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Where's the beef? Costco's meat supply chain and environmental justice in California

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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.

1. 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

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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).

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 1).

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 multi-billion 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 sub-suppliers 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 multi-stakeholder 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 generic industries and sectors. More broadly,

Table 1
Environmental Justice studies of livestock supply chains.

Authors, (year)	*Location*	Study Focus	*Environmental* Dimensions	*Social* Dimensions	*health* Dimensions	*Supply Chain* Scope
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		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

revealing the origins of Costco's beef – where it came from, how it was produced and who produced it – 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.

2. 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.

2.1. 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 μm 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.

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. Feedcrop 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).

2.2. 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 A.

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).

2.3. 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 B, C and D.

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.

2.4. 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

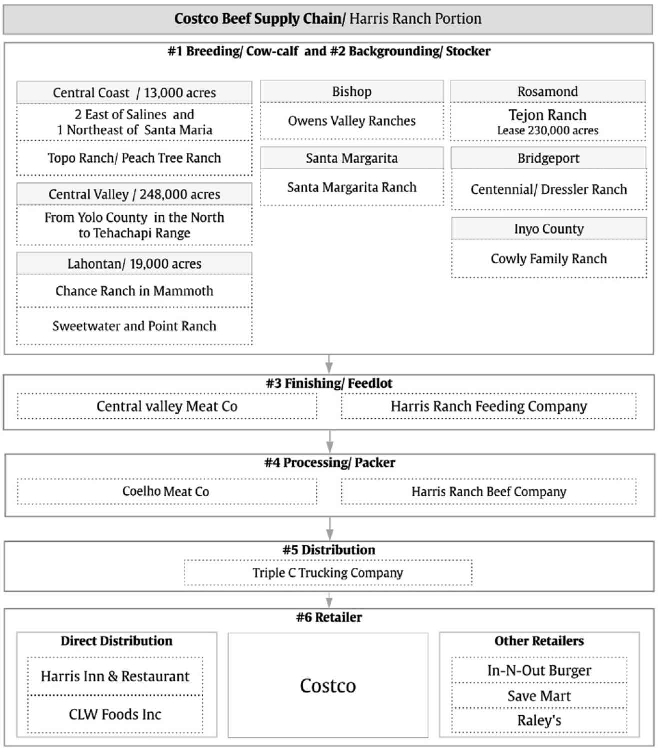

Fig. 1. Costco beef supply chain in California.

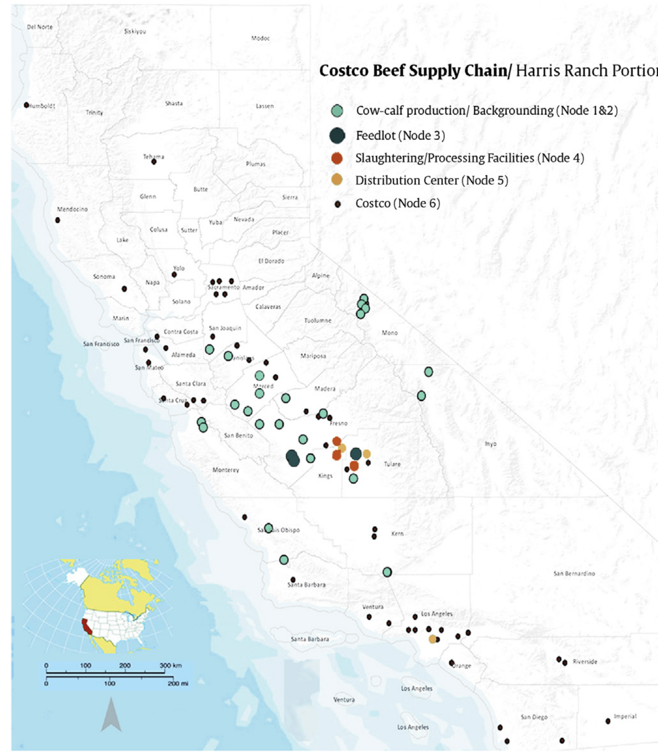

Fig. 2. Physical flow of beef in Harris Ranch Supply Chain.

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. 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.

3.1. Harris Ranch — Costco beef supply chain

3.1.1. 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 8–10 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).

3.1.2. 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 (Fig. 1).

3.1.3. 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 (Fig. 2). 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).

3.1.4. 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 though the Central Valley Meat Company subsidiary Triple C Trucking Company.

3.1.5. 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).

3.2. 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. Fig. 3A displays daily average $PM_{2.5}$ concentrations across California in $\mu g/m^3$. The San Joaquin Valley in the heart of California is awash in air pollution, as are urban areas. Fig. 3B breaks down total anthropogenic $PM_{2.5}$ emissions for the year 2017 across the San Joaquin Valley in $\mu g/m^3$. 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). Fig. 4A 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.

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 $\mu g/m^3$, exceeding both state and national averages, as well as the 12 $\mu g/m^3$ threshold set by both California and U.S. Environmental Protection Agency (Fig. 4B). Fig. 5 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.

3.3. 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 – alongside countless emergency room visits and lost days of school and work (Meng et al., 2012; Padula et al., 2013; American Lung Association, 2019).

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 ne arest feedlot. We use Student's t-tests at the 95% confidence-level to explore links between block-group proximity to a CAFO, demographics, and health outcomes. Fig. 6A 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

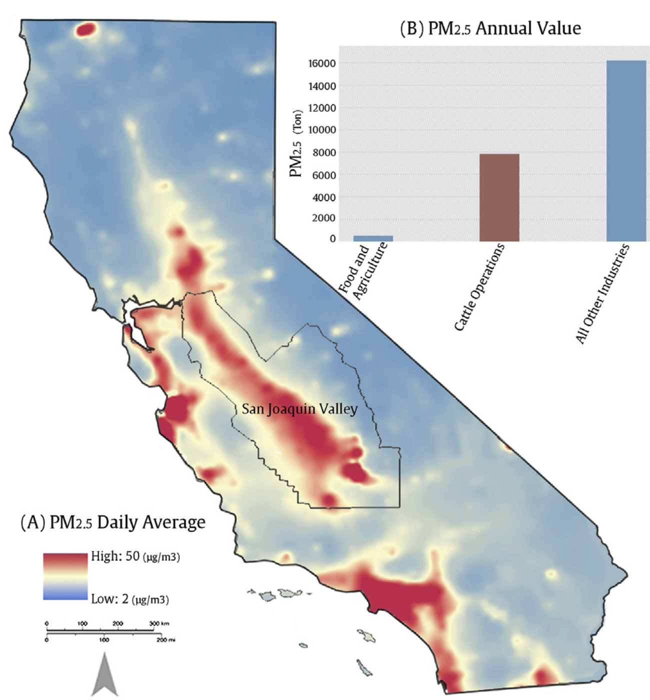

Fig. 3. (A) $PM_{2.5}$ daily average ($\mu g/m^3$) in California (resource: EPA, 2017). (B) $PM_{2.5}$ Annual Value across different industries (Resource: CARB, 2017).

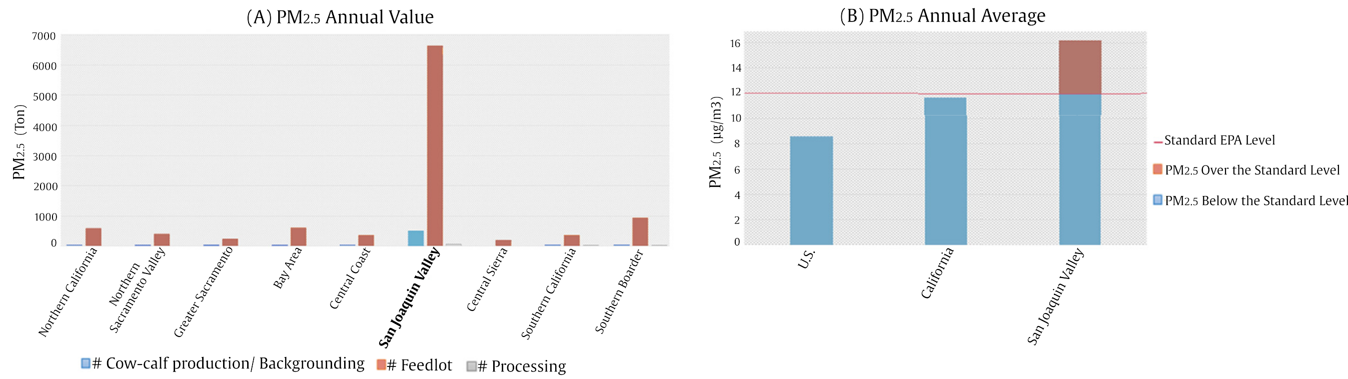

Fig. 4. (A) $PM_{2.5}$ Annual Value (Tons) in CA Regions (Resource: NEI, 2017). (B) $PM_{2.5}$ average (μg/m^3) in US, CA and San Joaquin valley (resource: NEI 2017)

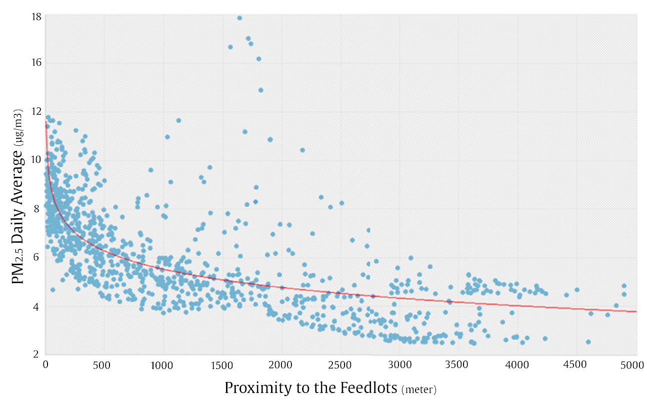

Fig. 5. PM2.5 concentration (μg/m^3) and proximity to the feedlots.

feedlot (see SI Table 2 for full *t*-test results).

We use census data from 2017 to explore which population groups are most burdened. Fig. 6B compares the percentages of different races within and outside a 1 km buffer from the nearest feedlot. Latinx (refers to Hispanic and Latino in National Census data) bear a disproportionate amount of this pollution. The proportion of latinx 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 latinx farmhands, 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 latinx and low-income communities, are the most affected.

4. Discussion

Our analysis showed that the cattle 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 marginalized 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). Nontrivial 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.

4.1. 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 San Joaquin 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

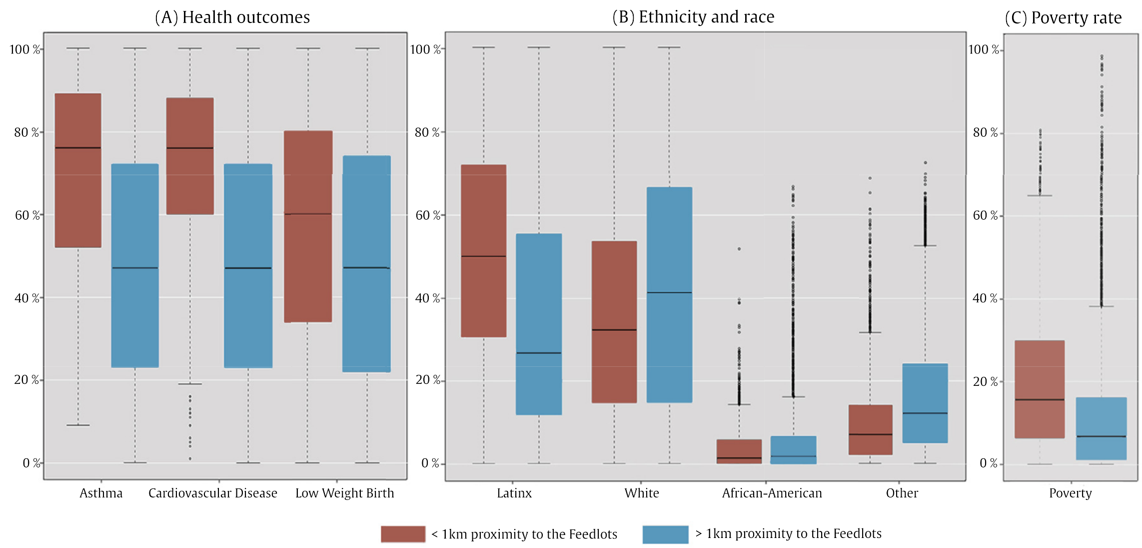

Fig. 6. Environmental justice and cattle feedlots in California's Central Valley. Box plots of health outcomes (A), ethnicity and race (B), and poverty rate (C) of census block-groups less than 1 km from a feedlot and more than 1 km from a feedlot (Resource: American Community Survey, 2017; OEHHA, 2018).

Table 2
Attributes of census block-groups within of 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	df	p-value	95% confidence interval	
Percent Latinx	26.638	2945	<2.2e-16	0.14870	0.17055
Percent White	−12.683	3062	<2.2e-16	−0.077890	−0.05703
Percent African-American	−9.612	3755	<2.2e-16	−0.01763	−0.01166
Percent Other	−31.000	3876	<2.2e-16	−0.082418	−0.07261
Percent Poverty	25.473	2542	<2.2e-16	19.79269	10.66257
Percent Asthma	23.678	1020	<2.2e-16	19.72913	23.29476
Percent Cardiovascular Disease	29.008	1080	<2.2e-16	22.56286	25.83667
Percent Low-Birth weight	8.116	952	<2.2e-16	6.572511	10.76433

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 found to be trying to influence the curriculum of "sustainable agriculture" at the California Polytechnic State University (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).

4.2. Implications for Costco

Costco sources beef for its California stores from multiple producers. Although Harris Ranch 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 domestic environmental issues from beef production. 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 way 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 adversely 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).

4.3. Moving beyond industry self-regulation

In addition to the industry led initiatives, powerful actors outside of the supply chain can promote sustainable beef production. The U.S. EPA has the remit under the Clean Air Act to monitor industrial facilities for violations of national pollution guidelines (Elefritz, 2018). Industry lobbying has effectively blocked application of this regulation to CAFOs (Wilson, 2007; Elefritz, 2018). The Clean Water Act, however, has been more rigorously used against CAFOs, showing how regulations can reduce CAFO impacts (Wilson, 2007; Elefritz, 2018). For instance, the EPA used the act to curtail unauthorized discharges of stormwater from CAFOs in Iowa, by \$160,000 civil penalty and requiring them to implement pollution controls to reduce future stormwater discharges (US EPA, 2017). The Clean Air Act could be used similarly to push for $PM_{2.5}$ abatement technologies at CAFOs or lower cattle densities if these are ineffective. Regional and local authorities can also contribute. California's Attorney General is tasked with upholding the principles of environmental justice (CA Department of Justice, 2020). NGOs and other civil society actors can organize on behalf of the marginalized communities that shoulder the heavy pollution burdens of CAFOs to orchestrate legal action against beef producers under existing California environmental laws. State regulators could also place a moratorium on CAFO expansion until owners demonstrate that their facilities can operate in an environmentally sensitive and socially just manner. In the absence of a statewide ban, individual municipalities could prevent CAFO expansion through exclusionary land-use zoning.

4.4. 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 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 life cycle 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 through supply chains (Hoffman, 2017).

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 San Joaquin 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.

5. 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 peoples 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 paper 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 Latinx 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.

CRediT authorship contribution statement

Sanaz Chamanara: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Project administration, Validation, Visualization, Writing - original draft, Writing - review & editing. **Benjamin Goldstein:** Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Writing - original draft, Writing - review & editing. **Joshua P. Newell:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Supervision, Writing - original draft, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix E. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.123744.

Appendix A. Harris Ranch Supply Chain References

Breeding		Backgrounding		Finishing		Packing		Retailer		
Actor	Reference	Actor	Reference	Actor	Reference	Actor	Reference	Actor		Reference
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)
		Santa Margarita Ranch	California State Water Board/ Grazing Regulatory Action Plan (LD)					International	Japan China Singapore	AgAlert (NA) US Meat Export Federation (LD)/USDA Foreign Agricultural Service, 2018
Centennial Livestock	California Cattleman Magazine Jan 2017 (NA)	David Wood Ranches (10 Ranches in Central Valley)						Regional	Costco	Costco Online (CW)
Dressler Ranch	Hereford World Magazine Feb 2019 (NA)	Sweetwater Ranch Point Ranch							In–N-Out Burger	The Guardian (NA)
									Save-Mart	Harris Beef Company (CW)
									Raley's	Raley's Online (CW)
									Broadway Market	Broadway Market Website (CW)
									Grocery Outlet	News Article (NA)
				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 Centennial Livestock							USDA supplier for 'National School Lunch Program'	
Cowley Family Ranch	Angus Beef Bulletin Jan 2014 (NA)	Mammoth Ranch Bridgeport Ranch	US Forest Service (ED)							
Topo Ranch										

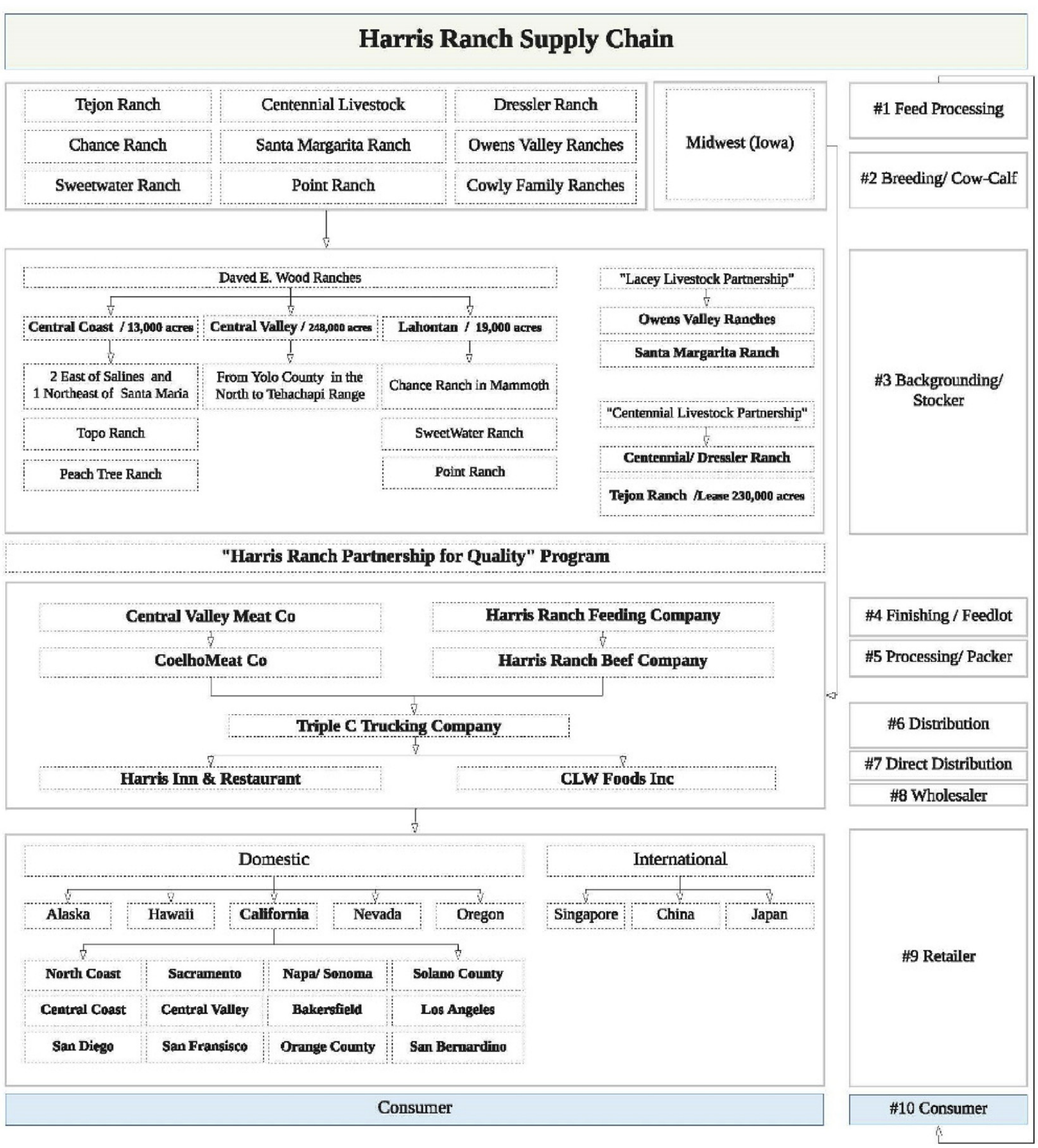
(*continued on next page*)

(*continued*)

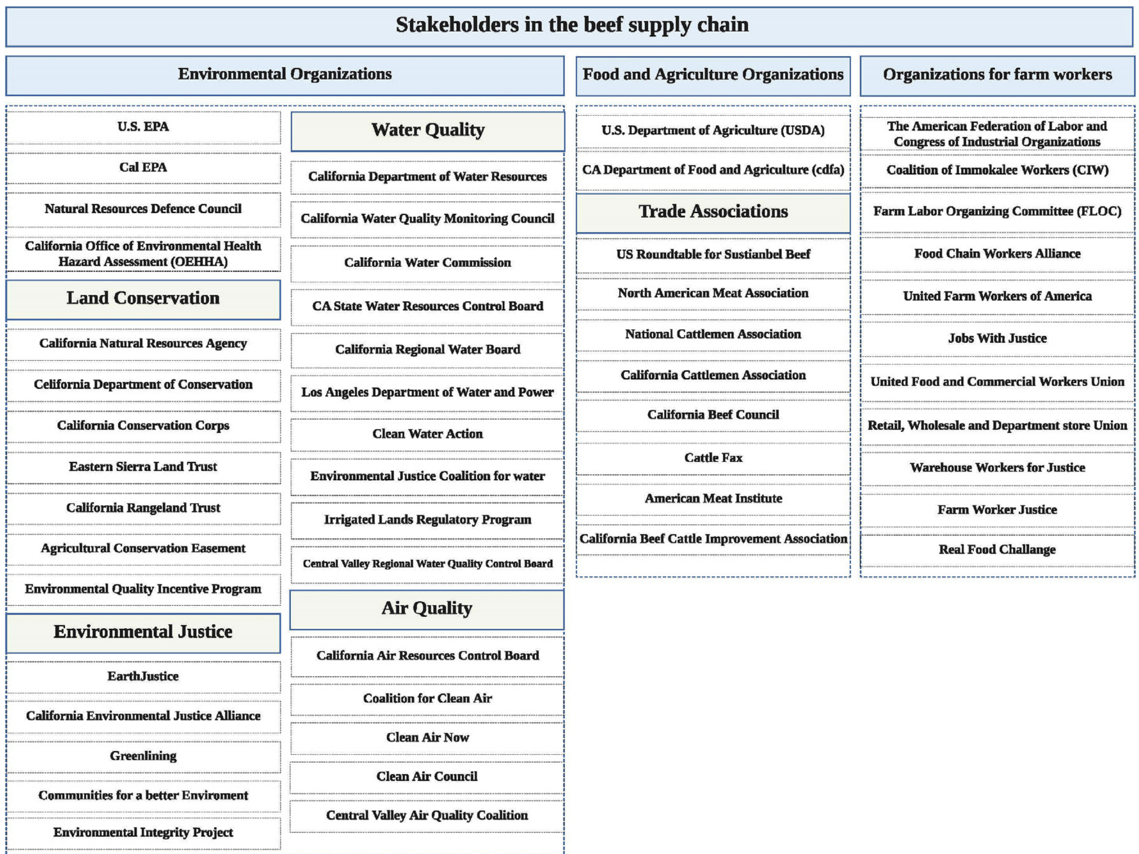
Breeding		Backgrounding		Finishing		Packing		Retailer	
Actor	Reference	Actor	Reference	Actor	Reference	Actor	Reference	Actor	Reference
	Drovers Cattle Network (NA)	Owens Valley Ranches	California Cattleman Magazine Jan 2017 (NA)						
		Tejon Ranch	Hereford World Magazine Feb 2019 (NA)						
		Cowley 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.
NA – news article.
ED – external document.
LD – legal document.

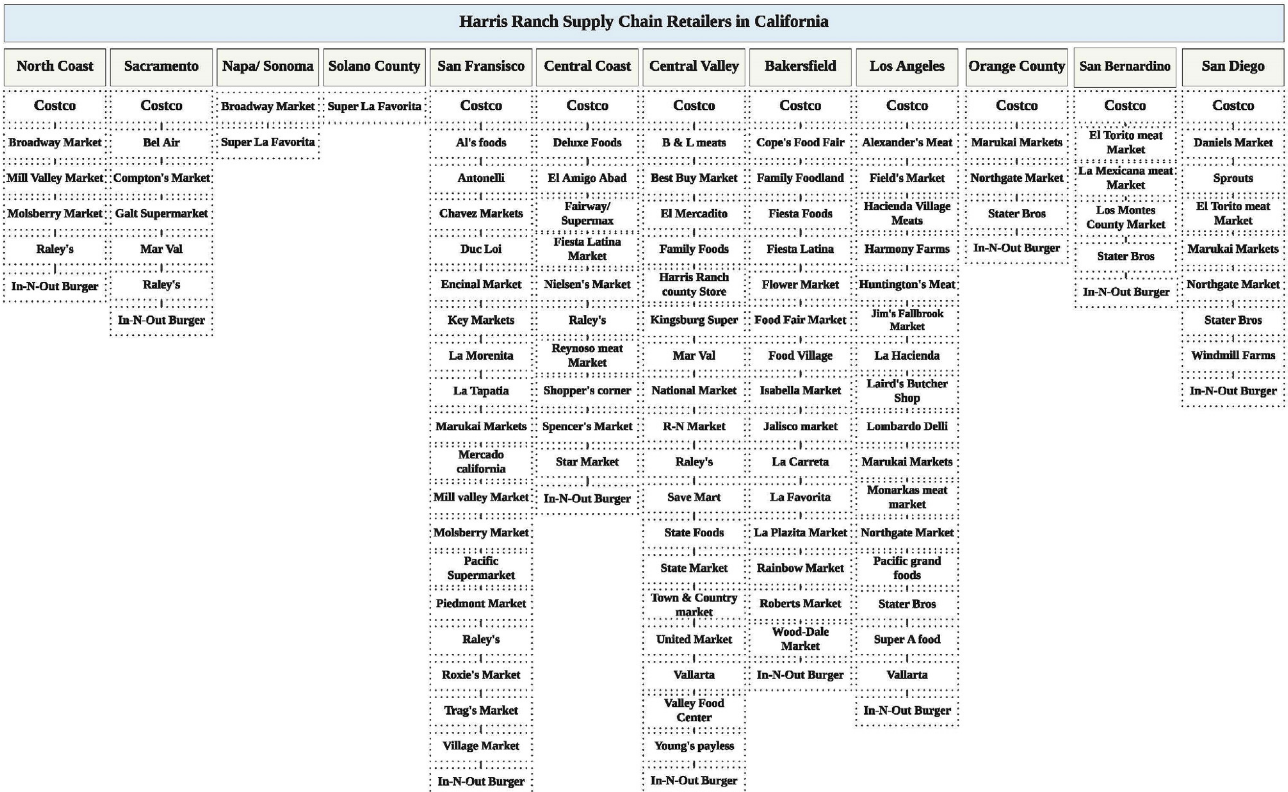
Appendix B. Detailed Structure of Harris Ranch Supply Chain



Appendix C. Detailed Structure of the Active Stakeholders in the California Beef Supply Chain



Appendix D. Detailed Structure of Harris Ranch Supply Chain Retailers in California



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