space and Time (TRACAST) (Goldstein and Newell, 2020). TRACAST allows us to identify Costco's linkages with beef suppliers and subsuppliers and to locate where the supply chain operates. Second, we investigate the environmental justice issues related to beef production in the California San Joaquin Valley, where many companies, including Costco, source their beef.

We focus on Costco for a number of reasons. Costco, with locations on four continents and nearly 100 million members, is the world's second largest brick-and-mortar retailer and one of the United States' largest beef retailers (Gabler, 2016). Moreover, alongside other large retailers and beef producers, Costco formed the U.S. Roundtable for Sustainable Beef (USRSB), a multistakeholder initiative to advance sustainability of U.S. beef producers. Although Costco uses a rotating roster of suppliers, they maintain a stable relationship with Harris Ranch Beef Company (herein "Harris Ranch"), which became a subsidiary of Central Valley Meat Company in 2019 to form the country's 7th largest beef producer. Harris Ranch operates the largest ranch in the Western United States, and it sells 70,000 tons of beef annually, making it California's largest producer (Castellon, 2019), and a powerful industry force in the state.

By examining linkages between different actors in the supply chain, we identify who acts as key nodes that shape environmental and socio-economic conditions along the supply chain.

Focusing on specific companies also provides richer insights into the relationship between supply chain governance and environmental outcomes than the study of generic industries and sectors. More broadly, revealing the origins of Costco's beef, where it came from, how it was produced, and who produced it e informs consumers of the unequal distribution of environmental burdens along Costco's supply chain, opening up multiple avenues to reorganize production and consumption around principles of equity and justice.

3.3 Materials and methods

To reconstruct Costco's beef supply chain in California, we used the TRACAST methodology, which blends concepts from theories of global production networks and global value chains with tools and data from industrial ecology (Goldstein and Newell, 2020). The method consists of four sequential steps that combine diverse data to build linkages between companies in supply chains, determine where they operate, and ascribe environmental and social *hotspots.* TRACAST helps identify *key nodes* of governance able to address those hotspots.

Our study focuses on the supply chain makeup from 2010 to 2020, while the $PM_{2.5}$ impacts are for the year 2017. To pinpoint hotspots across the entire supply chain, we examine all six stages of the beef supply chain: breeding, backgrounding on pasture, finishing on feedlots, slaughtering, distributing, and retailing. Feed crop production, which produces substantial $PM_{2.5}$ (Tessum, 2019), was not included due to data limitations. We focus on California, which after Texas, Nebraska, and Kansas, is the fourth largest beef producing state in the country (USDA, 2019a; USDA, 2019b).

3.3.1 Define study scope

Here we state the study goals, products to track, supply chain coverage, and spatiotemporal scope. Our goals are to partially map Costco's beef supply chain and to identify environmental impacts in the regions from which they source their beef. We focus on emissions of particulate matter less than 2.5 mm in diameter ($PM_{2.5}$) since there is no safe exposure level, and because of its confirmed links to asthma, heart disease, low weight birth, and lung cancer (Raaschou-Nielsen et al., 2013). We focus on beef, which is generally considered the most intensive meat in terms of greenhouse gases, resource demand, and local pollution (Eshel et al., 2014). We identify more than 40 beef suppliers to Costco; however, we selected one specific supplier -Harris Ranch- since it sells large volumes of beef to Costco. We use regulation agencies reports (USFS, 2011; SWRCB, 2015; USDA, 2019a) and academic articles (Mathews and Johnson, 2013) to construct the predominant beef supply chain in California.

3.3.2 Collect data

Here we collect and clean data needed to build linkages and identify hotspots. These data are either in-situ (interviews, surveys, site-visits) or ex-situ (trade data, company reports, and remote sensing data). We use the Harris Ranch website (www. harrisreanchbeef.com) to identify prominent retailers (node 6). We use certification programs, such as the 'Harris Ranch Partnership for Quality,' which certifies beef quality, to link Harris Ranch (nodes 3, 4, and 5) to find some of the cow-calf producers/breeding and backgrounders/stockers (nodes 1 and 2). Industry publications, like Angus Beef Bulletin, reveal links between Harris Ranch (node 3) and other cow-calf production and backgrounders (nodes 1 and 2). Field visits to retailers, such as Costco, verify linkages of Harris Ranch (nodes 3 and 4) to a few retailers (node 6).

External linkages between companies and influential actors outside the supply chain are useful in identifying levers to address environmental and social issues (Dauvergne, 2018; Ponte, 2019). Important linkages of this type include those with regulatory authorities (municipal, state, and federal), which we find using unstructured web searches. Non-Governmental Organizations (NGOs) are also active in monitoring and reforming the California livestock industry. We identify important NGOs through California Rangeland Trust and Sierra Club California (https://www. rangelandtrust.org/ and https://www.sierraclub.org/california). Lastly, we use reports by and websites of key industry groups, such as the California Beef Council, to capture their linkages to companies, NGOs, and regulators. For a full list of data sources used to build internal and external linkages, (see *Appendix D, Table 10)*.

For data on air quality, we use two sets of data from the National Emission Inventory (NEI) for statewide $PM_{2.5}$ emission (EPA, 2016) and $PM_{2.5}$ emission disaggregated by source (EPA, 2017), and the California Air Resources Board (CARB, 2017). For population and demographics data, we use National Census data in 2017 (American Community Survey, 2017). For health outcomes, asthma, low birth weight, and cardiovascular disease, we use California Office of Environmental Health Hazards Assessments dataset for the year 2017 (OEHHA, 2018).

3.3.3 Identify and validate linkages

This step builds internal linkages between companies within the supply chain and, occasionally, external linkages to other influential actors (e.g. NGOs and regulators). When using structured data, it is often possible to build linkages across supply chains using pivot tables, computer algorithms, or other automated processes (Goldstein and Newell, 2020). Here, we use document review to identify and build linkages from unstructured text documents (reports and websites).

Using this method, we construct all of the tiers of the Harris Ranch supply chain, stakeholders and retailers in *Appendix D, Figure 22, 23, and 24*.

We did not need to validate linkages through interviews and site visits because we are using self-reported data from the companies. It is often necessary to validate linkages when multiple sourcing streams mix at "pinch points" in the supply chain, for instance when backgrounders buy calves from numerous breeders and sell to numerous finishing operations. However, in California, breeding and backgrounding are often vertically integrated at a single ranch (Saitone, 2003), allowing us to assume a direct link from breeder to feedlot.

3.3.4 Evaluate environmental and socioeconomic hotspots

We use the NEI to determine $PM_{2.5}$ arising from different supply chain activities in each county, based on Source Classification Codes (SCCs). These SCCs describe specific human activities (e.g. manure spreading and truck transport) and related $PM_{2.5}$ emissions. We allocate $PM_{2.5}$ from cattle and calves on range/pasture (code 2805003100) to the nodes 1 (breeding) and 2 (backgrounding). Node 3, feedlots, is taken as dust emitted from bovine feedlots (code 2805001000). For node 4, slaughtering/processing, we used total emissions from all meat slaughtering facilities (code 2302010000), as the NEI does not disaggregate between cow, pig, and poultry slaughterhouses. Results show that this had a negligible impact on the analysis, due to the relatively small contribution of emissions at the slaughterhouse to the total emissions across the supply chain. NEI data do not include secondary $PM_{2.5}$ generated through emissions of $PM_{2.5}$ precursors at livestock facilities (Shih et al., 2008), and hence, can be viewed as a conservative estimate of air pollution burden from cattle. Emissions from nodes 5 and 6 are assumed negligible.

This approach lets us determine the pollution burden from the beef industry in all of California's counties. We also use tools from geography and remote sensing to document the co-location of livestock facilities and elevated pollution. We do this for all facilities, including those supplying Costco, to give both a sense of the problematic nature of beef production generally and to highlight Costco's contribution. We use the EPA Fused Air Quality Surface Downscaling (FAQSD) dataset to estimate annual average $PM_{2.5}$ concentrations across California for the year 2016, by linearly interpolating between estimates dispersed along a 12 km by 12 km grid (EPA, 2016). This produced a continuous surface of $PM_{2.5}$ concentrations across the state, which we then use to identify relationships between feedlots and air pollution. We also correlate distance to feedlot against race, poverty, and health outcomes (asthma, cardiovascular diseases, and low birth weight) at the census block-group level, to identify disparities in pollution burden from the beef industry in the San Joaquin Valley.

3.4 Results

Costco sources its beef from dozens of suppliers. Here, we outline the supply chain of one of their main beef suppliers, Harris Ranch. We detail this supply chain from retailer to feedlot back to pasture, finding that Costco is sourcing beef directly from pollution hotspots in California's San Joaquin Valley (Figs. 1 and 2). We then show how these hotspots coincide with higher poverty and negative health outcomes near feedlots in this part of California.

3.4.1 Harris Ranch — Costco beef supply chain

3.4.1.1 Node 1 — Cow-Calf Production

During cow-calf production, female cows, called heifers, produce calves for the beef industry and raise them to the age of 8e10 months. For Harris Ranch, node 1 occurs primarily in the San Joaquin

Valley, the Central Coast, areas east of Los Angeles and Lahontan (Fig. 2). In the San Joaquin Valley, Harris Ranch operates ten cow-calf facilities on a combined 248,000 acres from Yolo County to the top of the Tehachapi Range (SWRCB, 2015). On the Central Coast, they operate a total of 130,000 acres on two ranches east of the Salinas Valley, near Santa Maria (SWRCB, 2015). East of Los Angeles, they lease 230,000 acres of the Tejon Ranch, south of Bakersfield (Hereford World Magazine, 2010). In Lahontan, they operate the Chance Ranch, covering 9000 acres, and the Dressler, Sweetwater, and Point ranches, covering another 10,000 acres (SWRCB, 2015). Additional ranches are scattered around California, including 3000 acres in Inyo County, as well as activities in Santa Margarita and Montague (Angus Beef Bulletin, 2014; Hereford World Magazine, 2010).

3.4.1.2 Node 2 — Backgrounding/Stocker

Here, weaned calves are pasture-fed until they reach a weight of ~350 kg and are then sent to feedlots (node 3). As mentioned, many of the cow-calf operators are also stockers, and hence, nodes 1 and 2 are combined. However, Harris does source from dedicated stockers, such as Topo and Peach Tree ranches on the central coast (Figure 7).

3.4.1.3 Node 3 — Feedlots

Once big enough, beef cattle are sent to one of Harris Ranch's two feedlots where they gain ~150 kg in 200 days on a high-grain diet. The Harris Ranch feedlots are particularly large, with one containing as many as 250,000 cattle at a given time. Both are located in the San Joaquin Valley counties of Fresno and Tulare (Figure 8). Both counties have some of the worst air pollution in California (White, 2020).

It is worth noting that Harris Ranch was acquired in May 2019 by the Central Valley Meat Company (Fig. 1), making the two Harris Ranch operations an integral part of what is now the country's 7th largest beef producer. Central Valley Meat have supplied the National School Lunch Program since 2015, although their contract was suspended in 2012 for animal abuse, in 2014 for distributing plastic-contaminated beef, and in 2019 for hygienic reasons (US Department of Agriculture, 2012b; Meier, 2014; USDA, 2019c).

3.4.1.4 Node 4 — Slaughter/Processing — and Node 5 — Distribution

After reaching slaughter weight (~500 kg), cattle are sent to one of the Central Valley Meat Company's slaughterhouses, either the former Harris Ranch slaughterhouse or the Coelho Meat Company, another subsidiary of Central Valley Meat Company. These large plants slaughter and process up to 1500 cattle daily to produce both finished cuts of meat and prepared meals (e.g. beef-stuffed bell peppers). After this, products are distributed to a variety of customers through the Central Valley Meat Company Subsidiary Triple C Trucking Company.

3.4.1.5 Node 6 — Retail

Distribution to final customers occurs through three channels: direct retail via Harris Ranch branded retailers, wholesale and third-party retailers and restaurants. The Harris Ranch branded outlets include the Harris Ranch Inn & Restaurant in Fresno, California, which also has a store where customers can purchase beef. This location projects the image of Harris Ranch as a small-scale, bespoke purveyor of beef products, belying the reality that they are a subsidiary of one of the country's largest livestock producers. Customers can buy Harris Ranch products wholesale through CLW Foods Inc., also a part of the Central Valley Meat family.

The majority of Harris Ranch's products are sold by large and mid-size retailers throughout the western United States. It is at this point that beef from Harris Ranch enters the Costco beef supply chain. Other retailers selling this beef include Save Mart, Raley's, Grocery Outlet, and Broadway Market. Harris Ranch products are branded as "Western Premium Beef," "Blue Diamond Beef," and under the "Harris Ranch" label. The company also supplies restaurants, such as the prominent West Coast hamburger chain In-N-Out Burger. Harris Ranch also sells meat to international markets, including customers in China and Singapore through "One World Beef LLC" and to Japan (USMEF, 2017).

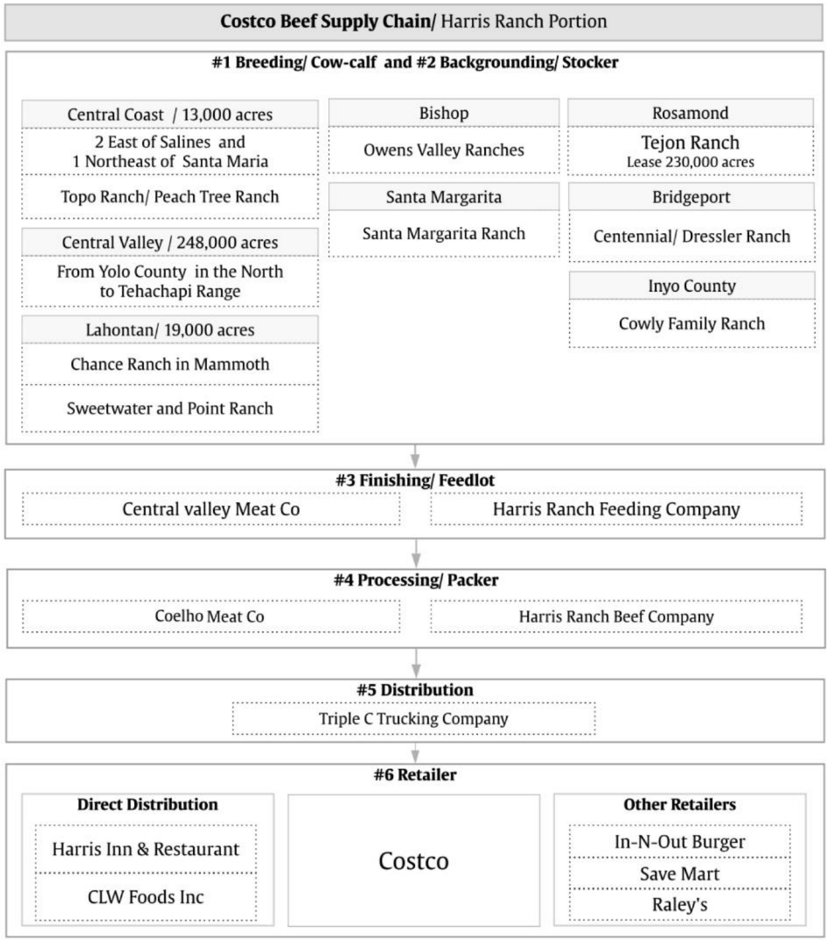

Figure 7. Costco beef supply chain in California

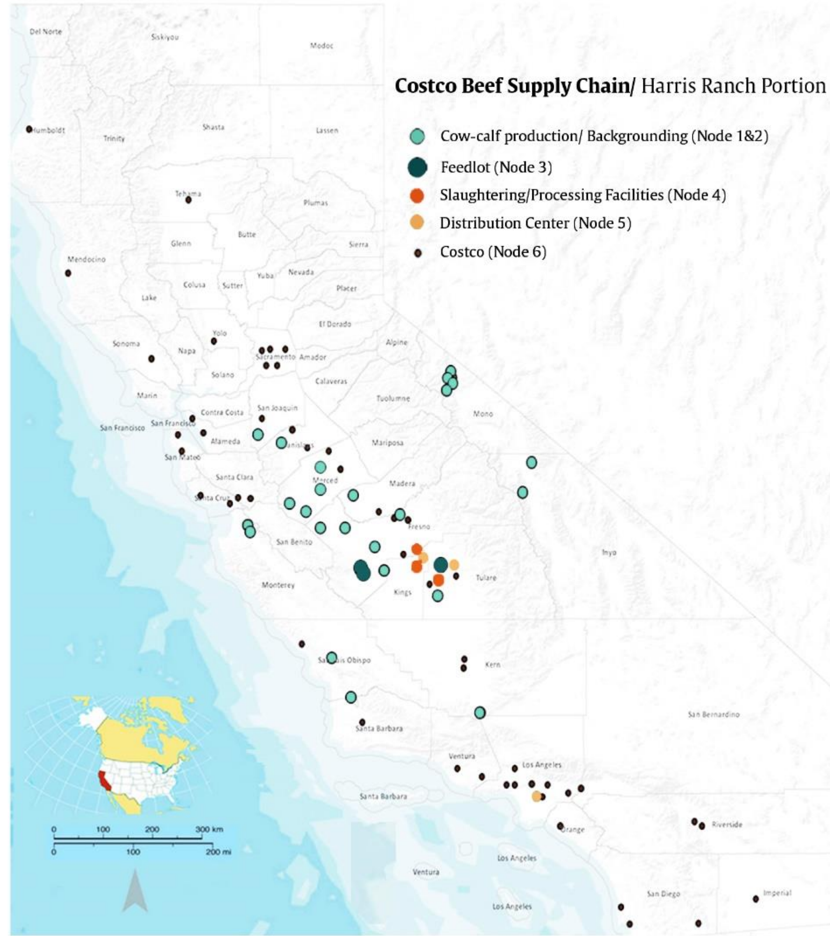

Figure 8. Physical flow of beef in Harris Ranch supply chain

3.4.2 Hotspots of particulate matter in California beef production

Here, we analyze air pollution at the different nodes along the California beef supply chain to identify the processes that emit the majority of $PM_{2.5}$ in 2017. We then use this knowledge to locate hotspots of air pollution in the California beef production landscape. *Figure 9A* displays daily average $PM_{2.5}$ concentrations across California in mg/m^3. The San Joaquin Valley in the heart of California is awash in air pollution, as are urban areas. *Figure 9B* breaks down total anthropogenic $PM_{2.5}$ emissions for the year 2017 across the San Joaquin Valley in mg/m^3. Over a third of these emissions stem from cattle operations. Five highly impacted counties in the San Joaquin, Tulare, Kings, Kern, Merced, and Fresno are intensely used for beef production. For instance, tax assessment records reveal that Kern County alone has more than 100 feedlots (CoreLogic, 2019).

We now look at the emissions from beef production by supply chain node. We focus on the cattle rearing and slaughtering/processing nodes of the supply chain since distribution and retailing produce negligible amounts of particulate matter in the beef life cycle (Asem-Hiablie et al., 2019). *Figure 10A* breaks down total emissions in the California regions based on the first four beef supply chain nodes: cow-calf, backgrounding, feedlots and slaughter. In all of the CARB regions, there is a prominent spike at the feedlot node of the supply chain. On average, the feedlot node accounts for 95% of total emissions from beef production. This makes sense, as feedlots house vast numbers of cattle on dusty ranches that are void of vegetation. These large, industrial feeding facilities are called Concentrated Animal Feeding Operations (CAFOs) in industry. Cattle hooves readily kick up dust and manure and urine produce $PM_{2.5}$ precursors, making CAFOs important sources of $PM_{2.5}$ (Bonifacio et al., 2015). Unsurprisingly, given that the San Joaquin

Valley contains more than 500 large CAFOs (>1000 animals), 67.5% of total emissions from beef production are concentrated in the area, identifying it as an environmental hotspot.

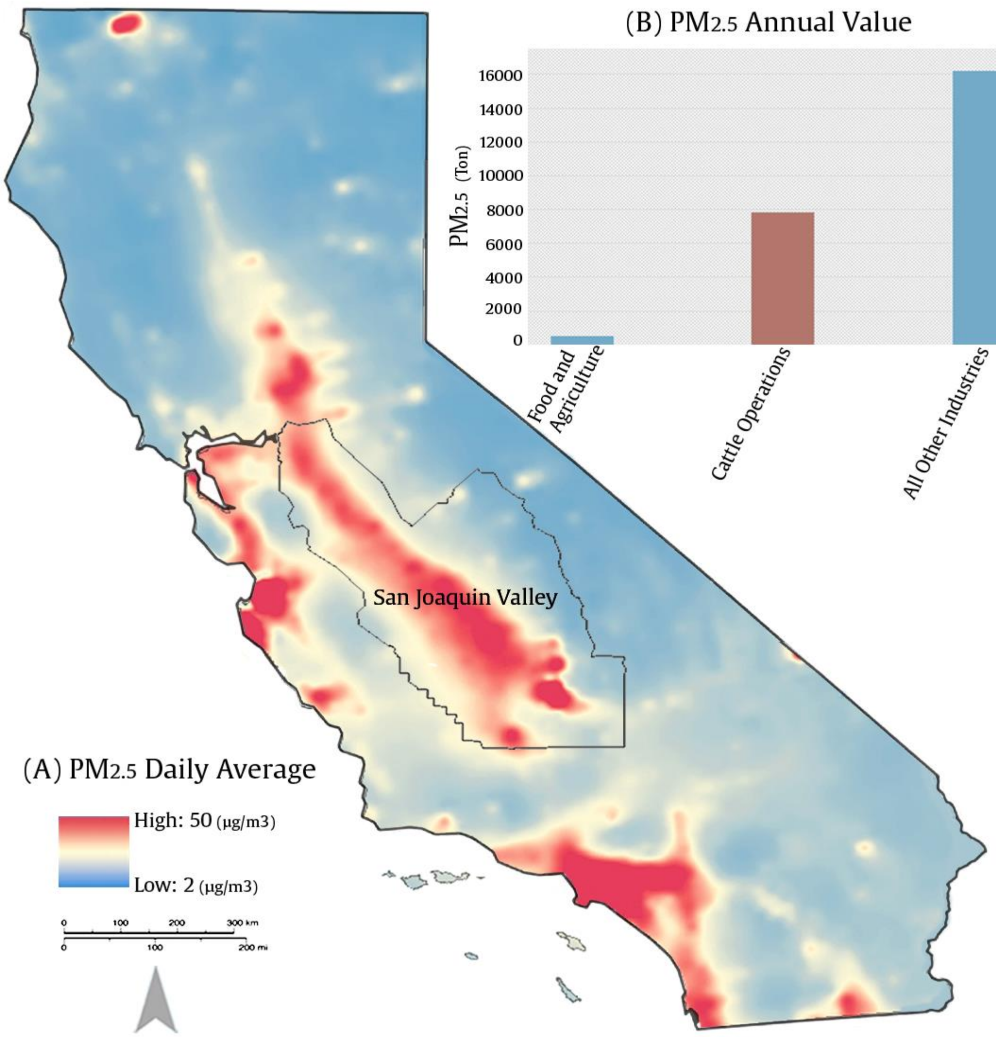

Figure 9. (A) $PM_{2.5}$ daily average (mg/m^3) in California (resource: EPA, 2017). (B) $PM_{2.5}$ annual value across different industries (Resource: CARB, 2017).

These emissions are contributing to chronic air pollution issues in the San Joaquin Valley where the annual average concentration of $PM_{2.5}$ for the year 2016 was 16 mg/m^3, exceeding both state and national averages, as well as the 12 mg/m^3 threshold set by both California and U.S. Environmental Protection Agency (*Figure 10B*). *Figure 11* plots the estimated annual average concentration of $PM_{2.5}$ in census block-groups in the San Joaquin Valley against their distance from the nearest CAFO. There is a clear inverse relationship between $PM_{2.5}$ concentration and distance (R-squared = 0.42), highlighting the important contributions that cattle production, and CAFOs specifically, to $PM_{2.5}$ in proximate communities.

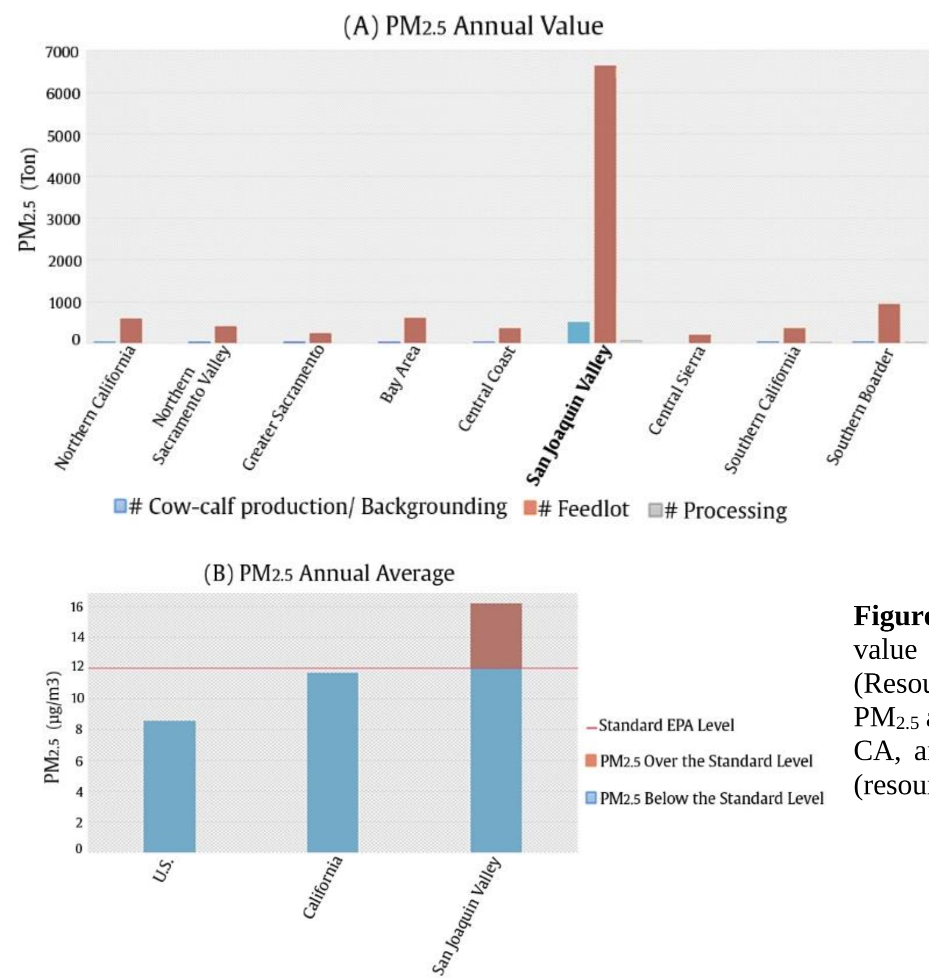

Figure 10. (A) $PM_{2.5}$ annual value (Tons) in CA regions (Resource: NEI, 2017). (B) $PM_{2.5}$ average (mg/m^3) in US, CA, and San Joaquin valley (resource: NEI 2017)

3.4.3 Environmental injustices around CAFOs

Our analysis shows that feedlots are a major source of $PM_{2.5}$ in the San Joaquin Valley. This is of concern, given that the American Lung Association estimates that the region experiences 40 days of unhealthy air annually and that it has up to 1300 premature human deaths occurring each year from noxious air e alongside countless emergency room visits and lost days of school and work (Meng et al., 2012; Padula et al., 2013; American Lung Association, 2019).

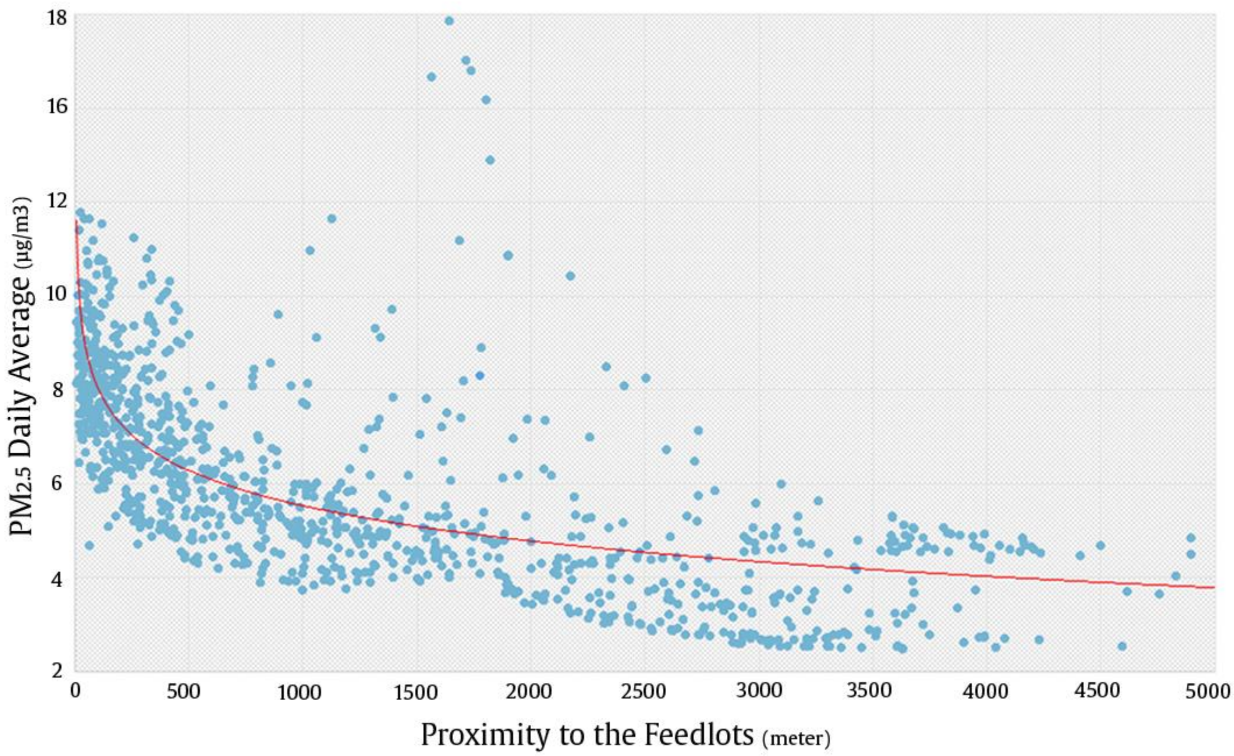

Figure 11. $PM_{2.5}$ concentration (mg/m^3) and proximity to the feedlots.

We now look for links between the distance from feedlot (locations from CoreLogic, 2019) and disease burdens to see if beef production in the San Joaquin Valley affects health outcomes in proximate communities. We compare the rates of asthma, cardiovascular disease, and low-birth weights in block-groups within and outside a 1 km buffer from the nearest feedlot. We use Student's tests at the 95% confidence-level to explore links between block group proximity to a CAFO, demographics, and health outcomes. *Figure 12A* shows that for all three indicators, block-groups near a feedlot have markedly higher negative health outcomes. Asthma rates are 23% higher (p-value <2.2e-16), cardiovascular disease rates are 29% higher (p-value <2.2e-16), and rates of low-birth weights are 8% higher (p-value <2.2e-16), within 1 km of a feedlot (see *Table 4* for full t-test results).

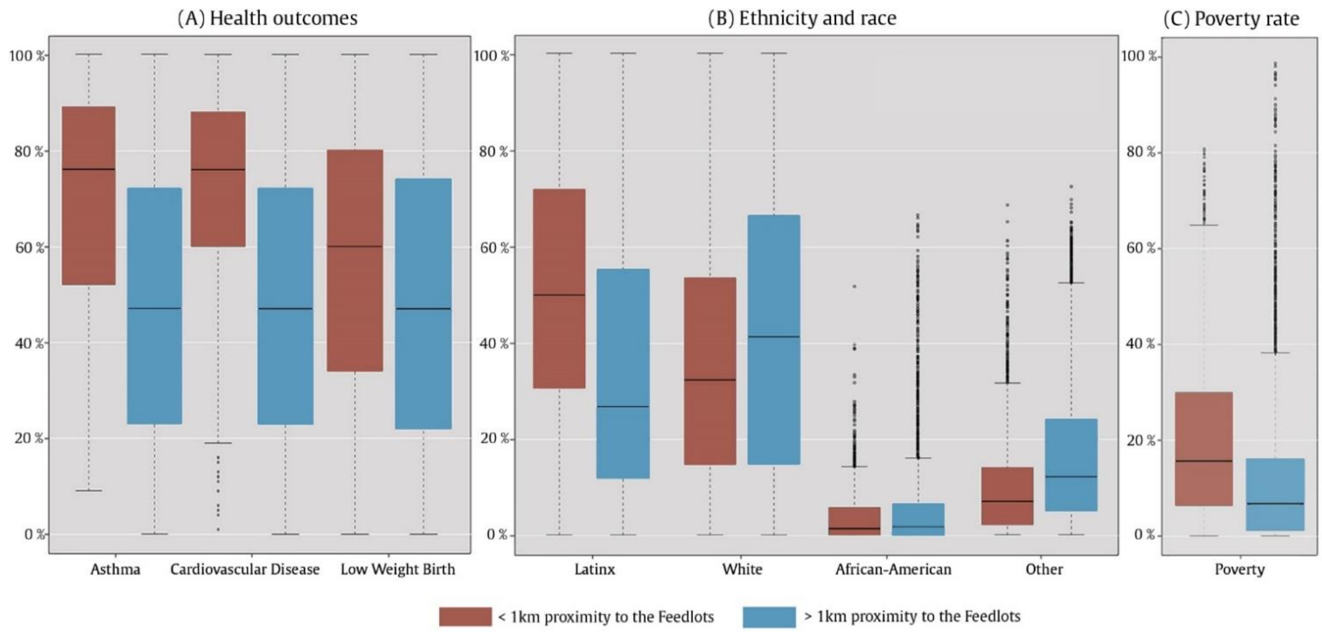

Figure 12. Environmental justice and cattle feedlots in California's Central Valley. Box plots of health outcomes (A), ethnicity and race (B), and poverty rate (C) of census block-groups less than 1 km from a feedlot and more than 1 km from a feedlot (Resource: American Community Survey, 2017; OEHHA, 2018).

Table 4. Attributes of census block-groups within 1 km of feedlot in California's San Joaquin Valley. Student's t-test results showing difference of mean compared to block-groups more than 1 km from a feedlot.

	T-test	p-value	95% confidence interval	
Percent Hispanic	26.638	<2.2e-16	0.14869	0.17056
Percent White	-12.683	<2.2e-16	-0.07789	-0.05703
Percent African-American	-9.6125	<2.2e-16	-0.01763	-0.01166
Percent Other	-31	<2.2e-16	-0.082418	-0.07261
Percent Poverty	25.473	<2.2e-16	19.79269	10.66257
Percent Asthma	23.678	<2.2e-16	19.72913	23.29476
Percent cardiovascular Disease	29.008	<2.2e-16	22.56286	25.83667
Percent Low-Birth weight	8.1165	<2.2e-16	6.572507	10.76433

We use census data from 2017 to explore which population groups are most burdened. *Figure 12B* compares the percentages of different races within and outside a 1 km buffer from the nearest feedlot. Hispanics bear a disproportionate amount of this pollution. The proportion of Hispanic residents rises by 26% near feedlots (p-value <2.2e-16), while the percentage of every other race is lower. A partial explanation for this finding may be the large contingent of Hispanics, both seasonal migrants and year-round residents, that work in U.S. agriculture (Holmes, 2013). Looking at the economic characteristics, we find that poverty rates are 25% higher in the vicinity of feedlots (p-value<2.2e-16).

Thus, we can see a clear environmental justice issue around the feedlots of the San Joaquin Valley. $PM_{2.5}$ concentrations are higher the closer one gets to beef producers, often exceeding federal guidelines. This pollution has no safe level and is associated with multiple health ailments, all of which are present at higher rates near feedlots. Census data suggest that historically marginalized populations, namely Hispanics and the poor, are the most affected.

3.5 Discussion

Our analysis showed that the beef and dairy industry accounts for one-third of the $PM_{2.5}$ emission in California. These emissions stem largely from the feedlot node of the supply chain, which is concentrated in the San Joaquin Valley along with 80% of total emissions from California beef production. CAFOs are situated near poor and Hispanic communities, where emissions are concentrated, and related disease burdens are higher. This injustice is hidden from consumers upstream in the beef supply chains of companies such as Costco.

Our example of particulate matter is but a glimpse of the myriad of environmental impacts from beef production in California. The sheer number of cattle confined at a feedlot makes these facilities considerable sources of other forms of air pollution (e.g. GHG emission, Nitrous Oxide and Methane emission, Ammonia deposition) and water pollution (e.g. Nitrogen and Phosphorus) (Wolch et al., 2017). Smaller, but significant, amounts of pollution from manure also arises during the first two nodes of the supply chain (cow-calf production and backgrounding), alongside land degradation from grazing (Xiong et al., 2010; Wolch et al., 2017).

Retailers are indirectly implicated in these challenges by virtue of the large quantities of beef they source and sell within California. Below, we propose actions that beef producers and retailers can take to become more sustainable using Harris Ranch and Costco as examples. We conclude with a discussion of methodological considerations.

3.5.1 Harris Ranch: reducing particulate matter at the CAFO

Harris Ranch is a hotspot for particulate matter in the Costco beef supply chain. Harris Ranch and its owner, Central Valley Meat Company, have vertically integrated operations, directly controlling production from the cow-calf stage (node 1) all the way to processing and final distribution (nodes 4 and 5). The supply chain management literature has demonstrated that vertically integrated supply chains, with their top-down command structures and stakeholder unity, are ideal cases for the effective implementation of policies (Rueda et al., 2017). This carries over to environmental sustainability, where there are numerous examples of companies successfully transmitting rules across their supply chains to reduce pollution and resource use (Costantini et al., 2017).

There are a number of policies that Harris Ranch could implement to reduce their $PM_{2.5}$ emissions. One dust control strategy at CAFOs is the use of sprinklers to keep manure and topsoil from drying out and becoming airborne when disturbed by hooves (Spellman and Whiting, 2007), but this is not used by Harris Ranch. Importantly, this technology would increase the cattle industry's copious water use in a region that already faces significant water stress. Moreover, this technology is only marginally effective in semi-arid regions like the Central Valley (Preece et al., 2012). Another less ambitious option is to remove manure before it dries, but it does not address the dust arising from topsoil (Spellman and Whiting, 2007).

Ultimately, these policies focus on increasing eco-efficiency by reducing the pollution burden per cow. Some argue that this addresses symptoms and not causes. Due to the untold amounts of pollution emanating from CAFOs, The American Public Health Association recently called for a moratorium on new CAFOs, a sentiment echoed in public opinion polls (APHA, 2019). Switching to a free-range model also imparts environmental costs. For instance, Harris Ranch's cow-calf/backgrounding operations already encroach on watersheds that supply Los Angeles as well as into national forests, including the Inyo, Los Padres, and Toiyabe (USFS, 2011; SWRCB, 2015). Moving their entire supply chain to a free-range model would likely mitigate dust, but this would need more land, water, and feed to raise the animals to slaughter weight (Navarrete-Molina et al., 2019).

Regardless, Harris Ranch has shown little inclination to self-govern its environmental impacts. Instead, the company has used its substantial power to influence the public perceptions and regulation of the California beef industry connections to non-supply chain actors (external linkages). For instance, the company has been accused of trying to influence the curriculum of “sustainable agriculture” at the Cal Poly in San Luis Obispo (Brown, 2010). Another important external linkage is Harris Ranch’s membership with the National Meat Association and the North American Beef Association. Both organizations have worked to stymie stricter regulations of air pollution from CAFOs, particularly through campaign donations to a cadre of California lawmakers who voted for the “Limit Regulations of Farm Dust” bill in 2011, which curbed Federal EPA authority to regulate dust from CAFOs (H.R.1633 - Farm Dust Regulation Prevention Act of 2011).

3.5.2 Implications for Costco

Costco sources beef for its California stores from multiple producers. Although Harris Ranch is one such supplier, it typifies many of the others who also operate CAFOs in the San Joaquin Valley and also maintain memberships in beef industry associations that lobby against regulating CAFOs (Johnson, 2002). How should Costco and other retailers address the unequal pollution burdens in their beef supply chains?

Costco has committed to reducing the environmental impacts from beef, for instance by not sourcing from Brazil due to links between the Brazilian beef industry and deforestation for feed and pastures, although contrary to this commitment there is evidence that Costco still sources from Brazil through JBS SA (Kindy, 2019). Moreover, Costco has not addressed the environmental issues from beef in its own backyard. The company, alongside Harris Ranch, is a member of the recently formed U.S. Roundtable on Sustainable Beef. This multi-stakeholder initiative aims to facilitate knowledge sharing between companies across the beef supply chain to improve the environmental and economic sustainability of the U.S. beef industry (https://www.usrsb.org/). Although laudable, it is uncertain how effective this initiative will be. Similar initiatives, for instance in palm oil, have allowed industry stakeholders to control the definition of sustainability for their industry without having to meaningfully reduce their environmental impacts (Dauvergne, 2018). Environmental sustainability, according to the beef roundtable's inaugural annual report, means increasing eco-efficiency around a set of vague indicators (e.g. water resources, land resources, employee safety, and well-being, etc.) (Buckley et al., 2019). Moreover, the lobbying activities of many members counteract Roundtable goals (Ramhormozi, 2019). The ability for the beef industry to address its significant environmental burdens in the San Joaquin Valley might be a litmus test for the efficacy of the Roundtable.

Costco has other options to source beef more sustainably. One option is for Costco to implement a policy requiring beef producers to implement effective air pollution controls at CAFOs. This would mean both documenting CAFO locations, technologies in place and monitoring outcomes. The ability for Costco to do this depends on their power over their suppliers. Research on global value chains shows that transnational corporations have been able to successfully make sustainability demands on their suppliers when the buyer has significant bargaining power (Ponte et al., 2019). Costco has additional approaches to consider if this is not the case. Instead of trying to influence current producer practices, it can switch to producers that do not lobby against stricter air pollution regulations or to those who do not use CAFOs. The latter would present a procurement challenge given Costco's immense beef demands since free-range beef makes up less than 5% of total U.S. production (USDA, 2019b). However, even a limited commitment to source a percentage of CAFO-free beef by Costco or another prominent retailer could catalyze positive change in the industry.

A more passive approach is transparency. Costco could work with suppliers to publish their beef supply chains, much like some of the world's largest food conglomerates have done with their supply chains of palm oil, cocoa, soy, and coffee (Pacheco et al., 2017; Grabs and Ponte, 2019; Ponte, 2019). This would put their beef suppliers under public scrutiny, making Costco and individual suppliers accountable for producing beef that degrades land, pollutes water and air, or affects the health and livelihoods of nearby communities. Making the domestic impacts of beef more visible could also spur consumer demand for more sustainable beef options, prompting Costco and other suppliers to oblige. For instance, big retailers like Walmart and Costco sell an array of certified organic products, not necessarily because they are concerned about the environment, but because consumers wanted these products and because these retailers realized they could earn greater profits by selling them (Ponte, 2019).

3.5.3 Policy recommendations

U.S. EPA has the authority to address CAFO air emissions through several federal environmental laws, including the Clean Air Act (CAA), which has two basic elements: nationwide air quality goals and individual state plans designed to meet those goals. CAA authorizes EPA to require any owner or operator of an emissions source to monitor and to report any information that EPA may require to determine whether a source is violating CAA requirements. Historically, EPA has only permitted and initiated enforcement actions against CAFOs under the Clean Water Act (CWA), primarily because CWA regulations have been in place since the early 1970s. However, failure to meet the recently upheld standards means that public health will continue to be at risk. While regulators have not been very strict in enforcing these requirements, the CAA is nonetheless a strict liability statute and it is well-settled that the burden is on the emissions source, not EPA, to know its emissions and comply with the law. Industry lobbyists have been able to effectively undermine enforcement of the CAA, jeopardizing public health and the environment. At a minimum, EPA needs to investigate air emissions at the largest industrial-sized facilities that present the highest risk, seek monitoring, and, if necessary, require them to install control technologies.

There is a need to limit operations in places where that are already overburdened with the air pollution from CAFOs such as San Joaquin Valley of California. Big agribusiness companies should take full responsibility to remove excess manure from their operations and ensure its sustainable use elsewhere. Big retailers such as Costco should use their leverage in the marketplace to insist on reduction of air pollution from their suppliers, and support more locally small supply chains instead of factory farms. EPA must ban the worst practices including waste piles or lagoons and the over-application of manure or other fertilizer, and it must establish moratorium on new or expanded CAFOs, especially in places already loaded by air pollution. EPA must make big retailers such as Costco to be legally responsible for air pollution produced by different producers that have contract with. With serious inspections, California EPA must ensure that repeated or serious violations of CAA are met with real penalties for both producers and retailers, and where states are failing to protect Citizen's health, US EPA must step in. The courts should uphold the clean air regulations to ensure federal protection for all citizens. EPA must provide the public with access to detailed information about the CAFOs and preserve the right of local communities to reject industrial scale livestock operations impacting their health and the quality of life where they live.

3.5.4 Methodological reflections

This paper combines life cycle thinking with environmental justice concerns in order to address research gaps in each area. By looking across the entirety of the beef supply chain, we were able to characterize $PM_{2.5}$ pollution at multiple supply chain nodes and ensure that we focused on environmental justice issues where they were most acute. Although we ended up focusing on the same node as other environmental justice studies (Table 1), this might not be true for other supply chains where hotspots occur at unexpected production processes. The supply chain perspective also lets us link consumption to distant impacts. This contrasts with much of the environmental justice literature, which often does not link producers to consumers along product life cycles (Hoffman, 2013).

Conversely, taking an environmental justice perspective grounded the study in those specific places most burdened by beef production. This not only incorporated spatiality into life cycle thinking, with potential impacts for how life cycle assessments could be performed (Chaplin-Kramer et al., 2017), but it also embedded the production system in a particular socio-economic context. Particulate matter from beef production in the Central Valley is not purely the result of inefficient production, but an outcome of deliberate political maneuvers by powerful agricultural interests in a region that is dependent on the livestock industry for jobs and tax revenues (Nunez, 2019). Such insights can help identify the mix of technological and social aspects of beef production that need to be amended to address the environmental injustices near CAFOs.

The TRACAST methodological framework and its focus on specific companies allowed us to map the supply chain to particular locations and capture external linkages that influence production conditions. Future work should focus on quantifying these linkages. For instance, quantifying trade between Costco and Harris (monetary or mass) would allow us to ascribe a certain volume of the environmental justice impacts to Costco and its consumers. Trade flows also hint at relative power in the supply chain. For instance, if Harris Ranch is a captive supplier that sells 90% of its beef to Costco, then Costco's ability to dictate conditions at Harris Ranch's CAFOs is much stronger than if Harris Ranch sells 10% of its beef to Costco (Gereffi et al., et al., 2005). Interviews and qualitative analysis can provide further context. Taking a systems approach across the supply chain can help clarify the links between supply chain form, governance dynamics, and environmental justice outcomes.

3.6 Conclusions

In recent years, more and more consumers want to know the 'story' behind the product. Consumers increasingly demand transparency in corporate supply chains. However, distance, multiple transacting companies, and supplier fluidity keep most supply chains opaque (Goldstein and Newell, 2020). This makes it difficult to know if the products we consume have positive or negative impacts on the people and places that produce them. LCA provides a window into the scale of environmental impacts and the processes that drive those impacts. Environmental justice looks at the unequal concentration of impacts on specific peoples and places, often at one spot in a supply chain. A lack of research on the specific corporate supply chains hampers more sustainable production and consumption (Goldstein and Newell, 2019).

This chapter addresses some of these challenges through a case study of $PM_{2.5}$ emissions from beef supply chains in California. Using the TRACAST methodological framework, we map the beef supply chain of Costco, America's largest beef retailer (Galber, 2016), and construct linkages with beef suppliers and sub-suppliers at high geographic specificity. We find that feedlots, concentrated in the San Joaquin Valley, are the hotspot for $PM_{2.5}$ in this supply chain. These large cattle operations, also called CAFOs, are situated mostly near Hispanic and low-income communities.

Costco and many other retailers source their beef from this environmental hotspot. Telling this 'story' opens up opportunities for these companies to start redressing this environmental injustice through amended production practices, such as by switching from CAFOs to free-range cattle or by changing suppliers. A relatively new multi-stakeholder initiative, the U.S. Roundtable for Sustainable Beef, aims to address pollution from the industry, but its efficacy has yet to be determined. Pressure from civil society and consumers to adhere to the goals of this initiative could compel Costco to directly address this challenge. It might ultimately require command and control measures by regulators or demand for more sustainable beef by consumers to meaningfully address the myriad of environmental and social issues stemming from industrial beef production.

Chapter 4

Power Asymmetries in Supply Chains and Implications for Environmental Governance: A study of the beef industry

This chapter is prepared as a journal article as

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4.1 Abstract

Supply chain governance constitutes the rules, structures, and institutions that guide supply chains towards various objectives, including environmental and social responsibility. Previous supply chain studies have provided insight into the relationship between governance and environmental sustainability but have overlooked two crucial dimensions: power dynamics and the influence of outside actors. The distribution of power among companies within a supply chain can foster sustainable outcomes or foment mistrust and conflict. Key outside actors (such as NGOs and regulatory agencies) can influence the environmental and social outcomes of supply chains. This chapter addresses these two gaps by measuring differential power (i.e. power asymmetries) among

actors across the supply chain, including external actors. We do this through a structured survey in which supply chain participants rank their peer's ability to affect environmental and social outcomes. We test this approach by surveying 200 industry professionals (e.g. feedlot operators, retailers) and external actors (e.g. NGOs) in the U.S. beef sector. Respondents ranked the most powerful actors as: 1) feedlot companies; 2) processing operations; and 3) regulatory agencies. The identification of regulatory agencies highlights the importance of external actors in supply chain governance. Results also revealed that trade associations, retailers, and cow-calf producers and backgrounders perceive a sense of powerlessness, which can hinder sustainability. This study provides a replicable approach for those interested in measuring and mapping perceptions of power (and related governance) in supply chains.

4.2 Introduction

Supply chains span multiple nodes, from sourcing to manufacturing and transportation, to the final point of sale. These networks are complex webs that include numerous companies (*internal nodes*) and stakeholders (*external nodes*), such as NGOs, governments, and marketers (Bartley, 2018). Companies face pressure from both internal and external nodes to develop and operationalize corporate codes of conduct to produce goods that are more environmentally and socially sustainable. This pressure is a form of supply chain governance in which institutions and organizations, through policies, regulations, standards, training, technology transfer, and financial incentives (Vurro et al., 2009), promote sustainable and socially responsible supply chains. Governance, however, does not occur spontaneously or automatically. Supply chains are governed by contracts, policies, codes of conduct, and other instruments and wielded by powerful actors in these chains (Ponte, 2019). As such, recognizing the underlying power dynamics– the potential to control a particular outcome and create change – in a chain is central to understanding supply chain governance (Touboulic et al., 2014).

Power dynamics play an important role in shaping supply chain environmental and social sustainability (Touboulic et al., 2014). Power emerges from the dependencies, and control over certain resources within and between companies (Provan, 1980). If one organization obtains a larger share of benefits resulting from a given relationship, then power asymmetry emerges (Ramsay, 1996). Much of the literature on power in supply chains assume that actors who are more powerful tend to exploit power for their own benefits. Many scholars acknowledge that power asymmetry works in favor of the powerful actors through manipulating the decisions in the supply chain (Donaldson, 1995; Pfeffer, 1997, chap 3; Muthusamy and White, 2006). Under an unequal relationship, exploitation rather than cooperation might result, (He et al., 2013), while an equal power structure results in cooperation towards a specific goal in the supply chain (Muthusamy and White, 2006). However, building long-term relationships in supply chains is inherently time consuming to develop and maintain (Newbert & Tornikoski, 2013) Equal distribution of power in a supply chain might be hard to achieve. Power doesn't have to have a negative meaning; it depends on the governance dynamics of the chain (Gereffi et al., 2005).

On the other hand, several authors identified power asymmetry as a mediation to safeguard codes of conduct (Pederson & Anderson, 2006), to establish corporate social responsibility (Boyd et al., 2007), and on sustainable performance (Pullman et al., 2009). Therefore, the important question is, who has the power in the supply chain and how do they choose to use it? We need empirical studies to see the distribution of power in a specific supply chain, especially in the environmental and social sustainability arena to understand how this distribution can benefit all the actors in the chain. Literature suggests that power asymmetry is especially relevant for the food sector, where a highly collaborative perspective might be idealistic (Pullman et al., 2009). Power asymmetry may enable the introduction and monitoring of environmentally and socially sustainable practices (Hall, 2000; Preuss, 2001).

Power asymmetry was initially understood as the role of lead companies as the powerful economic actors in commodity chains (Gereffi, 1990). Early work by Gereffi identified buyer-driven vs producer-driven supply chains. In the case of the former, end nodes of the chain (e.g retailers and consumers) use power asymmetry to drive standards and requirements up the chain thereby affecting its input-output structure, territoriality, and governance. Conversely, in producer-driven chains, producers (e.g. manufacturers, processing plants) use power asymmetry to shape this structure, territoriality, and governance in both downstream and upstream nodes of the supply chain. To do this, powerful actors use mediated versus non-mediated power. Mediated power is exercised purposefully by the powerful actors through rewards and exercise, while non-mediate power is created by the perceptions of other actors in the chain regarding who has knowledge or expertise in a specific area (Benton & Maloni, 2005). Although mediated power may bring conflict to the chain, non-mediated power can increase the positive appraisal of cooperation in the chain (Ponte, 2019). The dyadic idea of buyer-producer relationships is well-established in the literature, however, the perceptions of other internal and external nodes in the chain regarding who holds the most power with respect to a particular subject are a less explicitly researched area (Ponte et al., 2019). Studies have shown that the perception of who holds power in a supply chain (non-mediated power) plays an effective role in strengthening the relationships and can serve as a driving force toward environmental and social sustainability in a chain (Cox et al., 2002).

This perception of power includes external nodes managing supply chain relationships, which raises unique challenges that require stakeholder engagement in the supply chain (Bartley, 2018). For example, the food sector has been experiencing increased pressure from external nodes (e.g., NGOs) to achieve a set of diverse goals, ranging from improving food safety to sustainability to increasing transparency (Bartley, 2018). The do this, NGOs' campaigns often employ tactics like associating well-known brands to negative practices in their supply chains (Madichie & Yamoah, 2016). "Naming and shaming" is considered as one of the key strategies in voluntary approaches to induce duties across the supply chains (Madichie & Yamoah, 2016).

For example, after a massive public shaming and disapproval due to labor violation in the 1990s, which resulted in profit loss and reputation for Nike, the company implemented a strict corporate social responsibility (CSR) to its chain (Waller & Conaway, 2011). However, the success of NGOs' campaigns depends to a great extent on targeting the right node, the node that can induce change to the supply chain. NGOs are usually targeting the visible actors (retailers and the big brand name producers) in the chain, although they may not actually have the ability to change the outcomes of the chain. For any product, therefore, the success of external actors in motivating social or environmental change is constrained by their understanding of power within a supply chain. It is essential to have a more nuanced understanding of power to make meaningful changes in the supply chain.

In the food sector, power relations are rarely investigated, and the few empirical studies that do exist focus primarily on economic profitability (Boström et al., 2015). The majority of research in this area is either conceptual (e.g., Cox, 1999, 2004; Cox et al., 2001; Crook & Combs, 2007) or descriptive (e.g., Ogbonna & Wilkinson, 1998; Watson, 2001), and most studies of supply chains have relied on *qualitative* methods to derive theoretical and practical insights (Harland et al., 2001). Moreover, as the theoretical lens is expanded to a holistic approach of supply chains, the empirical work on power has been limited to the producer-buyer relationship (Dallas et al., 2017), which is often perceived as being negative (Nair et al., 2011). This focus on a single relationship is helpful and has revealed consistent communication and collaborative relationships between them (Crook & Combs, 2007), but does not provide much insight into the complex relationships in chains. Therefore, there is a profound need in supply chain governance studies for an empirical study that quantifies power across the *entire* chain, considering all internal and external nodes. In this study, we combine a structured survey with Social Network Analysis (SNA) to measure perceived power amongst internal and external nodes in supply chains. We use this approach to map and quantify the power relations within the beef sector in the United States. We include all internal nodes, from production to consumption, as well as all external nodes, such as governmental agencies, NGOs, trade associations, and the media (Goldstein & Newell, 2019), as efforts to improve sustainability takes place through a collective of actors (Bartley, 2018).

We focus on beef because of the global environmental impacts associated with livestock production. Livestock supply chains are increasingly under scrutiny for their contribution towards GHG emissions, air pollution, excessive water use, land degradation, and labor issues (Rojas-Downing et al., 2017). Although academics have studied ways to improve the sustainability of livestock production, there have been few attempts to identify which actors in livestock supply chains have the power to direct or implement these improvements. To address this fundamental gap, this paper builds on an in-depth case study to quantify power across the supply chain., We focused on five environmental and social indicators (GHG emissions, water use, air pollution, land use, and employee safety and well-being). These indicators are identified by the US Roundtable for Sustainable Beef (USRSB)- a multi-stakeholder initiative to advance sustainability of the US beef value chain- as indicators of sustainability in the beef supply chain. Our study addresses the following research questions: 1) Who has the most power (or the ability to change the outcomes) in the beef supply chain overall and each of the environmental and social indicators introduced by USRSB? and 2) Is there a power asymmetry between internal and external nodes of the supply chain?

Although our case-study approach confirms the beef supply chain as a producer-driven chain in general, it reveals multiple power nodes based on each indicator. Therefore, the dichotomy of buyer-producer might fall short of capturing the complexities of supply chains' governance structure. Our results reveal power asymmetries across the beef supply chain with production phase nodes (feedlots, processing plants, backgrounders/cow-calf, and feed producers respectively) perceived by other actors to hold the most power. Results also indicate that retailers and consumers in the internal nodes and NGOs, trade associations, and media in the external nodes are perceived to have the least ability to change supply chain outcomes. Our results confirm feed producers as the hidden node of the supply chain with power, which is often dismissed from the supply chain decision making. Although our study shows governmental agencies as the third powerful node of the supply chain, there is a significant power asymmetry between internal and external nodes of the chain. This significant power-differential between internal and external nodes as well as between producers and retailers has led to a power consolidation in the U.S. beef supply chain.

This novel approach to quantify power dynamics across the supply chain provides practical insight based on theoretically grounded research in supply chain governance. Uncovering differential power dynamics has the potential to improve the effectiveness of supply chain governance by developing opportunities for stronger cooperation and coordination among supply chain actors to bring about positive change. The structure of this chapter is as follows. Section 2 summarizes the literature on how power asymmetries affect supply chain governance dynamics and identifies research gaps. Section 3 describes our survey and SNA methodology, followed by our results (Section 4). In the final section, we discuss our findings and consider their implications for supply chain governance broadly.

4.3 Literature review: power asymmetries and supply chain governance

Power – one party's ability to enforce its will on another party even against resistance (Emerson, 1962) – has been recognized as an important aspect of supply chain governance (Benton & Maloni, 2005). In supply chain relationships, power might be used to demand a higher share of value (economic, social, etc.) that exists in the supply chain (Crook & Combs, 2007). While supply chain studies have emphasized the benefits of collaboration for joint value creation, much less attention has been paid to how the distribution of power among the involved parties in a supply chain also has a huge impact on value creation (Crook & Combs, 2007). Resource dependence theory offers a theoretical lens to explain how power differentials arise in supply chain relationships (Pfeffer & Salancik, 1978). It suggests that an organization must engage in transactions with other organizations to acquire resources. Although these transactions might be beneficial, they may also result in unequal exchanges, which creates differences in power, control, and access to other resources (Pfeffer & Salancik, 1978). The degree of the power differential depends on the shared value creation over time (Reimann & Ketchen, 2017). Differences in power create power asymmetry when one node is recognizably more influential and can exercise control over other nodes of the supply chain (Casciaro & Piskorski, 2005).

Although power asymmetry can bring conflict to the chain when there is no shared value creation (Reimann & Ketchen, 2017), it can bring stability to the chain in other circumstances. The literature suggests that the presence of more powerful nodes within the supply chain maintains the stability of the chain by establishing corporate social responsibility between supply chain partners (Byod et al., 2007), sharing sustainability practice costs and performance (Pullman et al., 2009), and auditing sustainability practices (Hall, 2000). Power asymmetry was initially derived from the "group of lead actors" (i.e., producers or buyers) that has historically played a critical role in resource allocation, value creation, and including or excluding other actors in the chain (Gereffi & Korzeniewicz, 1994; Gereffi et al., 2005). Gereffi (1994) famously introduced the concept with his paper on producer- versus buyer-driven chains. Producer-driven chains, usually a characteristic of capital- and technology-intensive industries, are those where manufacturers play the central role in coordinating the production network (Gereffi, 2001; Gereffi et al., 2005). Buyer-driven supply chains are those where large retailers and branded manufacturers, such as Walmart and Nike, play pivotal roles in chain organization and coordination (Gereffi, 2001; Gereffi et al., 2005). These supply chains have five different typologies - hierarchy, captive, relational, modular, and market – which range from high to low levels of power asymmetry, and low to high levels of explicit coordination respectively (Gereffi et al., 2005).

To lead the supply chain, powerful actors use mediated versus non-mediated power. Mediated power is used purposefully by the powerful actors through rewards, such as raises or promotions (i.e., reward power) or punishment (i.e., coercive power) (Benton & Maloni, 2005;

Ponte, 2019). Non-mediated power is created by the perceptions of other actors regarding who holds power regarding a particular subject; this can be in the form of knowledge or expertise (i.e., expert power), of being highly esteemed in that subject (i.e., referent power), or of actual authority in a subject (i.e., legitimate power) (Benton & Maloni, 2005; Ponte, 2019). Studies have found the existence of non-mediated power can strengthen the relationships among the nodes of a supply chain and suggest that it might be effective in long-term compliance demands (Handley & Benton, 2012). The perception of who has the power among supply chain actors plays an essential role in supply chain governance (Tedeschi and Bonoma, 1972); it can set the "rules of the game" by instilling a sense of dependence among weaker actors in the supply chain, which can result in act per the standards, codes of conducts and certifications from powerful actors (Luke, 1986). Therefore, realizing who has the power in the chain equals inducing change to the supply chain.

The idea that dyadic buyer-producer relationships are shaped by relative bargaining position in the chain is well established in the literature (Ponte, 2019). However, the non-mediated power dynamics, which result from the perceptions of a collective of actors across the chain, are a less explicitly researched area (Ponte et al., 2019). The 'collective of actors' can be internal nodes such as producers and buyers *and* external nodes with less explicit power such as NGOs, multi-stakeholder initiatives, or states. Efforts to improve supply chain environmental and/or social sustainability usually take place through a collective of actors; this notably distinguishes the power dynamics of a chain from the dyadic interactions between producers and buyers (Bartley, 2018). This collectively-defined power dynamic across the chain is rarely investigated. Identifying steps to improve outcomes for highly complex, multi-scalar environmental and social sustainability problems requires understanding both how these problems manifest across the supply chain and what respective influencing roles major actors play across the chain (Rodriguez et al., 2016).

Prior case studies indicate the power some types of actors wield across the chain. Mondliwa et al. (2020) found that retailers are perceived to have the power to define and drive sustainability measures up the chain in production and manufacturing nodes and their geographies. Their analysis showed that lead companies leverage power to shape the market. Ponte (2019) notes the situational ability of the producer to enforce standards, especially on sub-producers. Yet, other scholars note the inability of retailers to adequately enforce producer and, especially, sub-contractor adherence to sustainability initiatives (Börjeson et al, 2015; Madichie, 2015). It is very instructive to measure who has the power across the full supply chain, including all major internal and external actors (Alvarez et al., 2010; Formentini & Taticchi, 2016). For example, external stakeholders such as NGOs, regulatory agencies, trade associations, and the media can play an essential role in the supply chain (Liu et al., 2015) by providing certifications and standards, auditing reports and transparency, and by ensuring that all the nodes take an appropriate share of responsibility toward desired goals.

Current literature on power relations has mostly relied on indirect measures of power such as estimation of the cost of switching suppliers, potential punishments or assistance, and favorable position in the market, rather than directly analyzing power relations (Belaya et al, 2009). For example, Kanashiro & Fraisse (2015) suggests transnational supermarket chains as the most powerful actors in the Brazil beef supply chain because of a favorable position in the market. Hendrickson et al. (2008) consider processing plants as the nodes of power due to their economic share in the US beef supply chain. A few studies seek to measure power dynamics primarily through case studies that rely on qualitative assessments. These studies try to understand the power dynamics of the chain using interviews and sustainability reports and certifications. For example, in their interviews of 20 farmers, Brooks et al. (2013) show that the farmer’s lack of power produced mistrust between them, processors, and governmental agencies in the UK beef industry. Glover et al. (2014) interviewed 70 internal actors across the UK dairy supply chains to understand the role of retailers in sustainable practices. Their findings revealed that most of the actors believe that retailers are the dominant player in the supply chain.

The role of power in the supply chain and environmental sustainability is not fully understood. Although revealing the underlying power structure helps to identify the fulcrum for change in production networks and to ascribe blame for malfeasance in chains, there is a lack of focus on supply chain studies on how power and governance shape the environmental and social outcomes of a supply chain (Ponte, 2019). Although the literature on sustainable supply chains provides an entry point to the analysis of the complex interrelationships of sustainability and governance, scholars in this area tend to downplay the importance of the power structures underlying supply chains (Ponte, 2019). The literature lacks studies that incorporate power and governance dynamics in an effort to explain the environmental and social problems of a supply chain. Despite the value of the research in this area, no investigations have studied the power relations of a real supply chain by considering all the nodes of the supply chain. A methodology that combines the strengths of previous research to holistically understand the power in supply chains is needed. In this study, we, therefore, present different methods to shed new light on how power operates within supply chains.

4.4 Materials and methods

To quantify the non-mediated power across the beef supply chain, we crafted a short survey of questions that directly asks respondents about their *perceptions* of which entities in the beef supply chain hold the most power. We invited individuals who are experienced actors in the beef supply chain to participate in the survey. Data collected included the ordered ranking of entities that hold the most power with respect to five different environmental and social impacts (GHG emissions, water use, air pollution, land use, and employee safety and well-being). We converted the raw data (the rankings) into a *power score* for each entity in the supply chain (each actor-group), with respect to each of the environmental and social indicators. Then we conducted pairwise comparisons of the power scores of each actor-group pair to determine a rank hierarchy. We also visualized our power score results by creating a map showing all the nodes (the actor-groups) and all the linkages between pairs of actor-groups; this map represents the power relations of the supply chain.

4.4.1 Data collection

Our survey consists of four parts and a total of eight questions. In the first part, survey respondents identified, from a list, which actor-group within the beef supply chain they most closely align with. The list contained 6 categories that represent *internal* actors in the beef supply chain (feed producers, cow-calf producers/backgrounders, feedlot/packers, slaughtering/processing plants, retailers, and consumers) and 4 categories that represent *external* actors in the beef supply chain (government/regulatory agencies, non-

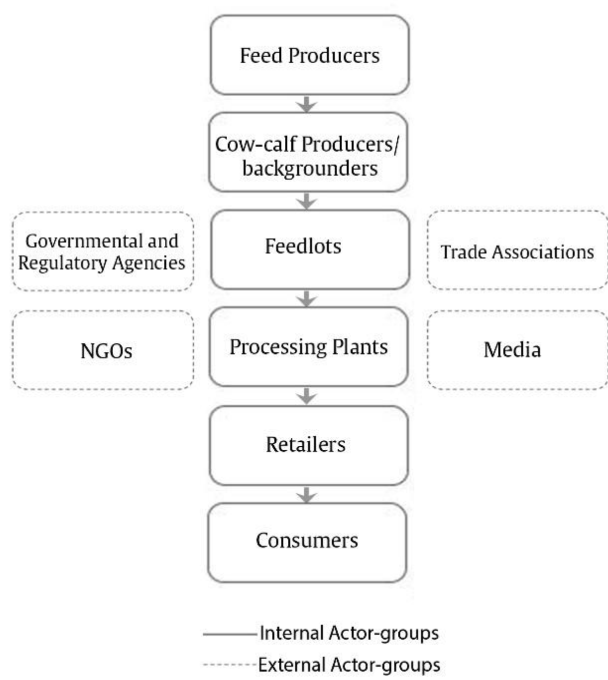

Figure 13. Beef supply chain nodes across the internal and external actor-groups.

governmental organizations, trade associations, and media) *(Figure 13).* We included restaurant chains (e.g., McDonald's, In-N-Out Burger) as part of the retailer's category.

In the second part of the survey, we asked respondents to rank the list of impacts (GHG Emissions, Water Use, Air Pollution, Land Use, Employee Safety, and Well-being) in order of perceived importance to US beef production. Definitions of the issues facing US beef production were taken from the US Roundtable for Sustainable Beef (USRSB). Many of the actors in the beef supply chain are members of USRSB and are familiar with these definitions.

In the third part of the survey, we asked respondents to *rank* the 5 most powerful entities (actor-groups) in the beef supply chain that can bring about change in each of the 5 areas of environmental impact (5 separate questions). We defined power as the ability of the actor-group to improve the environmental and social outcomes of the supply chain. In the fourth and final part of the survey, we asked respondents the following open-ended question: "In your opinion, what is the biggest challenge facing the U.S. beef industry over the next decade?" (see *Appendix E*)

A survey pre-test was given to academics, which resulted in minor changes to the wording. The survey content was then refined through iterative pilot testing with 15 participants with experience in the beef industry.

To locate potential survey participants who are *internal* actors in the beef supply chain, we used a database containing approximately 1,000 names of senior managers and executives in the US beef industry (Exact Data, 2002). We reviewed every name, company name, and title to locate qualified individuals who are currently active in the beef industry. We chose individuals that have at least ten years of experience in the beef supply chain and currently hold positions of significant responsibility, with job titles of manager, CEO, president, senior executive, vice president, senior director, or senior manager. We eventually sent survey requests to 347 individuals who are internal actors.

For *external* actors, we searched the websites of the US Environmental Protection Agency (EPA) and the US Department of Agriculture (USDA) to find people who are active in the beef supply chain. For *NGOs*, *trade associations*, and *media* we searched their websites and sent emails to find the people who have experience with the beef industry. We eventually sent survey requests to approximately 70 individuals who are external actors. (Note that we sent fewer surveys to external actors because there are fewer people working in these categories.

We conducted our survey through Qualtrics' online platform. One week before the survey was available, we emailed a pre-notice to each individual. When the survey was available, we emailed a link to the survey; and a week later we sent a reminder about completing the survey. Respondents had two weeks to complete the survey. We received 218 responses, a response rate of 54%. We removed 18 incomplete survey responses. This resulted in a total of 200 responses—138 internal actors and 62 external actors—which corresponds to a final response rate of 48%.

4.4.2 Data analysis

Respondents *subjectively ranked* entities based on their own *perceptions* of power. Therefore, our raw data does not refer to a quantitative, objective measurement of power but rather a subjective, ordered ranking. We converted our survey data into scores on a scale of 0 (no power) to 100 (high power) for each actor-group; we refer to these as "power scores". Then we conducted statistical analysis on these power scores. Finally, we employed techniques from Social Network Analysis (SNA) to visualize the power score data and linkages between actor-groups.

We converted our ranked data into scores on a scale of 0 to 100, where a higher score represents a higher power ranking, for each actor-group. Rather than asking the respondents to rank all 11 actor-groups, we asked them to rank only the top 5; from the collective responses, we ranked all 11 actor-groups. We did this for each of the five environmental and social impacts. For each question, we assigned "points" to each of the 11 categories. The actor-group that was ranked the highest by the respondent received the most points (11 points); the actor-group that was ranked the second highest received 10 points; the actor-group that was ranked third received 9 points, and so on down to 1 point, for a total of 66 points (11 + 10 + 9 + … + 2 + 1) to be distributed among 11 categories. The categories that were unranked by the respondent shared the remaining points equally. For each of the 5 questions about environmental and social indicators, we totaled all 200 respondents' point values to determine the final rankings of actor-groups, from 11 (highest) to 1 (lowest). And for simplicity, we converted the final rankings to a scale of 100 (highest) to 0 (lowest) for ease of interpretation, which is an actor-group's "power score."

We then used regression analysis and pairwise t-tests in R to compare the power scores of each pair of actor-groups and to determine which pairs are correlated with each other. We found the three most powerful actor-groups with respect to each environmental indicator. We also averaged the power score for each actor-group across all five environmental and social indicators, resulting in an overall power score for each actor-group. We imported the power scores for each actor-group with respect to each environmental indicator into Cytoscape, a software program that uses Social Network Analysis (SNA), to visually map the power scores and their dynamics across the supply chain. When illustrating the power dynamics of a supply chain, SNA considers the overall network structure of the chain and represents the relative importance of each node's position in the chain. We used this method to visualize the power dynamics with respect to each of the indicators as well as the averaged, overall power in the chain.

In addition to the five questions that ask respondents to rank the *most powerful entities* with respect to these indicators, we asked the respondent to rank the five environmental and social indicators "in order of importance." The final survey question asked, "In your opinion, what is the biggest challenge facing the U.S. beef industry over the next decade?" This was a way for us to understand the concerns of actors in the supply chain. We received 136 answers to this question.

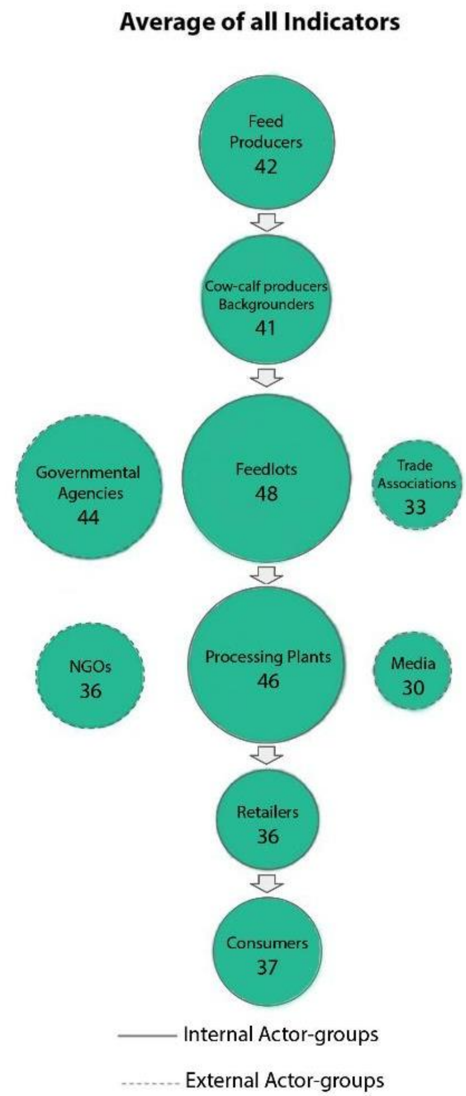

Figure 14. Power scores for each actor-group in the beef supply chain. (A node's diameter is proportional to its power score.)

4.5 Results

We quantified the power structure across the US beef supply chain using data from a survey that asked individual actors in the supply chain to identify which actor-groups hold the most power with respect to five different environmental and social indicators. By averaging these five answers, we scored each actor-group's perceived ability to improve environmental and social outcomes in the supply chain. The top three overall actors in descending order are feedlots, processing plants, and governmental and regulatory agencies. *Figure 14* shows the power differential across the beef supply chain, from a score of 0 score (the least power) to 100 (the most power). We found scores ranging from 30 for the Media to 48 for Feedlots. Among *internal* actor-groups, feedlots, processing plants, and feed producers hold the most power, while retailers hold the least power. Among *external* actor-groups, governmental and regulatory agencies hold the most power, while trade associations and media hold the least power.

4.5.1 Power asymmetry in the beef supply chain

A closer look at the dynamics in the supply chain shows an unequal distribution of power between the *internal* and *external* actor-groups of the supply chain. Internal actor-groups hold the most power in all areas of environmental impact *(Figure 15).* The difference in power is significantly greater for GHG emissions, but less in the areas of land use and air pollution. Using the power score across the internal linkages, we calculated the power asymmetry between producers (feed producers, cow-calf producers/backgrounders, feedlots, and processing plants) and retailers in the beef supply chain, (*Table 5)*. Retailers hold less power than producers in all of the environmental and social impacts areas that can confirm power consolidation in the supply chain.

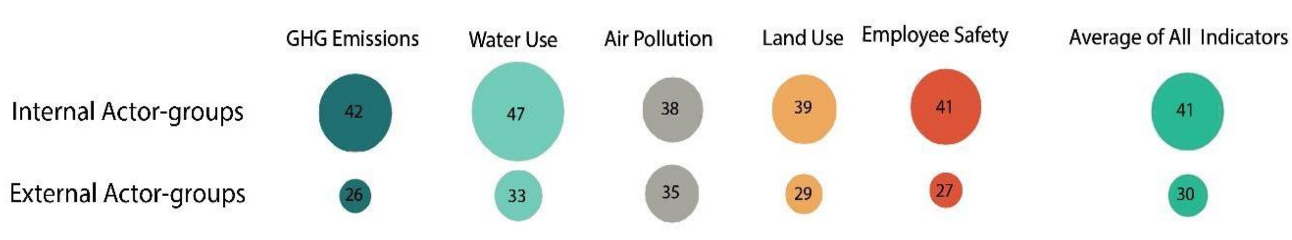

Figure 15. Power scores show an unequal distribution of power between internal and external actor-groups with respect to environmental indicators. (A node's diameter is proportional to its power score.)

Table 5. Power asymmetry score between producers (all phases of production) and retailers.

	GHG Emissions	Water Use	Air Pollution	Land Use	Employee Safety
Producers	44.25	50.25	45.25	41.75	45.5
Retailers	37	38	41	32	32
Power score	**1.12**	**1.32**	**1.1**	**1.3**	**1.42**

4.5.2 Power across the supply chain

Table 6 shows the regression coefficients for the pairings of the power scores of the three most powerful actor-groups in each of the five environmental and social impacts (and the average of all indicators) with the power scores of each of the 10 actor-groups. We assumed a P-value less than 0.05, corresponding to 95% confidence, as a significant relationship. For all five environmental and social impacts, the power scores of the top three actors are significantly higher than their correlations with retailers, consumers, NGOs, trade associations, and media. This confirms the statistically significant higher power scores for the internal actor-groups.

Table 6. Regression analysis of relative coefficient of the top three actors across the chain, rows relative to column. * shows a significant relationship (P value < 0.05).

	Internal Actor-groups					External Actor-groups				
	Feed producers	**Cow-calf producers/ Backgrounders**	**Feedlots**	**Processing Plants**	**Retailers**	**Consumers**	**Governmental or Regulatory Agencies**	**NGOs**	**Trade Associations**	**Media**
GHG Emissions										
1. Feedlots	1.5889	-5.4621		5.5499	**11.8551***	**-12.0705***	10.4518	**23.9554***	**16.8947***	**20.2008***
2. Feed producers		-7.0509	1.5889	7.1387	**13.4439***	**-13.6594***	**12.0406***	**25.5443***	**18.4835***	**21.7896***
3. Cow-calf producers/ Backgrounders	**12.0406***	4.9897	10.4518	-4.9019	1.4033	-1.6187		**13.5036***	6.4429	9.7490
Water Use										
1. Processing Plants	1.469	2.081	2.838		**18.626***	**-18.930***	-9.608	**-16.873***	**19.406***	**-23.265***
2. Feedlots	-1.370	-0.757		2.838	**22.244***	**-21.768***	**12.446***	**19.711***	**13.657***	**26.103***
3. Feed producers		0.612	1.370	1.469	**20.095***	**-20.399***	11.077	**18.342***	**20.875***	**24.734***
Air Pollution										
1. Processing Plants	**-14.737***	**-15.500***	**-2.146***		**11.882***	**-10.781***	**-16.904***	-8.612	**19.443***	**-19.791***
2. Governmental or Regulatory Agencies	**-16.904***	**-17.667***	-4.313	2.167	**14.049***	**-12.948***		**10.779***	**21.610***	**21.958***
3. Feedlots	**-12.591***	**-13.353***		**-2.146***	**9.736***	**-8.634**	-4.313	6.465	**17.296***	**17.645***
Land Use										
1. Cow-calf producers/ Backgrounders	3.19		9.06	**15.64***	**18.46***	**-17.44***	7.14	**12.41***	**19.89***	**22.93***
2. Feed producers		3.19	5.87	**12.45***	**15.27***	**-14.24***	3.95	9.21	**16.70***	**19.73***
3. Governmental or Regulatory Agencies	3.95	7.14	-1.92	8.50	**11.32***	**-10.29***		5.26	**12.75***	**15.79***
Employee Safety and Well-being										
1. Processing Plants	-1.772	-8.044	-5.751		**20.388***	**-17.275***	**-11.015***	**-18.598***	**23.703***	**-25.912***
2. Feedlots	-7.523	-2.293		-5.751	**14.637***	**-11.524***	5.265	**12.847***	**17.952***	**20.161***
3. Governmental or Regulatory Agencies	3.493	2.972	5.265	**-11.015***	9.373	-6.260		7.582	**12.688***	**14.897***
Average of All Indicators										
1. Feedlots	**-6.655***	-7.566		1.852	**13.744***	**-12.662***	4.370	**13.468***	**16.891***	**19.498***
2. Processing Plants	-4.803	-5.714	1.852		**11.891***	**-10.810***	-2.518	**-11.616***	**15.039***	**-17.646***
3. Governmental or Regulatory Agencies	-2.284	-3.195	4.370	-2.518	**9.373***	**-8.292***		**9.098***	**12.521***	**15.127***

4.5.2.1 Producers hold the most power. Beef production actor-groups (cow-calf producers, feedlots, and processing plants) hold the most power in the chain, which contributes to the unequal power distribution between producers and buyers, as well as internal and external actor-groups. Respondents chose feedlots and processing plants as the most powerful nodes of the supply chain. As *Table 2* shows, feedlots, and processing plants occupy a significantly higher position of power compared to retailers, consumers, NGOs, trade associations, and media in all five areas of environmental impact (P-value < 0.05). Processing plants and feedlots wield the most power over water-related issues. Cow-calf producers/backgrounders and feed producers hold the most power over land-use decisions *(Figure 16).* At the same time, governmental and regulatory agencies hold a third, statistically significant position in the power structure (P-value < 0.05). Our analysis showed that out of the five environmental areas, governmental agencies have the most power in the areas of air pollution, water use, and land use.

4.5.2.2 Feed producers hold significant power. Our analysis showed that feed producers, the first phase of the chain, notably not directly related to beef production, is an underappreciated node of the supply chain. Feed producers tie with Feedlots as the most powerful actor in GHG emissions and have the second most power in the area land use *(Figure 16).* The power that this actor-group holds shows the importance of including all the nodes in the analysis of the power dynamics of a supply chain. While feed production holds power in internal linkages, it has been disregarded in the formation of the trade associations such as USRSB.

Consumers are also an underappreciated node of power dynamics. Although they hold significantly less power in all environmental and social areas compared to the production phases (P-value < 0.05), but our respondents believe that consumers hold a higher level of power than retailers, NGOs and trade associations. Our respondents believe that the media communication industry does not hold power in the chain(P-value < 0.05). However, media has an essential role in consumer awareness, and it needs to be part of supply chain governance studies.

4.5.2.3 Retailers, NGOs, and trade associations lack power. Our results showed that retailers hold the least power among the internal actor-groups of the supply chain. As *Figure 16* indicates, the beef supply chain is dominated by supplier power, and there is a lack of power for local and brand name retailers. Retailers, NGOs, and trade associations all form bridging linkages in the supply chain – they link multiple disparate actors. Retailers are a connecting linkage between producers, consumers, NGOs, and media. NGOs often induce change and bring legitimacy to the supply chain. However, in the context of the beef supply chain, although NGOs hold power in the areas of land use, water use, and air pollution, their power is not statistically greater than the power held by retailers and a few production phases. Trade associations, a third bridging linkage, hold the least power across the supply chain (statistically significant with P-value < 0.05). Trade associations are founded and funded by the beef industry for purposes of collaboration, education, and advertisement. Their lack of power in the supply chain leads to ineffective strategies for achieving positive environmental and social change in the supply chain.

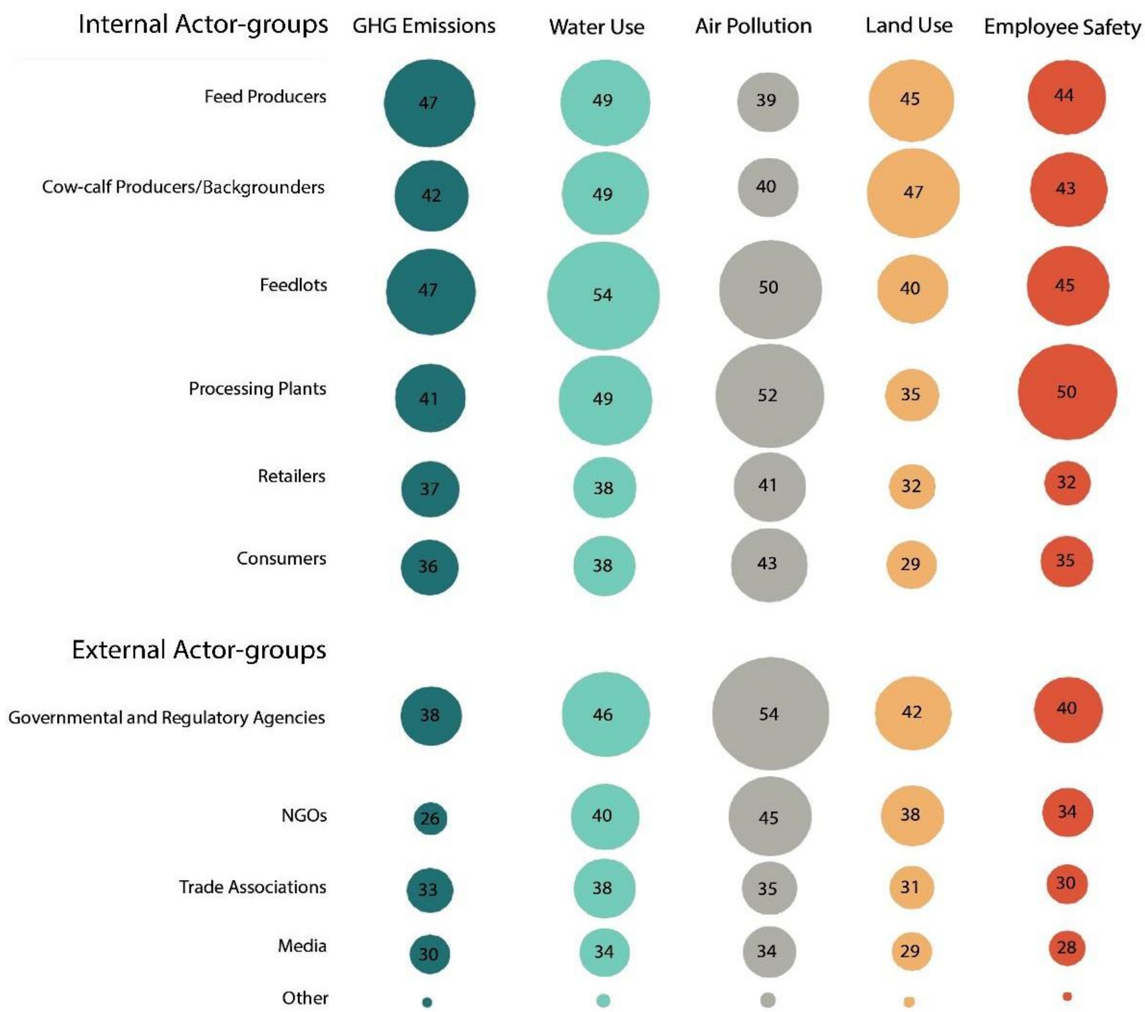

Figure 16. Power scores for all actor-groups in areas of environmental concern.

4.5.3 Challenges facing the beef supply chain

In addition to answering a question about each environmental impact, respondents also ranked the importance of five environmental and social impacts for the beef supply chain on a five-point scale from least important to most important. In our analysis 5 represents 'most important'. We find that actors in the beef supply chain believe that employee safety and well-being (average of 3.7), water use (average of 3.6), and land use (average of 3.4) are the top three challenges in the beef industry respectively. Air pollution (average of 2.1) and GHG emissions (average of 2.1) are the least important issues in the beef industry among the five indicators. The results confirmed that there is a tendency to prioritize environmental and social challenges based on cost (water use, land use) and legal issues (employee safety and well-being), with less concern for diffuse challenges of climate change and air pollution.

We also used SNA to map power scores grouped by the respondents' actor-group (rather than grouped by the environmental indicator). Our results *(Figure 17)* show that feedlots, governmental agencies, and processing plants respectively perceive themselves as the most powerful actors in the chain, and that trade associations, retailers, and cow-calf producers/backgrounders respectively ranked themselves as the least powerful. In *Figure 17*, the diameter of the circle representing an actor-group is based on the power score of that actor-group and the thickness of the lines between nodes represents the average ranking that each actor-group received from other actor-groups. The lines have arrows pointing *away from* the actor-group that is doing the judging. For example, the thickest lines leaving the "trade associations" node point to the "feedlots" node and the "processing plants" node, which means that trade associations perceive that feedlots and processing plants are the most powerful actor-groups. On the other hand, NGOs perceived cow-calf producers/ backgrounders and processing plants as the least powerful actors. Although we did not find a clear trend on perceived power among actor-groups, we found that in general *internal* actor-groups perceive internal actors as more powerful than *external* actor-groups.

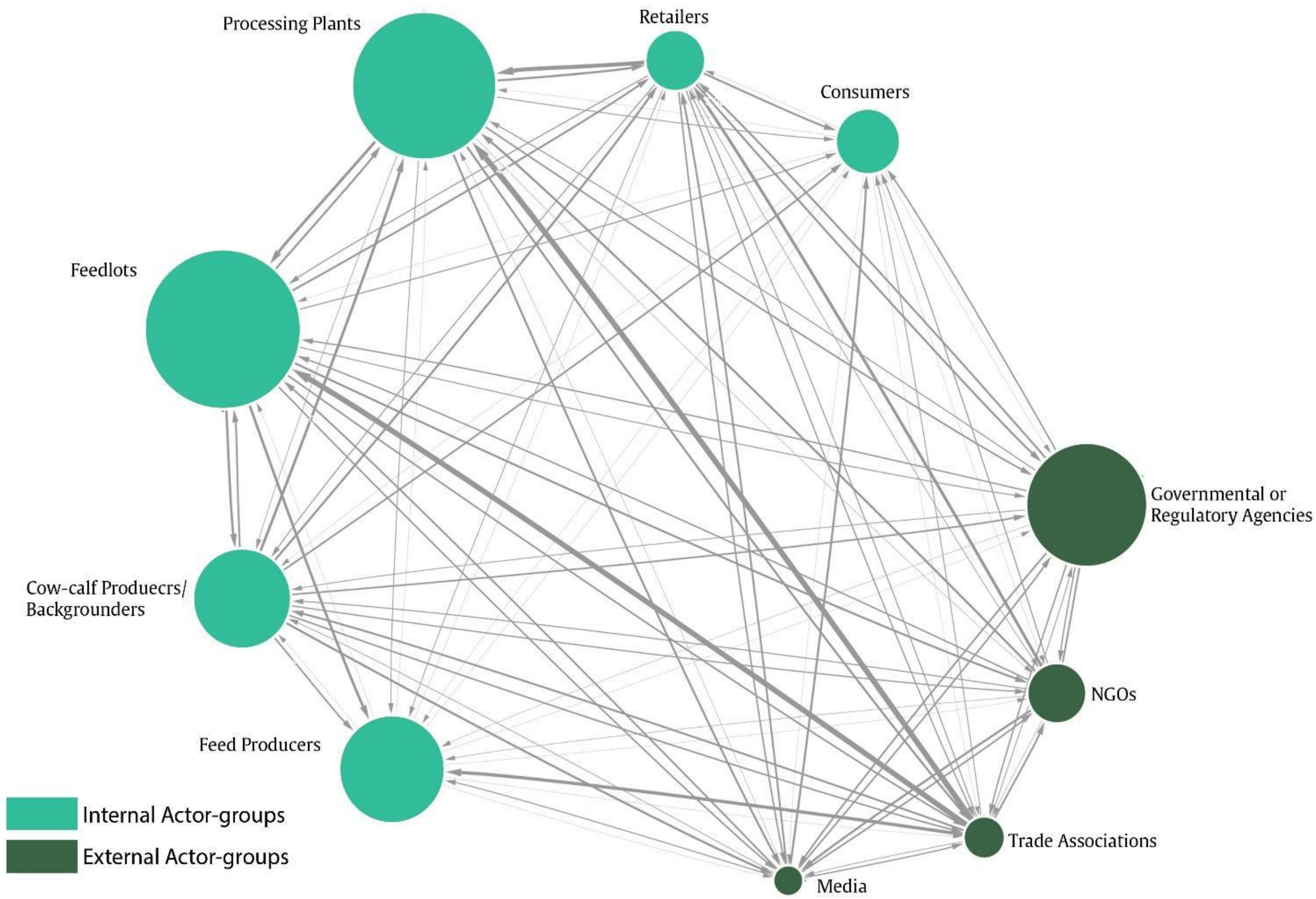

Figure 17. Actor-group perceptions of power. A node's diameter is proportional to the power score of that specific actor-group, and a line's thickness is proportional to the power score given by an actor-group to another actor-group; for example, trade associations perceive feedlots and processing plants to hold a great deal of power in the chain.

4.6 Discussion

In this study, we used a structured survey with Social Network Analysis (SNA) to map and quantify the power relations within the internal and external nodes of the beef sector in the United States. Our study addressed who has the most power (ability to improve the environmental and social outcomes) in the beef supply chain? Although our study shows beef supply chain as a producer-driven chain overall, it revealed multiple nodes of power in each area of environmental and social impacts. Production phase nodes (feedlots and processing plants) are perceived by other actors to hold the most power. Results also indicated retailers in the internal nodes and NGOs, trade associations, and media among the external nodes are perceived to have the least power. Also, although our study shows governmental agencies as the third powerful node of the supply chain, there is a significant power asymmetry between internal and external nodes of the chain. Below, we discuss power relations in the beef supply chain, the advantages of measuring and quantifying power across the supply chain, and discuss the methodological considerations. We conclude with a discussion of policy implications and future work.

4.6.1 Power asymmetry in the beef industry

Power in beef supply chains is concentrated in a few actor-groups in the production phases of the supply chain. We identified the top three actor-groups perceived by the respondents to have the highest capability to improve the environmental and social outcomes of the supply chain; they are (1) feedlots, (2) processing plants, and (3) regulatory agencies. However, we found multiple power nodes for each of the environmental and social outcomes . Our study also revealed that power might shift depending on the subject. For example, both feedlots and feed producers wield power over GHG emission issues. Governmental and regulatory agencies and processing plants hold the most power over air pollution problems. Therefore, the dichotomy of buyer-producer might fall short of capturing the complexity of supply networks. We suggest that power is subject-dependent as well as context-dependent. Depending on the geography, product and environmental and social indicators power can shift between actor-groups.

Our study confirmed a power consolidation in the chain, due to the power asymmetry between producers (all production phases) and retailers in all the environmental and social impacts. While power asymmetry can positively affect the supply chain relationships in certain situations, power consolidation can be detrimental to sustainable environmental governance depending on the behaviors and actions of powerful actors (Hoejmose et al., 2013). The consolidation of power is problematic if powerful producers exploit their power to put pressure on their suppliers (farmers, etc.) to take responsibility for environmental issues and thus avoid making any changes themselves within their own organizations.

In the US beef industry, four processing companies – Tyson Foods, National Beef, JBS SA, and Cargill – control over 75% of beef production (Hendrickson et al., 2021). Through vertical integration, these companies control several nodes from ranch to slaughter, giving them direct control over the beef supply chain. This consolidation of power has had environmental implications for the entire chain. For example, Harris Ranch Beef Company, the largest beef producer in California, has shown little inclination to improve environmental and social conditions at its facilities despite NGOs and media pressure. This negatively impacts its feedlots, thousands of acres of ranches, and processing facilities (Chamanara et al., 2021). Links between consolidation, vertical integration, and externalizing environmental impacts have also been found in the condiments sector (Kelloway and Miller 2019, Hendrickson et al 2021). Such accumulation of power can drive down standards across the industry. Independent, small, and local farmers with few alternatives to access processing plants and beef markets must copy practices of with large producers to compete economically.

When producers use their power to extract value from the supply chain, they might externalize the costs of beef production including the cost of environmental destruction (e.g., cleaning up polluted water and air), health care costs associated with employees of feedlots (e.g., asthma, cardiovascular diseases), property value lost, and small business closures. Laws that allow this externalization are partly the result of corporate control of regulatory processes and a few federal programs (e.g., the Beef Checkoff program, which is part of the US omnibus farm bill of 1985 and is designed to increase the demand for beef). However, this regulatory capture confirms the important role of select external actor-groups despite the generally unequal distribution of power across the supply chain between the internal and external actor-groups that we found. In the US beef supply chain, retailers are constrained, and thus beef producers cannot be held accountable through brand-activism. Therefore, by mapping the power structure of a supply chain, we can point to specific actors in the chain who might be shirking their share of responsibility for environmental changes. True sustainability requires collaborative chain-spanning efforts, however. Every actor needs to take responsibility for their actions and know what standards are necessary to uphold to operate (more) sustainably.

4.6.2 The advantages of measuring power across the supply chain

The method introduced here advances the supply chain governance literature on power in three key ways: it (1) allows comprehensive scoping of the entire supply chain, (2) quantifies power instead of qualifying relative power, and (3) facilitates the mapping of relative power dynamics in the supply chain. Comparing our study to other analyses of beef supply chains highlights the strengths of our method. For example, Lowe & Gereffi (2009) applied seven criteria (including control over manure management and cattle diet, concentrated market, single player, and significant name recognition) to analyze the degree of leverage of each economic actor in the US beef industry. They similarly found that feedlots and processing plants were key nodes of power in US beef supply chains, but they also identified retailers as powerful actors. Therefore, our results indicate that such indirect measures of power may be misleading in the case of beef production. While our study suggests a lack of power for NGOs, media, and consumers in the beef supply chain, the type of power they have is different from governmental and regulatory agencies' power. This soft power is considered as one of the key strategies in voluntary approaches to induce change in the supply chains, such as "naming and shaming" campaigns (Madichie & Yamoah, 2016). Therefore to take advantage of this soft power, it is essential to know whom to target for improving the environmental and social sustainability outcomes of the supply chain.

NGOs usually identify and target retailers as dominant players due to brand visibility in the food supply chains. Yet retailers cannot be automatically assumed to hold the most powerful supply chain positions simply because of their brand recognition. For example, during the European horsemeat scandal of 2013, when horsemeat entered the supply chain as beef and being sold in many products in parts of Europe, although NGOs and campaigns targeted the retailers, but a deeper look into the supply chain confirmed producers as dominant players in the livestock supply chain (Madichie & Yamoah, 2016). The same situation happened in Australia in 1981, where horsemeat and kangaroo meat were being substituted for beef in meat exported by Australia to the United States (Grabosky & Sutton, 1989). Therefore, the success of external nodes of the chain in motivating social and environmental sustainability in the chain depends on a more nuanced understanding of power dynamics across the chain.

Varied observations of chain power dynamics confirm the importance of including all actors in analyzing the governance dynamics of the chain.

Our study shows that retailers (including restaurant chains) are perceived to be the least powerful internal actor-group. This includes responses by retailers themselves, who self-assessed to be the second least powerful actor-group after cow-calf producers/backgrounders. The meager power of retailers in beef supply chains shows that brand recognition does not automatically confer power to high-profile actor-groups. This finding has implications for NGOs that attempt to compel corporations to source more sustainably by linking their popular brands to environmental and social issues in their supply chains. Powerful supply chain actors that lack brand-recognition are insulated from boycotts and brand damage, while powerless retailers will be hard pressed to effectively push sustainability standards above the supply chain (Bloomfield, 2017).

By measuring power across the entire supply chain, our study emphasizes the need to study all actor-groups, including those external to the supply chain, to identify effective leverage points in the system. This differs from the studies that have focused only on internal actor-groups, which tend to equate size (Kelloway and Miller 2019, Hendrickson et al. 2021) or brand-visibility with power (Clapp, 2018). Analyzing all the nodes in the supply chain also reveals real-world complexities that are not captured when only focusing on a portion of the supply chain. For instance, the calf-producers/backgrounders, feedlots, and processing plants nodes are organized as a vertically-integrated supply chain (Gereffi, 2005). Including additional nodes shows that different governance dynamics exist upstream and downstream of the cattle-rearing portion. Therefore, considering all of the nodes along the chain might have implications for deciding how to sustainably govern supply chains.

4.6.3 Policy implications and future work

There exist a bevy of standards and certifications from producers, retailers, and multistakeholder initiatives to make supply chains more sustainable; yet there is minimal positive progress on the ground (Bartley, 2018). Power consolidation grants the ability to shape the market, product availability, or sustainability standards and certifications to only a few players (Clapp, 2021). These players can shape the policy in that sector, which, depending on their sustainability perspectives can only serve themselves rather than the whole supply chain or communities (Kan and Vaheesan, 2017). When power is highly concentrated with a few corporations, those corporations have a higher capacity to engage in lobbying activities and are consequently more able to exercise political influence (Chamanara et al., 2021). Studies show that relying only on these power-laden companies to undertake their fair share of responsibility will have disappointing results (Le Baron, 2020). There is a need for stronger policies that articulate well with environmental, social, labor, and health regulations to prevent these corporations from exploiting their power to externalize costs to these goals to stay afloat in the market (Khan, 2018).

The role of external actor-groups such as governmental agencies and NGOs on research and grant supports for sustainability initiatives is essential. Stronger policies are needed to curb corporate power and limit their influence over regulatory policies, scientific research, and public disclosure (Clapp, 2021). Strict policies for transparency across the supply chains and public disclosure of lobbying activities in the food system ensure that powerful corporations cannot influence policymaking process (Barrett et al., 2020). NGOs and media need to engage in meaningful ways to be a voice for the dependent actor-group that have less power in a supply chain, as well as civil society and laborers in the policymaking process (Anderson, 2008). It is essential to have open communication about corporate power in the food supply chains and create dedicated spaces to discuss corporate power, its destructive tendencies, and ways to meaningfully achieve better sustainability outcomes through policy and development.

Civil society and regulatory agencies should look for opportunities to have an active role in the multistakeholder initiatives. There is a need for better participation from these external actors on the negotiating table for setting definitions, standards, and certifications (Bartley, 2018).). A deeper look at the USRSB shows that external actors are limited only to a few sustainability and land conservation groups, which can be the result of power consolidation in the chain. This is in contrast with Roundtable for Sustainable Palm Oil (RSPO), which is one of the successful multistakeholder initiatives spearheaded by the World Wide Fund for Nature (WWF), with many NGOs, civil societies, and institutions involved. Our study can be a starting point to empirically depict power across any supply chain. By selecting a legitimate group of participants across the chain, researchers could map the power dynamics in different supply chains with regards to environmental, labor, or other issues. Graphically depicting power dynamics clarifies who controls production conditions, and who needs to play a larger role to bring the desired outcomes to the supply chain.

Future research can help further refine the method introduced here. For simplification purposes, we assumed that each node (actor-group) is uniform, even though each node is often complex and consists of smaller divisions that can have a specific power structure. In our study, we assumed that the power in these smaller divisions could be simultaneously reflected in each node. Future research can further separate each node into distinct layers of power. Future research can also apply the same approach to different supply chains and compare their results to develop a framework for power dynamics in supply chain studies. While the contribution of this chapter is in empirically documenting a model of power in supply chain governance, developing a framework remains to be documented. Future research using this approach can test multiple supply chains to develop a framework for supply chain studies.

Lastly, this work contributes towards a collective effort to make supply chains more sustainable. Identifying the nodes with the most power can in turn clarify which specific approaches are necessary for successful governance. This can assist stakeholders in designing more effective regulation, multistakeholder initiatives, brand-activist campaigns, and the like.

4.7 Conclusion

With growing concerns over the sustainability of business practices, supply chain relationships have become even more critical. Companies are challenged to mitigate the reputational and operational risks that emerge from unsustainable practices (Krause et al., 2009; Chamanara et al., 2021). Power is a central but underexplored concept in supply chain studies (Reimann & Ketchen, 2017). No studies have yet quantified power across the supply chain by considering all internal and external decision-makers. Understanding where power resides in a chain is the first step toward managing power across the chain, which can help develop trust, collaboration, and long-term efficiency in economic and non-economic issues. Our study shows that producers (specially feedlots and processing plants) hold the most power in the US beef supply chain. Moreover, while production phases wield the most power in the supply chain, NGOs, retailers, and consumers hold a significantly lower amount of power, which contributes to the unequal distribution of power between internal and external actors of the chain.

Our study encourages awareness of power and its consequences for applications in both academia and industry with novel insight on how to measure power. Power analysis can be a source of competitive advantage for the supply chains. Industries aiming for environmental and social sustainability need to be especially conscious of the power dynamics in their chains. By considering both internal and external nodes and effectively managing this power, supply chains can improve their sustainability. In addition, power dynamics that characterize individual supply chains can provide important hints for regulatory agencies and NGOs to reduce this unequal bargaining position. Given the significance of power effects within the chain, power issues will continue to become more prevalent. Therefore, supply chain studies could be further extended to include different industries in measuring power. In addition, much more power research is needed to further clarify the role of power in different supply chains and their performance over time.

Chapter 5

Conclusion

This dissertation research was motivated by two interrelated theoretically and practically relevant questions: (1) How are environmental and health costs of beef supply chain distributed among local communities in terms of air quality ($PM_{2.5}$), nationally and at the supply chain level? And (2) How the underlying governance dynamics and its associated power structure in a supply chain influences the environmental and social sustainability outcomes? Or who has the power to change the environmental and social outcomes of the U.S. beef supply chain? The three preceding chapters provided important insights related to these questions, while also pointed to new avenues for future research. In this concluding chapter, I first summarize the key findings, contributions, then outline my future research plans, and then discuss the contributions to policy and planning.

5.1 Major findings

Despite the notable attention on the heavy burden unsustainable livestock consumption levels have on the environment, there has been little effort to understand the distributive local environmental impacts, especially where burdens follow familiar lines of vulnerability. I suggest that the three most important outcomes of this dissertation are: 1) Identified and measured the location and size of ~15,700 pig and cattle CAFOs across the U.S. using high resolution remote sensing techniques, and systematically clarified their relationship to local air quality measures and the socio-demographic characteristics of adjacent communities; 2) Mapped a specific beef supply chain, and constructed linkages with beef suppliers and sub-suppliers at high geographic specificity, and tried to clarify supply chain's relationship to California's hotspot of $PM_{2.5}$ and the environmental and health cost of living across the production phases of supply chains for nearby communities; and 3) Developed a new approach to quantify power structure across an entire supply chain, considering both internal and external nodes for strengthening the relationships in the chain in order to induce change to the environmental and social outcomes of the supply chain.

In *Chapter 2: Environmental justice of concentrated animal feeding operations (CAFOs)*, my co-authors and I generated a reliable and comprehensive dataset of CAFOs across the United States. Our study provided the first national assessment of how the location distribution and size of cattle and pigs CAFOs is consistently correlated with higher $PM_{2.5}$ concentrations in varying distances from these farms. We further examined the ramifications of living near a CAFO and highlighted that certain communities across the country are disproportionately exposed to the impacts of CAFOs and bear the costs of higher $PM_{2.5}$ concentrations. Estimation of exposure impacts of $PM_{2.5}$ on race/ethnicity and socio-economic variables showed that Latinx, POC, and communities with no high school education are disproportionately affected by $PM_{2.5}$ emissions from CAFOs. We complemented our model results with a geographic representation of our findings. Our clustering models revealed the central valley of California and east of North Carolina as the two major clusters of high $PM_{2.5}$ concentration coinciding with high rates of disadvantaged communities. However, in the largest part of the Midwest, we saw an inverse pattern. The analysis revealed significant clustering of CAFOs in a small number of counties, with more than 3,200 CAFOs alone in just 18 counties in California, the Upper Midwest, and North Carolina. This spatial concentration of CAFOs contributes to high pollution burdens in these counties, as well as environmental inequities in these areas. This study is the first step toward a national systematic analysis of $PM_{2.5}$ inequalities of industrial farming across the U.S.

In *Chapter 3: Where's the beef? Costco's meat supply chain and environmental justice in California*, my co-authors and I combined life cycle thinking with an environmental justice approach to map Costco's beef supply chain in California and to explore the environmental burden of air pollution ($PM_{2.5}$) due to beef production in the San Joaquin Valley, a region that has some of the worst air quality in the United States. To map the supply chain of one of Costco's primary suppliers, Harris Ranch, and the feedlots they operate, the study used a methodological framework known as Tracking Corporations Across Space and Time (TRACAST). Our modeling revealed that CAFOs produce ~95% of total $PM_{2.5}$ emissions across the beef supply chain, and they alone account for approximately 1/3 of total anthropogenic $PM_{2.5}$ emissions in the Valley. $PM_{2.5}$ concentrations are markedly higher around these facilities. The spatial analysis revealed that communities living near feedlots are often poor, predominantly Latinx, and have increased $PM_{2.5}$ related disease burdens, including asthma, heart disease, and low weight birth. Based on company documents and news reports, neither Costco nor Harris Ranch are addressing this environmental injustice.

We then proposed actions that beef producers and retailers can take to become more sustainable using Harris Ranch and Costco as examples. We proposed a number of policies and technological fixes that Harris Ranch could implement to reduce its $PM_{2.5}$ emissions at the CAFO level. We suggested options for Costco to source beef more sustainably such as implementing a policy requiring beef producers to implement effective air pollution controls at CAFOs, or instead of trying to influence current producer practices, it can switch to producers who do not use CAFOs. We also emphasized on the importance of transparency in the beef supply chain. This would put beef suppliers under public scrutiny, making Costco and individual suppliers accountable for producing beef that degrades land, pollutes water and air, or affects the health and livelihoods of nearby communities. Transparency could also spur consumer demand for more sustainable beef options, prompting Costco and other suppliers to oblige. We then called for needs to investigate air emissions at the largest industrial-sized facilities that present the highest risk, seek monitoring, and, if necessary, require them to install control technologies from EPA and other regulatory agencies.

In *Chapter 4: Power Asymmetries in supply chains and implications for environmental governance: A study of the beef industry,* my co-authors and I developed a replicable approach for scholars by introducing an approach to measure differential power among actors across the entire supply chain, including key external actors. We developed a structured survey in which supply chain participants rank their peer's ability to improve environmental and social outcomes of the supply chain and applied this method to the beef production sector in the United States by surveying 200 internal and external actors. Respondents ranked the most powerful actors as 1) feedlot companies, 2) processing plants, and 3) regulatory agencies. The identification of regulatory agencies as a powerful actor is particularly noteworthy as it highlights the importance of including external actors when studying supply chain governance. Results also revealed that trade associations, retailers, and cow-calf producers and backgrounders perceive a sense of powerlessness that can hinder sustainability. Graphically depicting power dynamics clarifies who has the ability to change, and who needs to play a larger role to bring the desired outcomes to the supply chain.

We then discussed the power consolidation in the supply chains that grants the ability to shape the policy in the sector to only a few players (Clapp, 2021) which, depending on their sustainability perspectives can only serve themselves rather than the whole supply chain or communities (Kan and Vaheesan, 2017). We emphasized on the need for clarity of definitions such as environmental and social sustainability in the multistakeholder initiatives, as well as stronger policies that articulate well with environmental, social, labor, and health regulations. Stronger policies are needed to curb corporate power and limit their influence over regulatory policies, scientific research, and public disclosure (Clapp, 2021). It is essential to create dedicated spaces to discuss power dynamics its destructive tendencies, and the ways to meaningfully achieve better sustainability outcomes through policy and development, involving all internal and external actors across the supply chain. Finally, we discussed the need for future research to apply the same approach to different supply chains and compare their results to develop a framework for power dynamics in supply chain studies. This framework can assist stakeholders in designing more effective regulation, multistakeholder initiatives, brand-activist campaigns, and the like.

5.2 Future research

This dissertation tried to provide society with the knowledge and tools necessary to make changes that can mitigate the environmental and social impacts across the beef supply chains. In my career I would like to impact society with my research through three interrelated primary long-term goals: First, by researching EJ associated with less studied products, I would like to be a voice for communities of color and low-income communities that have been affected by disparate siting of production phases of supply chains. In fact, industries are aware that placing unwanted facilities may result in local opposition by residents, which may generate bad publicity for the company. Thus, they prefer to place these facilities in communities where opposition will be ineffective due to scarce resources and little political clout. In my career, I aim to raise awareness about the "path of least resistance" in the supply chain siting phases through research and meetings with specific organizations for effective mitigation of the EJ impacts in the long term. Second, with the assistance of a few NGOs, I would like to develop a public website about the supply chains and their EJ impacts to inform consumers of the unfelt and unseen negative impacts of the products. This information can contribute to raising consumers' knowledge to reconsider their buying choices and consumption more broadly. Finally, by translating my research to accessible products (e.g., publications, policy documents), I would like to impact the transformation of supply chains structure toward more sustainable governance. This process represents a new form of political action in every geographic scale to promote sustainable supply chains, and as a result more stable communities.

As I move forward in my career, I plan to continue conducting research in two overlapping focus areas related to my previously stated overarching research questions: 1) Advancing theories and empirical understanding of power dynamics underlying supply chain governance; 2) Supply chain governance to enhance EJ outcomes by revealing how different types of governance lead to different EJ outcomes?

These questions were in the original proposal for my doctoral studies that needed to be modified because of the COVID-19 restrictions for fieldwork. In my dissertation after revealing the Costco-Harris Ranch supply chain environmental injustices in California, due to COVID-19 restrictions, I focused on the beef industry at the national level to understand how the underlying governance and power structure influences the environmental and social outcomes. However, as the next step, I will follow the original proposed hypothesis to understand how the types and interactions of governance dynamics underlying a supply chain structure shape the associated EJ outcomes. To do this, I will compare EJ impacts associated with three supply chains in California as case studies and the governance mechanism underlying the differences.

5.2.1 A broad range of supply chains

These three supply chains have different scales and different impacts in California. The first case is Cargill, one of the four biggest beef producers in the U.S., which produces more than eight billion pounds of beef and byproducts. From the initial observation of this supply chain, I *hypothesized* that power is concentrated on the processing plant phase of the supply chain. Due to a diffused power structure and increasing the number of chain links, the concentration of power on the processing plants has resulted in less transparency and sustainability implementation. At the same time, Cargill faces less negative publicity and pressure from consumers due to the existence of stakeholder USRSB in its supply chain. The second supply chain is the case study that I have focused on in the first part of my dissertation, Harris Ranch Beef, California's largest beef producer and the largest ranch in the Western United States. In this supply chain, I *hypothesized* that most of the reputation is on the brand name retailers, such as Costco and In-N-Out burger. These brands have a wide range of suppliers for beef products, which makes monitoring sustainability implementation in the upstream part of the chain very hard. The focus of reputation on immediate links has shifted power to Harris Ranch, which is less vulnerable to reputation and has little interest in addressing sustainability issues.

The third supply chain is Belcampo, a small organic beef supply chain approved by the U.S. Department of Agriculture (USDA). They operate 25,000 acres of farmland in Mt. Shasta with full ownership of the processing facility through the retail shops. The nature of this supply chain and the objectives of its founders for sustainability promises full transparency of the chain structure and practices. Because this supply chain doesn't include CAFO in its network and is potentially less associated with environmental and social injustice, it isn't the target of negative publicity or consumer pressure. However, there is a need to consider this supply chain as part of the EJ analysis to discover if there is a "sustainable beef." The goal of the comparison is to understand the diverging and converging perspectives driving sustainability performance in supply chain governance with different scales. The case study approach will provide insight into the variations between perceived unsustainable and sustainable supply chains *(Figure 18).*

5.2.2 Quantify governance dynamics of supply chains

To quantify the power structure of these supply chains, I will combine qualitative methods—including semi-structured interviews and analysis of policy and archival documents—with social network analysis to measure the network structure of the supply chain. I will interview all the nodes of the supply chains about their organizations' goals for sustainability performance, including social and environmental impacts (i.e., EJ impacts); preferred practices and policies for sustainability; and attitudes and perceptions toward EJ. Then I will ask interview informants to name individuals in other organizations with whom they had interacted in the past five years to plan, fund, or implement social and environmental sustainability; obtain information or expertise about social and environmental performance; give formal advice about environmental justice issues. These responses will be used to construct the social network of each supply chain, which will provide insight into the power structure of each supply chain. I will then analyze the network structure of each supply chain with SNA to visualize the networks, description of specific characteristics of the overall network structure, and building of statistical models of network structures and dynamics.

The next task then involves mapping the results of governance dynamics in GIS and overlaying them with the identified EJ hotspots to understand the correlation of governance mechanism and EJ outcomes. The outcomes of the three different case studies will allow me to discover the gaps and inefficiencies in the supply chain structure. I would like then to expand the analysis to other products in California to develop a relevant policy document about the types and interaction of governance dynamics underlying the EJ performance of supply chains. The outcomes also help the supply chains to transform their governance dynamics through introducing specific organizations (e.g., NGOs) and fostering collective action to reduce the gaps and efficiencies in the supply chain and to improve EJ outcomes.

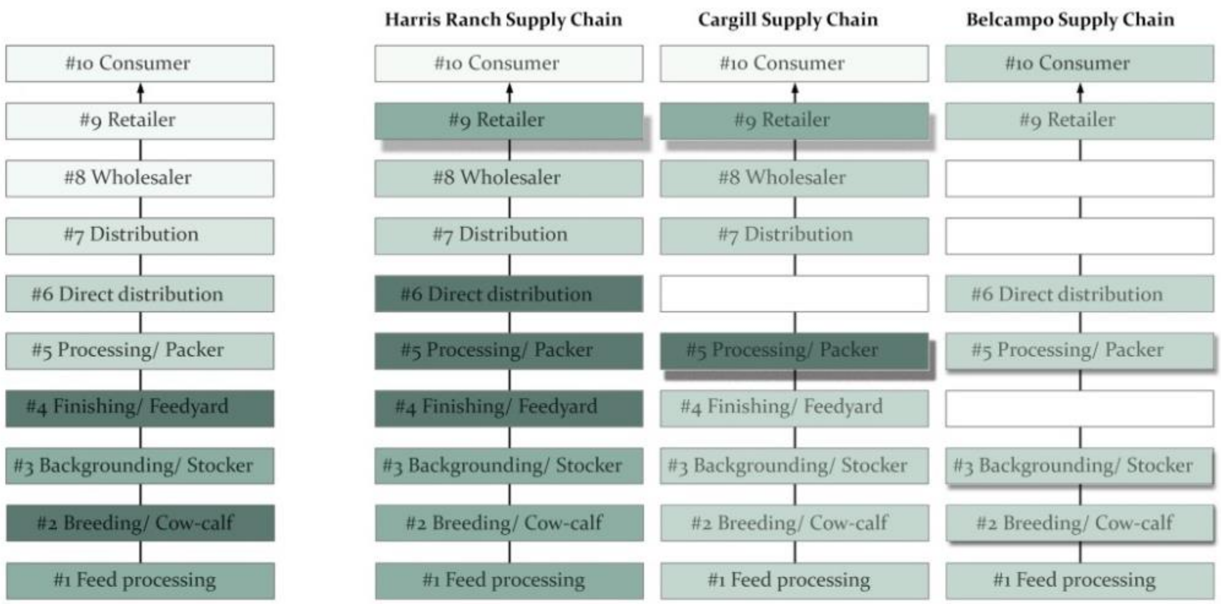

Figure 18. Beef supply chain environmental impact (color) AND hypothesized power structure (color) and reputation vulnerability (shadow) in the supply chain case studies.

5.3 Intellectual merit

This dissertation contributed to the intellectual and societal knowledge through three outcomes.

1. Novel methodologies to quantify environmental justice and power dynamics of supply chains. This dissertation developed quantitative methodologies for reliable, comprehensive analysis of supply chain structure and characterized power dynamics underlying the governance dynamics of production chains, which potentially reveals broader trends that influence changes in supply chain governance. Scaling down the analysis to a specific supply chain in California and analyzing its EJ outcomes have implications for supply chain governance worldwide that are shaped/reshaped by ongoing environmental and social degradation. Moreover, quantifying the perceptions of power among multiple actors across the supply chain through a structured survey provides policymakers with critical information and insights on how to improve environmental and social sustainability through policy and regulations.

2. Exploring gaps and efficiencies in power dynamics underlying environmental and social outcomes. Through interdisciplinary synthesis, this dissertation advanced supply chain governance scholarship by exploring fields such as supply chain management (supply chain governance, operational management, organizational studies, and social network theories), environmental sustainability (environmental justice, environmental governance, and sustainability science), and industrial ecology (LCA, input-output analysis). The study has implications for the future of supply chain governance research by exploring gaps and inefficiencies in the power dynamics across the supply chains through the lens of environmental and social sustainability. Moreover, the dissertation empirically applied a new conceptual framework by looking at the environmental impacts of an individual corporation through performing LCA research in a way sensitive to EJ, equity, and power dimensions.

3. Advocating for transparency in supply chains. By integrating fields that explore EJ with those exploring supply chain governance, this dissertation enhanced our understanding of the trade-offs in dynamics of power across the supply chain and who is likely to benefit most from the bargaining. This dissertation tried to give empirical evidence that will drive opportunities to improve environmental and social outcomes in a way that precludes winners and losers within and outside the supply chains. The study advocates for the transparency of supply chains regarding their environmental and social outcomes to raise awareness about the impacted communities and become their voice in the environmental challenge debates. Furthermore, effectively integrating environmental and social equity perspectives into current and future supply chain governance schemes have transformative implications for vulnerable communities in future EJ studies.

APPENDICES

Appendix A

CAFOs' Representativeness across The U.S.

To validate the accuracy of the generated dataset, an external person with knowledge about CAFOs and industrial farming randomly checked 100 cattle CAFOs and 100 pig CAFOs and checked them for accuracy. We also provided examples of different types, sizes, and forms of CAFOs in different states for better analyses. All 200 locations were identified as CAFOs in the selected dataset. However, differentiating between big pigs CAFOs and dairy CAFOs sometimes might be hard because of the same attributes. In the selected dataset 1 pig CAFO and 2 cattle CAFOs had the same attributes, which led to an accuracy of 99% for the pigs and 98% for the cattle CAFOs.

To test for representativeness across the US, we calculated Pearson correlation at the county level between counts of CAFOs from our dataset and the EPA estimated number of CAFOs per county (1). The EPA dataset reports an aggregated number of CAFOs for all types of animals including poultry. To normalize the two datasets, we used the 2019 USDA chicken sales per county (2), in order to exclude chicken-dominated counties from the equation. We found 150 counties with more than 3,000,000 chicken sales as chicken-dominated counties. From these 150 counties, we removed the counties that had more than 500,000 sales of pigs and 1000,000 sales of cattle (2), to exclude the counties that have a high number of cattle or pigs CAFOs. This process gave us 136 counties as chicken-dominated counties, which has been excluded from the correlation analysis. We finally aggregated the numbers at the state level and calculated the correlation *(Figure 16)*.

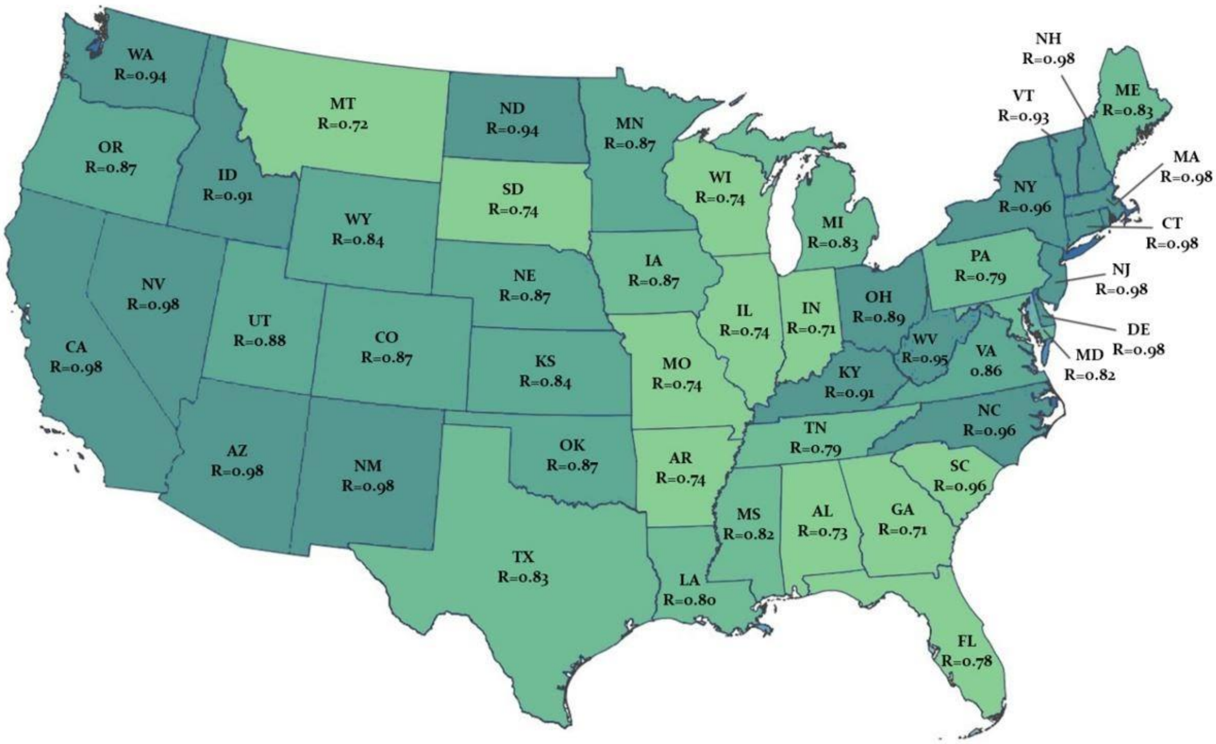

Figure 19. Correlation of CAFOs digitized and EPA estimated number of CAFOs per county per state

Appendix B

Descriptive Statistics of the Communities Living Near the CAFOs

To understand who lives near the cattle and pig CAFOs, we used descriptive statistics in R and found the mean, median, Standard Deviation, Minimum, and Maximum for each of the 3, 5, and 10 km distances across the cattle and pigs CAFOs at the national level for a set of variables. Our variables included race/ ethnicity, education, occupation, poverty, and income. We then calculated these statistics for the three most producing beef and dairy states such as California, Texas, and Wisconsin, and also the three most pigs producing states of Iowa, Minnesota, and North Carolina.

Figure 20 shows four integrated plots of the descriptive analysis at the state level of distance to the CAFOs by ethnicity or education, with a color fill to represent poverty/ education or race.

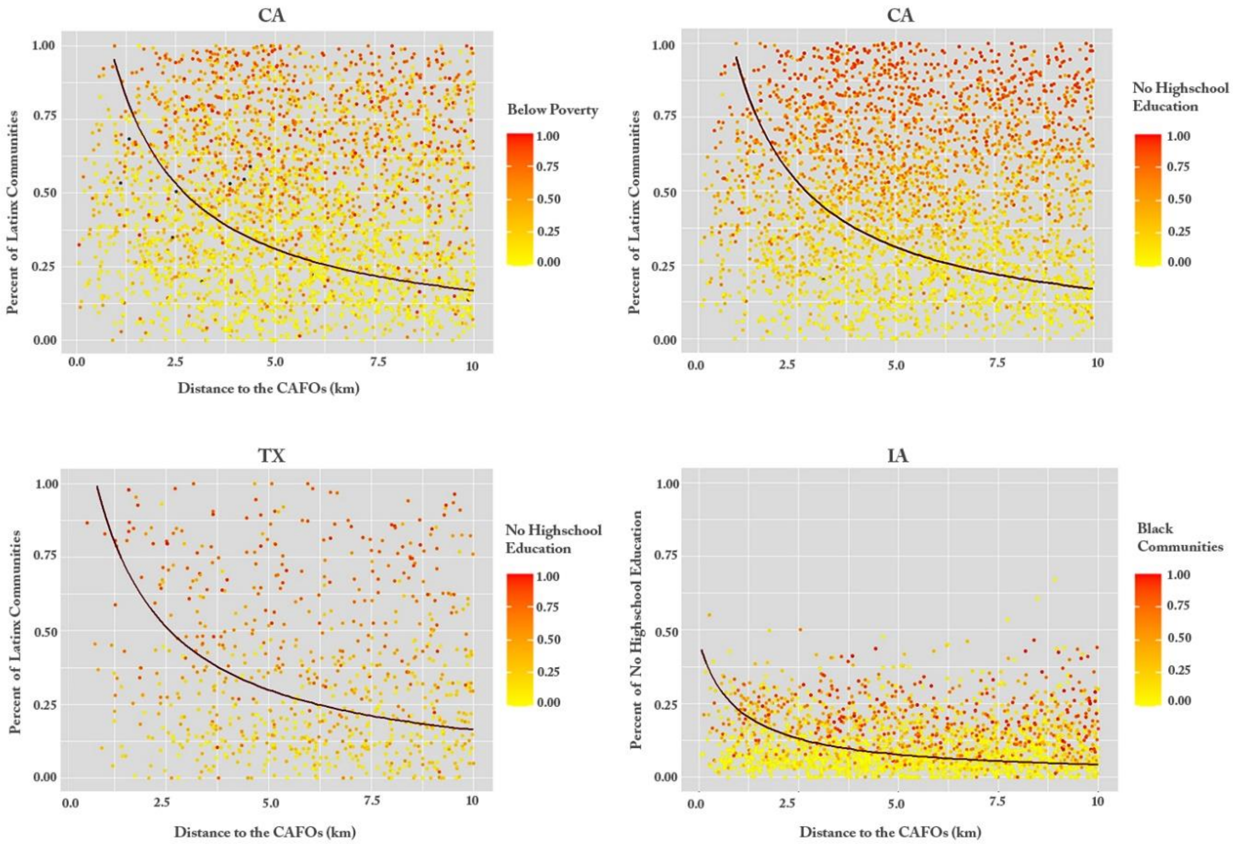

Figure 20. Integrated plots of distance to the CAFOs by (1) ethnicity and color fill to represent poverty in California, (2) ethnicity and color fill to represent education in California (3) ethnicity and color fill to represent no high school education in Texas, and (4) No high school education and color fill to represent black communities in Iowa.

Table 7. Descriptive statistics of the communities living near the CAFOs at the national scale

National	**Cattle 3km**					**Pigs 3km**				
	Mean	SD	Median	Min	Max	Mean	SD	Median	Min	Max
Latinx	0.21	0.25	0.09	0	1	0.07	0.12	0.02	0	0.88
Whites	0.86	0.15	0.92	0.12	1	0.86	0.19	0.95	0	1
Blacks	0.02	0.06	0	0	0.77	0.08	0.15	0	0	0.9
Asians	0.02	0.05	0	0	0.48	0.01	0.03	0	0	0.42
Native Americans	0.01	0.03	0	0	0.76	0.01	0.06	0	0	0.91
Hawaiians	0	0.01	0	0	0.19	0	0	0	0	0.09
POC	0.06	0.09	0.02	0	0.77	0.1	0.17	0.02	0	0.94
No High School	0.14	0.13	0.1	0	0.92	0.13	0.1	0.1	0	0.84
High School	0.54	0.11	0.55	0	0.92	0.57	0.1	0.58	0.07	0.86
College Degree	0.32	0.14	0.31	0	1	0.3	0.12	0.3	0	0.91
Management	0.32	0.12	0.31	0	0.92	0.32	0.11	0.32	0.04	0.78
Service	0.17	0.08	0.16	0	0.67	0.16	0.08	0.15	0	0.7
Sales	0.2	0.07	0.2	0	0.63	0.19	0.07	0.19	0	0.54
Natural	0.14	0.09	0.12	0	1	0.14	0.07	0.14	0	0.43
Production	0.17	0.09	0.16	0	0.76	0.19	0.09	0.18	0	0.58
Below Poverty	0.09	0.1	0.06	0	1	0.09	0.09	0.06	0	1

Mean Income	76696	23463	73995	20754	192020	69890	18470	68150	13421	135796
Income per Capita	29343	10394	28512	1270	112441	28262	8583	27797	546	81967

National	Cattle 5km					Pigs 5km				
	Mean	SD	Median	Min	Max	Mean	SD	Median	Min	Max
Latinx	0.2	0.25	0.08	0	1	0.07	0.11	0.03	0	0.88
Whites	0.86	0.15	0.92	0	1	0.86	0.19	0.95	0	1
Blacks	0.03	0.07	0	0	1	0.08	0.16	0	0	1
Asians	0.02	0.05	0	0	0.75	0.01	0.03	0	0	0.42
Native Americans	0.01	0.03	0	0	0.81	0.01	0.05	0	0	0.91
Hawaiians	0	0.01	0	0	0.19	0	0	0	0	0.13
POC	0.06	0.1	0.03	0	1	0.1	0.17	0.02	0	1
No High School	0.14	0.13	0.1	0	0.92	0.12	0.09	0.09	0	0.84
High School	0.54	0.11	0.55	0	1	0.57	0.11	0.58	0	0.93
College Degree	0.32	0.15	0.31	0	1	0.31	0.13	0.3	0	0.91
Management	0.31	0.13	0.31	0	0.94	0.32	0.11	0.31	0	0.91
Service	0.17	0.09	0.16	0	1	0.16	0.08	0.15	0	0.76
Sales	0.2	0.08	0.2	0	0.63	0.19	0.07	0.19	0	0.62
Natural	0.14	0.09	0.12	0	1	0.13	0.07	0.13	0	0.61
Production	0.17	0.09	0.16	0	0.77	0.19	0.1	0.19	0	0.92
Below Poverty	0.1	0.11	0.06	0	1	0.09	0.1	0.06	0	1
Mean Income	74944	24014	71986	10566	210526	69933	19953	67940	12764	210526
Income per Capita	29106	10766	28114	14	115809	28570	9181	27878	546	104949

National	Cattle 10km					Pigs 10km				
	Mean	SD	Median	Min	Max	Mean	SD	Median	Min	Max
Latinx	0.18	0.24	0.07	0	1	0.08	0.12	0.03	0	0.97
Whites	0.84	0.17	0.91	0	1	0.85	0.2	0.94	0	1
Blacks	0.04	0.1	0	0	1	0.08	0.17	0.01	0	1
Asians	0.03	0.06	0	0	0.75	0.01	0.03	0	0	0.71
Native Americans	0.01	0.04	0	0	0.97	0.01	0.05	0	0	0.95
Hawaiians	0	0.01	0	0	0.31	0	0.01	0	0	0.29
POC	0.08	0.12	0.03	0	1	0.1	0.18	0.03	0	1
No High School	0.14	0.12	0.1	0	1	0.12	0.1	0.1	0	1
High School	0.53	0.12	0.55	0	1	0.56	0.11	0.57	0	1
College Degree	0.33	0.16	0.31	0	1	0.32	0.14	0.3	0	0.93
Management	0.32	0.14	0.31	0	1	0.32	0.12	0.31	0	0.91
Service	0.18	0.09	0.16	0	1	0.17	0.09	0.16	0	1
Sales	0.21	0.08	0.2	0	1	0.2	0.08	0.19	0	1
Natural	0.12	0.09	0.11	0	1	0.12	0.07	0.11	0	0.85
Production	0.32	0.14	0.31	0	1	0.19	0.1	0.18	0	0.92
Below Poverty	0.1	0.11	0.06	0	1	0.1	0.11	0.07	0	1
Mean Income	74630	25655	70917	10566	250000	69580	21780	67026	12500	210526
Income per Capita	29604	11585	28239	14	157923	28600	9807	27638	546	119223

Table 8. Descriptive statistics of the communities living near the CAFOs in the most cattle producing states.

CA	**CAFOs 10km**				
	Mean	SD	Median	Min	Max
Latinx	0.47	0.26	0.46	0	1
Whites	0.68	0.19	0.7	0	1
Blacks	0.04	0.07	0.02	0	0.57
Asians	0.07	0.1	0.03	0	0.71
Native Americans	0.01	0.02	0	0	0.38
Hawaiians	0	0.01	0	0	0.28
POC	0.13	0.13	0.09	0	0.87
No High School	0.22	0.17	0.19	0	0.92

High School	0.49	0.12	0.5	0.02	0.93
College Degree	0.29	0.17	0.26	0	0.96
Management	0.29	0.16	0.27	0	0.94
Service	0.19	0.1	0.18	0	1
Sales	0.21	0.09	0.21	0	0.72
Natural	0.15	0.13	0.12	0	1
Production	0.15	0.1	0.14	0	0.77
Below Poverty	0.14	0.14	0.1	0	0.77
Mean Income	77305.38	29968.52	73154.12	10566.67	250000
Income per Capita	27579.82	14202.28	24945	881	157923

TX	CAFOs 10km				
	Mean	SD	Median	Min	Max
Latinx	0.35	0.26	0.29	0	1
Whites	0.85	0.15	0.9	0.09	1
Blacks	0.06	0.12	0.02	0	0.88
Asians	0.01	0.04	0	0	0.75
Native Americans	0.01	0.02	0	0	0.24
Hawaiians	0	0.01	0	0	0.1
POC	0.08	0.13	0.03	0	0.9
No High School	0.19	0.13	0.17	0	0.74
High School	0.56	0.12	0.56	0.08	0.93
College Degree	0.25	0.14	0.24	0	0.84
Management	0.27	0.13	0.26	0	0.73
Service	0.19	0.1	0.17	0	0.58
Sales	0.21	0.09	0.2	0	0.56
Natural	0.15	0.1	0.13	0	0.62
Production	0.19	0.11	0.17	0	0.68
Below Poverty	0.12	0.12	0.09	0	0.65
Mean Income	65899.69	22266.4	62926.32	24111.29	163921.05
Income per Capita	25685.76	10168.85	24565	1270	96515

WI	CAFOs 10km				
	Mean	SD	Median	Min	Max
Latinx	0.05	0.07	0.02	0	0.74
Whites	0.93	0.09	0.96	0.24	1
Blacks	0.02	0.05	0	0	0.65
Asians	0.02	0.04	0	0	0.46
Native Americans	0.01	0.03	0	0	0.6
Hawaiians	0	0	0	0	0.05
POC	0.04	0.07	0.01	0	0.66
No High School	0.08	0.06	0.06	0	0.56
High School	0.54	0.12	0.56	0.03	0.86
College Degree	0.38	0.14	0.36	0.01	0.96
Management	0.34	0.12	0.32	0	0.88
Service	0.16	0.07	0.14	0	0.53
Sales	0.2	0.07	0.2	0	0.52
Natural	0.1	0.06	0.1	0	0.41
Production	0.2	0.09	0.2	0	0.67
Below Poverty	0.07	0.08	0.04	0	0.73
Mean Income	77087	21507.42	74327.77	21120.12	185241.6
Income per Capita	32916.55	10069.74	31594	139	101210

Table 9. Descriptive statistics of the communities living near the CAFOs in the most pigs producing states.

NC	**CAFOs 10km**				
	Mean	SD	Median	Min	Max
Latinx	0.09	0.11	0.05	0	0.68
Whites	0.62	0.25	0.65	0	1
Blacks	0.29	0.23	0.23	0	1
Asians	0.01	0.02	0	0	0.26
Native Americans	0.03	0.11	0	0	0.95
Hawaiians	0	0	0	0	0.07
POC	0.33	0.25	0.27	0	1
No High School	0.17	0.09	0.16	0	0.61
High School	0.28	0.13	0.26	0	0.8
College Degree	0.28	0.13	0.26	0	0.8
Management	0.29	0.13	0.28	0	0.79
Service	0.19	0.1	0.18	0	0.76
Sales	0.2	0.09	0.2	0	1
Natural	0.13	0.09	0.12	0	0.85
Production	0.19	0.11	0.18	0	0.92
Below Poverty	0.15	0.14	0.12	0	0.96
Mean Income	57729.08	17199.95	55906.67	13884.61	151174.94
Income per Capita	24089.41	8524.05	22860	1256	81967

IA	CAFOs 10km				
	Mean	SD	Median	Min	Max
Latinx	0.07	0.1	0.03	0	0.77
Whites	0.78	0.25	0.88	0	1
Blacks	0.15	0.22	0.04	0	1
Asians	0.01	0.03	0	0	0.5
Native Americans	0.02	0.08	0	0	0.95
Hawaiians	0	0.01	0	0	0.13
POC	0.18	0.23	0.07	0	1
No High School	0.12	0.09	0.1	0	0.67
High School	0.55	0.12	0.56	0.09	1
College Degree	0.33	0.14	0.31	0	0.88
Management	0.32	0.12	0.31	0	0.81
Service	0.17	0.09	0.16	0	0.76
Sales	0.2	0.08	0.19	0	1
Natural	0.12	0.08	0.12	0	0.85
Production	0.19	0.1	0.18	0	0.92
Below Poverty	0.11	0.12	0.07	0	0.96
Mean Income	65303.29	19751	63639.35	12500	201396.55
Income per Capita	27692.65	9468.57	26888	1256	100128

MN	CAFOs 10km				
	Mean	SD	Median	Min	Max
Latinx	0.06	0.1	0.03	0	0.74
Whites	0.93	0.09	0.96	0.36	1
Blacks	0.01	0.04	0	0	0.34
Asians	0.01	0.04	0	0	0.33
Native Americans	0.01	0.03	0	0	0.45
Hawaiians	0	0.01	0	0	0.23
POC	0.04	0.06	0.01	0	0.46
No High School	0.09	0.07	0.07	0	0.63
High School	0.56	0.09	0.57	0.1	0.82
College Degree	0.35	0.1	0.34	0.06	0.78

Management	0.33	0.09	0.33	0	0.59
Service	0.16	0.07	0.15	0	0.54
Sales	0.19	0.06	0.19	0	0.57
Natural	0.13	0.06	0.13	0	0.32
Production	0.19	0.08	0.18	0.04	0.6
Below Poverty	0.07	0.07	0.04	0	0.58
Mean Income	73827.5	16623.57	73250	28322.52	139516.13
Income per Capita	31291.76	7949.69	30562	9843	104949

Table 10. Descriptive statistics of the communities living near the CAFOs. (i) Top 10, (ii) Top 50 dirtiest counties.

Top 10	**CAFOs 10km**				
	Mean	SD	Median	Min	Max
Latinx	0.44	0.28	0.34	0	1
Whites	0.74	0.18	0.18	0	1
Blacks	0.05	0.11	0.01	0	0.78
Asians	0.03	0.05	0.01	0	0.44
Native Americans	0.01	0.02	0	0	0.13
Hawaiians	0	0.01	0	0	0.19
POC	0.09	0.12	0.07	0	0.84
No High School	0.24	0.16	0.17	0	0.92
High School	0.52	0.11	0.11	0.08	0.93
College Degree	0.24	0.13	0.14	0	0.79
Management	0.27	0.14	0.14	0	0.76
Service	0.17	0.09	0.08	0	1
Sales	0.19	0.09	0.09	0	0.6
Natural	0.19	0.13	0.11	0	1
Production	0.18	0.1	0.1	0	0.59
Below Poverty	0.15	0.14	0.12	0	0.71
Mean Income	67673.32	21825.67	20772.4	19442.68	172096.77
Income per Capita	24757.85	10779.46	10695.48	1890	81967

Top 50	CAFOs 10km				
	Mean	SD	Median	Min	Max
Latinx	0.32	0.29	0.33	0	1
Whites	0.77	0.2	0.21	0	1
Blacks	0.05	0.11	0.01	0	1
Asians	0.04	0.08	0.01	0	0.71
Native Americans	0.01	0.03	0	0	0.68
Hawaiians	0	0.01	0	0	0.28
POC	0.1	0.14	0.07	0	1
No High School	0.18	0.15	0.13	0	0.92
High School	0.52	0.11	0.11	0.08	0.93
College Degree	0.29	0.15	0.14	0	0.84
Management	0.29	0.14	0.13	0	0.94
Service	0.17	0.09	0.08	0	1
Sales	0.2	0.08	0.07	0	0.72
Natural	0.15	0.11	0.09	0	1
Production	0.18	0.1	0.09	0	0.77
Below Poverty	0.12	0.13	0.09	0	0.79
Mean Income	71750.58	23917.12	22662.2	18607.87	250000
Income per Capita	27295.03	11140.74	10401.18	139	157923

Appendix C

Correlation of Elevation and $PM_{2.5}$ Concentrations across The U.S.

Looking into the literature showed that morphology and meteorology variations can partly explain the spatial variability of $PM_{2.5}$ across the US As an example, we chose elevation to confirm the correlation of elevation and $PM_{2.5}$ concentrations. The elevation is negatively correlated with $PM_{2.5}$ across the US, and higher elevation in the Northeast and West and the Appalachian Mountains contribute to less $PM_{2.5}$ in these areas.

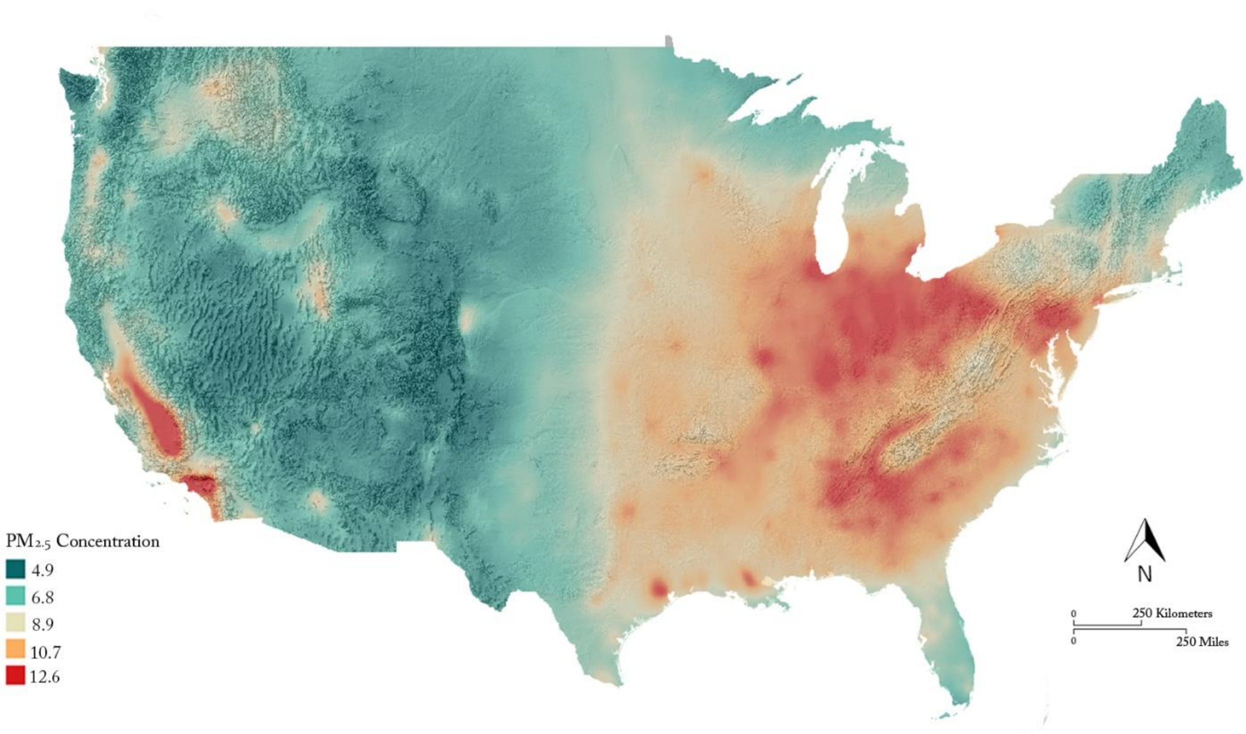

Figure 21. Correlation of elevation and PM2.5 concentrations across the U.S.

Appendix D: Costco-Harris Ranch Suppy Chain References and Structures

Table 11. Harris Ranch supply chain references

Breeding		Backgrounding		Finishing		Packing		Retailer		
Actor	**Resource**	**Actor**	**Resource**	**Actor**	**Resource**	**Actor**	**Resource**		**Actor**	**Resource**
Tejon Ranch	Hereford World Magazine Feb 2019 (NA)	David Wood Ranches (East of Salines, NE of Santa Maria Ranch)	*Congressional Record , V152, Page 1925 (LD)*	Harris Feeding Company	Harris Beef Company (CW)	Harris Ranch Beef Company	Harris Beef Company (CW)	Direct	Harris Inn & Restaurant	Harris Beef Company (CW)
			California State Water Board/ Grazing Regulatory Action Plan (LD)					International	Japan	AgAlert (NA)
									China	US Meat Export Federation (LD) / USDA Foreign Agricultural Service, 2018
		Santa Margarita Ranch							Singapore	
								Regional	Costco	Costco Online (CW)
Centennial Livestock	California Cattleman Magazine Jan 2017 (NA)	David Wood Ranches (10 Ranches in Central Valley)							In-N-Out Burger	The Guardian (NA)
									Save-Mart	Harris Beef Company (CW)
									Raley's	Raley's Online (CW)
Dressler Ranch	Hereford World Magazine Feb 2019 (NA)	Sweetwater Ranch							Broadway Market	Broadway Market Website (CW)
									Grocery Outlet	News Article (NA)
		Point Ranch								
				Central Valley Meat Co.	Central Valley Meat Co. (CW)	Coelho Meat Co.	Central Valley Meat Co. (CW)	Direct	CLW Foods	Central Valley Meat Co. (CW)
Owens Valley Ranches	California Cattleman Magazine Jan 2017 (NA)	Dressler Ranch						Regional	In-N-Out Burger	CBS News, 2015 (NA)
		Chance Ranch							USDA supplier for 'National School Lunch Program'	
		Centennial Livestock								
Cowley Family Ranch	Angus Beef Bulletin Jan 2014 (NA)	Mammoth Ranch	US Forest Service (ED)							
		Bridgeport Ranch								
Topo Ranch	*Drovers Cattle Network (NA)*	Owens Valley Ranches	California Cattleman Magazine Jan 2017 (NA)							
		Tejon Ranch	Hereford World Magazine Feb 2019 (NA)							
		Cowley Family Ranch	Angus Beef Bulletin Jan 2014 (NA)							
Peach Tree Ranch	*Drovers Cattle Network (NA)*									
		Topo Ranch	Drovers Cattle Network (NA)							
		Peach Tree Ranch	Drovers Cattle Network (NA)							

CW – company website ED – external document NA – news article LD – legal document

Figure 22. Detailed structure of Harris Ranch supply chain

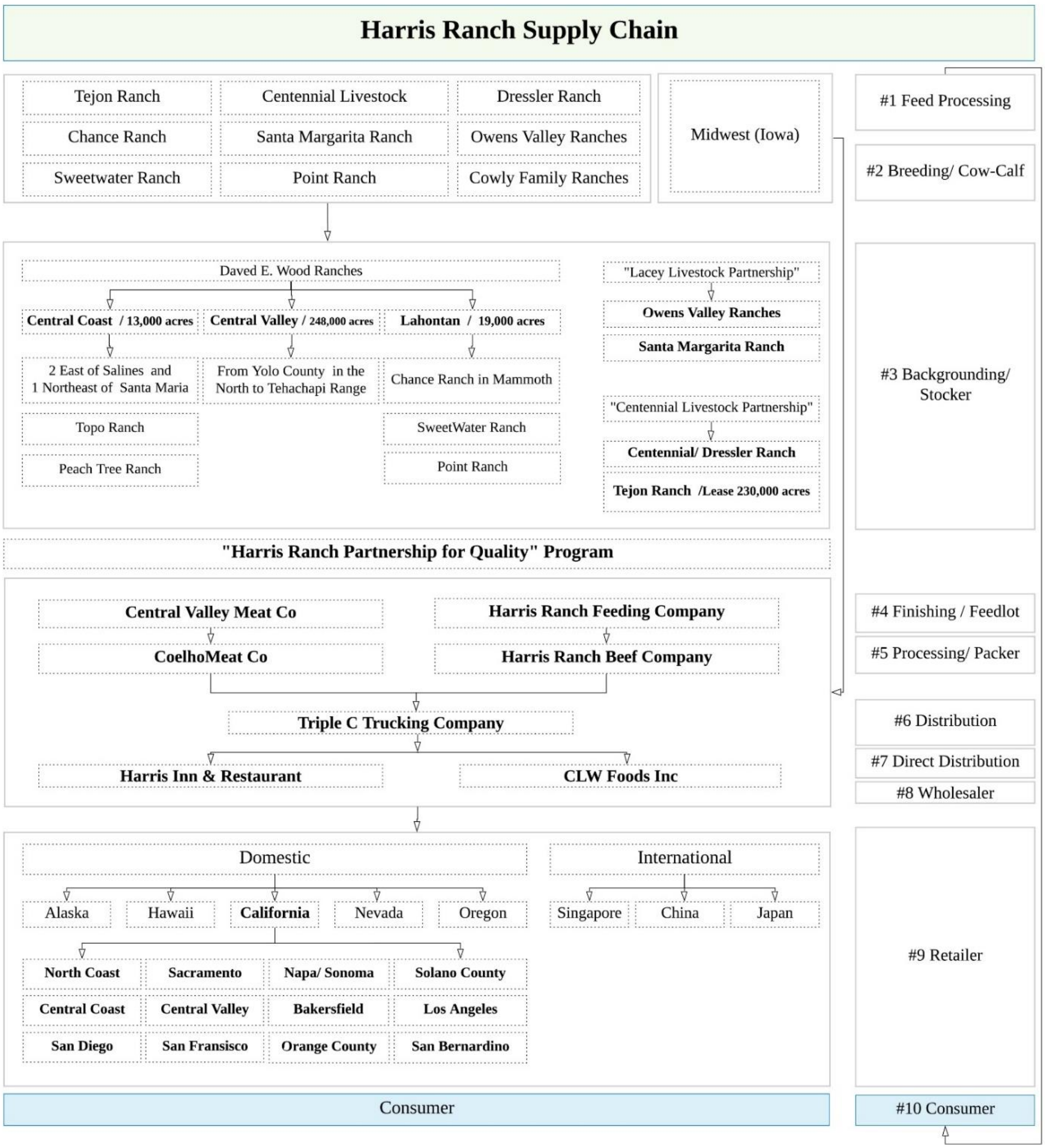

Figure 23. Detailed structure of the active stakeholders in the California beef supply chain

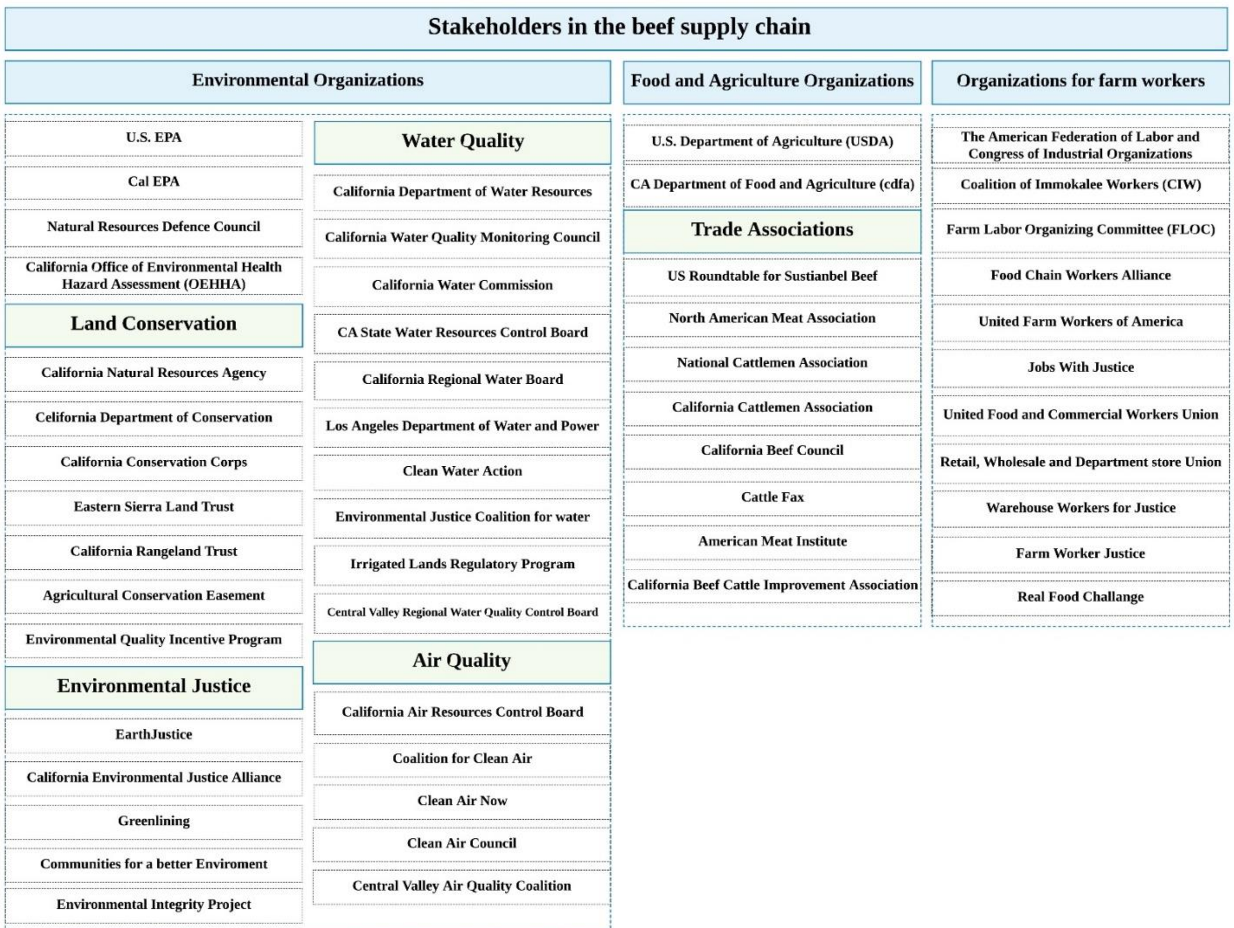

Figure 24. Detailed structure of Harris Ranch supply chain retailers in California

Appendix E

Beef Supply Chain Stakeholder Survey

Thank you for taking your time to do this survey. Your answers will enable us to better understand the governance of the **beef supply chain, from breeding to the final consumption of products**. We encourage you to think holistically about the actors that shape the efficiency, sustainability, and resiliency of this supply chain. This includes the producers and government agencies that regulate them of course, but also the retailers, consumers, trade associations, non-governmental organizations (NGOs), and media that shape the beef supply chain.

This survey will take **less than 5 minutes** to complete. We ask that you respond to this survey by **8/20/2020**.

Your privacy and identity will remain confidential. We will not share this information with anyone.

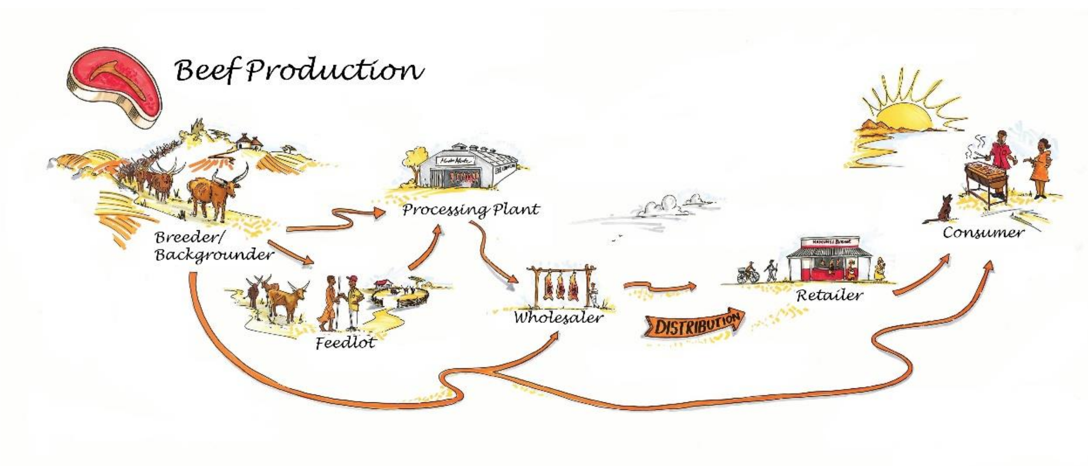

Figure 25. A simple sketch of beef supply chain (source: google)

Beef Supply Chain Actors: Which category do you most closely align with?

1. **Feed Producers:** Feed production refers to the farming, processing, and producing animal feed to use in different stage of animal's life.
2. **Cow-calf producers/ Breeders:** Cow-calf producers keep a permanent herd of cows to produce calves for later sale.
3. **Backgrounders/ Stockers:** Stockers usually have extra pasture to keep calves after weaning and background them to sell as yearlings for the feedlot.
4. **Feedlot/ Packers:** Feedlots are concentrated operations focused on efficient growth and weight gain of the animals by providing a readily digestible, high-energy diet.
5. **Slaughtering/ Processing Plants:** *Meatpacking, slaughtering or processing plants refer to the process of turning cattle into meat, including slaughter, processing, packaging and distribution.*
6. **Retailers:** Retailers are the services to sell beef to the consumers, such as Costco, Walmart, Target and etc.
7. **End Consumers:** The individuals or organizations that buy beef from the retailers.
8. **Governmental or Regulatory agencies:** Public authority or government agency responsible for exercising autonomous authority over some area in the beef supply chain such as USDA, US EPA, Regional EPA.
9. **NGOs:** Non-government organizations such as Sierra Club, Clean Air Now, Rangeland Trust and etc.
10. **Trade Associations:** Trade groups or business associations founded and funded by beef industry for collaboration, education and advertisement such as US Roundtable for Sustainable Beef, National Cattlemen Association, and American Meat Association.
11. **Media:** Media communication industry such as News Media, broadcasting or advertising.

Please rank the following issues related to the U.S. beef production in order of importance: (1:Highest, 5:Lowest).

- **GHG Emissions:** Cattle emit GHGs such as methane as they digest grass and plants.
- **Water Use:** Beef production has a sizable wastewater because of contaminated runoff from fertilizers and manure management.
- **Air Pollution:** Beef production by producing particulate matter, ammonia and etc. might affect the nearby residents.
- **Land Use:** Impacts of land use and land use conversion, both caused by and prevented by ranching and farming activities and other supply chain land use decisions.
- **Employee Safety and Well-being**: The implementation of safety programs and training to provide a safe workplace and the relative prosperity of workers employed in the beef production.

For the following questions, please **rank the five most** actors with the ability to improve the outcomes of the supply chain and induce change to chain in each category from 1 to 5: (1. Highest; 5. Lowest)

1. **Greenhouse Gas Emissions:** Please rank the top 5 entities with the greatest ability to improve the outcomes of the beef supply chain regarding greenhouse gas emissions. (1. Highest; 5. Lowest).

	1	2	3	4	5
Feed Producers					
Cow-calf producers/ Breeders					
Backgrounders/ Stockers					
Feedlot/ Packers					
Processing Plants					
Retailers					
End Consumers					
Governmental or Regulatory Agencies					
NGOs					
Media					
Trade Associations					
Other					

Other: Please list other influential organizations not listed above.

2. **Water Use:** Please rank the top 5 entities with the greatest ability to improve the outcomes of the beef supply chain regarding water use. (1. Highest; 5. Lowest)

	1	2	3	4	5
Feed Producers					
Cow-calf producers/ Breeders					
Backgrounders/ Stockers					
Feedlot/ Packers					
Processing Plants (e.g., Cargill, JBS, National Beef, and Tyson)					
Retailers (e.g., Costco, Walmart, In-N-Out Burger, McDonald's)					
End Consumers					
Governmental or Regulatory Agencies (EPA, Regional Water Boards)					
NGOs (e.g., Clean Water Action)					
Media					
Trade Associations (U.S. Roundtable for Sustainable Beef, Cattlemen associations)					
Other					

Other: Please list other influential organizations not listed above.

3. **Air Pollution:** Please rank the top 5 entities with the greatest ability to improve the outcomes of the beef supply chain regarding air pollution. (1. Highest; 5. Lowest)

	1	2	3	4	5
Feed Producers					
Cow-calf producers/ Breeders					
Backgrounders/ Stockers					
Feedlot/ Packers					
Processing Plants (e.g., Cargill, JBS, National Beef, and Tyson)					
Retailers (e.g., Costco, Walmart, In-N-Out Burger, McDonald's)					
End Consumers					
Governmental or Regulatory Agencies (EPA, Regional Air Boards)					
NGOs (e.g., Clean Air Council)					
Media					
Trade Associations (U.S. Roundtable for Sustainable Beef, Cattlemen associations)					
Other					

Other: Please list other influential organizations not listed above.

4. **Land Use:** Please rank the top 5 entities with the greatest ability to improve the outcomes of the beef supply chain regarding land use. (1. Highest; 5. Lowest)

	1	**2**	**3**	**4**	**5**
Feed Producers					
Cow-calf producers/ Breeders					
Backgrounders/ Stockers					
Feedlot/ Packers					
Processing Plants (e.g., Cargill, JBS, National Beef, and Tyson)					
Retailers (e.g., Costco, Walmart, In-N-Out Burger, McDonald's)					
End Consumers					
Governmental or Regulatory Agencies (EPA, USDA)					
NGOs (e.g., Sierra Club)					
Media					
Trade Associations (e.g., U.S. Roundtable for Sustainable Beef, Cattlemen associations)					
Other					

Other: Please list other influential organizations not listed above.

5. **Employee Safety and Well-being:** Please rank the top 5 entities with the greatest ability to improve the outcomes of the beef supply chain regarding employee safety and well-being. (1. Highest; 5. Lowest)

	1	**2**	**3**	**4**	**5**
Feed Producers					
Cow-calf producers/ Breeders					
Backgrounders/ Stockers					
Feedlot/ Packers					
Processing Plants (e.g., Cargill, JBS, National Beef, and Tyson)					
Retailers (e.g., Costco, Walmart, In-N-Out Burger, McDonald's)					
End Consumers					
Governmental or Regulatory Agencies (e.g., Department of Labor, Labor unions)					
NGOs (e.g., United Food and Commercial Workers Union)					
Media					
Trade Associations (e.g., U.S. Roundtable for Sustainable Beef, Cattlemen associations)					
Other					

Other: Please list other influential organizations not listed above.

6. In your opinion, what is the biggest challenge facing the U.S. beef industry over the next decade?

We appreciate your participation. Would you like to be contacted to schedule a semi-structured follow-up phone interview? if yes, please write your email here.

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