Deforestation, Certification, and Transnational Supply Chains: A Study of the Palm Oil Sector

by

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Dedication

To my parents. For their never-ending support.

To Grandma Betty. For her constant affirmations.

To Grandma and Pop. For teaching me to love the forest.

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DRC	Democratic Republic of Congo
D_n-score	Dynamic network score
ESG	Environmental Social Governance
FFB	Fresh (oil palm) Fruit Bunch
GIS	Geographic Information System
GPS	Geographic Positioning System
GREPALMA	The Guild of Palmicultores of Guatemala, GREPALMA, for its Spanish acronym
HS	Harmonized commodity description and coding System
IUU	Illegal, Unregulated, Unreported (fishing)
KBA	Key Biodiversity Area
MSI	Multi Stakeholder Initiative
NGO	Non-Governmental Organization
NIR	Near Infrared
PIE	Political-Industrial Ecology
RFID	Radio-Frequency Identification
RF	Random Forest
RSPO	Roundtable on Sustainable Palm Oil
SCM	Supply Chain Management

TRACAST	Tracking Corporations Across Space and Time
UN	United Nations
WCPO	Western and Central Pacific Ocean

Abstract

Commodity production increasingly drives environmental change and degradation. But globalization geographically separates production from consumption, making it difficult to assess *who* is driving these impacts. Although the literature has established general flows connecting land-use change in one region to consumption in another, we lack the methodological approaches necessary to connect specific actors (e.g., domestic and international corporations, state-owned enterprises, and traders), to their impacts. Unraveling often complex and opaque supply chains presents a distinct challenge. At the same time, voluntary certification schemes have emerged as primary mechanisms for advancing supply chain transparency and improving commodity production practices. However, there are gaps in our understanding of how certification influences supply chain structure and governance. This dissertation contributes to theory, methods, and practice by addressing these gaps through three mixed-methods studies on deforestation, certification, and transnational commodity supply chains. Chapter 1 introduces the work. Chapter 2 focuses on uncovering the supply chains of three transnational food conglomerates that link environmental impacts associated with palm oil production in Guatemala to consumption nodes in the U.S. It also assesses the performance of Roundtable on Sustainable Palm Oil (RSPO) certification in insulating these supply chains from deforestation risks. Results reveal supply chain connections to plantations that drove over 24,500 hectares of forest loss (2009-2019). Reliance on RSPO-certification does not insulate palm oil supply chains from risks associated with deforestation, at least in the context of palm oil sourced from Guatemala. Chapter 3 extends this work on supply chain reconstruction but narrows the focus to the "first-

mile" problem, i.e., the challenge of identifying supply chain origins. Through 14 propositions, the chapter outlines how variations in supply chain input-output structure, territoriality and temporality, and governance contribute to the problem. This chapter details how they unfold in practice across four divergent sectors (agriculture, fishing, timber, and mining). Emerging technologies provide a means, and legislation an impetus, for overcoming the challenge as various stakeholders assume their necessary roles for realizing equitable and just first-mile traceability. Chapter 4 revisits Guatemalan palm oil supply chains to explore the extent to which certification standards contribute to differences in the embeddedness, i.e., durability and stability, of trade relationships. A novel network analysis metric is used to quantitatively compare the embeddedness of RSPO-certified and non-certified supply chain actors across time. Results indicate that certification indeed fosters more embedded trade relationships between actors. This dissertation contributes to the research and practice of environmental supply chain governance in the palm oil sector and beyond as it generates rigorous spatiotemporal evidence of forest loss, captures supply chains from end-to-end, and discerns how certification-based governance influences both environmental outcomes and trade relationships. Although the empirical components of this research largely focus on palm oil supply chains originating in Guatemala, the findings are generalizable to other commodity supply chains. This work should be of broad interest to scholars working on the structural, geographical, and governance configurations of supply chains, as well as their impacts across time and space.

Introduction

The global palm oil industry's rapid expansion and impact on millions of hectares (ha) of biodiverse and carbon-rich tropical forests demands more sustainable production practices. There is an urgent need to monitor and understand the dynamics of plantation expansion in producing countries – especially in emerging frontiers. Understanding these dynamics not only entails identifying the actors directly responsible for expansion, but also to establishing their linkages to the transnational supply chains driving the process (Ramankutty & Graesser, 2017). However, the complexity and opacity of palm oil supply chains impedes knowledge of their organization (Kadarusman & Herabadi, 2018; Pye, 2019) – especially their "first-mile" (i.e., supply chain origins), where deforestation finds its way into the chain.

Voluntary certification schemes have developed as a primary mechanism for improving production practices for commodities like palm oil, as well as the transparency and accountability of their associated supply chains – especially in light of emerging deforestation-free regulation (DEFRA, 2021; Drost et al., 2022; European Commission, 2022; Garrett et al., 2019; Lambin et al., 2018; Milder et al., 2015; RSPO, 2022; FOREST Act of 2021, 2021). To date, the Roundtable on Sustainable Palm Oil (RSPO), a multi-stakeholder initiative founded in 2004 with the goal to "transform markets to make sustainable palm oil the norm", administers the largest certification system for palm oil production (Roundtable on Sustainable Palm Oil (RSPO), 2020b). According to RSPO, the impacts of palm oil cultivation can be minimized when its Principles and Criteria are applied (RSPO, 2020b). These include the protection of primary and natural forests, as well as High Conservation Value and High Carbon Stock areas.

Yet, in many ways the RSPO's effectiveness for forest protection is still unclear (Carlson et al., 2018; Dauvergne, 2018; EIA, 2015, 2019; Milder et al., 2015; Morgans et al., 2018). An additional knowledge gap exists on the RSPO's ability to meaningfully reconfigure trade to "transform markets." Whether environmental policies like the RSPO can alter trade networks by selectively encouraging actors to leave, create, or maintain trade relationships has implications for what production practices persist in the supply chain.

This dissertation helps to fill these gaps, contributing to research and practice of environmental supply chain governance in the palm oil sector and beyond. I meld the strengths of multiple disciplines in a mixed-method analysis (structured as three co-authored journal articles) to generate rigorous spatiotemporal evidence of forest loss, capture supply chains from end-to-end, and discern how certification-based governance impacts both environmental outcomes and trade relationships (Figure 1-1 and Figure 1-2).

1.1 Research questions and methods

Three interrelated research questions form the basis of this work. Below, I introduce each question as well as the methodological approach used to address them. Importantly, as an interdisciplinary research project, this dissertation is the product of collaborative efforts and team science. Instances of "I" often more truly reflect a collective "we".

Chapter 2 centers on understanding: *To what extent is (RSPO-certified) palm oil production and trade associated with measurable impacts on land-use patterns (i.e., the alteration of forest landscapes) over time (2009-2019)?* I address this question by conducting a systematic quantitative and qualitative analysis using the Tracking Corporate Actors Across Space and Time (TRACAST) methodology (Goldstein & Newell, 2020). With transaction-level customs data, we reveal the input-output structures of (RSPO-certified) palm oil supply chains and their linkages to deforestation. By combining remote sensing, machine learning, and spatial analysis, this chapter connects palm oil production to explicitly quantified areas of land use change in Guatemala. Maps show the spatial-temporal distribution of (RSPO-certified) oil palm[1] plantations and permanent forest cover loss and connect these outputs with trade flows. Many major corporations have committed to purchasing only palm oil certified as "sustainable" by the RSPO. However, it is unclear whether these measures effectively protect forests from oil palm expansion or limit associated deforestation risks in the supply chains of companies purchasing palm oil (Carlson et al., 2018; Gatti et al., 2019; Meijaard et al., 2017; Milder et al., 2015).

In the supply chain reconstruction process, establishing plantation-to-mill connections is particularly difficult. This challenge of establishing early supply chain linkages is not unique to palm oil. Across sectors, a lack of data on initial supply chain linkages hinders the development of end-to-end supply chain traceability and consequently, supply chain sustainability. Knowing initial supply chain connections – i.e., the first-mile – is critical so as to avoid the creation of opaque places where environmentally and socially harmful production practices can be hidden or ignored (Ibert et al., 2019). While opaque places can exist anywhere in a supply chain (Grabs & Carodenuto, 2021; Serdijn et al., 2020), they are arguably most pernicious at the base of the supply chain where they can hide permanently damaging environmental change. The understudied nature of this problem inspired a second research question: *How do we define the first-mile (problem)? What are the essential attributes of the first-mile and how do they influence our ability to connect this stage of production to the rest of the supply chain?* To answer these questions, I define the first-mile, the first-mile problem, and 14 unique propositions contributing to first-mile opacity (Chapter 3). This framework builds off of the three dimensions of Gereffi's

[1] "Palm oil" is a commodity made from the fruit of "oil palm" trees

(1994) global commodity chain framework – input-output structure, territoriality, and governance – with additional theory from the global value chain and global production network literatures (Bridge & Bradshaw, 2017; Coe & Yeung, 2019; Hess, 2004). The chapter illustrates how combination of resource- and context-specificities influence the relevance of each proposition in practice through illustrative vignettes of four divergent sectors (agriculture, fishing, timber, and mining).

With my final research question, I return to Gereffi (1994), interrogating supply chain input-output structure, territoriality, and governance from yet another angle: *How has the embeddedness of the input-output structure of the Guatemalan (RSPO-certified) palm oil supply chain changed over time (2011-2019)?* (Chapter 4). While prior research on convention theory (the idea that markets are organized on the basis of product quality; Ponte, 2022) predicts that policy instruments like certification schemes would promote embeddedness, little research exists on how this stabilization in trade relationships actually materializes. I apply a novel network analysis metric to quantitatively compare the embeddedness of RSPO-certified and non-certified supply chain actors across time. Drawing on my empirical results, I blend embeddedness and convention theories to develop a conceptual model of policy-driven embeddedness that expands on how policy instruments like certification interface with supply chain input-output structure, governance, and territoriality to alter firm embeddedness and overall trade network organization.

To summarize, this dissertation employs a mixed methods approach to address three research questions. I combine qualitative methods, such as textual analysis, quantitative methods, including input-output material flows, machine learning, and network analysis, and spatial analysis, like remote sensing and geographic information systems (GIS) modeling. I consider myself to be an interdisciplinary social scientist whose home is in human-environment geography. The empirical components of my research primarily focus on palm oil supply chains that span from Guatemala, through Mexico, and on to the U.S., but findings are broadly applicable. In Section 1.3, I provide an overview of the case study area, but first I briefly situate myself as a scholar.

1.2 Literature and theoretical overview

My research melds respective strengths of several thought traditions: industrial ecology, economic geography, supply chain management, network science, and land change science (Figure 1-1 and Figure 1-2). To quantify material flows in the context of production systems, I apply input-output material flow analysis methods from industrial ecology to systems supply chains modeled after economic geography approaches (Brunner & Rechberger, 2016; Coe et al., 2004, 2008; Dicken et al., 2001). To rigorously assess embeddedness, I engage with constructs of embeddedness and embeddedness cognates from economic geography, supply chain management, and network science literatures (e.g., Brass et al., 1998; Choi & Kim, 2008; Coe et al., 2008; dos Reis et al., 2020; Dyer et al., 1998; Gadde & Mattsson, 1987; Goenawan et al., 2016; Gulati, 1995; Kim & Choi, 2015; Larson, 1992; Marsden & Campbell, 1984; Rowley et al., 2000; Salamon et al., 2018). Through my dissertation I also consistently return to economic geography's framing of global commodity chains in terms of input-output structure, territoriality, and governance (Gereffi, 1994). From geography proper, I utilize spatial analysis tools such as GIS and remote sensing, in conjunction with machine learning, to analyze land use change (Breiman, 2001; Gounaridis et al., 2016; Liaw & Wiener, 2001). As such, this dissertation essentially adopts and applies a political-industrial ecology (PIE) approach (Newell et al., 2017; Newell & Cousins, 2015; Pincetl & Newell, 2017) to the palm oil supply chain with the aim of generating transformative scientific and engineering advances that can be harnessed to improve supply chain governance for environmental sustainability. While the individual chapters contain more extensive literature reviews, following subsections summarize the salient concepts and gaps in the literature.

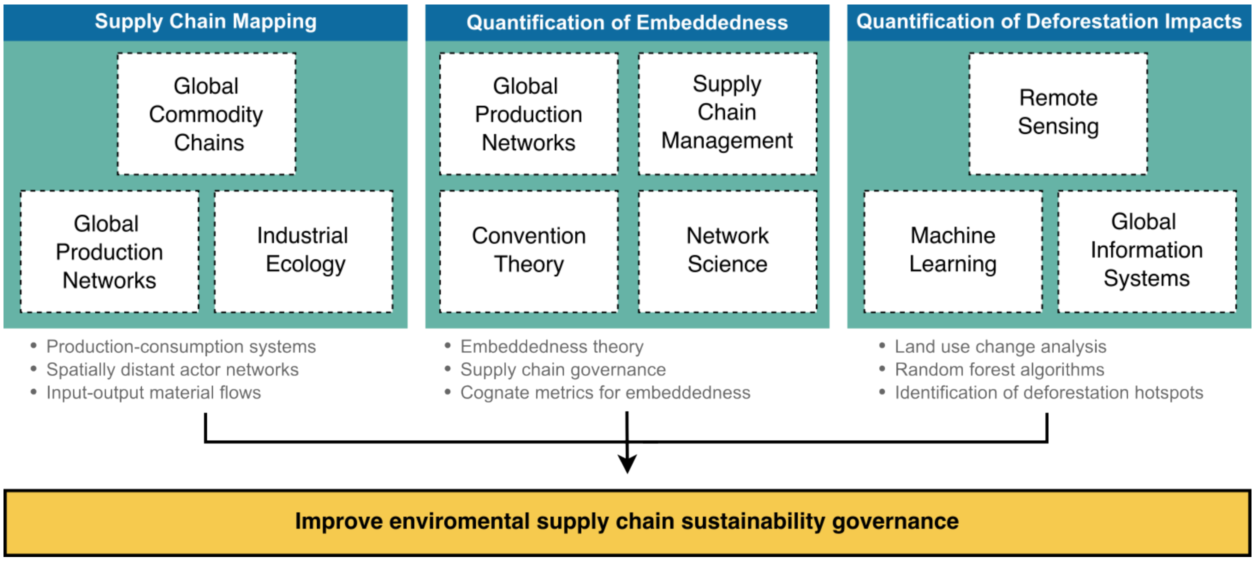

Figure 1-1. Conceptual and methodological research framework.

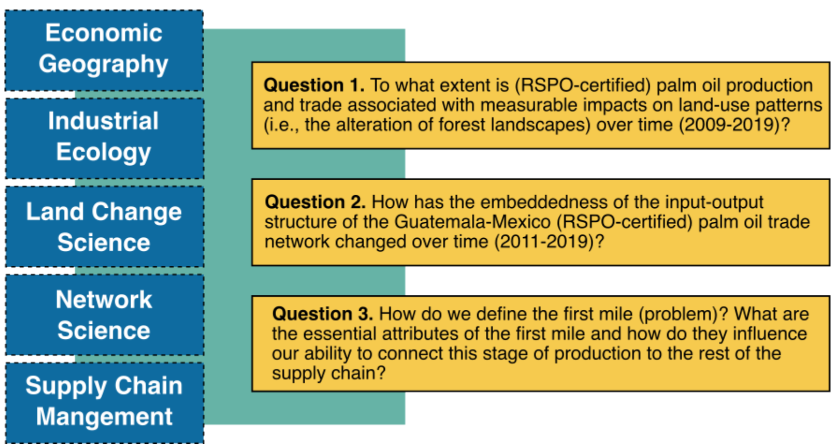

Figure 1-2. Disciplines informing the exploration of key research questions.

1.2.1 Supply chain tracking: Corporate actors and the first-mile

Land change science scholars describe the distal connections between geographies of production and consumption as teleconnections or telecoupled systems (Seto et al., 2012). Untangling the complex and often opaque supply chain linkages between these sites of production and consumption is a distinct challenge. While scholars have mapped sectoral flows to connect land cover change in one region to consumption in another (Friis & Nielsen, 2017), we lack sufficient tools to track the specific corporate supply chains (Escobar et al., 2020; Goldstein & Newell, 2019, 2020; Hansen et al., 2022). The latter, more granular focus is critical given the power corporations wield as powerful *movers and shapers* of the global economy (Dicken, 2014). Changing behavior is necessary for a sustainable transition of production-consumption systems (Goldstein & Newell, 2020). Given the enormity of their operations, we can achieve profound impact by focusing efforts on unveiling the impacts of a select few corporate actors in a few key sectors (Goldstein & Newell, 2020). I address this research gap on corporate supply chains by applying the Tracking Corporations Across Space and Time (TRACAST) methodological framework (Goldstein & Newell, 2020) to reconstruct palm oil supply chains for three transnational conglomerates – PepsiCo, Mondelēz International, and Grupo Bimbo – that sell food products made from palm oil in the U.S.

This supply chain reconstruction process revealed a related research gap on the invisibility of initial supply chain linkages. Products take a circuitous path from resource extraction to consumer markets that involves multiple actors (e.g., farmers, traders, sub-contractors, manufacturers, and retailers), significant transformations (e.g., fresh fruit bunch to crude palm oil to thousands of derivatives to comestible goods), and vast distances. This makes it exceedingly difficult to identify the first link, or "first-mile", of the supply chain where natural resources start their journey to end consumers. With a multitude of environmental and social impacts commonly associated with production, establishing the first-mile linkages to connect supply chains to impacts at sites of resource extraction is critical. Identifying impact hotspots is the first step to mitigating them, and to making production transparent, sustainable, and responsible. It is only by knowing the origin of their raw materials that companies can assure their customers that their products do not contribute to social or environmental harm. Even with the glaring implications for sustainability and the near universality of the first-mile identification challenge, there has been little academic inquiry into the first-mile and its persistent opacity.

The gray literature mentions of the first-mile describe the supply chain segment from farm (varyingly farm field to farm gate) to first point of purchase (Cargill, 2019; Dumay, 2022; Farmforce, 2022; Handley, 2020; Njenga et al., 2014, 2015; Provenance, 2016; Stoop et al., 2021). However, in the scholarly literature on supply chains, the first-mile receives only passing mention and has not been clearly defined (Bechini et al., 2008; Grantham et al., 2022; Kramer et al., 2021; Motta et al., 2020). Related concepts include: provenance – where and how a product, or its ingredients, are produced (Manning, 2018; Monahan et al., 2018); and, chain-of-custody – how a product moves from its source through the supply chain (Fox et al., 2018; Responsible Jewellery Council, 2017). The lack of a common understanding of the first-mile, and the challenge of its identification, makes it difficult to determine where and why we encounter traceability issues, as well as what areas of supply chain management need improvement.

1.2.2 Supply chain governance: The effectiveness of the RSPO

Governance refers to how authority and power relationships – in chains, of chains, and through chains (Bush et al., 2015) – control and coordinate raw material flows to downstream supply chain nodes, including what, how, when, how much of a product is produced (Humphrey & Schmitz, 2001).

The global palm oil industry is governed by a complex of public and private, formal and informal, mandatory and voluntary, regulations and initiatives at multiple scales (Pacheco et al., 2017). In both palm oil producing and importing countries, state regulations emanate from diverse policy domains (i.e. finance, trade, fiscal, production, and land) (Pacheco et al., 2017). At the same time, additional private standards govern the sector through certification systems, guidelines and codes of conduct, and self-regulatory initiatives. The RSPO is among the most prominent of these certification systems and it is the only global sustainability standard in the edible oil sector (Bennett, 2017; Cattau et al., 2016; Pacheco et al., 2020; Pattberg, 2007).

The RSPO was established in 2004 as a multi-stakeholder initiative to address conditions of palm oil production in Malaysia with the primary goal of transforming markets and making sustainable palm oil the norm (RSPO, 2020b). While initially an informal seven-member collaboration between the World Wildlife Fund and several industry actors, it has since expanded to include over 5,000 members spanning 92 countries (RSPO, 2020b). Members represent stakeholder groups from across the palm oil industry: producers, processors and traders, consumer goods manufacturers, retailers, banks and investors, and environmental and social NGOs.

Generally speaking, the RSPO aims to incentivize companies and producers to improve palm oil cultivation practices (RSPO, 2020b). Along these lines, the RSPO has established a set of Principles & Criteria that map to the triple-bottom line (i.e., prosperity, people, and planet) of oil palm plantation development, management, and production. This includes the protection of primary and natural forests, as well as High Conservation Value and High Carbon Stock areas given their importance for biodiversity conservation (Gatti et al., 2019; RSPO, 2020a). New plantings since 2005 may not clear any such areas.

However, the RSPO has been criticized as a soft governance instrument for corporate greenwash (Dauvergne, 2018) with even perfunctory reviews of member practices revealing gaping holes between sustainability rhetoric and reality (Pye, 2016). Multiple studies call the RSPO’s effectiveness as a governance tool into question (Dauvergne, 2018; EIA, 2015, 2019; Morgans et al., 2018). Specifically, the effects of RSPO certification on deforestation remains largely unmeasured (Milder et al., 2015) and unclear. The results of existing studies are at odds

(Carlson et al., 2018; Gatti et al., 2019; Gatti & Velichevskaya, 2020; Meijaard et al., 2017). Understanding the effectiveness of the RSPO with regards to forest protection is taking on new urgency as mandatory deforestation-free legislation emerges (DEFRA, 2021; European Commission, 2022; FOREST Act of 2021, 2021) and a growing number of companies pledge to address deforestation in their palm oil supply chains using the certification standard (Donofrio et al., 2017; Furumo et al., 2020; Lambin et al., 2018). Importantly, as major grower/producer conglomerates seek out new territories to meet growing demand for palm oil, it becomes increasingly important to understand whether the RSPO can effectively protect palm oil's newest frontiers. The deforestation risks associated with oil palm expansion has major, potentially irreversible, global implications for biodiversity (IUCN, 2018; Meijaard et al., 2018), ecosystem functioning (Barnes et al., 2014; Dislich et al., 2017), and carbon emissions (Carlson et al., 2013) – as well as myriad impacts on livelihoods and well-being (Alonso-Fradejas, 2012, 2015; Hervas, 2021; Mingorría et al., 2014; Pietilainen & Otero, 2019).

1.2.3 Supply chain embeddedness: Certification and input-output structure

In the academic literature, embeddedness draws attention to the interlinkages between economic and social activity and how these linkages collectively form patterns across time and space. Polanyi (1944) introduced the concept of embeddedness to describe the social structure of contemporary markets. Granovetter (1985) advanced the concept by shifting from relatively abstract economies and societies toward more concrete, analytical scales of actors and networks of relationships. Importantly, he emphasized how economic decisions and outcomes are influenced by both the embedded actor's existence within an overall structure of networked relationships (e.g., entire supply networks), and relationships with other actors (e.g., individual buyer-supplier dyads). His work helped catalyze a literature on embeddedness spanning multiple fields including sociology, economics, geography, and business, organizational, and management studies (Bathelt & Glückler, 2018; Beckert, 2003; Gulati, 1998; Hess, 2004; Hess & Coe, 2006; Moran, 2005; Rowley et al., 2000; Uzzi, 1996, 1997).

Typically, embeddedness studies within the SCM literature have focused on the positive and negative impacts of firm embeddedness on its economic decisions, behaviors, and performance (Autry & Griffis, 2008; Borgatti & Li, 2009). Embeddedness' influences is wide and varied. For example, it may: improve cost, quality, delivery, and flexibility (Krause et al., 2007); grant access to informational, reputational, and social benefits (Polidoro et al., 2011); decrease transaction costs or improve their strategic position (Gulati & Sytch, 2007); foster relationships founded in trust and coordination (Gulati & Singh, 1998); improve knowledge transfer and learning (Rowley et al., 2000); reduce monitoring costs (Hagedoorn & Frankort, 2008); and increase innovation (Bellamy et al., 2014). However, embeddedness may also contribute to opportunism and malfeasance (Bird & Soundararajan, 2019; Ratajczak-Mrozek, 2017; Villena et al., 2011, 2021). While embeddedness' outcomes are well-established in the SCM literature, there is comparatively little work its precursors.

To address this research gap, I blend embeddedness and convention theories to elaborate on how policy instruments like certification may influence firm embeddedness and overall trade network organization. Principles central to convention theory suggest that certification would foster embeddedness due to supply chain actors' shared concerns about quality (i.e., environmentally and socially sustainable palm oil products). Following convention theory, coordination between actors takes place as the product of accepting mutually agreed-upon definitions of quality, and over time, markets, sectors, or chains become articulated, coordinated, judged, and managed through the agreements (Ponte, 2016). Although objects, processes, and actions may be normatively evaluated by multiple types of quality conventions, environmental certification systems like the RSPO tend to incorporate *civic* and *industrial* conventions (Ponte & Sturgeon, 2014). While civic conventions grant importance to goods in terms of their general societal benefits, industrial conventions value goods according to their performance against technical standards (Ponte, 2016). By defining criteria that qualify goods for trade, the RSPO, and other certification systems, may foster the embeddedness of qualified actors as they shape trade participation, coordination, and management.

1.3 Case study

In this dissertation, I use the Guatemalan palm oil industry as a case study to understand the structural dynamics of (RSPO-certified) palm oil supply chains and their associated deforestation impacts (Chapters 2 and 4). Guatemala has the world's fastest developing palm oil economy (Tropical Forest Alliance, 2019); boasts myriad areas of key biological significance that are threatened by palm oil sector expansion (BirdLife International, 2020); and is a historically understudied area in the literature.

Production statistics indicate that Guatemalan palm oil production has grown over 1000% since 1998 (FAOSTAT, 2020) and that roughly a quarter of this expansion has replaced Guatemalan forestland (Furumo & Aide, 2017). Vast growth potential is still on the horizon: the 183,600 ha of oil palm cultivated at present represent only 23% of the total area (743,400 ha) deemed suitable for palm cultivation (El Observador, 2017; GREPALMA, 2021). As the industry continues to develop, there is heightened concern about encroachment on internationally important areas including the Maya Biosphere Reserve, Central America's largest continuous rainforest (Barnhart, 2020; Hodgdon et al., 2015).

Within Guatemala, palm oil production and processing is most concentrated in three states (*departamentos*): Alta Verapaz, Izabal, and Petén (GREPALMA, 2020). After initial processing, the palm oil from Guatemala finds its way into many food (and beverage and cosmetics) products that are manufactured in Mexico and then exported to a U.S. end-consumer market (Verite, 2014). I follow palm oil's flow through the respective supply chains of three major transnational corporations –Pepsico, Mondelēz International, and Grupo Bimbo – in order to link the impacts of palm oil production in Guatemala to U.S. consumer markets. Collective annual revenue for these three companies was over US$109 billion in 2021 (Mondelēz International, n.d.; PepsiCo, 2022a; Sosland, 2022). PepsiCo is the world's largest snack food company and Mondelēz International the world's second largest (Euromonitor International, 2022). Grupo Bimbo is the third most powerful "staple food" company in the U.S. (Euromonitor International, 2021). All three are members of the RSPO and rely on RSPO-certified palm oil for the majority, if not all, of their palm oil products (Grupo Bimbo, 2022; Mondelēz International, n.d.; PepsiCo, 2022b).

1.4 Dissertation structure

This dissertation comes together across three discrete, but interrelated, chapters or papers. **In chapter 2,** my co-authors and I investigate how demand for palm oil has driven deforestation and biodiversity loss in Guatemala. Although many major corporations have committed to purchasing only "sustainable" palm oil, relying on the Roundtable on Sustainable Palm Oil (RSPO)'s certification standard to fulfill their procurement policies, it is unclear whether certification effectively protects forests from oil palm expansion or limits associated deforestation risks in their palm oil supply chains. We therefore apply the TRACAST methodological framework (Goldstein & Newell, 2020) with remote sensing to simultaneously: (a) reconstruct the input-output structure of corporate supply chains conveying palm oil from Guatemala through Mexico and onto the U.S.; and (b) identify deforestation hotspots resulting from this trade. Our results indicate that the length and complexity of palm oil supply chains disconnects sites of production and consumption, limiting the ability of corporations to ensure the integrity of their "sustainable" and deforestation-free sourcing policies. Twenty-eight percent of oil palm expansion led to deforestation (24,608.64 ha) between 2009 and 2019. Over half of oil palm plantations are located in Key Biodiversity Areas (KBAs) and close to a third are located in protected areas (PAs), which suggests that crop expansion has, and continues to, contribute to biodiversity loss, habitat destruction and the endangerment of key species. Moreover, while RSPO certification has a cooling effect on deforestation, it is ineffective at completely removing deforestation risk, and does not reduce degradation of ecologically important areas. Corporations cannot be allowed to rely on such systems to reliably meet deforestation-free supply chain targets. Granular tracking of supply chain material flows and impacts, both in terms of scale (e.g., individual corporations) and scope (e.g., supply chain end-to-end), needs to be prioritized by corporations, private governance initiatives, and public sector regulation alike in order to ensure palm oil sources are known and documented, and truly follow sustainable cultivation practices. At the same time, deforestation laws and enforcement in both producing and consuming countries need to be strengthened. The utility of the research in this chapter extends beyond the case study context. The systematic TRACAST approach is (1) broadly replicable for unveiling the teleconnections between complex transnational supply chains and distant land use change; and (2) broadly applicable for addressing production-consumption linkages to environmental degradation, social justice and equity, corporate greenwash, and supply chain governance.

In chapter 3, my co-authors and I examine the "first-mile" and its persistent opacity. Although identifying specific locations, production conditions, and corporate actors is challenging across all portions of a supply chain, it remains notoriously difficult to track a supply chain to the "first-mile" – i.e., where it begins. These opaque places may hide permanent environmental damage at sites of natural resource extraction and hinder our ability to transition to sustainable economies. Despite the near universality of this first-mile problem, and its clear implications for sustainability, the topic remains critically understudied. We begin to tackle this research gap by defining the first-mile, the first-mile problem, and 14 unique propositions at the root of first-mile opacity. We then apply these propositions as we create vignettes of four divergent sectors – agriculture, fishing, timber, and mining. These glimpses into each sector demonstrate that context specificities, both in terms of product and place, uniquely shape the first-mile traceability challenge. While the challenge is near universal, the solutions are not. Novel and emerging technologies may help carve the path forward, but they are no silver bullet. We suggest potential proposition-actor pairings based on the unique strengths of key actors including traders, lead firms, NGOs, and governments. Stacking interdependent actions to collectively address the multitude of factors challenging first-mile traceability is the most strategic and effective path towards change.

In chapter 4, my co-authors and I evaluate the influence RSPO certification has on the embeddedness of buyers and suppliers in the Guatemala-Mexico palm oil trade. Although the embeddedness literature has a well-established understanding of the performance implications of firm embeddedness in a supply network, key research gaps remain when it comes to understanding what contributes to embeddedness over time. Certification schemes provide a unique opportunity to study how standards-based policy influences network organization. Some evidence suggests that the quality conventions underpinning certification would promote actor embeddedness in particular supply chain networks. In testing this, I elaborate on embeddedness theory. By applying graphing methods to transaction-level customs data, I empirically measure and compare individual firm embeddedness over time as a function of their certification status. Results indicate that more stable trade relationships indeed occur between those firms involved in trading RSPO-certified palm oil compared to non-certified palm oil. This has widespread implications for understanding convention theory more broadly as a mechanism that restructures the input-output structure and governance of supply chains; and for moving forward with a research agenda that investigates the potential "bright and dark" sides of embeddedness.

In chapter 5, I summarize the key findings as well as theoretical and practical implications of each of the chapters. I argue that the most important outcomes of my dissertation are: (1) Advancing the TRACAST framework to systematically uncover supply chains wall-to-wall, connect corporate actors to upstream environmental impacts, and reveal the ineffectiveness of environmental certification as a means to ensure supply chain sustainability; (2) An improved understanding of the first-mile and the characteristics contributing to the first-mile problem in practice; and, (3) The development and application of a theory of policy-driven embeddedness. I conclude by identifying avenues for future research that could build from the groundwork laid in this dissertation.

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Deforestation, Certification, and Transnational Palm Oil Supply Chains: A Case Study of Guatemala[2]

2.1 Abstract

Although causal links between tropical deforestation and palm oil are well-established, linking this land use change to where this palm oil is actually consumed remains a distinct gap and challenge. Supply chains are notoriously difficult to track back to their origin (i.e. the 'first-mile'). This poses a conundrum for corporations and governments as they commit to deforestation-free supply chains and turn to instruments like certification to increase transparency and sustainability. The Roundtable on Sustainable Palm Oil (RSPO) certification system is the most influential in the sector but whether it reduces deforestation is still unclear. This study provides a replicable approach to linking environmental change (i.e. deforestation) to end consumption using the case of RSPO-certified palm oil from Guatemala. It blends remote sensing, spatial data, and trade statistics to delineate the palm oil supply chains of three transnational conglomerates – Pepsico, Mondelēz International, and Grupo Bimbo – from plantation to consumer market. Results reveal that the plantations at the base of these supply chains were responsible for 28% of deforestation (2009-2019). Moreover, over half of plantations are in ecologically critical areas. We found no evidence that RSPO-certification reduces deforestation or ecological encroachment. We recommend that RSPO be strengthened by instituting more robust traceability and auditing systems, and that companies source physically-

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certified palm oil rather than relying on credit-based systems. This paper advances the literature on supply chain certification, traceability, and deforestation in an understudied region, while drawing attention to the need to change corporate behavior to realize a sustainable economic transition.

2.2 Introduction

Tropical deforestation – which is primarily driven by commodity production – has major, potentially irreversible, global implications for biodiversity (Benton et al., 2021), ecosystem functioning (IPBES, 2019), soil health (Foley et al., 2005), hydrological cycles (Bala et al., 2007), carbon emissions (Smith et al., 2014), and livelihoods (Newton & Benzeev, 2018). Beef, palm oil, soy, and wood products alone account for 40% of tropical deforestation globally (Henders et al., 2015).

Palm oil is particularly pernicious given its near ubiquity. Cheap, versatile, and easy to grow, it is the world's most consumed vegetable oil and is found in roughly half of all packaged supermarket products – from bread and butter to shampoo and toothpaste (WWF, 2022a). Since 2000, palm oil production has more than tripled (Ceres, 2022) and an additional 36 million hectares (ha) of land will be required by 2050 to meet projected demand (Meijaard et al., 2020).

Scholarship on the connection between palm oil and deforestation has primarily focused on Southeast Asia, especially Indonesia and Malaysia, where most production occurs (Pendrill et al., 2019). But the region's producers face shrinking land availability and increasing scrutiny, driving expansion in new production geographies. With the largest global forest reserves suitable for oil palm production, Latin America has emerged as the next frontier and is already the second largest producing region (Castellanos-Navarrete et al., 2021; Furumo & Aide, 2017). In the span of just one decade (2010-2020), palm oil production in Latin America has more than doubled (FAOSTAT, 2020).

Palm oil expansion has been especially rapid in Guatemala, which boasts the highest productivity per ha globally (Tropical Forest Alliance, 2019). By 2030, Guatemala is projected to become the world's third largest palm oil producer, after Indonesia and Malaysia (Tropical Forest Alliance, 2019). With conversion of forestland to palm oil plantations well-underway, conservationists are especially concerned about incursion into the Maya Biosphere Reserve, the largest contiguous rainforest in Guatemala (Barnhart, 2020; Furumo & Aide, 2017; Hodgon et al., 2015; Kuepper et al., 2021).

Unrelenting deforestation in the tropics from palm oil and other commodities has prompted the European Union to craft regulations requiring supply chains to be deforestation-free (European Commission, 2022). National governments are following suit, including in the U.K and the U.S. (DEFRA, 2021; FOREST Act of 2021, 2021). Climate change mitigation policies, in both public and private sectors, are also starting to require accounting for Scope 3 greenhouse gas emissions, including those associated with land use (Gensler, 2022).

Voluntary certification schemes have emerged as a primary mechanism for supply chain transparency and improving commodity production practices, including meeting deforestation-free targets (Drost et al., 2022; Garrett et al., 2019; Lambin et al., 2018; Milder et al., 2015; RSPO, 2022). The Roundtable on Sustainable Palm Oil (RSPO) is among the most prominent of these certification initiatives and it is the only global sustainability standard covering edible oils (Bennett, 2017; Cattau et al., 2016; Pacheco et al., 2020; Pattberg, 2007). Certified members conform to a set of "Principles and Criteria" that ostensibly address environmental and social impacts associated with production (RSPO, 2020). This includes the protection of High

Conservation Value and High Carbon Stock forests (Gatti et al., 2019; RSPO, 2020). Yet, in many ways the RSPO's effectiveness for forest protection is still debated (Carlson et al., 2018; Cattau et al., 2016; Dauvergne, 2018; EIA, 2015, 2019; Gatti et al., 2019; Gatti & Velichevskaya, 2020; Heilmayr, Carlson, et al., 2020; Lee et al., 2020; Meijaard et al., 2017; Morgans et al., 2018; Noojipady et al., 2017).

These policy efforts all seek to harness the power of consumer markets to shape production practices in distant geographies. Land change science scholars describe these linkages between geographies of production and consumption as teleconnections or telecoupled systems (Seto et al., 2012). But unweaving the complex, often opaque supply chain linkages between sites of production and consumption is a distinct challenge. Although scholars have mapped broad sectoral flows connecting land cover change in one region to consumption in another (Friis & Nielsen, 2017), we generally lack sufficient tools to track corporate-specific supply chains, whether for giant multinational food conglomerates or smaller commodity-specific companies (Escobar et al., 2020; Goldstein & Newell, 2019, 2020; Hansen et al., 2022). Yet, given the enormous power these actors wield in the global economy, changing their behavior is necessary for the sustainable transition of production-consumption systems (Goldstein & Newell, 2019). Targeting the actions of just a few corporate actors can have profound impact.

In light of this, this study tracks the palm oil sourced from forestland and other ecologically critical areas of Guatemala by three transnational conglomerates – PepsiCo, Mondelēz International (hereafter, "Mondelēz"), and Grupo Bimbo – that sell food products made from this palm oil in the U.S. PepsiCo and Mondelēz International are the world's largest snack food companies while Grupo Bimbo is the third most powerful "staple food" company in the U.S. (Euromonitor International, 2021, 2022). All three are members of the RSPO and rely on RSPO-certified palm oil for their products (Grupo Bimbo, 2022a; Mondelēz International, n.d.; PepsiCo, 2022a). Through this case study we seek to answer the following questions:

1. *Where is palm oil grown in Guatemala and to what degree is it contributing to deforestation and ecological encroachment?*
2. *From where in Guatemala are these conglomerates importing palm oil and what are their supply chain configurations, from forest to consumer market?*
3. *Is RSPO-certification effective in reducing risks related to deforestation and ecological encroachment in these supply chains?*

To answer these questions, we combined remote sensing, machine learning, and spatial analysis in concert with a methodological approach known as Tracking Corporations Across Space and Time (TRACAST) (Goldstein & Newell, 2020). Our results indicate that over a decade (2009-2019), a significant proportion of palm oil expansion in Guatemala led to deforestation and ecological encroachment. Supply chain reconstruction reveals explicit linkages between PepsiCo, Mondelēz, and Grupo Bimbo, these plantations, and their impacts. We do not find evidence that RSPO-certification effectively protects against deforestation or ecological encroachment. This suggests that despite company policies for complete or near complete RSPO coverage of their palm oil supplies, certification, at least in the context of Guatemala, is not an effective mechanism for guaranteeing corporate zero-deforestation commitments or robustly protecting against other environmental sourcing risks.

We conclude with concrete suggestions for improving the RSPO, as well as recommendations for advancing legislation and supply chain traceability and transparency, especially by tackling the "first-mile" problem. This problem is not limited to palm oil; opaque supply chain origins impede our ability to link transnational supply chains to environmental and social impacts across all sectors (VanderWilde et al., 2023). Although this study prioritizes environmental impacts, how palm expansion affects livelihoods and land rights is equally important, including those of indigenous peoples and communities.

The utility of this study extends beyond Guatemala, palm oil, or even commodity production. It presents a broadly replicable and systematic method to uncover connections between complex transnational supply chains and distant land use change. Excavating and mapping these teleconnections provides a springboard for future work on production-consumption linkages, environmental degradation, carbon emissions, justice and equity, and corporate greenwash and governance.

2.3 Materials and methods

This study used remote sensing and machine learning to quantify deforestation attributable to palm oil in Guatemala over a decade (2009-2019) and to assess whether RSPO-certification reduced this deforestation. To identify oil palm supply chain production-consumption linkages of three food conglomerates (PepsiCo, Mondelez, and Group Bimbo), we used the TRACAST methodological framework (Goldstein & Newell, 2020).

2.3.1 Assessment of deforestation

Our analysis covered 54,000 km^2 across the *departamentos* responsible for 75% of Guatemala's palm oil production during the study period: Alta Verapaz, Izabal, and (the lower, palm oil-producing portion of) Petén (Figure 2-1). In 2019, Petén accounted for 46.03% of national palm oil production; Izabal, 16.59%; and Alta Verapaz, 14.20% (GREPALMA, 2020).

This scope captures significant sectoral growth and permits land use change analysis with high-resolution satellite imagery. These *departamentos* also include ecologically significant subtropical forests, protected areas (PAs), and key biodiversity areas (KBAs) that provide important habitat for endangered species such as the jaguar (*Panthera onca*), Baird's tapir (*Tapirus bairdii*), and black howler monkey (*Alouatta pigra*), as well as hundreds of bird species (BirdLife International, 2020; Ecosphere, 2022; IUCN, 2022a; UNESCO, 2019).

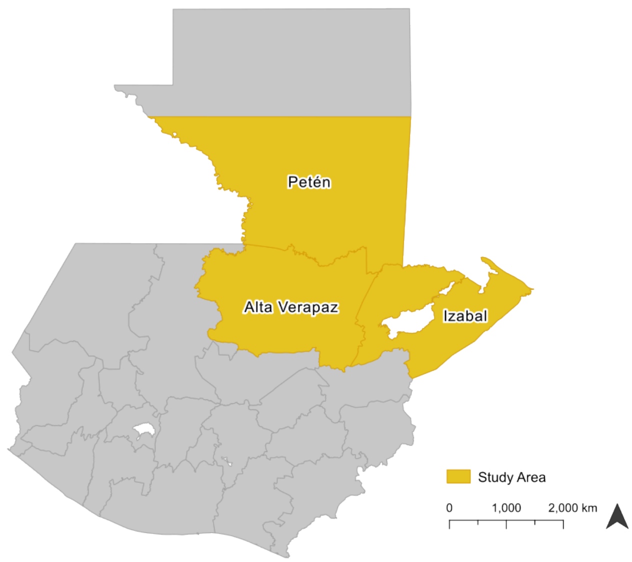

Figure 2-1. Extent of the study area.

Data pre-processing

For land change analysis we acquired 5-m resolution imagery from Planet (www.planet.com). Asset classes were downloaded as orthorectified, calibrated, and corrected 4-band (red, green, blue, and NIR) imagery products that we mosaicked into layers covering the entire study area for 2009 and 2019, respectively. To minimize phenological variation, we prioritized images from winter months, especially December and January, Guatemala's driest periods.

Random Forests classification

To map and quantify the deforestation (2009-2019) we utilized the Random Forest machine learning algorithm (Breiman, 2001) as it performs well in the face of heterogeneous classes, e.g., distinguishing between forests and monoculture plantations, and is computationally efficient compared to other methods (Belgiu & Drăguţ, 2016; Gislason et al., 2006).

To reduce complexity and increase accuracy, we approached land use classification per *departamento* per year which resulted in six models. We trained these models on 11 initial land cover types, collecting thousands of samples per class via visual interpretation of the acquired imagery (Table A-1). To aid in interpretation, we consulted historical high-resolution (1m) Google Earth imagery (nominal years 2009-2019) as well as historical land cover maps from the Guatemala Ministry of Agriculture, Livestock, and Food (*Ministerio de Agricultura, Ganadería y Alimentación*). The number of samples collected per class depended on class size and heterogeneity. Since similar spectral signatures present a challenge when working with heterogeneous classes like mature palm oil and forest, we avoided sampling along class boundaries (Gounaridis et al., 2016). To increase model performance and class representativeness, we also incorporated auxiliary vegetation and textural indices as predictors (Table A-2) (Xu et al., 2021).

We executed the models in R using the *randomForest*, *caret*, *sp*, and *raster* packages (Hijmans, 2017; Kuhn, 2019; Liaw & Wiener, 2001; Pebesma et al., 2012; Team, 2000). To improve model output, we identified and removed outliers from the training samples before running the Random Forest algorithm. For each run, we randomly selected 5 candidate variables at each split (mtry = 5) and grew 500 classification trees (ntree = 500). Most studies report error stabilization at fewer trees (Belgiu & Drăguţ, 2016; Lawrence et al., 2006).

Classification results post-processing

We post-processed results (by *departamento* and year), aggregating the initial land use classes into three categories: (1) palm plantation; (2) forest; and, (3) other. We replaced the values of individual isolated pixels with the mode of their neighborhood pixels (Gounaridis et al., 2014). Finally, we reclassified any obviously misidentified patches of land by consulting plantation data from the RSPO (RSPO, 2021). To assess model accuracy, we took randomly distributed validation samples and manually identified land use class using Google Earth imagery. We then assessed producer, user and overall accuracy of predictions per class and year (Table A-3).

For each *departamento*, we estimated deforestation rates by cross-classifying and cross-tabulating the land use class of individual pixels. As a second layer of validation, we evaluated the accuracy of land use changes by visually cross-checking against Google Earth imagery (Table A-4).

Identifying encroachment of critical areas

To determine the extent to which palm oil expansion has contributed to ecological encroachment, we cross-classified and cross-tabulated land change (2009-2019) within PAs and KBAs (BirdLife International, 2020; UNEP-WCMC, 2016). These datasets highlight ecological zones supporting a number of high conservation value species.

Evaluating RSPO certification

To add to the emerging literature on the effects of RSPO certification on deforestation deforestation while addressing gaps in the literature's geographic coverage, we used spatial regression modeling to determine whether RSPO-certification is associated with heightened deforestation and ecological encroachment, while accounting for other biophysical, climatic, economic, and geographic attributes of plantations (Table A-5) . This entailed combining our land change results with a suite of data from multiple sources (Table A-5) including concession data from the RSPO (RSPO, 2021). Initially, we ran generalized linear models (GLM) to assess which factors contribute to deforestation and ecological encroachment. To fine-tune the models, we selected the set of predictors that minimized the Akaike Information Criterion (AIC). We did not observe any multicollinearity effect among the independent variables (all variance inflation factor, VIF, values were less than 5) (Table 2-1).

Next, we calculated the Moran's I statistic which indicated significant spatial autocorrelation of fitted variables and model residuals (Dormann et al., 2007). To correct for spatial bias in our data we fitted a Spatial Lag model based on Lagrange multiplier test statistics (Anselin, 2005; Anselin et al., 2010). For both the deforestation and ecological encroachment models, we calculated spatial contiguity using first-order Queen's adjacency methods via the spatialreg package in R (Bivand & Piras, 2015; Team, 2000).

2.3.2 Supply chain reconstruction

To quantify corporate connections to palm oil driven deforestation, this study applied the TRACAST framework which has previously been used to locate and link corporate activities to environmental and social impacts for beef, avocados, rubber, and other commodities (Chamanara et al., 2021; Cho et al., 2021, 2022; Goldstein & Newell, 2020). Figures 2 and 3 outline our TRACAST approach to linking distal U.S. demand for palm oil to deforestation in Guatemala.

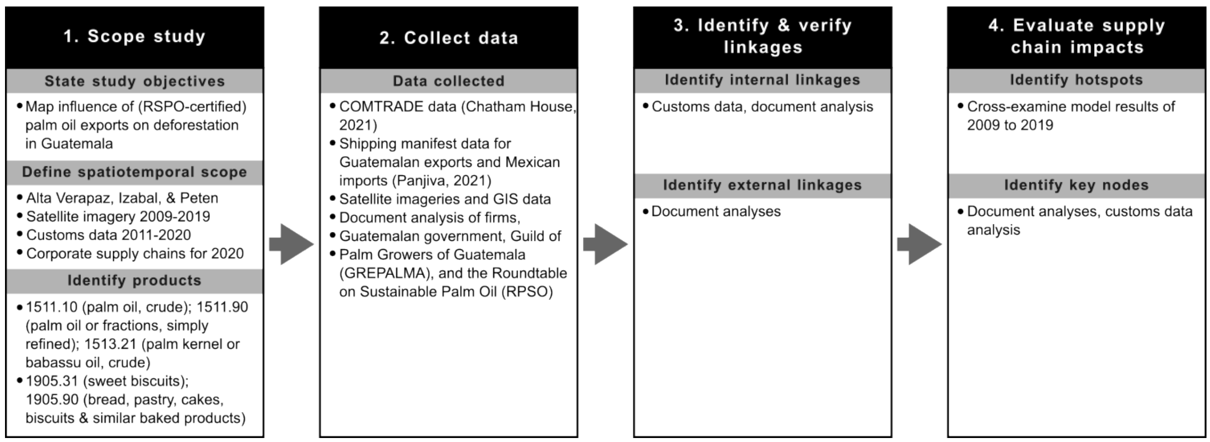

Figure 2-2. TRACAST methodological framework applied to exports of palm oil from Guatemala and baked goods from Mexico.

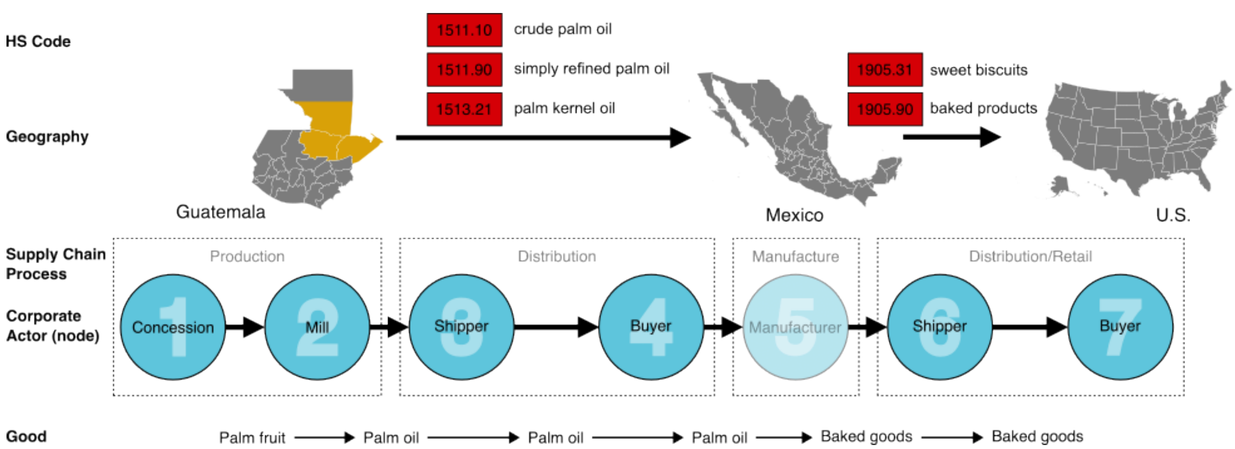

Figure 2-3. Corporate actor (node) diagram of the supply chain carrying palm oil from Guatemala through Mexico and on to the U.S., segmented by geography, role, and product Harmonized System (HS) codes. *Given that the domestic path palm oil takes from ingredient manufacturer to brand-name (food) product manufacturer is opaque, supply chain reconstruction does not include interactions between entities within Mexico.*

Step 1: Scope the study

We track Guatemalan exports of three palm oil products classified under the internationally standardized six-digit Harmonized Commodity Description and Coding System

(HS) as: palm oil, crude (HS 1511.10); palm oil or fractions, simply refined (HS 1511.90); and palm kernel or babassu oil, crude (HS 1513.21). These products comprised ~98% of the country's palm oil exports between 2011 and 2019 (Chatham House, 2021) (Table A-6). Mexico is the largest historical importer of palm oil from Guatemala (Chatham House, 2021; Figure A-1) and a major U.S. trade partner, so we scoped our study around Guatemala-Mexico-U.S. supply chain linkages. Once in Mexico, palm oil is used as an ingredient in many food products exported to U.S. consumer markets (Verite, 2014). We followed palm oil flows through Mexico-U.S. trade of food products classified as sweet biscuits (HS 1905.31) and bread, pastry, cakes, biscuits and similar baked products, and puddings (HS 1905.90). The U.S. is Mexico's largest historical export market for such goods (OEC, 2021). PepsiCo, Mondelēz, and Grupo Bimbo directed nearly 40% of these food product exports from Mexico in 2019.

Step 2: Collect data; and, Step 3: Identify and verify linkages

To uncover linkages between actors and processes along the supply chain, we combined the following data sources: transaction-level trade data (customs data), public mills lists, and public documents (e.g., NGO reports, GREPALMA[3] and RSPO publications, and newspaper articles) (Table A-7).

Supply chain origins: The first-mile

Opaque supply chain origins often impede our ability to link transnational supply chains to environmental impacts. However, the quick processing requirements for fresh oil palm fruit bunches allowed us to infer the first-mile (e.g., plantation-mill connections) by geographically analyzing plantation sites, mill locations, and surrounding road infrastructure (Ramli et al.,

[3] The Guild of Palmicultores of Guatemala, GREPALMA, for its Spanish acronym.

2020). We estimated the first-mile by: (1) creating an origin-destination matrix for all possible plantation-mill combinations using the QGIS Network Analysis Toolbox 3 (QNEAT3) plugin (Raffler, 2018); and (2) selecting the shortest path along the road network for each possible plantation-mill combination (Figure A-2; Table A-8). When results indicated equal distances between a given plantation and multiple mills, we consulted ownership data or matched flows with the most immediately adjacent plantation. To verify model output, we compared results to RSPO data on linkages between certified plantations and mills.

Using annual production statistics from GREPALMA (2020) and data on plantation area, we then estimated the palm oil and palm kernel oil flows originating from each plantation in 2019. In later steps, we relied on first-mile linkages to assess supply chain connections to forest and ecological encroachment and to compare sourcing risks between RSPO-certified and non-certified plantations.

Palm oil supply chain flows

Using transaction-level customs data from Panjiva (2021) – which includes the names of shipping and consigning companies, their locations, and trade volume in mass and value – we identified 2,348 palm oil shipment records between Guatemala and Mexico in 2019. Based on these records, we established supply chain connections between Nodes 2 and 3 (Figure 2-3) and estimated the mass of palm oil trade.

At manufacturing nodes, palm oil from various origins is intermixed and converted into ingredients destined for numerous end purposes. These palm-oil derived ingredients take many different names which makes tracking specific flows beyond this point especially difficult (WWF, 2014). Moreover, their export from Mexico is relatively limited. However, by combining import statistics, domestic production data, and export figures, we estimated how Guatemalan palm oil continues to flow through Mexico as it becomes embodied in food products. While palm oil can be put towards many uses, 72% of the global palm oil market is used for food and beverage applications worldwide (Voora et al., 2019).

We determined linkages and flows between Mexico and the U.S. through 420 Panjiva shipment records of food products containing palm oil. We estimated the amount of palm oil of Guatemalan origin embodied in these food products using data on shipment weights; nutrient profiles of products (USDA, 2022); and statistics for Mexico's total imports, domestic production, and domestic consumption of palm oil (Figure S3; Tables S10-18). Panjiva data covers 88% by mass of palm oil imports reported by Mexico (Chatham House, 2021; United Nations, 2021), which is suitable data coverage for tracking supply chains (Goldstein and Newell, 2020).

To establish linkages between mills and traders, and to geolocate mill nodes, we analyzed company documents, including annual reports and sourcing policies. While building linkages via text mining does not reveal mass flows of trade between companies, it does enable us to clarify how major conglomerates with a U.S. presence are linked to the production of Guatemalan palm oil. We also consulted corporate websites and annual reports to ascertain sourcing policies for palm oil, including any RSPO-based commitments.

2.4 Results

Our results indicate the supply chains of transnational conglomerates drove deforestation and ecological encroachment in Guatemala to support U.S. palm oil consumption. RSPO-certification appears ineffective at reducing palm oil sourcing risks. We estimated that oil palm plantations expanded 87,325 ha between 2009 and 2019 with 28% (24,609 ha) replacing forestland. Over half of oil palm plantations encroach on ecologically significant areas where they have replaced valuable habitat. We did not find evidence to suggest that RSPO-certification effectively protects against deforestation or ecological encroachment. Supply chain linkages reveal connections between palm oil production, certification, deforestation, and ecological encroachment. Despite RSPO membership and procurement policies, Pepsico, Mondelēz, and Grupo Bimbo incur deforestation risks in their palm oil supply chains.

2.4.1 Mapping oil palm expansion and deforestation

Our remote sensing results indicate that palm oil production has increased 191% (2009: 45,753 ha; 2019: 133,078 ha) (Figure 2-4). Findings for 2019 are comparable with GREPALMA statistics (131,712 ha of oil palm plantations) for the same year, providing additional validation for our results (GREPALMA, 2020). Differences between our results and GREPALMA statistics are likely due to misclassification between forest and mature oil palm plantations. Such discrepancies aside, the Random Forest models still correctly identify forest loss due to oil palm expansion, achieving 90% and 94% overall accuracy for 2009 and 2019, respectively (Table A-3). We find 371,835 ha of forest loss across the study area (Tables A-9 and A-10). Cross-classification results reveal 28% of palm oil expansion (24,609 ha) came at the expense of forestland.

Historically, agriculture has been a main deforestation driver, particularly due to expanding cropland and cattle pasture (Loening & Sautter, 2005). Extractive industries, including oil and timber, as well as expanding commercial agriculture, have also played a significant role (Cuéllar et al., 2011; Grandia, 2007). Illegal logging of rosewood (used to make musical instruments and high-end furniture) and infrastructure expansion for cocaine trafficking (Devine et al., 2020; Guo, 2019; McSweeney et al., 2014) are recent drivers of deforestation. Rates of oil palm-related deforestation vary by departamento: 2% in Alta Verapaz, 3% in Izabal, and 14% in Petén. Given that oil palm expansion is predicted to increase significantly in the coming years (Furumo & Aide, 2017; Tropical Forest Alliance, 2019), this deforestation pattern is likely to continue without changes to governance, both in local institutions and international supply chains.

Our results show oil palm expansion is encroaching on and causing deforestation in 7 KBAs and 23 PAs (Figure 2-5; Table A-11). We find 67,476 ha (51%) of oil palm plantations in the study area overlap with KBAs and 41,059 ha (31%) with PAs. This expansion likely occurred as deforestation prior to 2009. Between 2009 and 2019, oil palm replaced 7,231 ha of forestland in KBAs (11%) and 5,202 (13%) ha of forestland in PAs. These findings suggest that land change induced by palm oil contributes to biodiversity loss, habitat destruction, and the endangerment of key species.

Among the areas impacted, the KBAs with the largest palm extent include: Río La Pasión, Caribe de Guatemala, and the Sierra de las Minas Biosphere Reserve. The Río La Pasión is an especially rich area for endemic fish species making it an important area for conservation (Gobierno de la Republica de Guatemala, 2016). The area has already suffered significant environmental degradation at the hands of the palm oil industry (Abbott, 2015, 2018). Oil palm expansion threatens the integrity of the broader San Román Biological Reserve which encompasses the Río La Pasión (Leitón, 2018) and provides habitat for the jaguar (*Panthera onca*, near threatened) among others (de la Torre et al., 2017; IUCN, 2022a; Leitón, 2018). Oil palm encroachment on the Sierra de las Minas Biosphere similarly threatens fauna like the quetzal (Guatemala's national bird; *Pharomachrus mocino*) (Krchnak, 2013; UNESCO, 2019). Called the "jewel" of Guatemala, this biosphere is an irreplaceable gene bank for tropical reforestation and agroforestry, and supports the livelihoods of over 400,000 people (Krchnak, 2013).

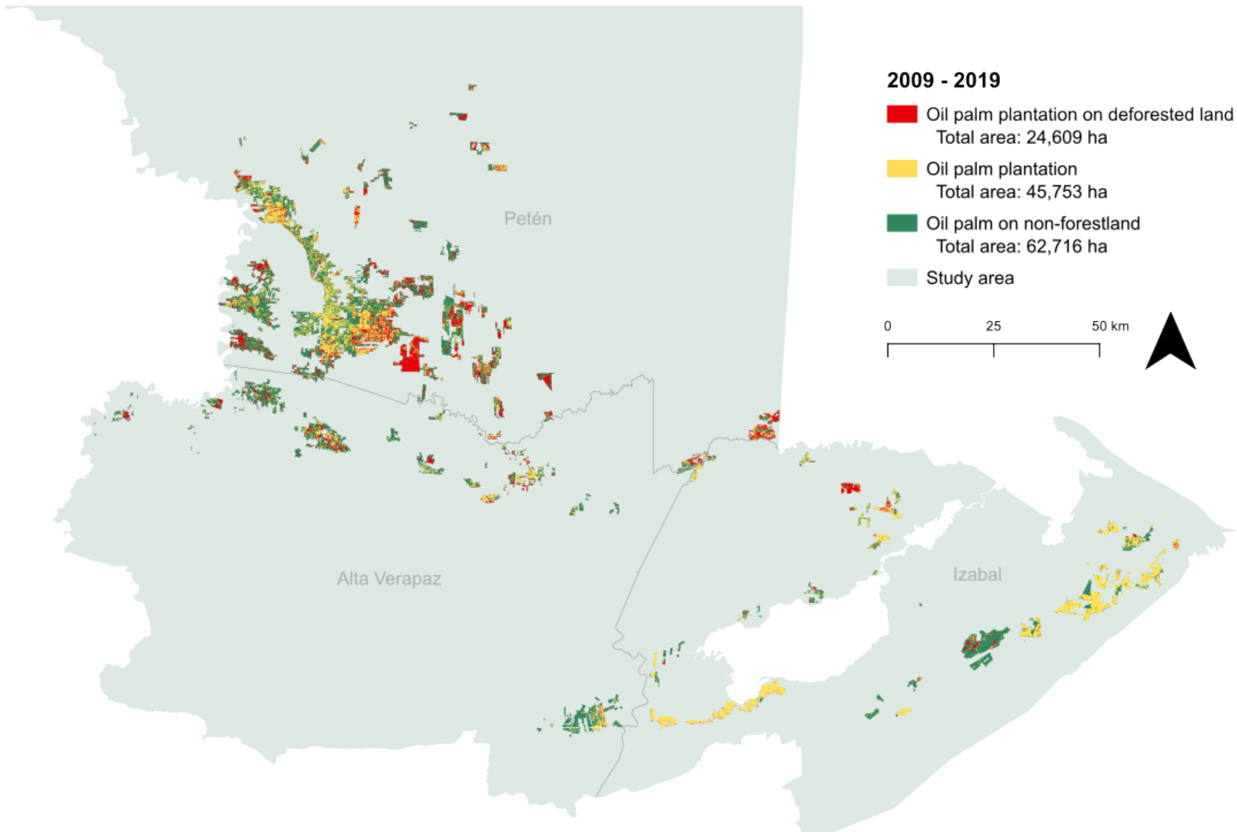

Figure 2-4. Oil palm driven deforestation across the study area, 2009-2019.

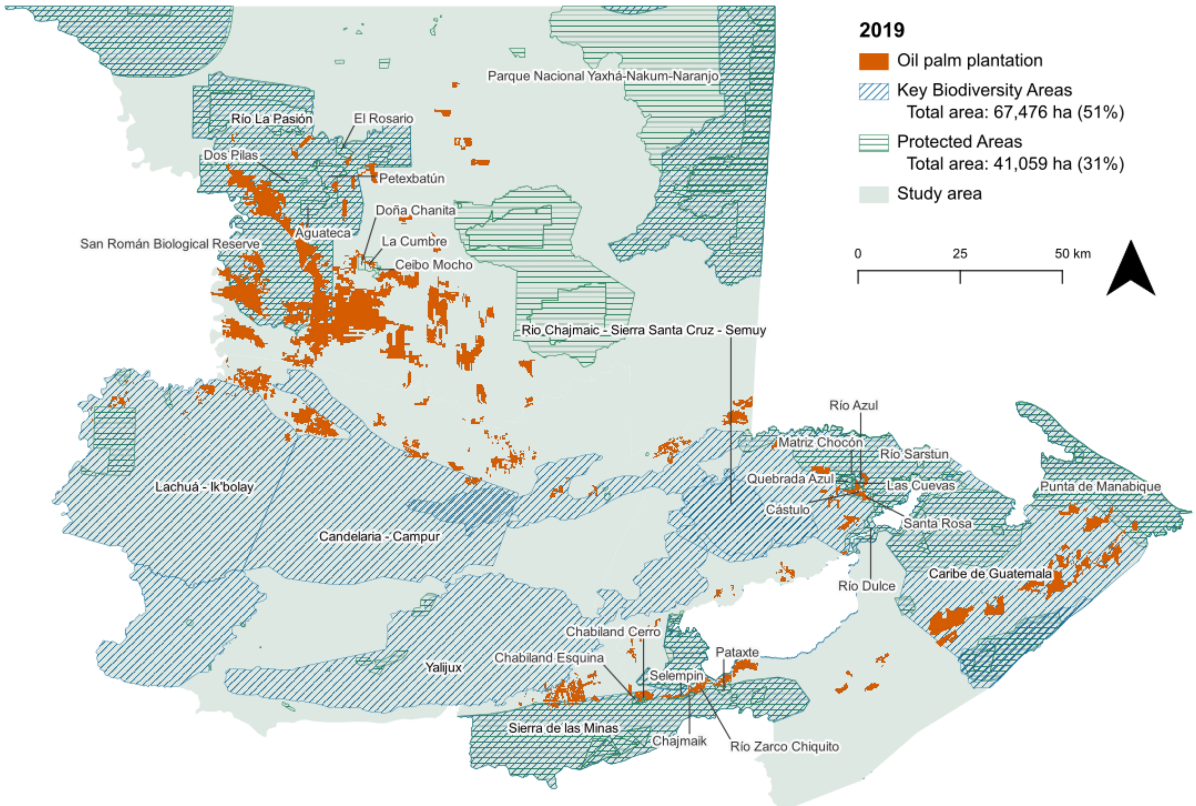

Figure 2-5. Encroachment of oil palm plantations in ecologically significant across the study area as of 2019.
Sources: Birdlife International (2020);UNEP-WCMC (2016)

2.4.2 RSPO Certification and deforestation

Regression results (Table 1) suggest that RSPO-certification does not provide effective protection against deforestation or ecological encroachment, as certification was not a statistically significant predictor in either model. These results are robust when controlling for the influence of total plantation area; average annual precipitation and temperature; distance to palm oil mill, pastureland, and roads; population density; and slope. We did find that climatic and locational features, as well as plantation size, were significant predictors of oil palm-driven forest loss and ecological encroachment. These findings align with prior research on determinants of oil palm-driven forest loss in other contexts (e.g., Armenteras et al., 20; Bax & Francesconi, 2018; Godar et al., 2012). Population density, slope, and distance to nearest palm oil mill and roads were not significant predictors in either of the models.

Table 2-1. *Results of the spatial Lag models used to determine whether RSPO-certification is are associated with heightened deforestation and ecological encroachment (*** p < 0.001; ** p < 0.01; * p < 0.05).*

Deforestation model							
	Estimate	*Standard error*	*z-value*	*P-value*		*VIF*	*95% CI*
(Intercept)	*-51.77*	*320.25*	*-0.16*	*0.87*			*-679.45–575.90*
RSPO-certification	*-6.56*	*13.16*	*-0.50*	*0.62*		*2.02*	*-32.34–19.23*
Total plantation area (ha)	*0.16*	*0.01*	*13.05*	*< 2.2e-16*	***	*1.42*	*0.14–0.19*
Ecological encroachment (ha)	*0.04*	*0.02*	*1.65*	*0.10*		*1.74*	*-0.01–0.08*
Average annual precipitation, mm	*0.05*	*0.01*	*4.03*	*0.00*	***	*3.38*	*0.03–0.08*
Average annual temperature, °C	*-3.96*	*11.64*	*-0.34*	*0.73*		*1.73*	*-26.78–18.86*
Distance to palm oil mill	*0.00*	*0.00*	*-1.09*	*0.28*		*1.24*	*-0.01–0.00*
Distance to pastureland	*-0.02*	*0.01*	*-1.95*	*0.05*	*	*1.70*	*-0.03–0.00*
Distance to road	*0.03*	*0.02*	*1.32*	*0.19*		*1.43*	*-0.02–0.08*
Population density, # of people per pixel	*-0.05*	*0.07*	*-0.65*	*0.52*		*1.38*	*-0.19–0.09*
Slope	*9.84*	*7.08*	*1.39*	*0.16*		*1.28*	*-4.03–23.71*

Ecological encroachment model						
	Estimate	*Standard error*	*z-value*	*P-value*	*VIF*	*95% CI*
(Intercept)	*3756.87*	*1004.64*	*3.74*	*0.00* ***		*1787.80–5725.93*
RSPO-certification	*-38.05*	*39.75*	*-0.96*	*0.34*	*2.01*	*-115.96–39.85*
Total plantation area (ha)	*0.20*	*0.05*	*4.00*	*0.00* ***	*2.48*	*0.10–0.29*
Deforestation (ha)	*0.29*	*0.21*	*1.38*	*0.17*	*2.46*	*-0.12–0.71*
Average annual precipitation, mm	*-119.10*	*36.06*	*-3.30*	*0.00* ***	*1.62*	*-189.78– -48.42*
Average annual temperature, °C	*-0.18*	*0.04*	*-4.04*	*0.00* ***	*3.35*	*-0.26–-0.09*
Distance to palm oil mill	*-0.01*	*0.01*	*-1.15*	*0.25*	*1.24*	*-0.02–0.01*
Distance to pastureland	*0.01*	*0.02*	*0.49*	*0.63*	*1.77*	*-0.03–0.06*
Distance to road	*0.10*	*0.07*	*1.41*	*0.16*	*1.43*	*-0.04–0.25*
Population density, # of people per pixel	*0.25*	*0.21*	*1.19*	*0.23*	*1.37*	*-0.16–0.67*
Slope	*-1.81*	*21.46*	*-0.08*	*0.93*	*1.29*	*-43.87–40.24*

2.4.3 Supply chain reconstruction

Guatemalan palm oil is incorporated into manufactured food products through a series of supply chain transformations and actors (Figure 2-3). Palm oil growers (Node 1), be they smallholders or plantation owners, deliver their harvested fresh fruit bunches to mills (Node 2), where both the oil palm fruit, a fleshy outer layer, and its seed, the kernel, are processed into crude palm oil and palm kernel oil respectively. In many cases, the Guatemalan trading and shipping companies (Node 3) are the same as the mill company or there are clear parent-subsidiary relationships. Mexican importers (Node 4), primarily companies in the edible oils manufacturing industry, produce a variety of palm oil derived ingredients that are used domestically in (food) product manufacturing (Node 5). Food products are then traded between Mexican shipping companies (Node 6) and U.S. distributors for major food brands (Node 7). Distributors stock a variety of retail outlets (Node 8) including groceries, supermarkets, convenience stores, and fast food restaurants.

We traced the supply chains for three leading multinational corporations – PepsiCo, Mondelēz, and Grupo Bimbo – establishing their respective supply chain linkages from oil palm plantations through to generalized U.S. retail outlets. Collectively, these three firms represent almost 40% of total exports (HS codes 1905.31, 1905.90) from Mexico to the U.S. in 2019.

PepsiCo has hundreds of brands. Its "Quaker Oats" arm consigns shipments from Mexico to the U.S. We estimate that these shipments embody 2,180 tons of palm oil sourced from 14 different mills (Figure 2-6, Figure A-2, and Table 2-3). Of these mills, two are RSPO-certified and three are RSPO members. RSPO membership precedes certification. Joining signals an intent to meet certification criteria over the coming years. As such, the supply bases of RSPO-member mills may only be partially certified.

Mondelēz manufactures and markets snack products under brands such as belVita, Chips Ahoy!, Honey Maid, Nabisco, Oreo, and Ritz. We estimate that Mexico-U.S. shipments of these products include 600 tons of palm oil sourced from 7 different mills across the study region (Figure 2-7, Figure A-2, and Table 2-2). Only two of these mills are associated with the RSPO, one is RSPO-certified and one is an RSPO member.

Grupo Bimbo produces a wide array of products, from breads and bagels to pastries and cookies. We estimate that shipments carry 4,330 tons of palm oil sourced from 14 different mills across the study area (Figure 2-8, Figure A-2, and Table 2-2). Two of these mills are RSPO-certified and three are RSPO members.

By reconstructing the supply chains of these conglomerates to first mile granularity, we reveal their connections to palm oil driven deforestation. Of the 24,609 ha of palm oil driven deforestation incurred across the study period, we connect more than 99% (24,518 ha) to the plantations supplying palm oil to PepsiCo's and Grupo Bimbo's palm oil mills and 72% (17,610 ha) to the subset of plantations supplying Mondelēz's palm oil mills (Table 2-2). The conglomerates' RSPO-certified mills collectively expanded on 3,584 ha of forestland.

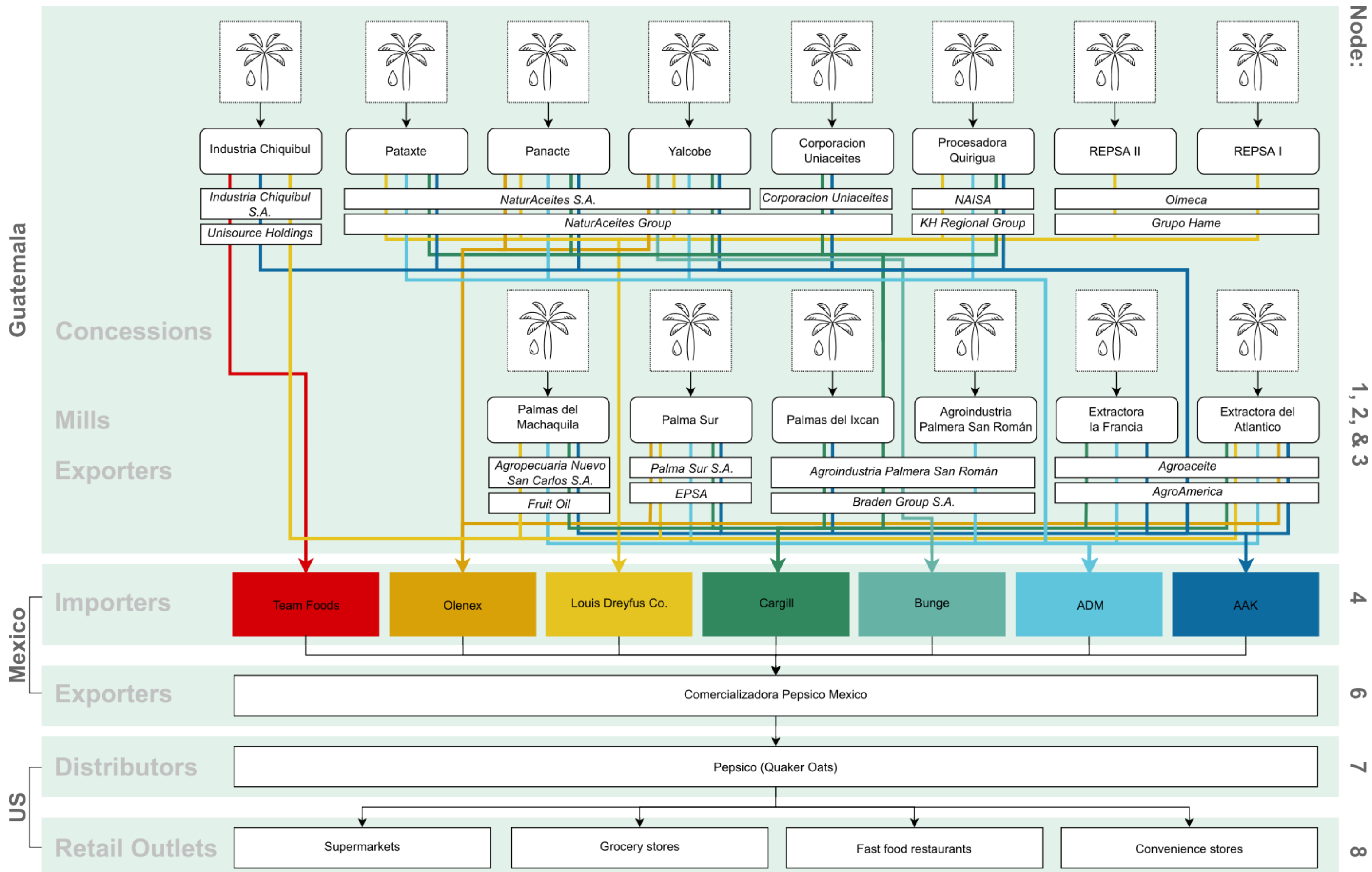

Figure 2-6. PepsiCo palm oil supply chain from Guatemala, through Mexico, to the U.S.

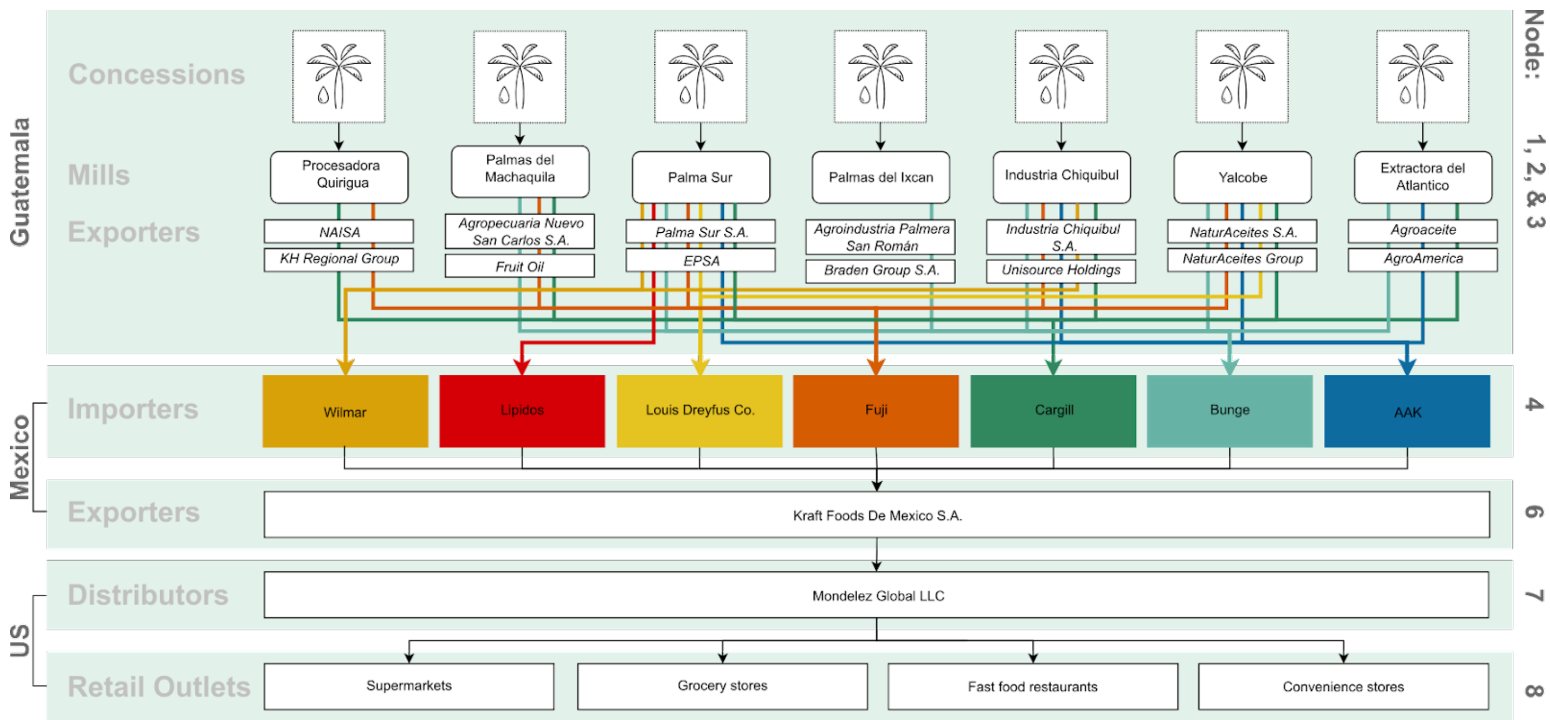

Figure 2-7. Mondelēz palm oil supply chain from Guatemala, through Mexico, to the U.S.

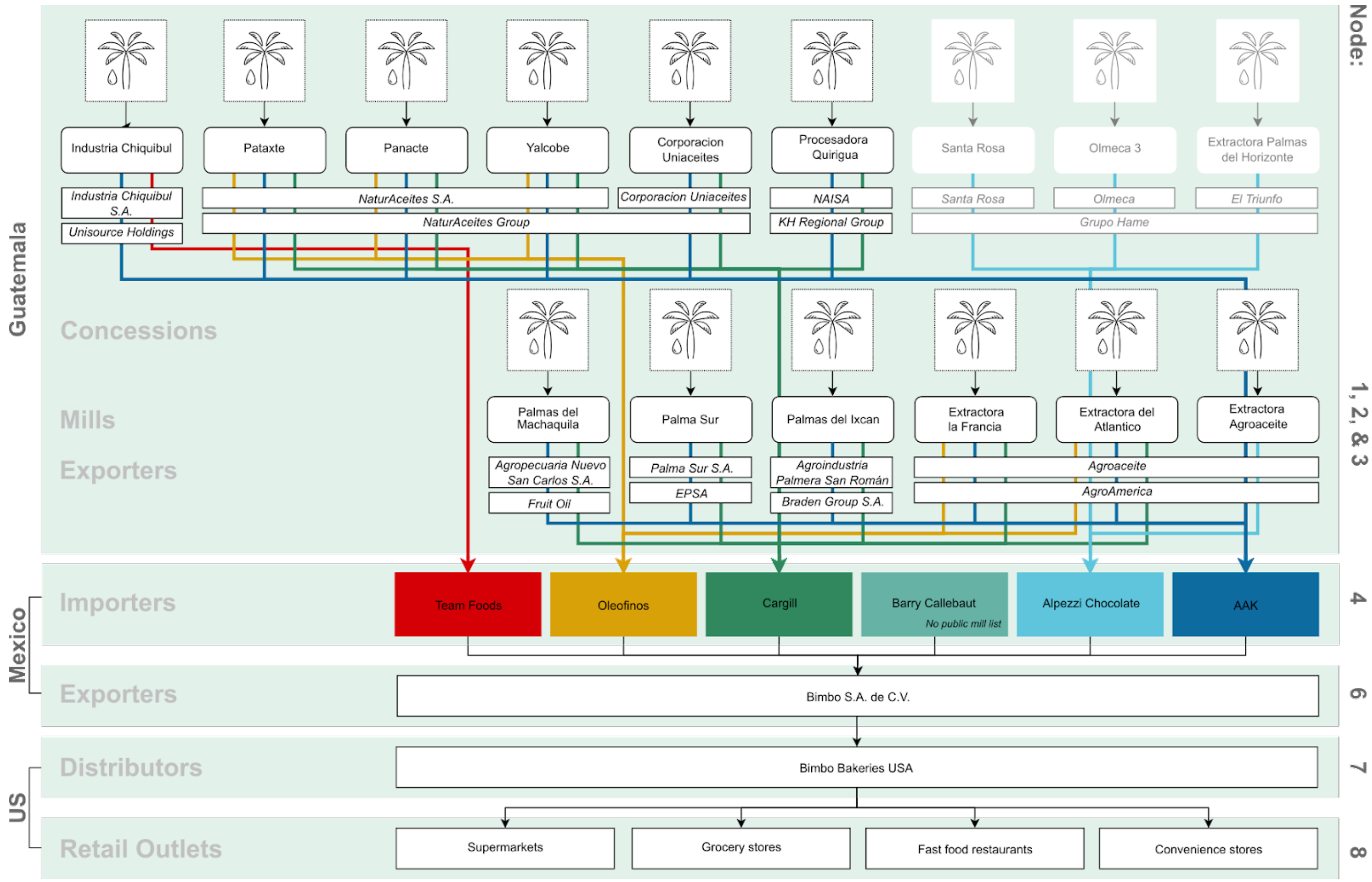

Figure 2-8. Grupo Bimbo palm oil supply chain from Guatemala, through Mexico, to the U.S.
Plantations/mills included in the study area are outlined with a black border.

Table 2-2. Palm oil production and deforestation rates by mill.
Note: RSPO membership is the first step, before becoming certified. Membership signals a company's intent to become sustainable, i.e., meet the criteria for certification, over the coming years.

Mill	RSPO status	Corporate connections	Oil palm plantations on forestland (ha)	Oil palm on non-forestland (ha)	Persistent oil palm plantations (ha)	% Deforested
Agroindustrial Palmera San Roman		Bimbo; PepsiCo	1,518	5,279	1,948	17%
Chiquibul		Bimbo; PepsiCo; Mondelēz	2,412	7,423	1,776	21%
Corporación Uniaceites		Bimbo; PepsiCo	719	1,464	463	27%
Extractora del Atlántico	Certified	Bimbo; PepsiCo; Mondelēz	1,203	3,316	10,924	8%
Extractora la Francia	Certified	Bimbo; PepsiCo	539	4,404	849	9%
Palma Sur		Bimbo; PepsiCo; Mondelēz	1,459	5,719	5,103	12%
Palmas del Ixcan		Bimbo; PepsiCo; Mondelēz	439	997	173	27%
Palmas del Machaquila		Bimbo; PepsiCo; Mondelēz	7,090	8,351	2,924	39%
Panacte		Bimbo; PepsiCo	496	4,505	2,533	7%
Pataxte		Bimbo; PepsiCo	166	458	3,065	4%
Procesadora Quirigua	Member	Bimbo; PepsiCo; Mondelēz	1,842	6,780	3,847	15%
REPSA I	Member	Bimbo; PepsiCo	1,248	975	1,430	34%
REPSA II	Member	Bimbo; PepsiCo	2,220	7,354	7,075	13%
Yalcobe		Bimbo; PepsiCo; Mondelēz	3,167	5,571	3,551	26%
Total			**24,518**	**62,496**	**45,661**	

2.5 Discussion

This work addresses gaps in the literature concerning corporate-specific supply chains, first-mile traceability, and the forest protection benefits offered by RSPO certification. Our findings reveal a number of interesting discussion points. First, the length and complexity of palm oil supply chains, like many other globalized product systems, make it difficult to establish causal links between land use change and consumption-based drivers. The first-mile problem in particular hinders the ability of corporations to identify their supply chain origins, which in turn hampers transparency and sustainability initiatives, including deforestation-free sourcing. Environmental certification does not effectively mitigate deforestation risk and firms cannot rely on (or be allowed to rely) on certification to achieve deforestation-free supply chains. Our results not only expand the existing literature on teleconnections and embodied deforestation, but also the literature on land-use related emission disclosures and corporate carbon performance, as we discuss below. In the following paragraphs, we discuss our findings and their implications as we suggest strategies that can help companies, and the sector writ large, eliminate risks in their palm oil supply chains.

2.5.1 First-mile traceability

The detailed end-to-end traceability established by this study adds precision to how and where deforestation dynamics and risks find their way into supply chains allowing corporations – and their regulators – to connect statements of sustainability with evidence. This kind of granular traceability knowledge is essential for corporations to stay ahead of emerging deforestation-free regulations as well as indirect (Scope 3) carbon emissions assessments. It is likewise critical for external actors, such as regulators and watchdog organizations, to monitor compliance and progress towards related targets.

The end-to-end detail we present is not necessarily what companies themselves know. PepsiCo, Mondelēz and Grupo Bimbo have varyingly granular and stringent traceability systems for their palm oil supply chains (Grupo Bimbo, 2019a, 2022b; Mondelēz International, n.d.; PepsiCo, 2022b). Mill-level traceability is relatively common. All three conglomerates, and many of their peers, make their mill lists readily available. However, Mondelēz is unique among the three conglomerates, and lead firms generally, in its prioritization of plantation-level traceability (Mondelēz International, 2022b). Yet, its plantation data is confidential.

This trend means corporate traceability stops short of the plantation and obscures the first mile, from the site of raw material extraction to the initial transfer of custody of those natural resources, where most environmental impacts occur. Without traceability back to sites of production it is impossible for corporations to guarantee deforestation-free sourcing (Mol & Oosterveer, 2015). As a result, their unverified corporate sustainability claims can obfuscate reality.

With first mile traceability, corporations can ground their claims to increase the credibility of their sustainable sourcing plans and mitigate external risk. Not only can first mile traceability equip actors with information and tools to proactively address problems, but it can also work as a means of governance via threat of discovery and scandal (Brad et al., 2018). Linkages revealed through end-to-end traceability can indirectly implicate lead firms in the conditions surrounding material production. NGOs have historically targeted multinational corporations, including PepsiCo and Mondelēz, through name-and-shame campaigns designed to drive behavior change (Greenpeace International, 2016, 2018). In fact, some of the most notable campaign successes in the palm oil industry were motivated by companies targeted by NGO brand-activism (Richardson, 2015). Transparent and accessible first mile traceability data has the potential to facilitate broader third-party monitoring and the ability to hold firms accountable.

Our first mile traceability approach concretely demonstrates a method for obtaining more precise estimates of indirect (Scope 3) supply chain emissions assessments (Plambeck, 2012). The scale of land use change driven greenhouse gas emissions makes tackling deforestation an increasing priority for companies working to decarbonize their supply chains. However, inconsistencies among existing methods for quantifying these emissions challenge corporate progress (Hansen et al., 2022), as does spatial aggregation of data (Escobar et al., 2020).

2.5.2 RSPO reform

The widespread adoption of and confidence in environmental certification to tackle commodity driven deforestation raises particular concern given our findings. Yet, these results echo other studies questioning the efficacy of voluntary corporate supply chain instruments (Dauvergne, 2018; Garrett et al., 2019; Pye, 2019) and they align with existing research on the (in)effectiveness of RSPO certification at reducing deforestation in other regions (Table 2-3).

Our findings indicate that despite their RSPO-membership and sourcing policies, PepsiCo, Mondelēz, and Grupo Bimbo are predominately sourcing from non-certified mills in Guatemala. Under the RSPO Credit system, they are able to claim fully sustainable palm oil while continuing to sell products containing uncertified oil. To account for the gaps in certified uptake they purchase additional sustainability certificates (Grupo Bimbo, 2019b; Mondelēz International, 2019; PepsiCo, 2019). Critics are skeptical of the indulgences the system permits, arguing it facilitates greenwash by absolving firms of supply chains monitoring responsibilities

(Brad et al., 2018; Gallemore et al., 2022). Our findings support this claim, highlighting the importance of physically-certified palm oil models.

Troublingly, our findings also suggest that RSPO-certified mills and plantations still contribute to deforestation. Although RSPO criteria stipulates any new land clearing after 2005 cannot cause deforestation, or damage primary, High Conservation Value, and High Carbon Stock forests (RSPO, 2020), this is happening in Guatemala. The standard not only fails to provide sufficient protection against deforestation, but also fails to protect ecologically important areas. As deforestation-free regulations proliferate, and as companies – and even countries (RSPO, 2016) – increasingly promise deforestation-free palm oil using the RSPO, acknowledging and addressing its shortcomings is particularly urgent (Donofrio et al., 2017; Furumo et al., 2020; Lambin et al., 2018). Otherwise, corporate greenwashing may continue to threaten the integrity of the RSPO and its ability to effect meaningful change.

Reports indicate that violations of the RSPO are systemic (EIA, 2019) providing little reassurance of its integrity. Others have suggested improving monitoring, verification, and enforcement with an expanded traceability system and improved audit structure to verify the first mile (Bishop & Carlson, 2022; EIA, 2019; Kusumaningtyas, 2017). While growers are required to submit spatial data on their concessions, we found gaps indicating a need for further oversight. This could fall on the RSPO Assurance Committee who could then utilize the dataset to remotely monitor land clearing and new plantings (EIA, 2019). Based on the results of their study in Indonesia, Carlson et al. (2018) also recommend the RSPO incentivize forest protection by creating price premiums linked to forest conservation. We recommend such incentives be extended to protect natural ecosystems broadly.

Although an important governing body for the palm oil sector, the RSPO is no silver bullet. Sustainable palm oil production also requires organized efforts and collaborations beyond the RSPO (Ruysschaert, 2016; Ruysschaert & Salles, 2018). Other action-oriented groups like the Palm Oil Innovation Group (POIG) and national or regional sustainable palm oil alliances can facilitate collective advocacy for sustainable palm oil (WWF, 2022b)..

Table 2-3. Overview of the research on the (in)effectiveness of RSPO certification at reducing deforestation.

Country/Region	Time period	Findings	Reference
Guatemala	2009-2019	Reduced but did not stop deforestation or ecological encroachment; More frequent overlap with protected areas	VanderWilde et al. (2023)
Indonesia	1984-2020	Strong relationship between deforestation and certified palm oil	Gatti et al. (2020)
Indonesia	2009-2016	Reduced illegal deforestation but not deforestation rate	Heilmayr et al. (2020)
Indonesia	2003-2014	Reduced deforestation and increased primary forest protection	Lee et al. (2020)
Indonesia, Malaysia, Papua New Guinea	2001-2016	Extensive forest loss prior to RSPO certification of plantations; Similar, if not higher, rates on certified plantations	Gatti et al. (2019)
Indonesia	2001-2015	Reduced but did not stop deforestation; Certified plantations had little remaining forest	Carslon et al. (2018)
Indonesia	1999-2015	No significant difference in fire outbreaks on certified vs. non-certified plantations	Morgans et al. (2018)
Indonesia and Malaysia	2002-2014	Reduced, but did not stop, forest loss or fire activity; Plantations had little remaining forest	Noojipady et al. (2017)
Indonesia	2012-2015	Reduced fires only in areas with low likelihood of fires	Cattau et al. (2016)

2.5.3 Deforestation policies

Promising legislation emerging in consumer countries aims to ensure that imported commodities, including palm oil, do not cause deforestation in producer countries (DEFRA, 2021; European Commission, 2022; FOREST Act of 2021, 2021). PepsiCo, Mondelēz, and Grupo Bimbo distribute products across the United Kingdom and EU which subjects them to both the UK Environment Act and the EU Deforestation Law. Whether these companies maintain distinct supply chains to separate material flows and production based on final product destination is unclear. However, our results indicate that existing sources are problematic and non-compliant with regulations. Sourcing risks will continue to grow as other countries, including the U.S., enact deforestation legislation.

Scholars caution these policies may not be enough to protect forests and may harm smallholder livelihoods (Grabs et al., 2023; Zhunusova et al., 2022). For example, EU regulation benchmarks deforestation risk at the country-level, masking subnational variation that excludes regional variation, and exacerbating the potential for deforestation leakage to other countries (Villoria et al., 2022). To improve this legislation, Grabs et al. (2023) suggest sub-national risk ratings for sourcing regions, common international standards, and financial incentives for first movers. Smallholders may not have the knowledge or resources to meet new requirements, suggesting a need for policy measures that incentivize capacity building (Grabs et al., 2023; Zhunusova et al., 2022).

Many non-forested, but nonetheless critical ecosystems, are equally threatened by commodity expansion, as we have seen in the case of Guatemala. However, deforestation-centric legislation stands to leave these systems unprotected (Li et al., 2022; TNC, 2022). The IUCN (2022b) therefore calls for expanding legislation to protect all ecosystems threatened by commodity trade.

Although Guatemala's constitution includes provisos for preserving the environment and natural resources, legislation conflicts with these aspirations (Briz et al., 2021). For example, the Forestry Law allows for deforestation (Art. 46) and incentivizes the establishment of monoculture plantations (Art. 80) (Ley Forestal, 2013). Incentives for sustainable intensification, i.e., intensively managing plantations to enhance productivity on existing areas (Monzon et al., 2021; Sharma et al., 2019), and planting on degraded land (Gingold et al., 2012) could make land clearing less attractive. The success of the Amazon Soy Moratorium indicates the potential for enacting a moratoria on the purchase of palm oil from deforested lands (Heilmayr, Rausch, et al., 2020; Lambin et al., 2018; Rausch, 2021).

Protecting the rights of local communities to manage and restore forests can help improve forest conservation and climate change mitigation while promoting environmental justice and strengthening local incomes, livelihoods and food sovereignty (Erbaugh et al., 2020; Palm Oil Detectives, 2021; Tenure Facility, 2021). However, in Guatemala and many other producer countries, long-standing tenure issues impede local peoples' ability to secure such benefits (Brent et al., 2018; Tramel, 2019; Zhunusova et al., 2022).

2.5.4 Future research opportunities

Oil palm plantations established prior to 2009 likely occupy previously forested land but data availability limited the temporal scope of this study. With better data, future work may be able to assess these historical land use changes. We structured the models in this study to identify forest-to-oil palm land use change dynamics, but it would also be of interest to understand other deforestation drivers in detail. In addition, it is critical to continuously monitor land use change impacts associated with commodity production; our study provides a snapshot that ends in 2019 but the story continues to evolve.

While this study focused on teleconnections that embody the environmental risks of palm oil production, social risks are also pressing. This suggests an opportunity for an important future application of the presented methods: to identify corporate linkages to social impacts of production. For example, across the study area, aggressive expansion has led to serious implications for the livelihoods and food security of indigenous populations, particularly the Mayan-Q'eqchi (Hervas, 2021). The land area now occupied by oil palm plantations covers the area equivalent to land once used by more than 60,000 subsistence farmers (Milton, 2018).

Dozens of rural communities have been subsumed by oil palm plantations and others have disappeared entirely (Pietilainen & Otero, 2019). Dispossessed of the land they rely on for food, water, materials, shelter, and medicine – for life – already vulnerable populations experience further deteriorated food security, health, freedom of choice, and social ties (Alonso-Fradejas, 2012; Mingorría et al., 2014; Pietilainen & Otero, 2019). For Guatemala's Indigenous Peoples, oil palm expansion represents the latest manifestation of longstanding historical processes of land-control grabbing (Pietilainen & Otero, 2019). These patterns of accumulation only perpetuate deeply inequitable land distribution in the country.

Further clarification of the land rights of Indigenous Peoples is critically needed as oil palm, and other export-oriented crops, encroach on historically Indigenous areas (Figure 2-9). Future research could focus on clarifying these land rights, identifying supply chain ties to dispossession, and documenting land conversion to oil palm (and other export-oriented crops). While best available data indicates the location of traditional territories, it does not necessarily reflect the views of local nations, definitive or legal boundaries, or current population distributions (Native Land, 2022). In the absence of concrete maps and adequate legal protections to delineate and protect their territories, communities remain vulnerable to systematic dispossession. Ancestral claims to land are disregarded for the benefit of large private landowners, ranchers and companies (Garcia, 2021; Mingorría, 2014). Community and national-level data layers on lands managed, owned, and held under customary tenure should be generated in partnership with Indigenous Peoples and communities.

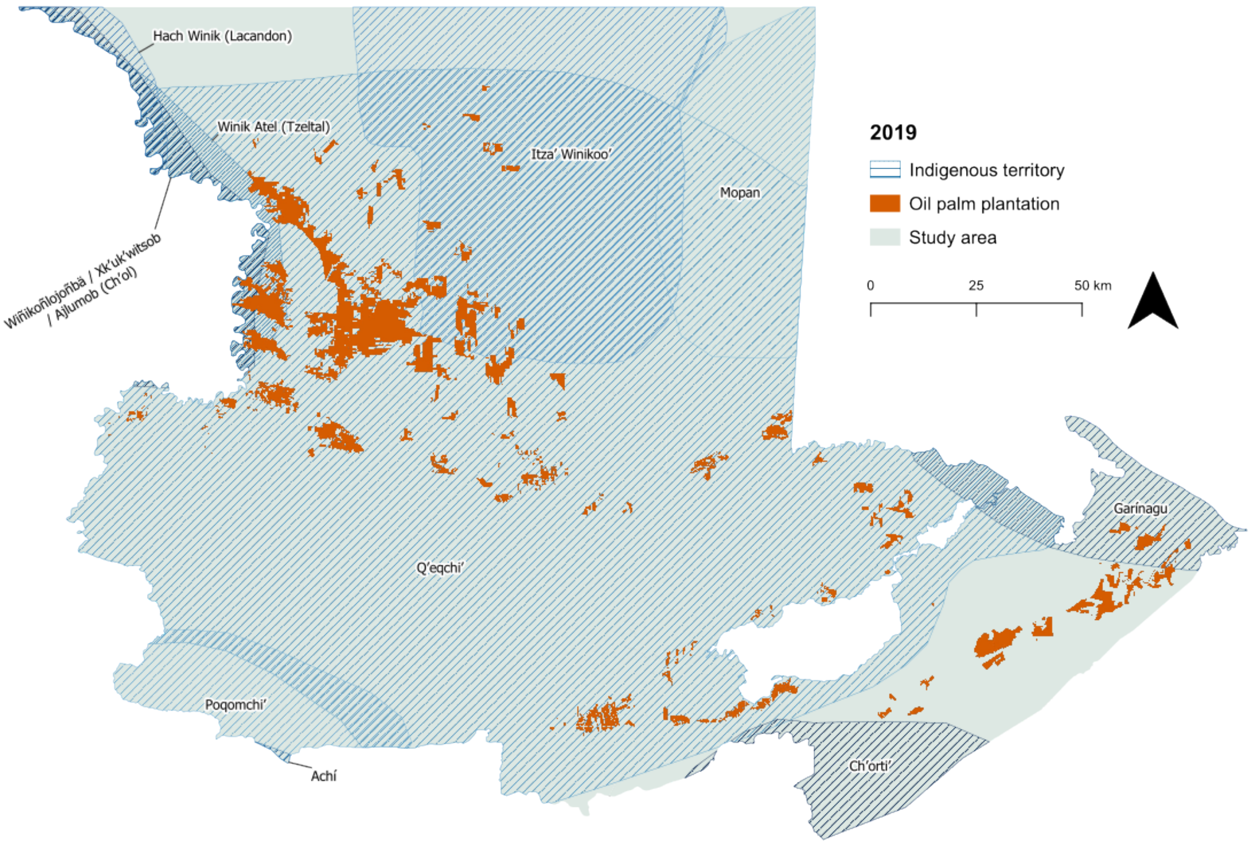

Figure 2-9. Oil palm expansion on Indigenous land across the study area, 2009-2019.
Boundaries indicate traditional territories and do not represent definitive or legal boundaries of any Indigenous nations. Source: Native Land (2022).

2.6 Conclusion

Palm oil has attracted significant attention for its ties to widespread forest destruction and biodiversity loss across Southeast Asia. However, the literature has paid minimal attention to newer spaces of production and issues of corporate supply chain traceability. Understanding corporate-specific supply chains, from their origins, is critical for creating targeted interventions to address teleconnections to environmental and social impacts – and for empowering companies themselves with the knowledge to act. In this paper, we therefore sought to expose how the plight of "sustainable" palm oil production is playing out in an emerging frontier. Our analysis suggests a tale foretold, with forests and other biodiverse landscapes replaced by large-scale monoculture plantations. Across the study area, 28% of plantation expansion caused deforestation (2009-2019) and over half of plantations are in Key Biodiversity Areas, while over a third are in protected areas. We revealed corporate linkages to plantations and found that their RSPO-dependent sustainable palm oil commitments do not effectively protect them against environmental risks as certification is not effectively curbing deforestation or ecological encroachment. As it stands, the environmental certification makes unjustified claims of "sustainability" and fails to serve as a reliable tool for fulfilling emerging zero-deforestation requirements. The strategies we have identified can help companies, and the sector writ large, eliminate environmental risks in their supply chains.

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Out of Sight, Out of Mind: First Mile Problem in Supply Chains [4]

3.1 Abstract

Although opaque places can occur anywhere in a supply chain, they predominate at the origin – at the fishery, forest, plantation, mine, and other sites where a natural resource is first extracted from the Earth. We label this the first-mile problem: the challenge of identifying the first stage of a supply chain, from raw material extraction to initial transfer of custody. Opacity obscures the link between production impacts and consumption drivers, inhibiting our ability to address environmental and social hotspots. In this perspective piece, we identify 14 propositions based on supply chain input-out structure, territoriality and temporality, and governance features that make the first-mile problem more or less challenging. To ground this theory, we illustrate how the fishing, forestry, agriculture, and mining sectors face related but uniquely first-mile traceability problems. We conclude by identifying promising technologies, legislation, and governance strategies to overcome this persistent, yet overlooked, challenge to supply chain sustainability.

3.2 Introduction

Supply chains have a traceability problem. Despite a broad push for increased visibility across supply chains, including rare examples of wall-to-wall transparency, opacity remains the norm. Although identifying specific locations, production conditions, and corporate actors is challenging across all portions of a supply chain, it remains notoriously difficult to track a supply

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chain to the “first-mile” where it begins (Acquaye et al., 2014; Bramanti et al., 2020; Egilmez et al., 2014; Grabs & Carodenuto, 2021; O’Rourke, 2014; Phillips, 2017; Sen, 2017; Serdijn et al., 2020).

Take palm oil as an example. Linking retailers of products containing palm oil to manufacturers is straightforward. It is also possible to link palm oil importers to exporters using emerging data. While traders tend to have insight on the mills they source from, product traceability further upstream quickly diminishes as they mix palm oil from multiple mills and the mills themselves source palm fruit from a shifting roster of tens to thousands of plantations (Matondang et al., 2020; Musim Mas, 2019). This renders it nearly impossible to trace consumers, retailers, and manufacturers to plantations and potential deforestation from their expansion. Lack of traceability back to the first-mile — the first-mile problem — afflicts companies, large and small, domestic and international, across all sectors.

Supply chain opacity creates places where environmentally and socially harmful production practices can hide, embed, and flourish (Ibert et al., 2019). These opaque places can occur anywhere in a supply chain, but we argue they are most acute at the plantations, mines, forests, farms, fisheries, and other sites where supply chains pull vast quantities of resources into the global economy, often causing negative and permanent environmental change. To address these environmental hotspots, consumers, NGOs, investors, and regulators increasingly demand supply chain traceability.

Existing and emerging regulations including the U.S. Lacey Act, European Supply Chain Act, UK Environment Act, and others, either explicitly or implicitly require that companies identify all of their suppliers or avoid environmental crimes in their supply chains (Campbell, 2022; DEFRA et al., 2021; European Commission, 2022; Proposal for a Directive of the

European Parliament and of the Council on Corporate Sustainability Due Diligence and Amending Directive (EU) 2019/1937, 2022; FOREST Act of 2021, 2021; Leisering, 2022; Norton et al., 2014). In addition to legal peril, companies also risk financial or reputational damage to their brands or consumer boycotts in response to NGO campaigns exposing unsustainable business practices in their supply chains (Burley & Thomson, 2021; Dashwood, 2014; Donofrio et al., 2017; Gulbrandsen, 2009). The first-mile problem hampers the ability for companies to comply with regulations, satisfy the demands of increasingly eco-conscious consumers or use their immense buying power more sustainably. Governments also cannot effectively enforce supply chain laws, address domestic environmental crimes, nor combat institutionalized corruption and co-option of regulators when the first-mile remains invisible.

Despite its near universality and clear implications for sustainability, the first-mile problem remains critically understudied. In this perspective piece, we define the first-mile and identify the root of its opacity. Using 14 propositions, we argue that supply chain input-output structure, territoriality, and governance are three important determinants of first-mile traceability. We demonstrate this with examples from four divergent sectors: agriculture, fishing, timber, and mining. While addressing the first-mile problem presents a formidable challenge, we argue that key actors including traders, lead firms, NGOs, and governments, can overcome this challenge by targeting specific complicating factors based on their unique strengths. Novel technologies can help but do not offer a panacea.

First-mile traceability coverage is needed across whole sectors to create broad, positive impact. While traceability itself does not alter the conditions of production – it is not a solution to the root causes of social and environmental harm – it can reveal where and when firms can make concerted efforts by providing additional support to producers, developing targeted programs, and establishing strategic partnerships. Identifying impact hotspots is the first step to mitigating them, and to making production transparent, sustainable, and responsible. It is only by knowing the origin of their raw materials that companies can assure their customers that their products do not contribute to social or environmental harm.

3.3 Defining the first-mile and its discontents

The "first-mile" was originally coined by logistics experts to describe the final step in distributing products to customers. In contrast, supply chain scholars understand the first-mile as "early in the supply chain" (Spertus-Melhus & von Engelbrechten, 2020, p. 6). Studies of traceability challenges in various supply chains, as well as studies of blockchain applications for supply chains, casually mention, but do not define the first-mile (Bechini et al., 2008; Grantham et al., 2022; Kramer et al., 2021; Motta et al., 2020). The agri-food industry does provide a definition, but this is narrowly focused on the first supply chain segment from farm or field to initial purchase (Cargill, 2019; Dumay, 2022; Farmforce, 2022; Handley, 2020; Provenance, 2016; Stoop et al., 2021). Thus, scholars and practitioners lack a general definition of the first-mile.

To define the first-mile, we consider how it explicitly links location, actor(s), and flows to the larger supply chain (Figure 3-1). Here, *location* refers to the site of natural resource extraction, i.e., the physical process of separating and removing one component of a larger ecosystem. *Actors* are those involved in extracting and transferring resources. *Flows* describe the physical movement of traceable units of raw material to the next stage of the supply chain. Taken together, we define the first-mile as:

The location where nature becomes commodified – transformed and often degraded – by a particular set of actors who subsequently transfer a flow of materials to a downstream supply chain node.

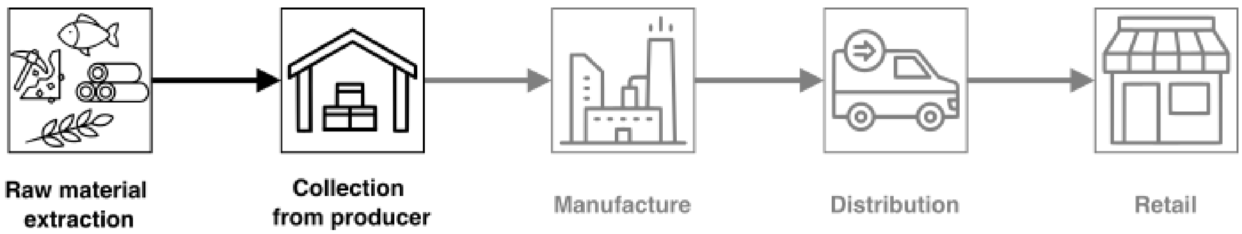

Figure 3-1. The first-mile of a stylized supply chain.
The first-mile is the first stage of a supply chain, from the site of raw material extraction to the initial transfer of custody of those natural resources. It is rarely captured in company supply chain maps.

The first-mile is related to the concepts of provenance and chain-of-custody. Provenance denotes the geographic origin of a supply chain (Manning, 2018; Monahan et al., 2018). The chain-of-custody is the chronological documentation of the control and transfer of material goods between supply chain actors (Fox et al., 2018; Responsible Jewellery Council, 2017). Knowledge of the provenance and chain-of-custody of a supply chain is essential to monitoring and improving supply chain sustainability but is predicated on accurate information on the first-mile. However, this information becomes increasingly absent the "closer one gets to the dirt" at the base of a supply chain (Bechini et al., 2008, p. 349). This data gap typifies the first-mile problem, which we define as:

The challenge of identifying the first link of a supply chain, from the site of raw material extraction to the initial transfer of custody of those natural resources.

Addressing this problem is imperative given that environmental change is often most acute at the base of a supply chain.

Yet, a combination of resource- and context-specificities uniquely shape the first-mile of a supply chain and can frustrate traceability efforts. Below, we classify these factors in categories based on the three fundamental dimensions of global commodity chains – input-output structure, territoriality and temporality, and governance – which we complement with theory from the global value chain and global production network literature (Bridge & Bradshaw, 2017; Coe & Yeung, 2019; Gereffi, 1994; Hess, 2004). We then use this framing to derive a number of propositions about the first-mile problem.

3.3.1 Input-output structure

Input-output structure is the physical connection between raw material extraction point and subsequent supply chain stages. We suggest five propositions related to input-output structure and first-mile traceability.

- **Proposition 1a:** *Increasing the number of actors responsible for extraction and at the subsequent supply chain stage increases complexity of first-mile traceability.* Tracing flows back to a single source requires less effort than tracing flows to multiple sources. Complexity increases exponentially when there are multiple sources and actors at the next supply chain stage (e.g. n oil-palm plantations and m mills).

- **Proposition 1b:** *Aggregating flows from multiple sources increases complexity of first-mile traceability.* Source segregation enhances first-mile traceability, but is rare for bulk commodities. For instance, crops from different farms are often aggregated by traders

(Bollen et al., 2007; Orzechowski, 2019). Semi-processed goods (e.g., oils, cocoa, and grains) from different sources are mixed and stored in huge containers that are only periodically emptied (Dabbene et al., 2014).

- **Proposition 1c:** *Increasing the number of stages in a supply chain increases complexity of first-mile traceability.* More stages mean more opportunities for aggregation of flows (including illegal leakage); higher likelihood of deterioration of or tampering with chain-of-custody data; and generally greater complexity of the trade network. Some supply chains, such as critical metals, have eight stages separating resource extraction from finished goods (Voisin et al., 2012).

- **Proposition 1d:** *Distance between nodes increases complexity of first-mile traceability.* Geographical, cultural, and organizational distance shape supply chain linkages (Awaysheh & Klassen, 2010). Increasing geographical distance decreases interaction frequency and access to (traceability) information. Increasing cultural differences between actors can hinder information sharing, produce uneven expectations about data needs and data management and reduce overall data compatibility (Busse et al., 2016; Thakur & Donnelly, 2010). See Proposition 1c for organizational distance.

- **Proposition 1e:** *Fluid trading partnerships increases complexity of first-mile traceability.* Frequently changing suppliers increases network complexity and data demands for traceability (see Propositions 1a-c). Moreover, close-tie, stable, relationships between and beyond first-mile actors facilitate the exchange of high-quality (and more) information – rather than the simple price, quality, and quantity data used in market transactions (Uzzi, 1997).

3.3.2 Territoriality and temporality

Territoriality and *temporality* capture the space-time dimensions of raw material extraction. Environmental factors, such as climate or geochemistry, and resource mobility (e.g. wild fish vs. minerals) influence territoriality. The areal extent of a resource base impacts the time it takes to transfer custody of raw materials. Territoriality, temporality, and first-mile traceability relate in four ways.

- **Proposition 2a:** *Dispersed supply bases increase complexity of first-mile traceability.* Resources and extraction sites may be concentrated or dispersed. For example, timber concessions might limit harvest to a single, bounded area; while sanitary logging permits might allow logging across many locations. Traceability is more difficult in the latter case.

- **Proposition 2b:** *More extensive and/or remote supply bases increases complexity of first-mile traceability.* Remoteness "lengthens" the first-mile and can obscure both locations of extraction and environmental change. Examples include ocean fisheries or logging deep in boreal forests. Infrastructure deficits, like poor-quality roads or limited cellular coverage, hamper monitoring supply chain connections or digital data collection at remote sites.

- **Proposition 2c:** *Time gaps between extraction and first transfer of custody increases complexity of first-mile traceability.* Time gaps after extraction increase the likelihood of mixing resources of different provenance or data tampering. For instance, fish from different regions and periods are blended on fishing expeditions that can last years (Buakamsri, 2015). Timber yards, where trees are cured for several months, are popular sites for mixing illegally harvested trees (Newell, 2008).

- **Proposition 2d:** *Resource mobility increases complexity of first-mile traceability. Fixed resources are easier to track than mobile ones.* For instance, mineral commodities, like coltan, can only be extracted where reserves are present, limiting where the first-mile can start. In contrast, fisheries can have shifting geographies; as fish move so does the first-mile. Even here, however, biological and geophysical conditions (e.g., depth and temperature ranges) can restrict habitat ranges and constrain the first-mile.

3.3.3 Governance

Governance refers to how authority and power relationships control and coordinate raw material flows, record keeping, value capture, and production conditions along a supply chain (Humphrey & Schmitz, 2001). Companies, regulators, and other stakeholders leverage a variety of formal and informal, mandatory and voluntary, instruments (policies and guidelines, rules or laws, norms, standards) to shape governance (Boström et al., 2015). Governance and first-mile traceability relate in five key ways.

- **Proposition 3a:** *Coordination across supply chains can support first-mile traceability.* Modes of supply chain governance differ in their levels of coordination. Hierarchical governance has high coordination, whereby lead firms control production across multiple supply chain stages. This vertical integration has the potential to enhance traceability across those stages, sometimes to the first-mile. However, in some instances high levels of coordination may produce "unholy alliances" among actors as they collaborate to hide illegality and corruption (e.g., coltan miners and traders who maintain close trade relationships with smugglers). Pure market transactions have little coordination and only exchange the bare minimum of information between stages, limiting first-mile insight.

- **Proposition 3b:** *Illegality and corruption can inhibit first-mile traceability.* Global commodity trade is rife with illegality and corruption (Grant et al., 2021; WWF, 2022b). Illegal commodities are seamlessly blended with legal counterparts using falsified documents and data, often with assistance from corrupt government officials. Illicit production and trade are hidden by design and inhibit first-mile traceability.

- **Proposition 3c:** *First-mile traceability depends on capacity.* Even if they have the desire to advance traceability, companies may be limited by the knowledge and expertise held by first-mile actors, as well as their capacity to collect and share data (Leong et al., 2018). Deficits in state institutional capacity may also limit efforts.

- **Proposition 3d:** *Secrecy can inhibit first-mile traceability.* Competitive advantage (e.g., hiding suppliers from peers or customers) might trump traceability for some firms (Glew et al., 2022; Hirbli, 2018). Firms may also engage in obfuscation to mask illegal activity, dodge standards, or circumvent buyer requirements.

- **Proposition 3e:** *Lack of governing authority can inhibit first-mile traceability.* Locations without sovereign territorial claims or in contested territories often lack enforceable chain-of-custody rules. These territories fall outside government land registries and have no formal owner that can be tied to the first-mile. Examples include fisheries in international waters or conflict minerals in Africa. Lax governance allows fraudulent or nonexistent record keeping and overexploitation of resources to flourish.

Below, we demonstrate the first-mile traceability implications of these 14 propositions (simplified in Figure 3-2) through vignettes of four different sectors.

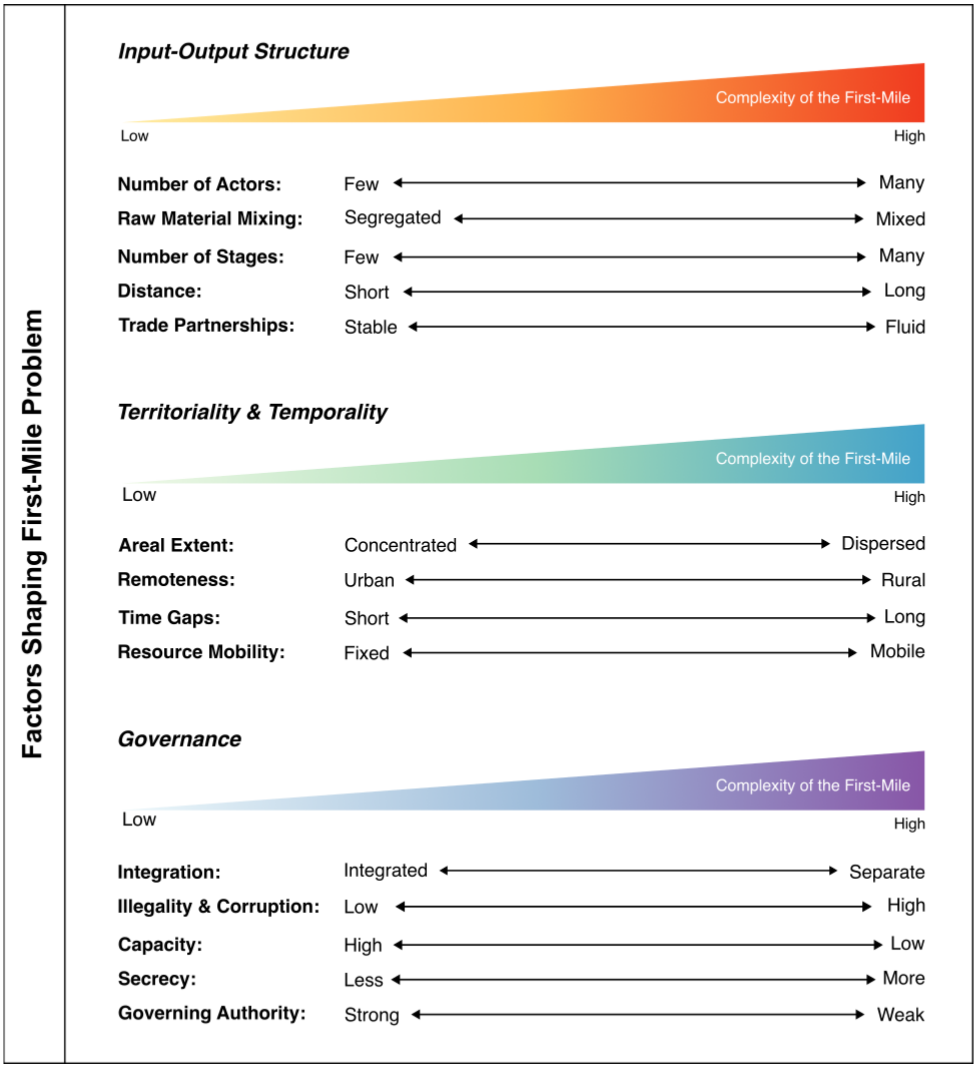

Figure 3-2. Factors complicating first-mile traceability.
Factors are categorized based on how they interface with supply chains: input-output structure, territoriality and temporality, and governance. Arrows indicate the directionality of their influence on first-mile traceability (down: decrease; up: increase).

3.4 First-mile profiles in four sectors

We use sectoral profiles to provide non-exhaustive vignettes illustrating how key supply chain attributes inform first-mile traceability (Figure 3-3). We selected four sectors – commercial fishing, timber, palm oil, and coltan mining – based on clear differences in commodity form, extraction region, supply chain structure, and governance. Figure 3-4 shows how the input-output structure and territoriality of the first-mile differ in these sectors.

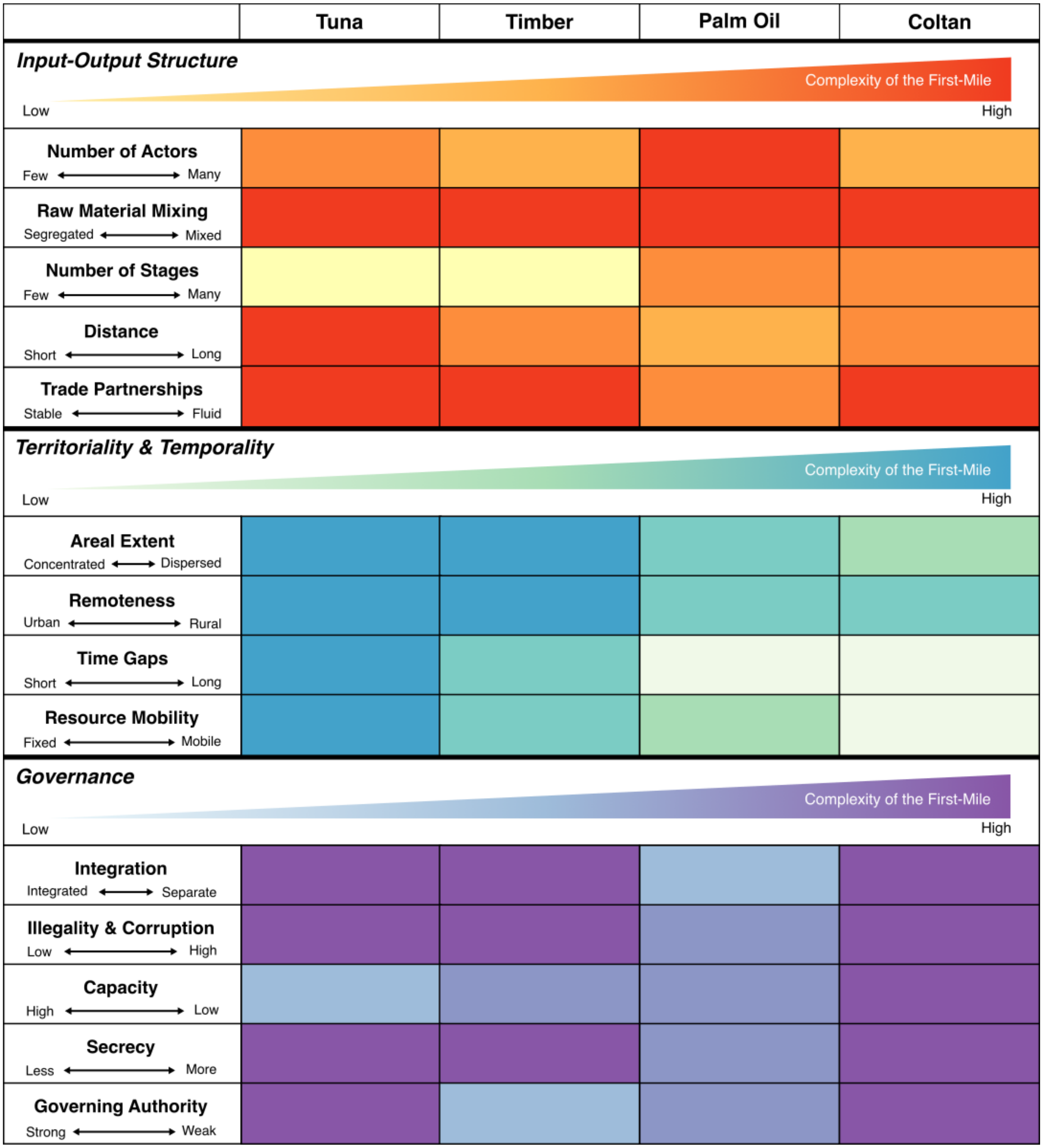

Figure 3-3. Comparison of key supply chain attributes impacting first-mile traceability across four sectors.

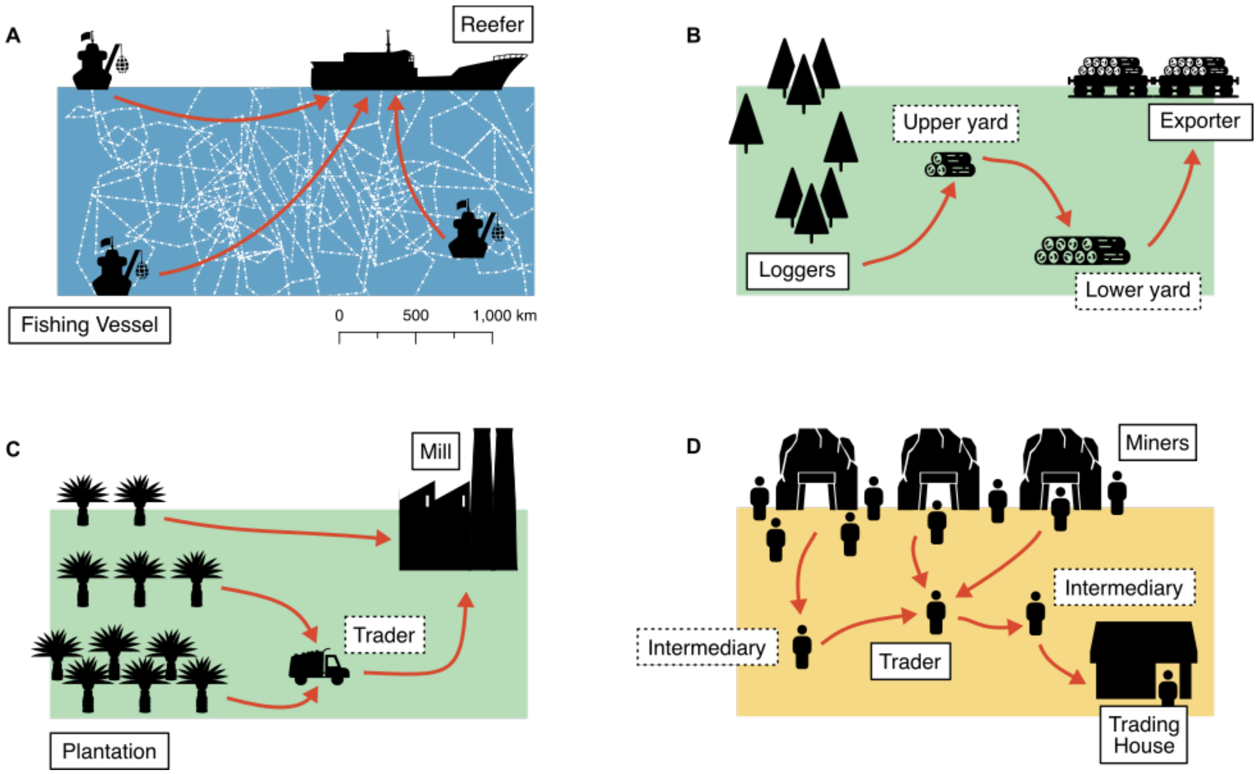

Figure 3-4. Comparison of selected first-mile input-output structures by sector based on case studies. *(A) Western Pacific Ocean tuna fisheries: catch by purse seiner vessel is transferred a transshipment reefer (Seto et al., 2022); (B) Russian timber: Small logging companies conduct sanitary logging on leased concessions, aggregate timber in log yards, and then transfer it to traders for export (Newell, 2008); (C) Indonesian palm oil: Independent and organized smallholder farmers, traders, and company-affiliated plantations supply mills with fresh oil palm fruit bunches(Matondang et al., 2020); and, (D) Democratic Republic of Congo coltan: Miners sell their coltan to traders (Wakenge, 2018). Many different first-mile input-output structure configurations are possible and the reality is more complex than shown in the stylized examples.*

3.4.1 Western and Central Pacific Tuna: From net to reefer or port

Tuna is the most consumed fish globally and most is sourced from the Western and Central Pacific Ocean (WCPO) (FAO, 2022; Holmes & Wozniak, 2021). Overfishing threatens future viability of WCPO tuna stocks and tuna supply chains are linked to habitat destruction, forced labor, and unsafe working conditions (Seto et al., 2022; United Nations, 2021). Rampant illegal, unreported, and unregulated (IUU) fishing in the region obscures these practices. First-mile traceability is needed, but input-output fluidity, fuzzy territoriality, and IUU fishing in tuna supply chains pose challenges.

Input-output structure

The input-output structure of this first-mile is hyper-fluid. A mobile fleet of over 2,000 vessels continually harvest the high seas (Proposition 1a) (Koehler, 2020; Oceanic Fisheries Programme, 2021). These ships periodically offload cargo at sea via transshipments by floating beside a rotating cast of refrigerated cargo ships (reefers) for short periods (1-2 days), making it difficult to link actors involved in the first-mile (Proposition 1e). Fishing vessels also occasionally travel vast distances to offload catch at ports throughout the region (Proposition 1d) (SALT, 2021). During transshipment or at port, fish from multiple vessels and geographies are mixed (either whole or as individual cuts) (Proposition 1b) (Future of Fish, 2015; Global Fishing Watch, 2022; SALT, 2021). This first-mile fluidity and blending of tuna obscures where, when, and how a catch was made, and allows IUU fishing in global tuna supply chains (Koehler, 2020; SALT, 2021).

Territoriality

The areal extent, remoteness, and mobility of tuna stocks blurs the territoriality of the first-mile for this supply chain. The sheer extent of the resource base (vast ocean territories) (Proposition 2a) and the long distances between where fish are caught and processed (Proposition 2b) makes it difficult to pinpoint where fish are caught. The raw material base is highly mobile, necessitating a highly mobile set of first-mile actors – both fishing and transshipment vessels (Proposition 2d). Taken together, these factors spread the first-mile across hundreds of thousands of square miles of some of the Earth’s most remote areas, in turn, making monitoring of the first-mile labor intensive and uncertain.

Governance

WCPO fisheries lie primarily in international waters (Proposition 3e). As such, there is no legal owner of WCPO fisheries, which inhibits first-mile tracking relative to situations where territories are leased or owned (e.g., wood harvested at forest concessions tied to legal entities) (SALT, 2021). Moreover, international fisheries lack enforceable government regulations to require robust chain-of-custody tracking. Instead there exists a patchwork of voluntary multi-stakeholder initiatives that have yet to bring first-mile traceability to the sector (Koehler, 2022; Koehler & Cohen, 2020; Marine Stewardship Council, 2022; McCauley et al., 2016; Western and Central Pacific Fisheries Commission, 2010). Even when national and regional bodies attempt to regulate, such as the mandated use of Automatic Identification Systems to broadcast fishing vessel ID and location, most vessels have either not installed systems or turned them off to evade authorities (Proposition 3d) (Malarky & Lowell, 2018; McCauley et al., 2016). The absence of effective regulation, monitoring, and data collection provides a loophole for IUU fish to enter supply chains and disrupt traceability (Seto et al., 2022). The low coordination across tuna supply chains also undermines traceability (Proposition 3a). While a handful of companies own both reefers and fishing vessels, in most instances they are owned separate companies related through market transactions (Park et al., 2023).

3.4.2 Russian Timber: From forest to processor

The Russian Taiga is the largest forested region on Earth (FAO, 2020; Shuman et al., 2011). The area plays a critical role in climate change mitigation, biodiversity conservation, and general ecosystem function especially for the polar Arctic, but also globally (Newell & Henry, 2016). Non-commercial salvage logging is but one form of logging riddled by illegal practices that contribute to forest destruction (UNEP-WCMC, 2018; WWF Russia, 2007). First-mile traceability is needed to address these issues but is complicated by a fragmented input-output structure, a vast, remote timbershed, and systemic corruption.

Input-output structure

The input-output structure of the first-mile is widespread and varied. Approximately 12,000 companies lease forest concessions (Proposition 1a) (Forest Legality Initiative, 2022). Felled timber may take several paths: direct export, mill processing, or storage in a timber yard (EIA, 2013; Vilkov & Tian, 2019; WWF, 2007). Export typically follows storage and/or processing stages (Proposition 1c). Timber is blended at felling sites, during logging truck loading and transfer, and at mills, timber yards or fuel terminals (Proposition 1b) (Efimova et al., 2010). Wood from unknown, suspicious, or illegal origins can be combined with legally harvested timber at these locations.

Territoriality

Russian timbersheds are extensive and remote (Proposition 2b). Logging permits set legal boundaries and responsibility for harvest, but companies are known to log beyond permits. Selective logging, such as salvage logging, can be widely dispersed across a permitted area making it difficult to pinpoint where harvesting happens (Proposition 2a). Consolidating logs in storage yards introduces time gaps between harvesting and processing or export (Proposition 2c). Short-term leases contribute to shifting material bases as old leases expire and companies obtain new leases (Proposition 2d).

Governance

The first-mile has relatively high coordination, with logging companies control felling and storage in timber yards (Proposition 3a). However, institutionalized corruption weakens the forest sector capacity to implement or enforce regulations (Proposition 3b and 3c)(Forest Legality Initiative, 2022; Newell & Henry, 2016; Smirov et al., 2013; Turkova & Arkhipova, 2019). Forest management authorities, local administration, and other agencies are often complicit in illegal logging (Newell & Henry, 2016; Smirov et al., 2013). An estimated 10-60% of total logging in the region is illicit (UNEP-WCMC, 2018). Russian timber companies often prioritize short-term profits that can be most quickly obtained from illegal sources, which generate five to ten times the revenue of legal practices (Nellemann & Nellemann, 2012; Proskurina et al., 2018). Traceability is anathema to these companies – it is better for business if one hides their source and obscures first-mile traceability (Proposition 3d).

3.4.3 Indonesian Palm oil: from plantation to mill

Palm oil, the world's most consumed vegetable oil, is cheap, versatile, and easy to grow (Furumo, 2018; Murphy et al., 2021). Roughly half of all packaged supermarket products from bread and butter, to deodorant and toothpaste, contain some form of palm oil (WWF, 2022a). Indonesia, produces 57% of the world's palm oil to great economic benefit (Ritchie & Roser, 2021). Yet, oil palm plantations drive land use change, carbon emissions, and social dislocation (Amnesty International, 2016; Austin et al., 2017; Gellert, 2015; Jordan, 2014; Koh & Wilcove, 2007; Linder & Palkovitz, 2016; Miettinen et al., 2012; Vijay et al., 2016). First-mile traceability is needed to ensure that plantations adhere to practices that promote environmental and social sustainability. However, a complex input-output structure, scattered territoriality, and limited government support challenge first-mile traceability.

Input-output structure

The Indonesian palm oil sector includes an estimated 2.6 million smallholder farmers, 1,500 private companies, and 15 fully state-owned businesses (Glenday & Paoli, 2015;

Matondang et al., 2020; Musim Mas, 2022). Mill companies may procure fresh fruit bunches (FFB) from multiple sources: core estates, plasma plantations, and independent smallholders (Proposition 1e). Smallholders can be independent or associated with plasma plantations and contractually bound to a particular mill (Suhada et al., 2018). The extent of a mill's supply base may number from the tens to the ten thousands (Proposition 1a) (Asian Agri, 2016; Matondang et al., 2020; Musim Mas, 2022). Before arriving at a mill, FFB may be traded between multiple smallholders and/or aggregated by local traders (Proposition 1b and 1c) (Lyons-White & Knight, 2018). Additional mixing occurs at the mill as FFBs supplied by hundreds of harvesters are blended and indiscriminately processed throughout the day (van Duijn, 2013). Mills store crude oil in large storage tanks that hold approximately a week's production made from mixed supply bases, harvested at different times.

Territoriality

The oil palm supply base is widely dispersed with over 16 million hectares cultivated by millions of producers (Proposition 2a), many of whom are smallholders (those who own < 20 ha of land) (Glenday & Paoli, 2015; Musim Mas, 2019; Reuters Staff, 2022). Mill and plantation locations provide insight into the first-mile across the supply chains vast territoriality; FFBs are highly perishable and must be processed within 24-hours of harvest which limits plantation sourcing to a roughly 50-kilometer radius of the nearest mill (Proposition 2b) (Dowell et al., 2015). Oil palm plantations operate on average for 25 years. Despite the fixity of production locations, continuous expansion into new land or forest adds some fluidity to the supply base (Proposition 2d).

Governance

Actions taken by the Indonesian government impede first-mile traceability. Despite a 2017 ruling by the Supreme Court that national plantation data and maps be made publicly accessible, the Land Ministry bars companies from publishing and sharing their concession maps digitally (Jong, 2021). The unavailability of authoritative spatial data provides rent-seeking opportunities for government officials (Proposition 3b) (Astuti et al., 2022). Corruption in the national palm oil licensing regime produced inconsistent data on the extent and legality of oil palm plantations, overlapping concession areas, and competing claims to ownership. At the same time, many companies remain secretive about their plantation data, especially pertaining to their plasma schemes (Proposition 3d) (Walker, 2023). Given that over 41% of Indonesia's palm oil plantations belong to smallholders, there is low supply chain coordination across much of the sector (Proposition 3a).

3.4.4 Coltan in the Democratic Republic of the Congo: from mine to middleman

Columbite-tantalite ore (coltan) is an essential component in the manufacture of modern technological devices from smartphones to jet engines (McBain, 2019; USGS, 2017). With 80% of the world's coltan reserves, the Democratic Republic of the Congo (DRC) leads global coltan production by a wide margin (Ojewale, 2022b, 2022c). However, large-scale environmental degradation, land use conflicts, violence, and numerous human rights violations plague the coltan mining industry (Global Witness, 2022; Ojewale, 2022b, 2022c; Schütte, 2021). First-mile traceability is key to decoupling supply chains from such harmful practices, but informal trade arrangements, remote territoriality, and widespread corruption make it far from straightforward.

Input-output structure

Informal trade relationships direct coltan flows from over 350 mining sites in Eastern DRC (International Peace Information Service, 2022). Hundreds of miners working on numerous mine shafts sell their coltan – often on the spot – to dozens of traders, who function as buying and transporting agents for distant trading houses and exporters (Propositions 1a, 1d, 1e) (Nlandu Bayekula, 2016; Wakenge, 2018). Traders aggregate coltan from multiple mines, effectively erasing traceability to the source (Proposition 1b). Intermediaries may further mix minerals before they reach traders and/or exporters (Proposition 1c) (Nlandu Bayekula, 2016). At the same time, miners and traders alike maintain close trade relationships with smugglers (Proposition 3a) (Wakenge, 2018).

Territoriality

Coltan reserves are scattered everywhere, across farms, forests, savannahs, private and public lands, and protected areas (Moyroud & Katunga, 2002). Most mining locations are remote and characterized by with significant infrastructure deficits: roads, electricity, cellular networks are limited at best (Proposition 2b) (Nlandu Bayekula, 2016). Sites are dispersed across 512,000 square kilometers (Proposition 2a) (International Peace Information Service, 2022). Poor transportation infrastructure makes it difficult for monitoring and data collection to occur. Due to deficient electricity and cellular network infrastructure, traceability systems rely on manual, paper-based processes that are inefficient and provide inadequate protection against fraud (Ojewale, 2022a).

Governance

Low coordination, informality, opacity, illegality, and corruption surround the sector (Proposition 3a and 3b). Most artisanal mines and traders are unlicensed or unregistered (Lezhnev, 2009; Ojewale, 2022a) which makes it easier for actors to lie about coltan origins and connections to conflict-ridden mines. Even at certified mines that practice bagging and tagging, traders regularly mix illegitimate coltan in with legally sourced minerals and/or utilize counterfeit bag tags (Global Witness, 2022; Ojewale, 2022a). Counterfeiting is only one of several forms of organized crime plaguing the coltan trade. Armed groups or local militias frequently control mining operations, making traceability audits dangerous and wealth-seeking government agents regularly collude with rebel leaders, as well as international businesses, to facilitate coltan smuggling (Lezhnev, 2009; Ojewale, 2022a). Widespread government collusion is symptomatic of a broader deficit in regulatory capacity (Proposition 3c).

3.5 Towards first-mile traceability

There is an urgent need for improved traceability of the first-mile to understand where and how production occurs, who is involved, what materials are traded. Our sectoral profiles demonstrate how aspects of supply chain structure, territoriality and temporality, and governance can complicate first-mile traceability and supply chain sustainability. Despite impressive advances by researchers and companies (e.g., https://insights.trase.earth/, https://www.fineprint.global/, and https://sourcemap.com/), even the newest supply chain transparency methods rarely trace resources back to their point of extraction. Nonetheless, we are confident that the first-mile problem can be addressed by applying existing and emerging technologies in conjunction with improvements to environmental governance.

3.5.1 Technologies for traceability

Table 3-1 provides a non-exhaustive list of technologies available to enhance first-mile traceability. We group the technologies into four classes by their underlying method: database, tagging, spatially-explicit monitoring, and scientific. For each method we provide a brief description, list generally applicable strengths and weaknesses, and indicate sources of interest to consult for further detail. Many of these technologies have applications across entire supply chains, but we focus on their utility for the first-mile.

Distributed ledger databases, such as blockchain, maintain a digital chain-of-custody by recording, storing, and communicating provenance information as products flow through the supply chain. This has no impact on the input-output structure or territoriality of the chain, but reliable documentation of all transactions with time stamps and locations can overcome temporality issues (Proposition 2c) and increase supply chain coordination (Proposition 3a). Moreover, the immutability and transparency of distributed ledgers make it impossible to surreptitiously contaminate supply chains with products from different locations or illicit sources (Propositions 1b, 3b). A number of actors across industries have adopted blockchain technologies to enhance product traceability, including Nestlé (coffee) and Bumble Bee Foods (tuna) (Haskell, 2022). For blockchain to address the first-mile problem, it must be implemented across the entire supply chain, including at the base, and supply chain actors must have access to telecommunications technologies.

Tagging technologies can also be used at the first-mile. For example, radio-frequency identification (RFID) tags or barcodes can be affixed to resources immediately after harvest and linked to a chain-of-custody to support evidence of provenance. Popular fast casual restaurant Chipotle has incorporated an automated, digital RFID system to trace its meat, dairy, and avocado supplies (Chipotle Mexican Grill, Inc., 2022). Other companies like Costco are working with Applied DNA Sciences to trace products using synthetic DNA tags (Swanson, 2023). Since the physical ledgers documenting the flows of labeled products can be corrupted, e.g., by duplicating a barcode and affixing it to commodities from different sources, combining tagging and database technologies can protect against supply chain leakage (Proposition 3b).

In contrast to databases and tagging, spatially-explicit monitoring does not need to interact with the supply chain. Satellite imagery can be used to identify environmental hotspots and related risks. For example, palm oil purchasers can utilize imagery to risk-rate and remove suppliers with the highest deforestation risk, or to deduce first-mile territoriality by locating (dispersed, remote) plantations that fall within 50 kilometers of their supplying mills (Propositions 2a, 2b) (Ramli et al., 2020). Other technologies, like GPS transmitters on fishing vessels, can tell where seafood is caught or identify trading partners on the high seas (Global Fishing Watch, 2022). Using GPS for first-mile traceability is only possible if vessels keep their transmitters on and if source segregation is maintained.

Sophisticated lab analysis can also zero-in on the first-mile when product attributes are unique to given geographies. In timber, the DNA fingerprints of logs can be traced to specific regions or even concessions to verify timber sources (Lowe & Cross, 2011). Elemental analysis can be used in a similar manner for minerals (Wang et al., 2016). However promising, the expertise and expense required for lab analysis often hinders scalability. Their greatest asset for first-mile traceability is their potential to catch fraud and illegal product mixing (Proposition 3b).

Table 3-1. Technologies for traceability.

	Examples	Description	Possible data source(s)	Strengths	Challenges	Suggested sources for further detail
Database	Blockchain	Product data digitally recorded	Manual inputs or automatic data collection (e.g., via digital tags)	• Immutable record • Task automation	• High cost • Immature technology • Interoperability • Lack of harmonized standards • No manual fallback if technology fails • Digital literacy	Patelli and Mandrioli, (2020); UNDP (2021)
Tagging	• Barcodes • Integrated circuit chips • QR codes • Radio frequency identification (RFID) systems	Printed or electronic tags applied to materials and "read" as they travel through the supply chain	Automatic transmission of stored data	• Ability to encode history, process, and location data • Data collection can be automated to improve effectiveness and efficiency • Enables cross-checking of products against official standards	• Costs • Counterfeiting • Lack of harmonized standards • No manual fallback if technology fails	Costa et al. (2013); Dabbene et al. (2016)
Spatially-Explicit	• Global positioning systems • Satellite monitoring • Spatiotemporal trade modeling	Production systems mapped and linked to actors and/or impacts	Satellite imagery; concession and field maps; trade data; global positioning and transmitter devices	• Accurate and timely spatial information about resource extraction and environmental impact	• Computational demands • Ground-truthing • Establishing supply chain linkages	Global Forest Watch, Global Fishing Watch, Maus & Giljum (2020), Moran et al., (2020), Satelligence, Starling, Trase

Scientific	• DNA barcoding • DNA fingerprinting • Isotope analysis • Phylogeography • Spectroscopy / chemometrics • Trace element composition	Products identified via biological and/or chemical signatures	Direct analysis of products	• Geographic origin data • Provides information on product properties (e.g., agricultural practices, diet, etc.) • Rapid, low cost options	• Resource intensive reference database • May require expensive, highly technical equipment • Difficulty differentiating between highly similar products (e.g., between individuals of the species from the same area) • Difficulty determining origin below a regional level	Badia-Melis et al. (2015); Dormontt et al. (2015); Dou et al. (2022); Gopi et al. (2019); Wang et al. (2016)

Table 3-2. A selection of stakeholder groups and aspects of the first-mile problem they are well-positioned to address.

Actors	Proposition	Example actions	
Traders	**Number of Actors** (Few ↔ Many) **Number of Stages** (Few ↔ Many)	**Palm Oil**	Implement direct sourcing strategies, favor mills tied to core estate and plasma plantations
	Raw Material Mixing (Segregated ↔ Mixed)		Segregate products by source
Lead firms	**Raw Material Mixing** (Segregated ↔ Mixed)	**Timber**	Require chain-of-custody certification through the Forest Stewardship Council
	Trade Partnerships (Stable ↔ Fluid)		Establish long-term contracts with high performing suppliers
Governments	**Remoteness** (Urban ↔ Rural)	**Coltan**	Fund infrastructure projects
	Illegality & Corruption (Low ↔ High)		Turn to rule of law in importing countries
NGOs	**Capacity** (High ↔ Low)	**Tuna**	Utilize market-based instruments like the Marine Stewardship Council; Provide technical assistance and training
	Secrecy (Less ↔ More)		Collect data in-situ via surveillance, site visits, surveys, interviews, etc.

3.5.2 Governance for first-mile traceability

Technology can only go so far in addressing the first-mile problem. First-mile traceability also rests on concerted efforts by supply chain actors. Table 3-2 identifies key actors and the aspects of the first-mile problem they are well-positioned to address.

Traders

Traders procure, process, aggregate, and export commodities, often early on in the supply chain. One way they can reduce first-mile complexity and length (Propositions 1a and 1c) is by prioritizing direct sourcing channels to eliminate intermediaries. For example, palm oil traders can purchase directly from mills tied to core estates or plasma plantations.

As they purchase commodities from multiple suppliers – introducing opportunities for product mixing (Proposition 1b) – traders have a critical role in maintaining source segmentation to bridge traceability up and down the supply chain. Traders must maintain consistent systems for source segmentation with robust (ideally incorruptible) chain-of-custody systems. These systems should be audited by NGOs or other third parties.

Traders who handle multiple commodity types may be uniquely positioned to bridge commodity-specific working groups and share insights, lessons learned, and best-practices related to addressing these and other aspects of the first-mile problem across sectors (Grabs & Carodenuto, 2021).

Transnational corporations

Transnationals coordinate production which gives them critical power in shaping the input-output structure, territoriality, and governance of their supply chains (Yeung & Coe, 2015). While they seldom handle procurement directly, they can dictate sourcing strategies to their suppliers. For example, as major firms like IKEA, Home Depot and Walmart source timber, they can require chain-of-custody certification – and consequently product segregation – through organizations like the Forest Stewardship Council (Proposition 1b). Transnationals can also establish long-term contracts with their suppliers to reduce supplier fluidity (Proposition 1e). In some situations, they may benefit from risk-rating suppliers before awarding contracts (Proposition 3b). In the context of the timber vignette, logging companies could be screened for the percentage of timber: harvested using sanitary logging licenses; harvested from conservation forests; and sourced from other companies (Newell, 2008).

Tighter supply chain coordination can also include vertical integration up to and including the first-mile (Proposition 3a). Intel and Motorola established “closed-pipe” sourcing systems to enable traceability from conflict-free coltan mines to their end products (Taka, 2016; Young et al., 2019). Nestlé's direct engagement with cocoa farmers shows how this could work in the agricultural sector (Nestlé, 2023).

Governments

Governments in importing countries can promote first-mile traceability by establishing binding, legally enforceable supply chain due diligence legislation. The aforementioned EU Supply Chain Regulation and other emerging laws provide a start (Campbell, 2022; DEFRA, 2021; European Commission, 2022; European Commission, Directorate-General for Justice and Consumers, 2022; FOREST Act of 2021; Leisering, 2022; Norton et al., 2014). Legislation should be expanded to address critical shortcomings to the current, bespoke nature of corporate traceability systems (WEF, 2019) as select pockets of traceability introduce risks that undermine potential benefits (Gardner et al., 2019; Garrett et al., 2021; Lambin et al., 2018). Regulation that establishes wide sweeping first-mile traceability that covers whole supply chains is needed to avoid unscrupulous actors simply taking their business elsewhere.

At the same time, nation-states are key players for setting and enforcing international treaties, like the UN Law of the Seas and the Agreement on Port State Measures. Establishing a transshipment ban could be one way to help with first-mile traceability (Propositions 1b, 1e, and 3b).

Governments can also promote first-mile traceability within their borders. Investment in improved telecommunications and road infrastructure can support traceability technologies and monitoring (Proposition 2b). Availability of these technologies can undergird legislation requiring first-mile traceability. State enforcement and capacity building (e.g., training smallholders to use digital ledgers) (Propositions 3b, 3c, and 3d) will increase the impact of this legislation.

By providing publicly available digital land registries, governments could reveal where resources are extracted and by whom, aiding both traceability and accountability. Relatedly, governments could use their authority to grant land titles to legitimize and bring illicit activities out of the black-market. When local governmental capacity is limited or corruption endemic, such as in the DRC, third-party support may be needed.

NGOs

NGOs often provide capacity and reduce secrecy in supply chains (Proposition 3c and 3d). For example, organizations like Greenpeace, Environmental Investigation Agency, and Earthsight have successfully overcome supply chain secrecy to reveal where and how production happens in global supply chains (Earthsight, 2021; EIA, 2013; Greenpeace International, 2022). For example, a 2022 Greenpeace expose on the tuna sector revealed corporate connections to IUU fishing and forced labor (Greenpeace International, 2022). By exposing corporate connections to environmental and social concerns NGOs both draw significant attention to the need for first-mile traceability and show that it is possible even under adverse conditions. Brand-activism campaigns by NGOs also have the potential to nudge corporations, and even entire sectors, to change (Klooster, 2005, 2006).

When regulatory capacity is limited, NGOs often orchestrate sustainability via multi-stakeholder initiatives (e.g., the Marine Stewardship Council, Forest Stewardship Council, Roundtable on Sustainable Palm Oil) (Proposition 3c). NGOs can use their power to lobby for first-mile traceability as a standard or even precondition for membership.

NGOs may also spearhead and organize extension services to expand the knowledge and expertise of producers, regulators, and other stakeholders (Proposition 3c). For example, in the tuna sector, Trygg Mat Tracking provides technical assistance to expand satellite tracking capacity and Global Fishing Watch offers an open-access online platform for monitoring commercial fishing activity (Copeland, 2022). Importantly, public goods models for technologies that collect and share data on the first-mile, may increase their effectiveness as supply chain governance tools (Gallemore et al., 2022).

Academics

Although not directly engaged in supply chains, scholars can still advance first-mile traceability. Blockchain, chemical analysis, and other traceability aids emerged from university labs and research projects before spilling over to industry. Academics can continue developing technologies and identifying when and where they are most effective for first-mile traceability.

In recent decades, academics have developed multiple theoretical lenses for analyzing supply chains (Coe et al., 2008; Coe & Yeung, 2019; Gereffi, 1994). This paper represents a first attempt to apply these to the first-mile problem. Future empirical work could test our propositions, develop new theories, or apply alternative lenses to uncover the antecedents, processes, and environments that affect first-mile traceability.

Lastly, academics can tackle thorny questions of justice in first-mile traceability. Direct sourcing or vertical integration increases traceability by excluding informal small-scale producers, thereby concentrating corporate power and further marginalizing these groups (Gardner et al., 2019). Stringent traceability standards can also ruin the livelihoods of smallholders lacking capacity to meet these standards (Lambin et al., 2018). The fact that women make up a disproportionate percentage of smallholders globally raises further issues of gender equity (Kizu et al., 2019). Researchers should collaborate with companies to explore these unintended consequences of first-mile traceability and develop mitigation strategies.

3.6 Conclusion

The first-mile problem has long been a dirty secret of global supply chains. We argue that accelerating environmental collapse, widespread social injustices, and increasing scrutiny of corporate practices make it impossible to ignore the consequences of not knowing where, when, and how nature enters the global economy. Our 14 propositions pinpoint key attributes of supply chain structure, territoriality and temporality, and governance that influence first-mile traceability. As demonstrated in our sectoral profiles, the first-mile problem is complex and multi-dimensional. Nevertheless, the emergence of technologies to robustly track the first-mile and a growing number of supply chain transparency laws provide both the means and impetus for overcoming this formidable challenge. Producers, NGOs, governments, traders, academics, and other stakeholders all have roles to play in realizing equitable and just first-mile traceability. Given current business, legislative, consumer, and investment trends, we anticipate that such radical traceability will become the new normal.

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Theorizing Certification-Driven Supply Chain Embeddedness [5]

4.1 Abstract

While theory suggests that policy instruments, such as certification schemes, foster embeddedness, or durable and stable relationships between trade network actors, little research exists on how this embeddedness actually forms over time and across space. This paper therefore takes an abductive approach, combining quantitative and qualitative data on the Guatemala-Mexico palm oil trade network (2011-2020), to examine sustainability certification as an unexplored driver of embeddedness. We introduce and apply a method that draws on graph theory and trade statistics to empirically measure embeddedness between trade network actors, and then perform a thematic analysis of company reports to gain further insight into the certification-embeddedness dynamic. Results indicate that certification indeed fosters more durable and stable trade network relationships between actors, and that dialectal certification-embeddedness interactions mutually reinforce one another. This provides evidence that quality conventions established through certification schemes do shape trade network input-output structure. Informed by this case study, we present a conceptual model of certification-driven embeddedness, advancing embeddedness theory as we link changes to the organizational structure of companies within a trade network to the quality conventions set by a prominent sustainability certification system. Whether embeddedness-fostered certification actually fosters better environmental governance needs further study. Future research is necessary to research the

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impacts of certification-driven embeddedness on network trust, transparency, and investment between actors, as well as opportunism and risk. The measurement of embeddedness using network analysis should be of broad interest to those scholars working on the structural, geographical, and governance configurations of trade networks and commodity flows.

4.2 Introduction

Economic activity often embeds in particular geographies and actor networks. Supply chain management (SCM) scholars have primarily focused on the outcomes of this embeddedness by researching how an actor's dyadic relationships and network position influence its business decisions and performance (Choi & Kim, 2008; Gulati & Sytch, 2007; Kim et al., 2015; Skilton et al., 2020; Uzzi, 1996, 1997). However, little research exists on what contributes to the accretion of company embeddedness over time and across space (Reis et al., 2023). Scholars have generally neglected to study embeddedness itself as an outcome and, have relatedly, underappreciated its durability and stability dimensions. This raises important questions regarding what contributes to embeddedness with implications for moderating supply chain impacts and designing related interventions.

In this article, we examine sustainability certification as an unexplored driver of embeddedness – here understood as the relational and structural durability and stability of a company's relational and structural positioning in a trade network (Hess, 2004). In an era of increasing private supply chain governance via sustainability certification schemes, it is critical to understand the extent to which they are effective governance tools (Lambin & Thorlakson, 2018; MSI Integrity, 2017; Thorlakson et al., 2018). We argue that meaningful certification outcomes not only include a reduction in the environmental and social impacts of production, but also a reshaping of markets around common sustainability goals. Moreover, the two may go hand-in-hand as certification (re)configures trade networks by selectively encouraging buyers to leave, create, or maintain supplier relationships and thereby influences what production practices persist. For example, if certification indeed contributes to embeddedness, it could cement more sustainable production practices in the supply chain. Yet, if certification is unreliable, embeddedness may conversely entrench green- or social wash. Both dimensions are critical to understand, however research to date has prioritized whether certification reduces production impacts across a range of sectors (Bakker et al., 2019). In this paper, we present a method to assess whether certification fosters embeddedness – more durable and stable trade relationships.

Given that certification establishes a convention, or socially constructed norm for product quality that guides actor decision-making and behavior, we would indeed expect certification to promote actor embeddedness in particular trade networks (Ponte & Sturgeon, 2014). As these quality concerns inform buyer-supplier coordination, they may come to articulate, judge, and manage broader supply chains, sectors, and markets over time. We explore this hypothesis by asking: Do certification standards explain differences in embeddedness among companies in a trade network over time? In doing so, we identify unexplored links between convention and embeddedness theories and make important contributions to embeddedness theory with a conceptual model of certification-driven embeddedness. We also establish a methodological approach for initiating future lines of inquiry into the sustainability consequences of certification-driven embeddedness.

To assess how certification interacts with embeddedness, this paper uses an abductive approach, in which data and theory inform insights in parallel (Alvesson & Kärreman, 2007; Gioia et al., 2013). We start with a longitudinal case study of palm oil traded between Guatemala and Mexico to capture the world's most produced and consumed vegetable oil (FAOSTAT,

2020) in the context of the world's fastest-growing – but widely understudied – palm oil producing region (Tropical Forest Alliance, 2019). By 2030, Guatemala is projected to become the world's third largest palm oil producer-country. Mexico is Guatemala's strongest historical palm oil trade partner (Figure B-1) and offers the most robust trade data for modeling.

The prevalence of Roundtable on Sustainable Palm Oil (RSPO) certified palm oil production in Guatemala – the leading Latin American producer of RSPO-certified palm oil – also presents an opportunity to study the influence an important commodity certification system has on embeddedness (GREPALMA, 2020). The RSPO, a multi-stakeholder initiative founded in 2004, seeks to "transform markets to make sustainable palm oil the norm" with a two-pronged certification system that: (1) minimizes the impacts of palm oil production through standardized Principles & Criteria (P&C); and (2) controls the trade of RSPO certified products through the Supply Chain Certification Standard (SCCS). It is the only global sustainability standard in the edible oil sector (Bennett, 2017; Pacheco et al., 2020; RSPO, 2020b).

By conforming to the P&C, RSPO-certified growers ostensibly curb the environmental and social impacts typically associated with production (RSPO, 2020a). In comparison, the SCCS seeks to ensure the credibility of RSPO-based sustainability claims as RSPO-certified palm oil products are traded among supply chain actors (RSPO, 2022). While existing studies focus on RSPO-certified production (Bishop & Carlson, 2022; Carlson et al., 2018; Cattau et al., 2016; Gatti et al., 2019; Johnson, 2014; Morgans et al., 2018; Noojipady et al., 2017), reporting mixed results on the system's ability to minimize impact environmental damage and social injustice, little work has been done on RSPO supply chains (Nupueng et al., 2022). Minimal research has been conducted on the ability of the RSPO SCCS to meaningfully reconfigure trade relationships to "transform markets." Certification systems like the RSPO can alter trade networks by selectively encouraging actors to leave, create, or maintain trade relationships. When they effectively reduce production impacts, this has implications for what production practices persist in the supply chain. Moreover, with ongoing debate surrounding the RSPO's effectiveness at reducing production-related impacts, it is critical to understand the extent to which certification may be stabilizing the trade of green- and social-washed products.

To assess the effect of RSPO on embeddedness, we apply network metrics to quantify and compare the embeddedness of RSPO-certified and non-certified companies in the Guatemala-Mexico palm oil trade network. Our results support our hypothesis: RSPO membership correlates with greater embeddedness. To understand what fosters this, we perform a thematic analysis (Braun & Clarke, 2006) of company reports detailing their engagement with RSPO certification. These data reveal a dialectal interaction between certification and embeddedness that suggests mutually reinforcing processes. With this mixed-methods approach, we advance embeddedness theory as we link changes to the organizational structure of a trade network to the quality conventions set by a prominent sustainability certification system.

The structure of this article is as follows. We first review the literature on embeddedness and convention theory before introducing our research methods. Then, we apply our mixed-method approach to compare and explore patterns of embeddedness between RSPO-certified and non-certified companies. Next, we present our results and discuss their implications. To conclude, we extend our discussion by proposing further research opportunities at the intersection of certification and embeddedness' potential bright and dark sides.

4.3 Theoretical background and motivations

SCM scholars have developed a rich literature on embeddedness that explores how embeddedness impacts business decisions and performance outcomes. However, few have investigated embeddedness itself as an outcome. Understanding whether certification in particular contributes to more durable and stable trade relationships has important implications for moderating supply chain impacts and designing better interventions. Below, we provide an overview of the SCM literature on embeddedness; elaborate on the literature grounding our theoretical and methodological focus on its durability and stability dimensions; and discuss how certification provides an opportunity to explore understudied linkages between embeddedness and convention theory.

4.3.1 Embeddedness in supply chain management

Embeddedness generally refers to the interconnectedness of economic activity and socialized networks of knowledge, norms, and institutions. While initially introduced by Polanyi (1944) to describe the social structure of contemporary markets, it was not until Granovetter (1985) advanced the concept toward more concrete, analytical scales of actors and their social networks that a broader body of embeddedness literature formed. Importantly, Granovetter (1985) emphasizes how economic decisions and outcomes are influenced by both the embedded actor's dyadic relationships with other actors (e.g., individual buyer-supplier linkages) and their existence within an overall structure of networked relationships (e.g., entire supply networks). Moreover, his theory of embeddedness distinguished between network configuration (i.e., structural embeddedness) and relationship quality (i.e., relational embeddedness) (Granovetter, 1985, 1992). Embeddedness has since been studied across a range of fields including sociology (e.g., Uzzi, 1996, 1997), economics (e.g., Bathelt & Glückler, 2018; Beckert, 2003), geography (e.g., Hess, 2004; Hess & Coe, 2006), and organizational, business and management studies (e.g., Gulati, 1998; Moran, 2005; Rowley et al., 2000). Additional literature on supply chain knowledge, norms, or institutions may similarly apply embeddedness, albeit in different terms.

Structural embeddedness draws attention to the impersonal position a focal company holds in a network as a result of its direct and indirect connections to other companies (Gulati, 1998; Moran, 2005; Nahapiet & Ghoshal, 1998). A longitudinal view of structural embeddedness has similarities with buyer-seller interaction frequency (Marsden & Campbell, 1984), duration and durability (Dyer et al., 1998), stability (Gadde & Mattsson, 1987), and stickiness (dos Reis et al., 2020), as found in other literatures. In contrast, relational embeddedness distinguishes the strength of both the direct and indirect personal relations a focal company has developed with others over time (Gulati, 1998; Moran, 2005; Nahapiet & Ghoshal, 1998). The relational postures and intensities between companies may be deep, sticky, transient, or gracious (Kim et al., 2015). Relational aspects of embeddedness relate to other interaction-based buyer-seller concepts like: trust (Gulati, 1995), commitment (Larson, 1992), and information sharing (Rowley et al., 2000). While the literature has paid more attention to structural rather than relational embeddedness (Moran, 2005), both are of primary interest given their potential impacts on supply chain performance.

Embeddedness in either form has typically been studied as a de facto characteristic of a trade network with scholarly efforts focused on understanding how company embeddedness benefits or hinders economic decisions, behaviors, and performance (Autry & Griffis, 2008; Borgatti & Li, 2009). Both forms of embeddedness may: engender improvements in cost, quality, delivery, and flexibility (Krause et al., 2007); allow actors to accrue informational, reputational, and social to mitigate collaboration risks (Polidoro et al., 2011); decrease transaction costs or improve strategic positioning (Gulati & Sytch, 2007); develop relationships founded in trust and coordination (Gulati & Singh, 1998; Uzzi, 1996); improve knowledge transfer and learning (Rowley et al., 2000; Uzzi, 1996); reduce monitoring costs (Hagedoorn &

Frankort, 2008); and increase innovation (Bellamy et al., 2014). Yet, structural and relational embeddedness may become a liability (Sting et al., 2019; Villena et al., 2011, 2021) by fostering opportunistic behaviors and malfeasance (Ratajczak-Mrozek, 2017), or even unholy alliances of buyer-supplier collusion to avoid sanctions for harmful or even illicit practices (Bird & Soundararajan, 2019).

4.3.2 New embeddedness perspectives and methods

Here we emphasize embeddedness in a different way, adopting a temporal understanding of both structural and relational embeddedness to accentuate that embeddedness is not so much a single snapshot in time but rather a state *maintained* over time. We elaborate on embeddedness as both relational and structural *durability* and *stability* (i.e., the temporal endurance of company connections and position in a network) based on its conceptualization in economic geography (Hess, 2004). The durability and stability of individual actors in a given network captures relational aspects of embeddedness, while the durability and stability of the structure of the network as a whole captures structural aspects of embeddedness (Hess, 2004). This differs from traditional SCM views of embeddedness as relational and structural positionality – i.e., the performance dependency of a company on its direct and indirect partners within a network architecture (Choi & Kim, 2008). This perspective is important because it facilitates an investigation into what contributes to embeddedness over time.

Much of the SCM literature on embeddedness relies on case study methods. Although this has generated numerous critical theoretical and managerial insights, the approach faces fundamental limitations due to the challenge of tracking the same set of companies and their supply networks across time (Park et al., 2018). For example, Sting et al. (2019) reveal how the frequency, duration, and intensity of changes to embeddedness affect supply chain performance, but the study is limited to one buyer-supplier relationship. Others, such as Pathak et al. (2014), have advanced a temporal aspect in the literature by theorizing how relational changes among individual companies may lead to structural changes in a network over time. But they do not specify how to empirically test their theory.

Scholars have used archival data to conduct large-scale empirical studies and cross-sectional analyses of supply networks, yet most have paid limited attention to structural dynamics (Bellamy et al., 2014; Park et al., 2018). For example, Gulati and Gargiulo (1999) explicitly quantified multiple dimensions of embeddedness (including relational and structural) in their longitudinal study on alliance formation as they captured whether a connection exists in a given year. Kim and Henderson (2015) similarly applied measures of dependence to assess relational and structural embeddedness' influence on various outcomes across time; likewise using annualized data. These and other similar studies have shown how embeddedness tends to improve network operations, performance, and optimization potential. However, they fall short of tracking critical temporally-bound durability and stability dimensions of embeddedness.

Novel metrics from network theory, that build off existing analysis in SCM, are well-suited to address this gap. However, a scan of the SCM literature shows that network analysis has not been applied in this way. Borgatti and Li (2009) present key network analysis concepts for supply chain researchers to assess company dependency on direct and indirect network partners, including: various measures of centrality, structural holes, and equivalence. Kim et al. (2011) apply degree, closeness, and betweenness centrality metrics to measure various supply network constructs (supply load, demand load, operational criticality, influential scope, informational independence, and relational mediation) that shape individual node embeddedness in a network. Many other researchers have since likewise applied various centrality measures to capture embeddedness (Han et al., 2020). For example, Carnovale et al. (2017) use eigenvector centrality to assess the role of embeddedness on joint venture formations and Skilton et al. (2020) apply degree, two-step reach, and beta centrality metrics to evaluate cooperative embeddedness' influences on product development strategies. These existing embeddedness measures provide important insights on the correlation between company importance, network connectivity, and many behavioral, economic, and performance outcomes. In general, the focus has been on centrality, which indicates company importance from connectivity to other network actors (e.g., the number and length of paths connected to a focal company), but little on network durability and stability.

Outside the SCM literature, dos Reis et al. (2020; 2023) quantify durability and stability dimensions of supply chain patterns as "stickiness." They define two metrics to separately track biannual changes to company connections ("temporal correlation coefficients") and to volume traded ("weighted persistence indices"). We propose the application of a network graphing technique that likewise captures durability and stability dimensions of embeddedness in terms of who and how much an individual company trades with over time, incrementally advancing incipient research using a composite metric that captures and compares all network time steps. With this approach, we address a second critical research gap as we demonstrate the metric's utility for examining certification as a potential driver of embeddedness.

Heeding Tokar and Swink's (2019) call for scholars to examine how the regulatory environment surrounding a supply chain influences and constrains its shape and operations, we scope our study to focus on whether and how certification systems from multi-stakeholder initiatives (MSIs) drive embeddedness. MSIs are voluntary rule-systems for addressing social and/or environmental issues that are collectively governed by stakeholders representing profit/nonprofit and state/nonstate entities (Bakker et al., 2019). In an effort to manage increasingly complex supply chains and growing environmental and social demands from stakeholders, thousands of companies across more than 170 countries are joining MSIs to govern their extended supply chains (MSI Integrity, 2017; Thorlakson et al., 2018). While some MSIs are created around certification systems (e.g., the Roundtable on Sustainable Palm Oil), others promote broader business principles without verification (e.g., the UN Global Compact). This paper focuses on the former.

Convention theory and certification

We turn to convention theory to guide our inquiry into certification as a possible contributing factor of embeddedness. One might hypothesize that certification and other policies would promote embeddedness due to shared concerns about quality among companies in the supply network. Principles central to convention theory suggest such: coordination between actors takes place as the product of accepting mutually agreed-upon definitions of quality that come to articulate, coordinate, and manage markets over time (Ponte, 2016). While multiple types of quality conventions are used to normatively evaluate objects, processes, and actions, environmental certification systems tend to incorporate civic and industrial conventions to communicate quality (Ponte & Sturgeon, 2014). Civic conventions grant importance to goods in terms of their general societal benefits while industrial conventions value goods according to their performance against technical standards (Ponte, 2016).

When quality is established through certification, an independent, third-party certifier or certification body assesses a system, process, service, or product against a set of predetermined standards and provides written assurance of conformity (Rametsteiner & Simula, 2003). For example, organic certification requires practices that maintain or enhance soil and water quality, while simultaneously protecting wetlands, forests, and wildlife (Organic Produce Network, 2017). Certification systems, which may be voluntary (e.g., organic) or mandatory (e.g., Food and Drug Administration approval in the U.S.), are becoming key tools of governance across global supply networks for major industries. Examples include the organic certification of agriculture; Fair Trade certification of products such as coffee, chocolate, and bananas; Marine Stewardship Council certification of seafood; Forest Stewardship Council certification of timber products; roundtables on sustainable soy, beef, and palm; and certifications guaranteeing the provenance of specialty wines, olive oil, and cheese.

Regardless of their focus, certification institutions include guiding principles that assert particular expectations (i.e., quality conventions) for products, actions, goals, and intentions involved in production, distribution, and consumption (Diaz-Bone, 2016). Over time, markets come to embrace particular criteria that qualify goods for trade, serve as prerequisites for trade partnerships, and subsequently inform trade coordination and management (Ponte, 2016). They can thus promote, and limit, which partners an economic actor chooses to engage with. In this sense, convention theory interfaces with embeddedness, enriching its theory by identifying a mechanism that purportedly engenders it.

4.4 Methods

To test our hypothesis of whether certification standards can explain differences in embeddedness, we first quantify company embeddedness by applying network metrics to thousands of transaction-level customs records of individual palm oil shipments. Then, we construct an empirical model to estimate and compare the average embeddedness of RSPO-certified companies and non-certified companies. Finally, we conduct a thematic analysis to further elaborate how certification influences trade partnership decisions. This abductive approach puts our data in conversation with extant theory (Alvesson & Kärreman, 2007).

4.4.1 Data and analysis

Trade data

The dataset of transaction-level customs records, provided by Panjiva, covers the period from January 2011 to March 2020 (Panjiva, 2021). We selected this time period to capture all available data leading up to COVID-19 pandemic and related trade disruptions. The dataset includes the names of importing and exporting companies (specifically, strategic business units; including larger producers, manufacturers, traders, wholesalers, and transportation agents), shipment mass, shipment value, product description, and Harmonized System (HS) code. HS codes are established by the United Nations (UN) to ensure that countries consistently classify products when they calculate tariffs, document trade, and monitor trade agreements. We identified transactions of interest by searching for records labeled with any of three HS codes specific to palm oil and its primary derivatives: 1511.10 (palm oil, crude); 1511.90 (palm oil or fractions, simply refined); and 1513.21 (palm kernel or babassu oil, crude). While palm oil may be shipped under other codes, we found the three selected codes consistently captured nearly all (~98 percent) of the trade originating in Guatemala (UNSD, 2022). Although occasionally mislabeled HS codes can produce discrepancies between customs records and UN trade statistics, we found 88% congruence between the Panjiva and authoritative UN data suggesting high confidence in the customs data. Our final dataset included 20,650 records.

After generating summary statistics (e.g., annual shipments, annual shipment weights, number of exporters, number of importers, etc.), we refined the dataset in preparation for the next stages of analysis: quantifying embeddedness and assessing the relationship between embeddedness and certification. We excluded companies that went defunct over the course of the study period. The vast majority of companies in our dataset were certified prior to 2011 preventing us from performing a difference-in-differences or coarsened exact matching approach to assessing the relationship between embeddedness and certification. Only seven companies were certified between 2011 and 2020 and of those, three were certified in 2012, one in 2014, one in 2016, and two in 2020. These companies were excluded from the model. We only included those companies (50 total) with constant status (either RSPO-certified or non-certified) across the entire study period.

We included data from several other sources: the RSPO membership database – to cross-reference company names and classify their certification year and status; D&B Hoovers, Mergent Intellect, Mergent Online – to determine company size; and D&B Hoovers, EMIS, individual company websites, and NGO reports (Yagenova, 2019) – to identify company age.

Degree of embeddedness

We calculated the dynamic network scores (D_n-scores) of firms involved in the Guatemalan-Mexican palm oil supply network to (1) quantify embeddedness as the stability and durability of company-company connections in a trade network; and (2) explore the effects of RSPO membership on embeddedness. Using the DyNet application (Goenawan et al., 2016) in the open-source software Cytoscape (Shannon et al., 2003), we were able to measure embeddedness and visualize temporal changes to the trade network's overall structure. Although D_n-scores were originally developed for use in network biology (Goenawan et al., 2016), they offer a powerful means to visualize and analyze any type of dynamic network data – including trade relationships.

In the context of this study, we define D_n-score as a measure of the durability and stability of a given firm's position in a trade network, as a factor of temporal changes (variance) in both its connections (e.g., who it trades with) and its connecting edge weights (e.g., how much it trades). It is calculated by extending the standard weighted node adjacency matrix typically used to model networks with a third dimension (S) to describe the state-space, i.e., $\mathcal{M}(P,Q,S)$. Following this model, the D_n-score of a firm is based on the variance of its corresponding row across the various network states relative to the mean (centroid, *c*), where the base dissimilarity measure (*d*) is the Euclidean distance and the vector x_i represents the neighborhood $\mathcal{M}(p,Q,s_i)$ after standardization (see Goenawan et al., 2016 for further details). The D_n-score is therefore defined as:

$$Dn(Firm\ X) = \frac{\sum_{i=1}^{S} d(x_i, c)}{S - 1}$$

In the most general of terms, D_n-scores quantify the reorganization of firm trade linkages over time. A higher D_n-scores indicates a given firm traded more consistently – both in the number of connections it made with other companies and the volume it traded with them – over time.

To capture changes to company-company relationships between 2011 and 2020 in D_n-scores, we entered transaction data (aggregated monthly) into the DyNet App by defining "to" (importers) and "from" (exporters) nodes and "edge weight" (shipment mass). We interpreted resulting D_n-scores as embeddedness with higher Dn-scores signifying stronger embeddedness and greater importance to the network in terms of the amount and intensity of trade interactions over time. We also visualized changes in trade in relation to the entire network to track and visually compare company positioning among multiple network states (i.e., months).

Control Variables

e added control variables to our empirical model to account for covariates that may affect a company's embeddedness or RSPO membership. Larger companies have more resources, financial and otherwise, to invest in trade relationships and to use to control against trade volatility which may influence embeddedness. At the same time, larger companies are also thus better equipped to handle the cost and complexity of certification. We controlled for company size using the natural logarithm of sales (to reduce the skewness of the distribution). We controlled for company age as the number of years since they were founded as of 2023. Older companies may accumulate legacy relationships that contribute to a more stable network structure. In comparison, younger companies may have more freedom and flexibility in constructing their supply chain partnerships. We also included a dummy variable for the New York Declaration on Forests. Adopted in 2014, the Declaration brought commodity-driven deforestation issues to the global stage and increased scrutiny on palm oil production (Forest Declaration, 2022). As such, it may affect a company’s preference for RSPO-certified trade partners. Finally, we accounted for time as the different years of the study.

Model Specification

To test for a relationship between embeddedness and certification we estimated a linear mixed effects model using company-level panel data covering the years 2011 through 2019 because it was most appropriate for reconciling both repeated data (e.g., Dn-Score over multiple years) and fixed data (e.g., year the company was founded, which stays the same year-to-year). Our empirical model is as follows:

$$DnScore_{ij} = B_0 + B_{0i} + B_1 RSPO_i + B_2 year_{ij} + B_3 Age_i + B_4 log(Sales)_i + B_5 NYDF_{ij} + \varepsilon_{ij}$$

$$B_{0i} \sim N\left(0,_I^2\right), \; \varepsilon_{ij} \sim N\left(0,_\varepsilon^2\right)$$

Where $DnScore_{ij}$ is the embeddedness of firm *i* at observation (trade) *j*; $RSPO_i$ is a dummy variable indicating the certification status of firm *i*; $year_{ij}$ the calendar year when the *j*th observation was made for firm *i*; Age_{ij} is a time-constant variable for the natural logarithm of the year firm *i* was founded; $Sales_{ij}$ is a time-constant variable for firm size proxied by the natural logarithm of sales; and $NYDF_{ij}$ is a dummy variable indicating whether the New York Declaration on Forests was in effect for firm *i* when the *j*th observation was taken.

Thematic analysis

We employed a recursive thematic analysis approach adapted from Braun and Clarke (2006) to identify, analyze, and report patterns of meaning within Annual Communication of Progress (ACOP) company reports submitted to the RSPO. All ordinary RSPO members (i.e., entities directly involved the annual purchase, use or trade of over 500 metric tons of palm oil) and affiliate RSPO members (i.e., individuals or organizations indirectly involved in the palm oil supply chain) that have been members for at least a year are required to submit ACOP reports. These reports document member activities, experiences, and obstacles with respect to their support for the RSPO-certified palm oil market. Following Gallemore et al. (2018), we utilized these reports as an alternative to survey data, which is often challenged by low response rates. The RSPO annually compiles responses by member category (e.g., oil palm producers, palm oil processors and/or traders, consumer goods manufacturers, retailers, banks/investors, environmental/nature conservation NGOs, and social/developmental NGOs) and makes the data publicly available on its website.

We collected 2,895 reports prepared by processors and traders (i.e., the group that most closely aligns with the companies studied in our network analysis) between the 2015 through 2019 submission cycles (consistent data is not available for earlier years). To identify patterns of RSPO-influence on traders' supplier relationships, we filtered reports for those mentioning supplier relationships in open-ended questions concerning company activities to support certification and the uptake of RSPO-certified palm oil. This narrowed our sample to 516.

After importing this data into the Atlas.ti qualitative data analysis software (Muhr, 1998), we followed the six steps of thematic analysis (Braun and Clark, 2006). After familiarizing ourselves with the data (Step 1), we coded interesting features of the data, sentence by sentence, in vivo (Step 2). We then collated codes into potential themes that we iteratively reviewed and refined (Steps 3 and 4). In Step 5, we solidified, defined and named these themes. For example, after identifying the quote, "We will also continue to source only from supply chain certified suppliers and require such documentation as evidence of their compliance" in Step 2, we ultimately coded it under a common *certification requirement* theme in Step 5. To conclude the analysis (Step 6), we related our findings back to the research question and literature to produce a final analytical report. This stage also included selected compelling examples for each theme.

4.5 Results

Our analysis of ~20,000 individual shipments of palm oil from Guatemala to Mexico utilizes data on shipment volume and trade relationships to calculate and compare average D_n-score averages between RSPO-certified and non-certified companies. We find that: companies traded 1.5 billion tons of palm oil and palm oil derivatives between January 2011 and March 2020; the share of shipments by RSPO-certified companies is growing; and RSPO status positively correlates with higher D_n-scores. On average, RSPO-certification increases Dn-score by 0.39 points (95% CI: 0.16, 0.61) resulting in average scores of 0.79 and 0.40 for RSPO-certified and non-certified companies, respectively. These findings suggest that RSPO certification contributes to company embeddedness. Thematic analysis contextualizes the certification-embeddedness dialectic and reveals multiple ways that certification contributes to embeddedness while also suggesting how embeddedness may promote certification.

4.5.1 Trends in Guatemalan-Mexican Palm Oil Trade

Guatemala is a stable and significant exporter of RSPO-certified palm oil to Mexico. Annual exports average 168,000 tons from 2011 to 2019, ranging from 95,000 (2013) tons to 231,000 tons (2016) (standard deviation of 43,000 tons). RSPO-certified palm oil averages 70% of exports (by mass fraction), which is above the national production average (44%) (GREPALMA, 2020). RSPO-certified exports drop from 90% in 2011 to 18% in 2014 (due to low prices; Butler, 2013), but then rebound to 88% by 2017 (Table 4-1; Figure B-2).

Table 4-1. Trade Statistics for the Guatemala-Mexico Palm Oil Supply Chain, 2011-2020.
Considerable temporal fluidity exists in terms of exporters and importers. Firms trading one year did not necessary trade the next year. Source: (Panjiva, 2021)

	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
# of Exporting Firms	13	11	13	17	16	15	19	14	13
RSPO-certified	*7*	*5*	*6*	*9*	*8*	*8*	*9*	*8*	*8*
# of Importing Firms	9	9	11	12	13	13	15	12	18
RSPO-certified	*6*	*5*	*6*	*8*	*7*	*7*	*10*	*6*	*8*
# of Shipments	2,286	1,753	1,050	1,678	2,391	3,857	3,599	2,015	1,637
*RSPO-certified**	*1,986*	*1,557*	*225*	*118*	*548*	*834*	*3,427*	*1,955*	*1,582*
Shipment Weight (1,000 tons)	175.4	146.7	94.7	116.2	170.4	231.2	208.7	168.1	197.9
*RSPO-certified**	*158.0*	*135.5*	*35.8*	*15.9*	*32.4*	*49.3*	*146.4*	*142.6*	*173.6*
*% RSPO-certified**	*(90%)*	*(92%)*	*(38%)*	*(14%)*	*(19%)*	*(21%)*	*(70%)*	*(85%)*	*(88%)*

**Based on palm oil exporters*

Supply network membership varies, both in the number of companies and company identity, with 42 different exporters and 34 different importers active between 2011 and March 2020 (Figure 4-1 and Table 4-1). While the network grew overall, membership fluctuated as companies left and (re)joined the network. Companies were not all simultaneously active. Only a subset are present in each monthly network snapshot (Figure 4-1). On average, 15 exporters traded with 12 importers each year. Comparing company identity and shipment volume suggests that sector growth is driven by the entry of new companies, rather than the expansion of existing businesses.

Data indicate that no single company consistently dominates the Guatemalan-Mexican palm oil trade network. Instead, a rotating set of “major” importers and exporters (here defined by their collective direction of the top ~90 percent of trade flows by mass each year) vary their trade volume across individual years while remaining anchored in the trade network (Figure 4-2 and Figure B-3). The top five traders by weight often differ annually. Companies with “major” importer or exporter status for at least one year tend to remain within the trade network. This aligns with past research that has identified a relationship between network structure and actor size (Bernard & Wagner, 2001). For example, we observe that Santa Rosa S.A. (RSPO-certified) leads exports in 2011 and 2012, drops to a lesser status between 2013 and 2016, and again rises to importance from 2017 onwards. Pasternak Baum & Co (RSPO-certified) is a “top 5” exporter from 2011 to 2014, drops in ranking between 2015 and 2017, but regains importance in 2018 and 2019. Among importers, Cargill (RSPO-certified), AAK (RSPO-certified), Fab Jabon Corona S.A. C.V., and Industrializadora Oleofinos S.A. De C.V. (RSPO-certified) trade large volumes consistently (e.g., are in the “top 5”) throughout the study period.

Among the palm oil exporters in our dataset, 20 are RSPO-certified and 22 are non-certified. Of the 34 different importers, 13 are RSPO-certified and 21 are not. The top importer is RSPO-certified every year (2011-2019). However, this is not the case among exporters: from 2013 to 2016 the top exporter is not RSPO-certified.

Each year includes unique exporter-importer pairings. Dyads including RSPO-certified exporters and/or importers (i.e., where one or both trade partners is certified) trade more intensely, in terms of both frequency and volume. As measured monthly across the study period (January 2011-March 2020), there are 48 unique fully RSPO-certified dyads (i.e., both companies RSPO-certified), 40 with one RSPO-certified company, and 14 where neither company is RSPO-certified. Average annual trade volume between dyads of RSPO-certified companies is 85,800 tons; between dyads with one RSPO-certified company is 57,200 tons; and, between non-certified dyads is only 7,200 tons.

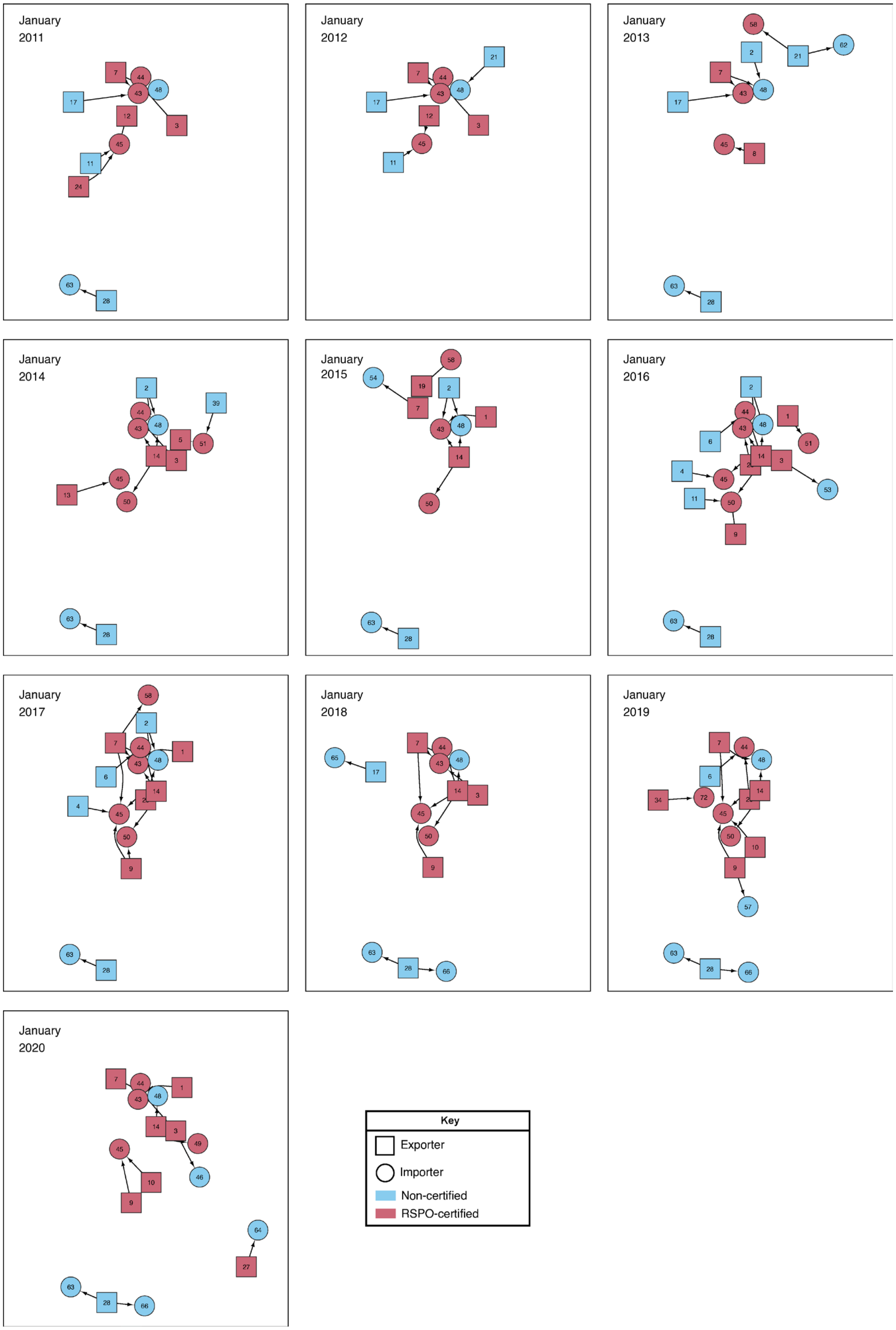

Figure 4-1. Selected Snapshots of Changes to Networked Actors Across the Study Period.
The number inside each node represents a company name (see list of names in Table 2). Node color is representative of RSPO status.

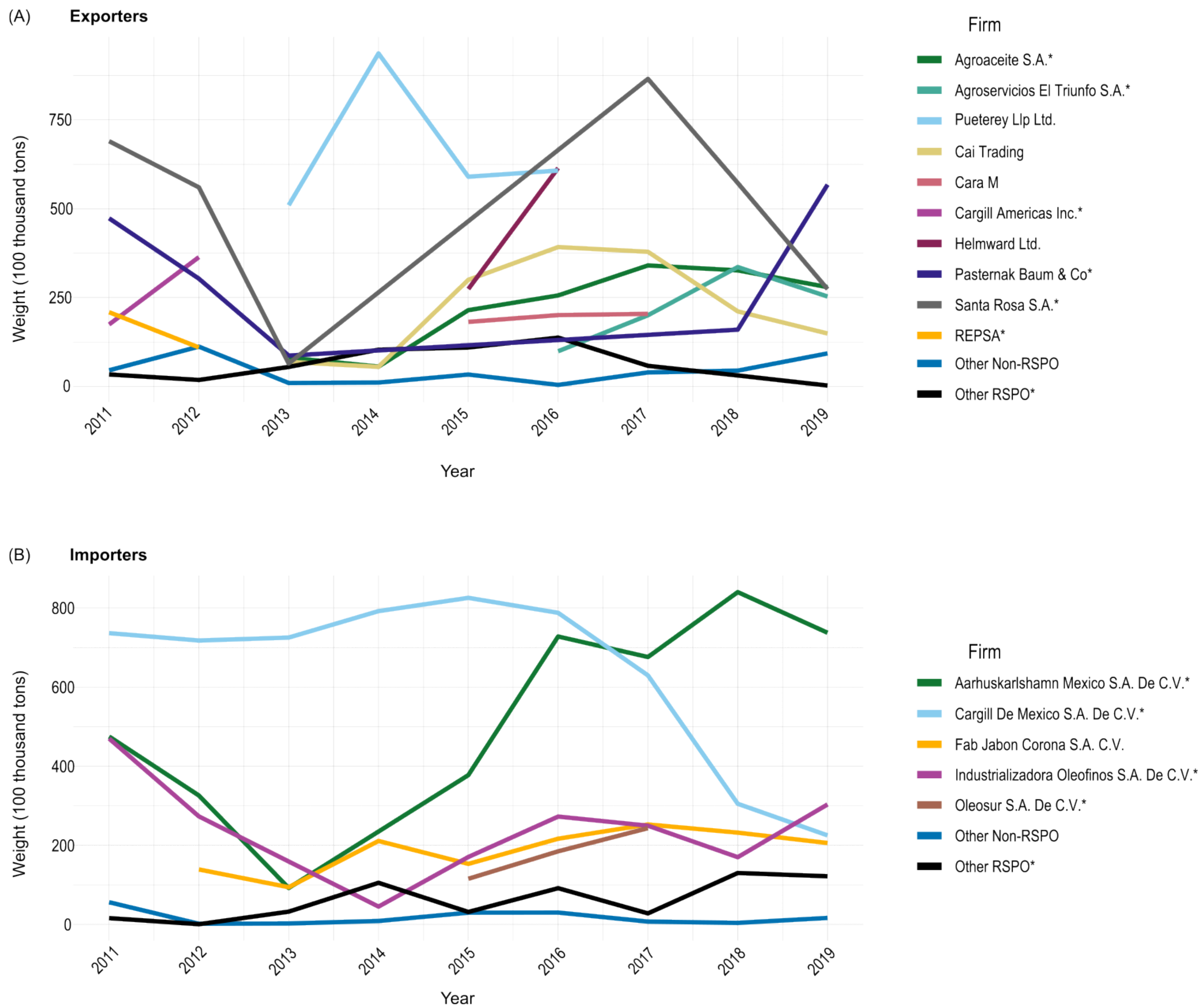

Figure 4-2. Major Exporters and Importers of Palm Oil from Guatemala, 2011-2019.
*Exporters are shown in (A), while importers are shown in (B). An * indicates RSPO membership. For each year, ~90% of certified and non-certified trade flows by weight are assigned to an explicitly named major company, while the remaining 10% are aggregated under "other."*

4.5.2 Embeddedness and RSPO-certification

Figure 4-3 and Table 4-2 depict the relationships between Guatemalan exporters and Mexican importers and average company embeddedness for all companies present in the network between January 2011 and March 2020. D_n-scores reveal that the Guatemalan-Mexican palm oil trade is moderately embedded from 2011 to 2019. Over the study period, the average embeddedness across all companies in the network is 0.46. The average D_n-score increases from the first half of the study period (0.38; 2011-2015) to second (0.54; 2016-2020).

The average embeddedness of all RSPO-certified companies across the study period is 0.70. The average D_n-score increases from the first half of the study period (0.52; 2011-2015) to the second half (0.86; 2016- 2020). In comparison, the average embeddedness of all non-certified companies across the study period is 0.23 and the average D_n-score decreases from the first half of the study period (0.26; 2011-2015) to the second (0.21; 2016-2020).

Model results indicate that RSPO-certification is a statistically significant (95% CI: 0.16, 0.59) and robust predictor of company embeddedness (Table 4-3). On average, the D_n-score for an RSPO-certified company is 0.39 points (98%) higher than a non-certified company. From our findings, we conclude that certification fosters company embeddedness in a trade network.

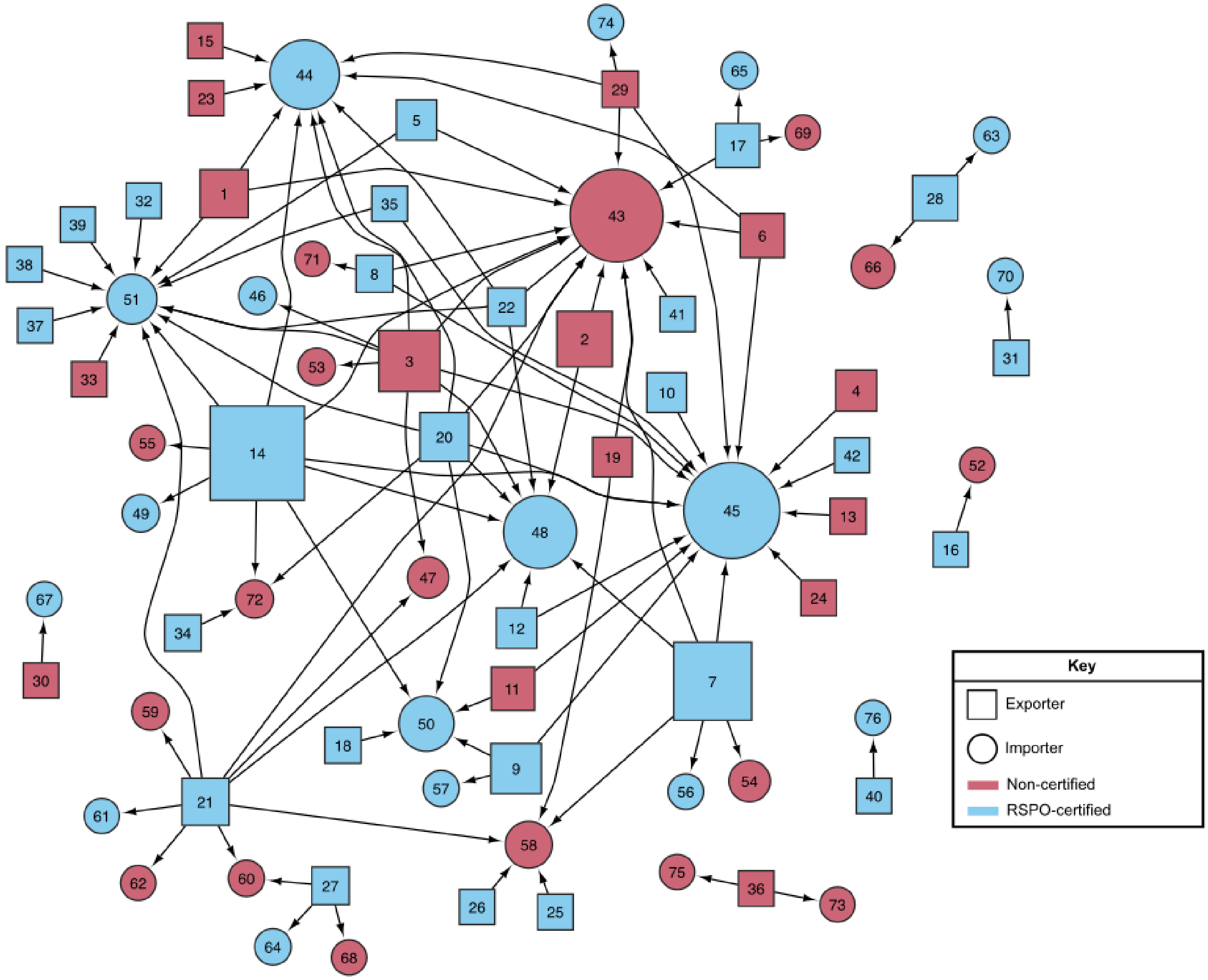

Figure 4-3. Average embeddedness of firms in the Guatemalan palm oil trade, January 2011-March 2020.
Node size is proportional to D_n-score (i.e., embeddedness) and node number corresponds to company name as listed in Table 4-2. More strongly embedded companies tend to be RSPO-certified (red).

Table 4-2. Average embeddedness (D_n-score) of firms in the Guatemala-Mexico palm oil trade, January 2019-March 2020.

EXPORTERS				IMPORTERS			
Node	**Actor**	**D_n-Score**	**RSPO-Certified?**	**Node**	**Actor**	**D_n-Score**	**RSPO-Certified?**
14	Agroaceite S.A.	1.55	✓	45	Aarhuskarlshamn Mexico S.A. De C.V.	1.03	✓
20	Agrocaribe S.A.	0.64	✓	44	Industrializadora Oleofinos S.A. De C.V.	1.01	✓
1	Cai Trading Llc	0.53	✓	43	Cargill De Mexico S.A. De C.V.	1.00	✓
6	Cara M	0.48		65	Alimentos Grasas Y Derivados Aligrade S.A. De C.V.	0.53	
21	Desopech	0.44		48	Fab Jabon Corona S.A. C.V.	0.53	
11	Palmas Del Horizonte S.A.	0.39		57	Grupo Pecuario San Antonio S.A. De C.V.	0.40	
22	Extractora La Francia S.A.	0.35	✓	51	Team Foods Mexico S.A. De C.V.	0.39	✓
17	Produccion Y Negocios Industriales S.A.	0.28		46	Industrial Aceitera S.A. De C.V.	0.37	
5	Cargill Americas Inc.	0.27	✓	64	Alesur S.A De C.V.	0.29	
2	Pueterey Llp Ltd.	0.23		54	Buenaventura Grupo Pecuario	0.28	
25	Kda Trading Inc.	0.20		53	Industrializadora De Mantecas S.A. De C.V.	0.27	
31	Bayer Sociedad Anonima	0.19		70	Sud Chemie De Mexico S.A. De C.V.	0.19	
28	Pollo Campero S.A.	0.19		72	Colgate Palmolive S.A. De C.V.	0.18	✓
24	Extractora Del Atlantico S.A.	0.18	✓	49	Agro Palm Ingredients S.A. De C.V.	0.18	✓
4	Helmward Ltd.	0.13		56	Palmas De Candelaria S.A. De C.V.	0.17	
29	Nestle Guatemala S.A.	0.11	✓	59	Sanchez Y Martin S.A. C.V.	0.14	
34	Colgate Palmolive	0.10	✓	63	Varesse S.A. De C.V.	0.14	
13	Servicios Integrales Montanas Del Norte S.A.	0.08	✓	66	Pollo Granjero S.A. De C.V.	0.12	
15	Comercializadora Phax S.A.	0.08		60	Fab De Jabones Princesa S.A.	0.11	
16	Procter & Gamble Distributing	0.08	✓	52	Procter & Gamble International Oper	0.08	✓
23	Nucleo Logistica Guatemala S.A.	0.08		55	Plantaciones Del Soconusco S.A. De C.V.	0.08	
26	Industria De Aceites Y Grasas Suprema S.A.	0.08		61	Quimic S.A. De C.V.	0.08	
30	Labo Biologie Vegetale Yves Rocher	0.08		62	Servicios Administrativos Purepechas S.A De C.V.	0.08	
32	Corporacion Agroindustria	0.08		67	Stanhome De Mexico S.A. C.V.	0.08	
33	Bananera Nacional	0.08		68	Exim Del Caribe S.A. De C.V.	0.08	

35	Industria Chiquibul S.A.	0.08	
36	Fabrica De Productos Alimenticios Rene Y Cia S.C.A.	0.08	
37	Intertek Guatemala S. A.	0.08	
38	Sgs Central America S.A.	0.08	
39	Sealed Air Central America S.A.	0.08	
40	Sensient Guatemala S.A.	0.08	
41	Palma Sur S.A.	0.08	
69	Comercializadora Y Distribuidora Ardi Ozuna S. A. De C.V.	0.08	
71	Clariant (Mexico) S.A. De C.V.	0.08	✓
73	Pepsico Mexico R&D Savory S. De R.L. De C.V.	0.08	✓
74	Marcas Nestle S.A. De C.V.	0.08	✓
75	Sabritas S De Rl De C.V.	0.08	
76	Sensient Flavors Mexico S.A. De C.V.	0.08	

Table 4-3. Results from fitting the linear mixed model.

	Embeddedness (Dn-Score)	
Predictors	*Estimates*	*CI*
(Intercept)	0.40	-0.37 –1.16
RSPO [1]	0.39**	0.16 – 0.61
Year	0.03	-0.01 – 0.06
Age	0.00	-0.00 – 0.01
Sales	-0.05	-0.17 – 0.07
NYDF [1]	-0.01	-0.25 – 0.23
Random Effects		
σ^2	0.17	
$\tau 00_{id}$	0.07	
ICC	0.29	
N_{id}	48	
Observations	166	
Marginal R^2/Conditional R^2	0.156/0.402	

* p<0.05 ** p<0.01 *** p<0.001

Across the study period, RSPO-certified exporter Agroaceite S.A. (node 14 in Figure 4-3 and Table 4-2) has the highest annual D_n-score (3.46) based on its trade interactions in 2019. It also has the highest average D_n-score (1.55; 2011-2020). This is more than triple that of exporter Cara M (node 6), which holds the highest annual and average D_n-score (0.90 in 2018; 0.48, 2011-2020) among non-certified companies. However, certification is not always associated with greater embeddedness. RSPO-certified and non-certified companies have the same lowest average D_n-score (0.08). Non-certified companies (Pollo Campero S.A., exporter, node 28; Varesse S.A. De C.V., importer, node 63) share the lowest overall annual D_n-score (0.02, 2016). In contrast, the lowest annual D_n-score for multiple RSPO-certified companies is 0.08.

Patterns in the trade network indicate a preference for RSPO-certified importers to seek out certified exporter partners, likely to ensure their physical SCCS certification. As there are a relatively small number of RSPO-certified Guatemalan exporters, Mexican importers face constrained purchasing choices, which contribute to more durable and stable buyer relationships.

Instances where RSPO-certified importers trade with non-certified exporters (e.g., nodes 23 and 44) suggest the use of the RSPO's Mass Balance or Book & Claim supply chain models. With Mass Balance, palm oil from certified and non-certified sources can be mixed at any stage in the supply chain, provided that the purchase and sales of certified palm oil materials are constantly balanced. It is currently an important part (51%) of the volumes of RSPO-certified palm oil sold on the market (RSPO, 2022). Under a Book & Claim model, manufacturers can purchase credits from RSPO-certified growers or mills independent of their physically sourced palm oil products. Critics are skeptical of the indulgences the credit trading system permits, arguing it facilitates greenwash by absolving companies of monitoring responsibilities (Brad et al., 2018; Gallemore et al., 2022). Low demand for certified palm oil may drive trade between RSPO-certified exporters and non-certified importers (e.g., nodes 14 and 55).

Guatemala's status as the leading producer of RSPO-certified palm oil in Latin American (GREPALMA, 2019), alongside the lack of RSPO-certified producers in Mexico (Wilcox, 2019), may foster deeper embedding of Mexican importers of RSPO-certified palm oil. New agreements between the Mexican Federation of Oil Palm Producers (FEMEXPALMA) and the Guild of Palm Growers of Guatemala (GREPALMA) to strengthen relationships between palm oil sectors in both countries (RSPO, 2021) will likely reinforce this trend.

4.5.3 Thematic Analysis

The results of our empirical model present evidence that a correlation exists between embeddedness and certification – that RSPO-certified companies are, on average, 98% more embedded in the trade network than non-certified companies. However, this correlation does not clarify the processes linking certification and embeddedness. To gain greater insight into the relationship, we thematically analyzed the content of 516 company reports and distilled five common themes describing the certification-embeddedness dialectic (Table B-1).

The most frequent theme (272 occurrences) is a buyer (exporter) established Certification Requirement that sets RSPO-certification as a priority and/or requirement for supplier (importer) partnerships. As one company details, "We require that all our suppliers are RSPO certified." Data fitting this theme suggests that buyers' commitments and policies for sourcing 100% RSPO-certified palm oil inform supplier selection and the continuation of supplier relationships.

The next most frequent theme is Socializing Certification (144). Buyers may choose to promote RSPO certification to their suppliers instead of establishing it as a prerequisite for partnership. They try to encourage, push, or otherwise influence their suppliers to pursue the standard as they regularly hold meetings, make presentations, and offer seminars to promote its benefits. For example, company statements include: “We will push our existing suppliers to participate in RSPO certification” and “[We will] Encourage CPO suppliers who are not certified to implement RSPO P&C and go for certification.”

The Supplier Certification (102) theme captures buyer commitments to support, train, and fund their suppliers through the certification process. For example, buyers stated: “We plan to fund to [sic] our key suppliers in or do [sic] to promote the RSPO. / with training program” and “We are preparing RSPO certificates with our suppliers.” These and other similar sentiments suggest that the durable and stable relationship a buyer has already established with a supplier may ultimately contribute to that supplier’s certification.

Buyers also express a tendency to invest additional time, money, or expertise in their RSPO-certified suppliers in a number of places, contributing to the emergence of a Relational Investment theme (76). Companies mention the development of robust supply chain mapping activities and continuous engagement to ensure compliance and communicate any updates to the RSPO standard. For example, one buyer says they will maintain “Close coordination with suppliers of palm oil sourced materials to ensure the long term vision of RSPO is uphold [sic] and supported.” These sunk costs could discourage supplier switching.

A minority of buyers express a Certification Neutral (25) attitude. These actors rely do not use supplier certification to guide their trade decisions, instead relying on market supply and demand. As one company clearly states, “[We] Address the demand from our customers to our suppliers. If availability and demand meet requirements, we look forward to distributing more RSPO products.” Collectively, these qualitative results indicate a dialectical relationship between certification and embeddedness, as we further discuss below.

4.6 Discussion

This article asks "*Do certification standards explain differences in embeddedness among companies in a trade network over time?*" to address a primary research gap on precursors to embeddedness, particularly whether policy instruments like certification systems drive embeddedness. We focused on trade between Guatemalan shippers and Mexican buyers and empirically measured the embeddedness of companies by calculating D_n-scores using transaction-level customs data from 2011 to 2020. Statistical analyses of the D_n-scores indicate RSPO-certification is a strong predictor of company embeddedness in a trade network independent of company size, age, and deforestation commitments. Our qualitative results suggest that this difference in embeddedness occurs dialectically as certification fosters embeddedness at the same time that embeddedness fosters certification. Below, we advance a conceptual model of certification-driven embeddedness as we put our findings in dialogue with existing theory. Then we discuss the bright and dark sides of embeddedness, highlighting possible avenues for future research.

4.6.1 Advancing a conceptual model of certification-driven embeddedness

Our conceptual model of certification-driven embeddedness (Figure 4-4) synthesizes the results from our empirical and qualitative analysis to elaborate how certification drives embeddedness to structurally alter trade networks. We define certification-driven embeddedness as: the ways in which the durability and stability of company relationships in a trade network are shaped by supply chain certification policies. While our quantitative results provide evidence that certification is a strong predictor of embeddedness, the results from our thematic analysis suggest how this unfolds. We find that certification promotes embeddedness in several ways.

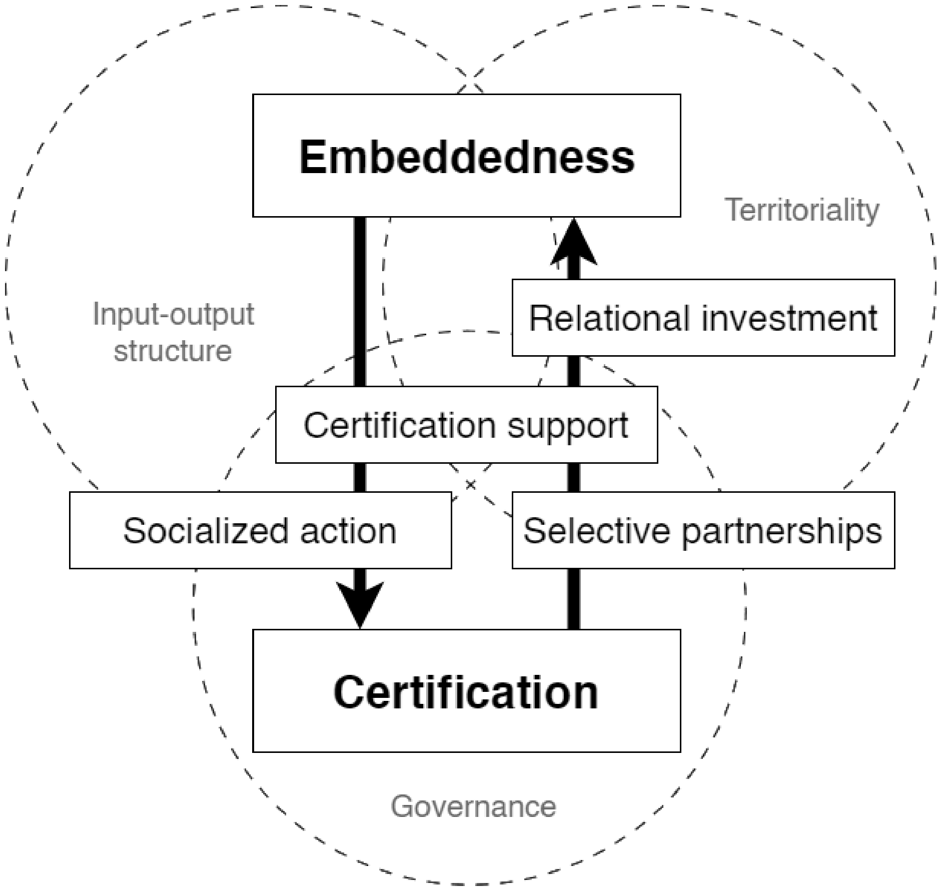

Figure 4-4. A conceptual model of certification-driven embeddedness.
The certification-embeddedness dialectic is shaped by various buyer-supplier interactions and takes place in the broader context of three interconnected dimensions of global commodity chains: (1) input-output structure: the physical connections between a set of products and services; (2) governance: the authority and power relationships that control and coordinate product flows and resource allocations within a chain; and, (3) territoriality: the spatial dispersion or concentration of trade networks (Gereffi, 1994).

For instance, following the dominant *Certification Requirement* theme, certification increases embeddedness by impacting whether a buyer-supplier relationship is formed and maintained overtime. The observed empirical divergence in embeddedness may result from buyers choosing to continue relationships with certified suppliers, and end their relationships with non-certified suppliers, sentiments expressed in the ACOP reports. Requiring certification also limits the pool of suppliers, forcing buyers to strengthen relationships with certified sellers to maintain supplies. As it forms the ground for selective partnerships, certification drives embeddedness.

At the same time, buyers invest more in their relationships with certified suppliers as they work to ensure supplier adherence to certification standards. For example, they devote extra time and resources to compliance activities through "continuous training programs" and "mapping and monitoring" systems (*Relational Investment*). As sunk investments deter buyers from ending such relationships (Goldstein & Newell, 2020), we observe greater supplier embeddedness.

Relatedly, the strong *Supplier Certification* theme suggests that buyers likewise invest extra time and resources in current suppliers as they support and guide them through the certification process. The data suggests that buyers often facilitate the complex and expensive certification process. While buyers may prioritize suppliers with whom they have already established a relatively strong relationship, their dedicated supplier development efforts may further increase the durability and stability of such relationships – fostering greater embeddedness among already moderately embedded suppliers. Data limitations prevented us from studying embeddedness before and after certification but future research could explore this hypothesis.

Embeddedness could foster supplier certification when buyers use their network position to encourage uptake of the RSPO standard among current suppliers (*Socializing Certification*). It is possible that buyers would strategically promote certification to suppliers with whom they have a stronger relationship and accordingly more knowledge of their capacity to pursue certification. On the other hand, *Socializing Certification* could be relatively embeddedness neutral if buyers indiscriminately promote the RSPO to their supplier network.

Our findings therefore suggest that certification contributes to embeddedness as it establishes a condition for forming or maintaining relationships, and as it strengthens existing relationships due to the labor associated with processes of certification and compliance. Theories from the global commodity chain and global value chain literatures provide additional insight on how policy instruments like certification drive differences in embeddedness.

Gereffi (1994) defines three interconnected dimensions of global commodity chains: (1) input-output structure: the physical connections between a set of products and services; (2) governance: the authority and power relationships that control and coordinate product flows and resource allocations within a chain; and, (3) territoriality: the spatial dispersion or concentration of trade networks. An alteration to one dimension generates a difference in the others. There is evidence to suggest that this is indeed what we have witnessed in our case study. Quality conventions codified in certification formalized requirements for goods to qualify for trade. These guidelines for supply chain governance in turn altered the input-output structure and territoriality of the trade network by selectively fostering embeddedness among certified actors.

Certification-based chain governance altered both the physical product-exchange connections between companies, as well as the organization of the overall trade network. This is empirically captured in higher D_n-scores, indicating greater degrees of embeddedness, among certified companies compared to lower D_n-scores, indicating lesser degrees of embeddedness, among non-certified companies.

This difference may reflect a shift in governance from a market to relational typology, from lower to higher coordination (Gereffi et al., 2005). With market governance, price and market competitiveness take precedence. Exchanges are conducted at arms-length with fleeting relationships between actors. Buyers approach suppliers to negotiate a price based on prevailing market conditions, then the supplier arranges the delivery of the palm oil. Under this trade model, buyers can switch to new suppliers at a minimal cost. Among non-certified companies, we expect market governance to coordinate trade and inform the input-output structure of the trade network as the fungibility of the non-certified commodity allows for relatively simple transactions (Gereffi et al., 2005; Gereffi & Fernandez-Stark, 2016).

In comparison, relational governance likely dominates when suppliers are providing quality-differentiated goods (Gereffi et al., 2005; Gereffi & Fernandez-Stark, 2016) such as those differentiated by the civic and industrial conventions of a certification standard. The *Certification Requirement* theme suggests as much: buyers control and coordinate their supply networks on the basis of supplier certification status. Frequent interactions that require trust and generate mutual reliance characterize relational governance. Since relational linkages take time to build, switching to new trade partners carries a higher cost. We observe this via the *Supplier Certification* theme and buyers' investment in supplier development (*Relational Investment*). Although RSPO-certification is not a perfect solution, it may be the best available (Meijaard et al., 2018; Sundaraja et al., 2020). Perhaps then, the durability/stability of actor connections captured in embeddedness metrics may be able to strategically inform the management of such an initiative. The most embedded companies, the most consistent players in the game, may be the most effective points to target for action. To advance the uptake of sustainability initiatives, one could apply embeddedness metrics to effectively identify and target powerful, non-certified companies for conversion. Similarly, one could apply embeddedness metrics to effectively identify and target powerful, certified companies that could serve as advocates for certification. These more embedded, certified buyers could have greater leverage and influence to change non-certified suppliers' behavior accordingly due to their purchasing power and/or deeper relationships. In these ways, embeddedness metrics may be useful to highlight which companies could serve as key leverage points for catalyzing broader change.

Bright and dark sides of embeddedness

Our paper has found that certification standards indeed produce differences in embeddedness. Yet, with both bright and dark sides to embeddedness, does this heightened embeddedness advance or hinder the governance goals of certification? On the bright side, greater embeddedness may increase trust, improve transparency, and spur investment (Gundlach et al., 1995; Kwon & Suh, 2005; Martins et al., 2017; Paulraj et al., 2008; Uzzi, 2011; Xin & Qin, 2011). Perceived trustworthiness benefits supply chain management by reducing procurement costs for buyers and creating value through greater information sharing (Dyer & Chu, 2003). Transparency may improve supply chain outcomes in terms of social, ecological, and operational performance (Bastian & Zentes, 2013). Buyer investment could help suppliers maintain compliance with certification regulations that require additional time and resource inputs. Accordingly, certification-driven embeddedness might create conditions that enable actors to strengthen environmental governance.

However, embeddedness also has a dark side. Opportunism may result from "inappropriate trust" enabled by embeddedness and undermine both SCM and environmental governance (Day et al., 2013; Gargiulo & Ertug, 2006; Rowley et al., 2000; Villena et al., 2011). For example, an embedded supplier may take advantage of the trust awarded to them by misrepresenting their product to buyers, or by selling trusting buyers tainted products. Certification-driven embeddedness might also contribute to counterproductive transformations to the supply chain structure. If certification-driven embeddedness favors the development of a certification-based trade network that fails to create meaningful change to the conditions of production, it might institutionalize greenwash. Both civil society reports and the scholarly literature expose significant shortcomings of the RSPO standard (EIA, 2015, 2019; Greenpeace International, 2019; Pye, 2016, 2019).

When combined with complementary approaches, the presented embeddedness metric can provide a foundation to investigate these two-sides of embeddedness and the potential implications for environmental governance (Figure 4-5 and Table 4-4). As pressing environmental impacts continue to surround supply chains, it is increasingly important to understand opportunities within these linkages to leverage supply chain durability/stability – or fluidity – to improve environmental governance.

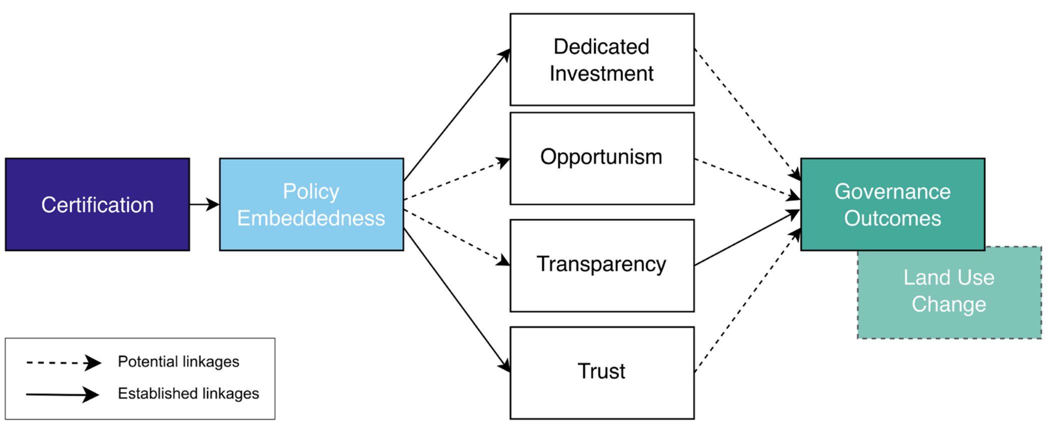

Figure 4-5. Linkages between environmental certification, embeddedness, supply chain characteristics and the environmental governance between supply chain nodes.
Land use change is included as a proxy measure for environmental governance. Dashed lines represent potential linkages between concepts, with solid lines indicating connections established in the literature.

Table 4-4. Proposed research agenda to explore linkages between embeddedness and critical supply chain characteristics.

Supply chain characteristic	Definition	Research approaches and references for approach	Potential research questions
Dedicated investment	Relationship-specific investments made by one firm to another (Heidi and John 1990)	Questionnaires/Surveys Interviews Rinehart et al. 2004	• Do more embedded palm oil exporters experience higher degrees of investment? • If so, does this investment coincide with greater compliance with RSPO-certification?
Opportunism	Self-interest seeking with guile (Williamson 1975); includes behaviors such as stealing, cheating, breaching contracts, acting dishonestly, falsifying data, obscuring issues, making false threats and promises, withholding information, and misrepresenting products (Hawkins et al., 2008)	Questionnaires/Surveys Interviews Luo et al. 2015	• Does embeddedness foster or hinder opportunism among palm oil exporters?
Transparency	Disclosing detailed, reliable data about supply chain operations between actors within and outside of the supply chain (Montecchi, Plangger, West 2021; Schäfer 2022)	Transparency Index Scorecards Bloomberg ESG ratings Questionnaires/Surveys Interviews Document review Carter, Rogers, and Choi 2015; Cheung, Jiang, and Tan 2010; Gualandris et al. 2021; Morgan et al. 2018; Tamimi and Sebastianelli 2017	• Do more embedded firms have more transparent supply chains? • Are more embedded palm oil exporters more aware of the extent of their chains? Do they know more about the existence, location, and activities of a greater number of nodes at a further distance?
Trust	Inclination to depend on and place faith in the reliability and integrity of a trade partner (Moorman, Deshpande, and Zaltman 1993; Zhao and Cavusgil 2006)	Questionnaires/Surveys Interviews Anderson and Narus 1990; Morgan and Hunt 1994; Zhao and Cavusgil 2006	• How does a palm oil exporter's embeddedness, and the embeddedness of their trade partners, impact the trust between them? • How does the RSPO-certification status of a firm impact the level of trust partners place in trade relationships?

Below, we briefly suggest how future work could evaluate hypothesized, but largely unexplored, linkages between embeddedness and two supply chain characteristics (transparency and opportunism), and document associated environmental governance outcomes via land use change detection. Other supply chain characteristics (e.g., trust or dedicated investment) could be similarly investigated (Table 4-4).

Transparency entails disclosing detailed, reliable data about supply chain operations between actors within and outside of the supply chain, as well as monitoring, surveilling, and verifying standards (Mol, 2015; Montecchi et al., 2021; Schäfer, 2022). Embeddedness may have an important influence on supply chain transparency as it improves communication and the exchange of higher quality information between actors (Kwon & Suh, 2005; Paulraj et al., 2008; Xin & Qin, 2011). This could, for example, have ramifications for addressing challenges with illegally cultivated palm oil (Jong, 2021; WWF, 2013) if more embedded companies are able to gain greater insight into their operations to more easily monitor and verify product provenance.

While the reality of the embeddedness-transparency relationship requires further study, a number of existing transparency measures present opportunities for conducting such research. For example, researchers could couple D_n-scores with transparency metrics derived from document analysis, survey instruments, or environmental-social-governance (ESG) disclosure scores (Cheung et al., 2010; Gualandris et al., 2021; Morgans et al., 2018; Tamimi & Sebastianelli, 2017).

Embeddedness may undermine environmental governance as close relationships leave the door open to opportunism, be it stealing, cheating, making false threats or promises, or exploiting information asymmetries (Hawkins et al., 2008). Research indicates that certification systems are vulnerable to opportunistic behavior, noting that a supplier’s primary interest is often to acquire certification as easily as possible (Jahn et al., 2005). In the context of palm oil production, there is significant motivation and scope for smallholders to alter or misreport data to auditors in order to become certified (Shukla & Tiwari, 2017). To explore the relationship between embeddedness and opportunism in the Guatemala-Mexico palm oil supply chain, one could adopt a mixed-methods approach that combines D_n-scores with opportunism measurements. Following Luo et al. (2015), these could be collected by surveying executives at exporting-importing companies.

After establishing how embeddedness and transparency (or other supply chain characteristics) are linked, the question still remains, to what effect? Understanding consequential environmental outcomes is critical to improve the implementation and effectiveness of environmental governance. We therefore suggest combining supply chain reconstruction methods, embeddedness metrics, and transparency scores with remote-sensing-based land change analysis. In the palm oil context, this could allow one to explore how certification, embeddedness, and transparency are related to oil palm plantation expansion and deforestation.

To illustrate, we describe a theoretical application of the Tracking Corporations Across Space and Time (TRACAST) methodological framework below (Goldstein & Newell, 2020). Scoping and data collection processes for quantifying embeddedness mirror that of TRACAST; the same transaction-level customs records for Guatemala-Mexico palm oil shipments are applicable. Using a combination of *ex situ* (e.g., GIS analysis, document analysis) and *in situ* (interviews, site visits, surveillance) approaches to corporate actor tracking, one can build out linkages from the differently embedded Guatemalan palm oil exporting companies to actors that lie further upstream, and ultimately to the specific (RSPO-certified) oil palm concessions those actors hold. Then, by applying remote sensing techniques we can identify co-occurrences of palm plantations and impacts such as deforestation, ecological encroachment, and the degradation of indigenous lands. Final results have the potential to reveal connections between RSPO-certification, embeddedness, and localized impacts of production. Moreover, such research could address a historically persistent environment:economy dichotomy that renders economic geography research on production-consumption largely separate from the natural environment (Bridge, 2008).

4.7 Conclusion

While the rich SCM literature is no stranger to embeddedness, it has largely overlooked what contributes to embeddedness. To address this gap and advance SCM, this paper used an abductive approach to explore whether certification standards can explain differences in embeddedness among companies in a trade network. Through a longitudinal case study of palm oil traded between Guatemala and Mexico, we showed that environmental certification indeed appears to create a predictable difference in company embeddedness providing empirical support for previously unexplored linkages between embeddedness and convention theory. We complemented this quantitative work with thematic analysis, dissecting company reports to elaborate a certification-embeddedness dialectic that informed the development of a conceptual model of certification-driven embeddedness. We argue that certification-driven embeddedness raises pressing questions about the bright and dark sides of increased embeddedness – questions that should inform a future research agenda.

Our novel approach of applying D_n-scores to measure embeddedness in supply chains is broadly applicable to other research questions and is a potent complement to the methods and approaches traditionally used to study embeddedness. The research agenda we propose provides a means to advance our understanding of the certification-driven embeddedness' influence on supply chain characteristics and outcomes in terms of environmental governance. Such work is increasingly timely as certification schemes continue to proliferate and it becomes increasingly necessary to clarify how these and other mechanisms of private governance restructure supply chains and influence their sustainability.

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Conclusion

This dissertation was motivated by a desire to make relevant contributions to the theory, methods, and practice of environmental supply chain governance. I have focused on interrelated questions concerning: supply chain input-output structure, environmental certification, and land use change (Chapter 1); the first-mile and its complicating factors (Chapter 2); and the linkages between supply chain embeddedness and supply chain governance tools like certification (Chapter 3). While each question has pulled my research in a unique direction, a common thread also unites them: the inseparable and dialectical dynamic of supply chain input-output structure, territoriality, and governance, as framed in the global commodity chains literature (Gereffi, 1994).

The mixed-method approaches I have utilized in the preceding chapters provide important insights on the ways: trade by transnational corporations influences land use patterns; first-mile attributes influence our ability to establish granular traceability; and supply chain governance choices foster network stability over time. These insights in turn have raised new questions that suggest additional avenues of inquiry. In this final chapter, I summarize the key findings, broader significance, and limitations of this dissertation before concluding with a discussion of future research directions.

5.1 Summary of major findings and contributions

My research helps to advance existing knowledge of supply chain governance, traceability, embeddedness, land use change, especially as they relate to (economic) geography, (political) industrial ecology, and supply chain management fields. I suggest that the three most important contributions of this dissertation are: (1) Advancing the TRACAST framework to systematically reveal supply chains wall-to-wall and assess the effectiveness of certification at reducing supply chain deforestation risk exposure; (2) An improved understanding of the first-mile and the factors contributing to the first-mile problem in practice; and, (3) The development and application of a theory of policy-driven embeddedness.

In *Chapter 2: Deforestation, certification, and transnational palm oil supply chains*, my colleagues and I applied the TRACAST methodological framework and remote sensing to identify hidden deforestation hotspots in supply chains that convey flows of (certified sustainable) palm oil from Guatemala, through Mexico, and on to the U.S. This was motivated by gaps in teleconnections and the supply chain governance literatures concerning: tools for mapping corporate-specific production-consumption linkages; and, certification's effectiveness at reducing supply chain exposure to deforestation and other environmental impacts. As voluntary certification schemes take root as a primary mechanism for improving commodity production practices, supply chain transparency, and corporate accountability – including compliance with deforestation-free sourcing mandates – uncovering the complex and often opaque supply chain linkages between sites of production and consumption is an increasingly critical challenge to address.

In reconstructing the supply chains of three transnational conglomerates, Pepsico, Mondelēz International, and Grupo Bimbo, we revealed how the length and complexity of palm oil supply chains disconnects sites of production and consumption, limiting their ability to ensure the integrity of their "sustainable" and deforestation-free sourcing policies. We found RSPO certification to be ineffective at mitigating deforestation risk or ecological encroachment. These findings are applicable to transnational supply chains generally: they cannot rely on (or be allowed to rely on) certification to meet deforestation-free supply chain targets. We offer concrete suggestions for making certification a more robust instrument, and for addressing deforestation risk, including by tackling the opacity of plantation-mill linkages. This “first-mile” problem increases the risk of unsustainably produced palm oil entering supply chains.

The challenge is not unique to palm oil – supply chains in general have a first-mile traceability problem. Despite a broad push for increased supply chain visibility, examples of end-to-end traceability are rare and opacity remains the norm. Although the identification of specific locations, production conditions, and corporate actors may be challenging along any part of the supply chain, it is notoriously difficult to track a supply chain to the “first-mile” where it begins (Acquaye et al., 2014; Bramanti et al., 2020; Egilmez et al., 2014; Grabs & Carodenuto, 2021; O’Rourke, 2014; Phillips, 2017; Sen, 2017; Serdijn et al., 2020). I further elaborated on the first-mile problem in Chapter 3.

In *Chapter 3: Out of sight, out of mind: Defining and addressing the first-mile problem in supply chains*, my co-authors and I addressed a gap in the supply chain traceability literature by defining both the first-mile and the first-mile problem. We first established 14 propositions concerning the essential attributes of the first-mile and how they influence our ability to connect this initial stage of production to the rest of the supply chain. Then, we demonstrated the first-mile problem in practice with examples from four divergent sectors: agriculture, fishing, timber, and mining.

In applying the 14 propositions across these different sectoral vignettes, we demonstrated how context uniquely shapes proposition salience. The factors impacting the first-mile problem vastly differ in some proposition-sector combinations. For example, large distances between catch site and transfer of custody hinder traceability in the tuna sector, whereas the perishability of fresh oil palm fruit necessitates that harvesting take place near a mill. These differences highlight a need for tailored approaches to the first-mile problem. There is not a one-size-fits-all solution. In other instances, a proposition may cross-cut sectors, impacting first-mile traceability in markedly similar ways. For example, product aggregation and fluid trading partnerships universally challenge all four sectors, albeit in a nuanced manner. Areas of similarity reveal opportunities for cross-sectoral exchanges, joint learning, and the co-innovation of solutions.

We conclude the chapter by offering recommendations for how key actors including traders, lead firms, NGOs, and governments, can target specific propositions based on their unique strengths to collectively overcome the first-mile traceability challenge. While first-mile traceability will not alter the conditions of production itself – it will not solve root causes of the social and environmental harms driven by production-consumption systems – it can reveal where and actors can make concerted efforts. Identifying impact hotspots and their drivers is a key step to making production transparent, sustainable, and responsible.

In *Chapter 4: A theory of policy-driven embeddedness in supply chains and implications for governance*, my colleagues and I addressed a primary research gap on the relationship between embeddedness and certification. At the same time, our work advanced embeddedness by theoretically and methodologically elaborating on the conceptualization and quantification of embeddedness' durability and stability aspects. Our novel calculation and subsequent modeling of dynamic network scores (D_n-scores) revealed that RSPO-certification fostered the embeddedness of firms in the case study trade network. This is important as it suggests that certification systems can structurally alter trade networks by promoting the generalizable supply chain characteristic of embeddedness.

Drawing on the results of our case study, as well as existing work on quality conventions and global commodity chains, we proposed a conceptual model to elaborate on how policy instruments like certification simultaneously interface with supply chain governance, input-output structure, and territoriality to alter firm embeddedness and overall trade network organization. To conclude, we explored the potential bright and dark sides of policy-driven embeddedness. Embeddedness has the potential to present several opportunities as well as a number of barriers for effective supply chain governance. We accordingly outlined paths for future research. Our novel D_n-score approach to measuring embeddedness should be of broad interest to scholars working on the structural, geographical, and governance configurations of supply chains, commodity flows, and global production networks.

5.2 Limitations and opportunities for future research

While fieldwork was initially planned as an integral part of this dissertation, the world had other plans. Due to the global pandemic in 2020 and personal health issues in subsequent years, my original research agenda and methods shifted. There are a number of ways fieldwork could have deepened – and still could deepen – the story told in this dissertation. In the context of Chapter 2, experiences and observations in the field, e.g., at palm oil plantations, mills, and other nodes along the supply chain, could offer a stronger grounding and richer understanding of the palm oil trade. For example, while I have a birds-eye-view of the environmental changes oil palm expansion is causing, conversations with the populations intimately impacted would allow me to more fully understand what the expansion means, what communities need, and what powers are at play.

The same applies to any of the first-miles studied in Chapter 3. For instance, witnessing the challenge of first-mile traceability firsthand and interviewing producers (e.g., about what they would be open changing, what support they would require, and what impediments stand in their way) could provide better insight into the feasibility of solutions. In a similar manner, visiting and interviewing the firms included in Chapter 4 could add further detail and context to how certification contributes to embeddedness. A "Follow the Thing" (Cook, 2004) approach to tracking material flows could bridge the divide between research desk, the ivory tower, and the real world.

In other instances data availability limited the reach of this work. For example, the spatial and temporal scope of Chapter 2 is limited by both the availability of high-resolution satellite imagery and trade data. Access to trade data similarly limited my research design in Chapter 4. Had data been available for earlier years, I could have used a differences-in-differences approach to studying the relationship between certification and embeddedness. These limitations suggest opportunities future research can look to improve upon.

A number of additional possibilities for future research emerge from the research I was able to perform. I discuss these below, outlining the potential in three overlapping focus areas: Supply chain teleconnections and social risks; Justice implications of first-mile traceability; and Elaborating on theories of supply chain embeddedness and governance outcomes.

5.2.1 Supply chain teleconnections and social risks

In this dissertation, I focused on teleconnections embodying the environmental risks of palm oil production, but social risks are also alarming. For example, aggressive palm oil expansion in Guatemala has seriously compromised the livelihoods and food security of indigenous populations (Alonso-Fradejas, 2012; Hervas, 2021; Mingorría et al., 2014; Pietilainen & Otero, 2019). More than 60,000 subsistence farmers and dozens of rural communities have been subsumed or "disappeared" by oil palm (Milton, 2018; Pietilainen & Otero, 2019). While best available data indicates the location of traditional territories, it does not necessarily reflect the views of local nations, definitive or legal boundaries, or current population distributions (Native Land, 2022). One specific project could therefore build on my dissertation research by partnering with Indigenous Peoples and communities to clarify land rights and then to identify supply chain ties to both dispossession and the conversion of Indigenous land to oil palm. This type of work is broadly needed across contexts – other places, products, and supply chains – as export-oriented agricultural industries across the global economy continue to grow and expand at the expense of socially and spatially marginalized peoples.

5.2.2 Justice implications of first-mile traceability

The general concept of first-mile traceability is increasingly present as emerging legislation starts to incentivize a shift towards radical supply chain transparency. I see countless opportunities to expand on my dissertation work in this area. First, while traceability is a critical tool for unveiling impact hotspots to promote more just and equitable production-consumption systems, it has the potential to paradoxically achieve the opposite. For example, one way traders and lead firms can reduce first-mile complexity and length is through direct sourcing channels or vertical integration. Yet, both strategies tend to exclude informal small-scale producers and thereby further marginalize them while concentrating corporate power (Gardner et al., 2019). Moreover, the disproportionate percentage of female smallholders globally raises further questions related to gender equity (Kizu et al., 2019). Future research can investigate these and other unintended consequences of prioritizing first-mile traceability, and develop mitigation strategies accordingly.

It also would be of interest to more deeply explore the first-mile barriers I have highlighted in my dissertation by engaging with supply chain actors themselves. One could move between first-mile nodes to observe documentation practices – or the lack thereof – and interview actors to ascertain the barriers they perceive to stand in the way of first-mile traceability as well as the incentives and support they would need to implement a given traceability technology.

5.2.3 Supply chain embeddedness and environmental governance outcomes

In my dissertation, I revealed how supply chain governance choices, like certification, can foster actor embeddedness. But, the implications of this embeddedness remains to be seen. I see a number of opportunities to explore the possible bright and dark sides of this policy-driven embeddedness. One possibility would be to link embeddedness to different environmental governance outcomes. My dissertation chapters collectively provide a foundation: pairing land use change analysis (Chapter 2) and the quantification of supply chain embeddedness (Chapter 4) in terms of first-mile grounding (Chapter 3). In the palm oil context, one could investigate how actor embeddedness is related to certification, oil palm plantation expansion, deforestation, and biodiversity loss by building out linkages from differently embedded exporting firms to actors that lie further upstream, i.e., all the way to specific (RSPO-certified) oil palm concessions. Then, remote sensing techniques could be used to identify co-occurrences of palm plantations, deforestation, and biodiversity loss. This fusion of industrial ecology, economic geography, and land change science could further transform embeddedness in both theory and practice. Understanding the consequential environmental outcomes of embeddedness is critical for improving the implementation and effectiveness of environmental governance.

5.3 Intellectual merit and broader impacts

The work presented in this dissertation complements existing economic geography literature by linking production, consumption, and global production network configurations. It confronts a historically persistent environment:economy dichotomy (Bridge, 2008) that has rendered economic geography research on production-consumption largely separate from the natural environment. At the same time, this dissertation complements emerging literature on how the RSPO shapes land use change. By elaborating on the conceptualization and quantification of embeddedness' durability and stability aspects using novel network analysis methods, this dissertation also expands our understanding of the generalizable supply chain characteristic of embeddedness.

Importantly, the presented study forms a representative case. The original methods presented in each chapter are generalizable to supply chains spanning various places and commodities. This research's interdisciplinary design combines respective strengths of multiple fields to challenge and progress individual areas. Beyond academia, the quantification of land use change from (RSPO-certified) palm oil flowing through specific supply chains has the potential to foster change by compelling supply chain actors to more actively consider connections to distant places.

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Appendices

Appendix A

Supplementary Information: Deforestation, Certification, and Transnational Palm Oil Supply Chains

Table A-1. Random forest samples by region and date.

Region	2009	2019
Alta Verapaz	119,762	219,948
Izabal	269,810	420,013
Petén	222,180	231,133

Table A-2. Predictors used for random forest classification by region and date.
Predictors are varied by region and year depending on best results in trial runs for oil palm and forest differentiation.

		2009			**2019**		
	Predictor	Alta Verapaz	Izabal	Petén	Alta Verapaz	Izabal	Petén
1	RapidEye spectral band 1 (Blue)	√	√	√	√	√	√
2	RapidEye spectral band 2 (Green)	√	√	√	√	√	√
3	RapidEye spectral band 3 (Red)	√	√	√	√	√	√
4	RapidEye spectral band 4 (NIR)	√	√	√	√	√	√
5	RapidEye spectral band 5 (Red Edge)		√				
6	Normalized difference vegetation index (NDVI) (Tucker, 1979)	√	√	√	√	√	√
7	Information Measures of Correlation-1 (MOC_1)	√	√		√	√	√
8	Information Measures of Correlation-2 (MOC_2) (Haralick et al., 1973)	√	√	√	√	√	√
9	Chlorophyll Index (Buschmann & Nagel, 1993; le Maire et al., 2004)	√	√		√	√	
10	Correlation (Haralick et al., 1973)			√			

Table A-3. Confusion matrices of 2009 and 2019 prediction results.

2009					
	Validation				
Classification Result	**Forest**	**Palm**	**Others**	**Total**	**User Accuracy**
Forest	4,945	201	621	5,767	85.75%
Palm	227	10,366	2,328	12,921	80.23%
Others	631	2,021	36,330	38,982	93.20%
Total	5,803	12,588	39,279	57,670	
Producer Accuracy	85.21%	82.35%	92.49%		
Overall accuracy	89.55%				
2019					
	Validation				
Classification Result	**Forest**	**Palm**	**Others**	**Total**	**User Accuracy**
Forest	4,507	134	161	4,802	93.86%
Palm	115	10,172	1,727	12,014	84.67%
Others	195	550	31,207	31,952	97.67%
Total	4,817	10,856	33,095	48,768	
Producer Accuracy	93.56%	93.70%	94.30%		
Overall accuracy	94.09%				

Table A-4. Validation of cross – manually checking 100 polygons for each category/departmento combination in Google Earth.
Counts of valid polygons out of a sample of 100 for each transition within each region.

	departmento	2009 Validation		2019 Validation	
Forest to Palm	Alta	91	91%	96	96%
	Izabal	89	89%	83	83%
	Petén	79	79%	94	94%
Other to Palm	Alta	76	76%	99	99%
	Izabal	89	89%	89	89%
	Petén	88	88%	97	97%

Table A- 5. **Independent variables and data sources used in the general linear model.**

Independent Variable	**Source**
Total deforestation per plantation, ha (2009-2019)	Calculated
Total ecological encroachment per plantation, ha (2019)	Calculated
Average annual temperature, °C (1970-2000)	Fick and Hijmans (2017)
Average annual precipitation, mm (1970-2000)	Fick and Hijmans (2017)
Total plantation area, ha	RSPO (2021)
Distance to the nearest palm oil mill	World Resources Institute (2019)
Distance to pastureland	Secretaría de Planificación y Programación de la Presidencia (SEGEPLAN)
Distance to road	Open Street Map (2021)
Population density, number of people per pixel	Tatem (2017)
Slope	Jarvis et al. (2008)

Table A- 6. Annual proportions of Guatemalan palm oil export flows by Harmonized System (HS) code for selected years.

This study scope included 1511.10, 1511.90, and 1513.21. Source: Panjiva (2021)

HS Code	Description	2011	2015	2019	Average
1207.10	Palm nuts & kernels	0.0%	0.1%	1.4%	0.50%
1511.10	Palm oil, crude	**79.7%**	**83.2%**	**80.4%**	**81.10%**
1511.90	Palm oil or fractions, simply refined	**12.3%**	**7.8%**	**5.3%**	**8.47%**
1513.21	Palm kernel or babassu oil, crude	**7.9%**	**7.7%**	**8.2%**	**7.93%**
1513.29	Palm kernel & babassu oil, fractions, simply refined	0.0%	0.3%	0.1%	0.13%
2306.60	Palm nut or kernel oil cake & other solid residues	0.1%	0.9%	4.6%	1.87%
	Total Weight (1000kg)	220,480	505,071	940,936	

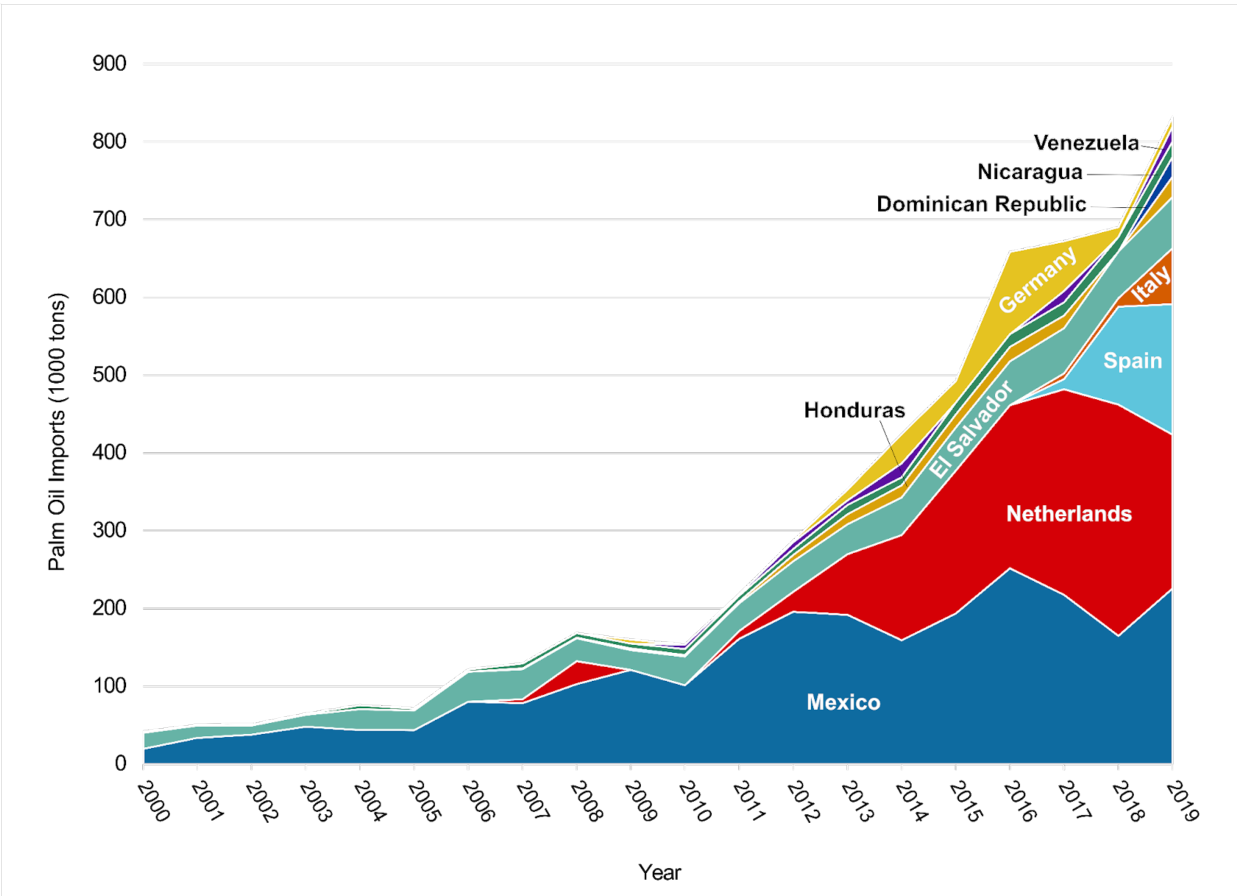

Figure A-1. Top Importers Of Palm Oil from Guatemala, 2000-2019. Note: Data are based on Harmonized System (HS) tariff codes for three primary palm oil products.
Source: Chatham House (2020).

Table A- 7. Approaches and data sources used to track corporate actors and related environmental impacts in Guatemala-Mexico-U.S. palm oil trade.

Approaches	Applications				
	Stakeholder identification	Constructing linkages	Geocoding	Analysis of stakeholder perceptions	Documenting environmental impact
Trade data	✔	✔	✔		
Customs data analysis	✔	✔	✔		
Mill lists	✔	✔	✔		
GIS analysis			✔		✔
Document analysis	✔	✔		✔	

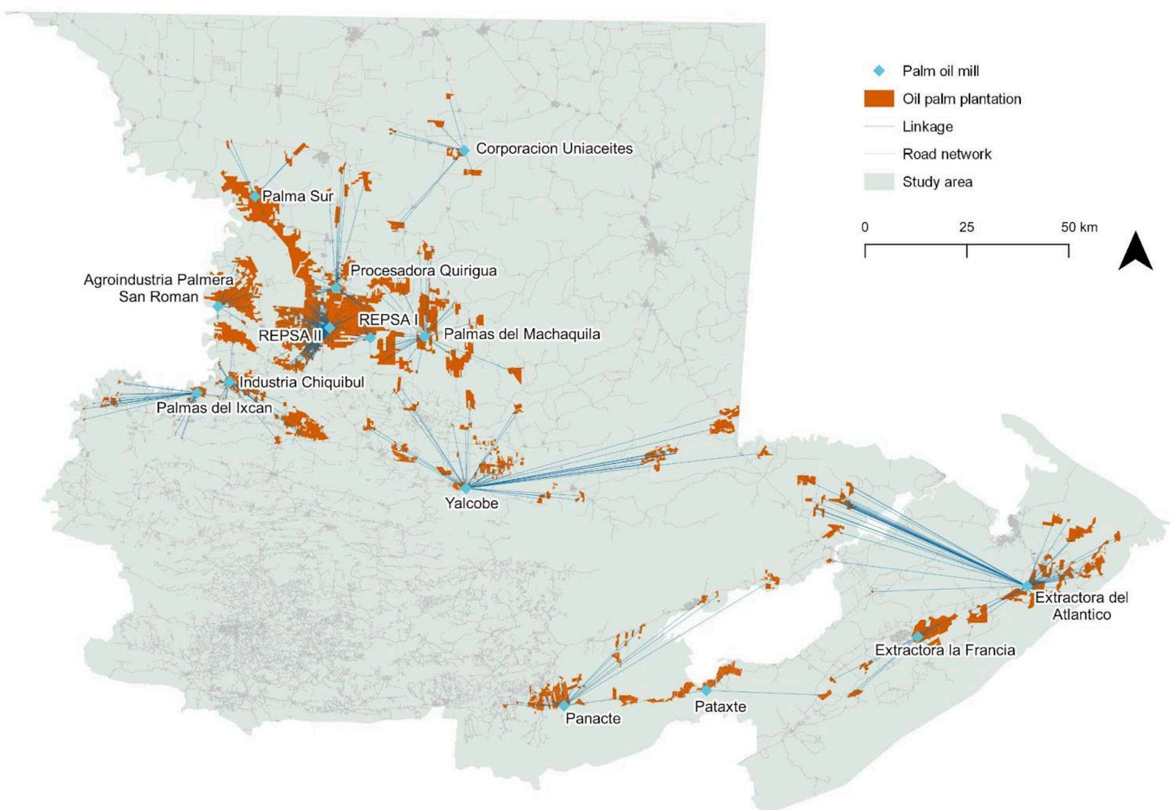

Figure A-2. Plantation-mill linkages in the palm oil supply chains originating in the Guatemalan departamentos of Alta Verapaz, Izabal, and Petén.
Sources: GADM (2018), Open Street Map (2021), REPSA (2020), RSPO (2021), World Resources Institute et al. (2019)

Table A- 8. Data sources used to reconstruct the first-mile of the supply chain.

Data	Description	Source
Universal Mill List	Global collection of palm oil mill locations based on data from major organizations working on supply chain transparency. Although the dataset is not comprehensive, it provides a nonetheless robust, verified collection of mills from major supply chains.	World Resources Institute et al. (2019)
Administrative boundaries	Country outlines and administrative subdivisions for all countries. The level of subdivision varies between countries	Database of Global Administrative Areas (GADM) gadm.org/download_country.html
Road infrastructure	Shapefile of OpenStreetMap data for Guatemala	DIVA-GIS https://www.diva-gis.org/gdata
Palm oil plantations	A single layer shapefile of plantation data aggregated from various sources including government agencies, NGOs, and the RSPO.	RSPO (2021)
	Publicly available PDF map of company operations.	REPSA (2020)
	Google Satellite basemaps used to identify and manually digitize palm oil plantations	Manual digitization
Annual production statistics	Published report on primary economic, social, and market data related to the Guatemalan palm oil sector. Includes detailed statistics on state-level palm oil production data.	GREPALMA (2020)

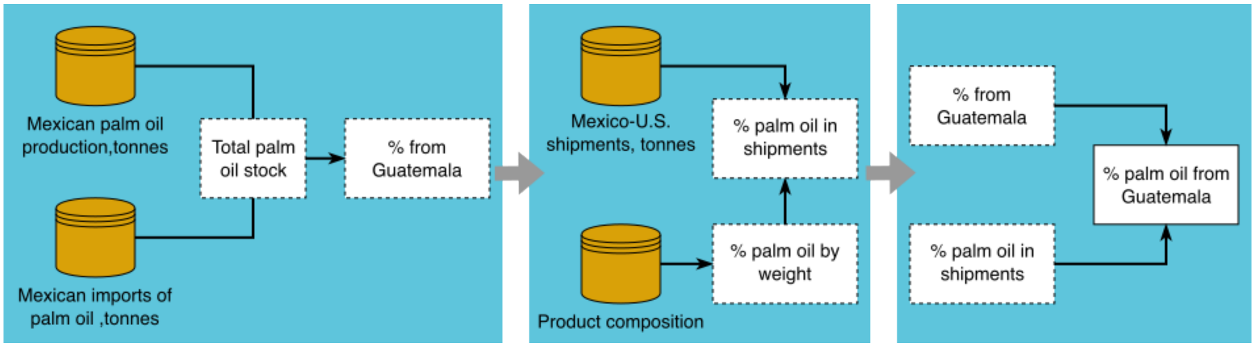

Figure A-3. Process for establishing linkages and flows of Guatemalan palm oil in trade between Mexico and the U.S.

We identified shipments of popularly consumed food products known to contain palm oil (based on ingredient lists) and then calculated estimates of palm oil of Guatemalan origin embodied within them. Calculations are based on shipment weights; product composition; and statistics for Mexico's total palm oil imports, domestic production of palm oil, and domestic consumption of palm oil.

Table A- 9. Cross-tabulation of classification results, 2009-2019.

Description	Land cover (2009)	Land cover (2019)	Area (ha)
Forestland	Forest	Forest	1,155,966
Other	Other	Other	1,208,314
Oil palm plantation	Palm	Palm	45,753
Oil palm plantation on deforested land	Forest	Palm	24,609
Oil palm plantation on non-forestland	Other	Palm	62,716
Non-oil palm deforestation	Forest	Other	347,226
Total			2,811,584

Table A-10. Cross-tabulation of classification results, by region (2009-2019).

Description	Land cover (2009)	Land cover (2019)	Area (hectares)
Alta Verapaz			
Persistent forest	Forest	Forest	535,640.00
Persistent oil palm	Palm	Palm	4,613.00
Other	Other	Other	241,545.00
Palm on deforested area	Forest	Palm	3,238.00
Other deforestation	Forest	Other	146,761.00
Palm with no deforestation	Other	Palm	13,808.00
Reforestation	Other	Forest	112,132.00
Total			1,057,737.00
Izabal			
Persistent forest	Forest	Forest	300,988.61
Persistent oil palm	Palm	Palm	17,033.53
Other	Other	Other	283,433.45
Palm on deforested area	Forest	Palm	2,253.64
Other deforestation	Forest	Other	78,445.37
Palm with no deforestation	Other	Palm	9,717.33
Reforestation	Other	Forest	51,147.22
Total			743,019.15
Petén			
Persistent forest	Forest	Forest	319,337.00
Persistent oil palm	Palm	Palm	24,106.00
Other	Other	Other	683,336.00
Palm on deforested area	Forest	Palm	19,117.00
Other deforestation	Forest	Other	122,020.00
Palm with no deforestation	Other	Palm	39,191.00
Reforestation	Other	Forest	150,138.00
Total			1,357,245.00

Table A-11. Encroachment of oil palm plantations into Key Biodiversity Areas (KBAs) and protected areas (PAs) across the Guatemalan departmentos of Alta Verapaz, Izabal, and Petén, 2009-2019.

	Site name	Palm on deforested area (ha)	Persistent oil palm (ha)	Palm with no deforestation (ha)	Total palm (ha)
KBAs	Río La Pasión	4,221.55	13,767.23	18,016.06	36,004.85
	Caribe de Guatemala	2,059.17	13,660.41	8,610.71	24,330.28
	Sierra de las Minas - Motagua	210.20	2,080.36	709.16	2,999.72
	Lachuá - Ik'bolay	557.79	222.67	1,564.28	2,344.75
	Rio Chajmaic - Sierra Santa Cruz - Semuy	52.43	223.80	581.29	857.52
	Candelaria - Campur	129.53	424.55	292.35	846.42
	Yalijux	0.22	1.67	91.20	93.09
	Total	*7,230.88*	*30,380.69*	*29,865.05*	*67,476.61*
PAs	San Roman	4,126.82	13,492.45	17,747.07	35,366.33
	Sierra de las Minas	171.45	1,122.42	554.14	1,848.00
	Rio Sarstun	406.42	675.22	342.92	1,424.55
	Punta de Manabique	95.16	453.52	180.33	729.01
	Castulo	145.02	245.88	78.31	469.22
	Petexbatun	51.89	137.14	109.54	298.57
	Santa Rosa	7.43	209.57	70.80	287.80
	La Cumbre Flor de la Pasion	99.40	11.31	113.16	223.87
	Dos Pilas	1.85	38.86	60.40	101.11
	Dona Chanita Flor de la Pasion	37.31	3.09	52.39	92.80
	Ceibo Mocho Flor de la Pasion	18.75	0.36	68.42	87.53
	Rio Dulce	0.00	26.75	22.67	49.43
	Quebrada Azul	7.46	14.03	0.16	21.65
	Chabiland Esquina	13.08	5.68	0.18	18.94
	Chajmaik	10.99	2.71	0.89	14.59
	Pataxte	2.37	4.97	0.44	7.78

Site name	Palm on deforested area (ha)	Persistent oil palm (ha)	Palm with no deforestation (ha)	Total palm (ha)
Rio Azul	0.87	3.47	2.53	6.87
Chabiland Cerro	0.91	1.83	0.04	2.78
El Rosario	1.84	0.00	0.45	2.29
Las Cuevas	1.44	0.53	0.19	2.16
Rio Zarco Chiquito	1.25	0.66	0.00	1.90
Selempin	0.33	0.29	0.03	0.64
Matriz Chocon	0.00	0.06	0.01	0.07
Total	*5,202.02*	*16,450.79*	*19,405.05*	*41,057.86*

Table A-12. Count of PepsiCo products included in shipments from Mexico to the U.S., 2019.
Data source: Panjiva (2021)

Product	Count	% of Shipments
Animalitos	36	4%
Arcoiris	37	4%
Barras de coco	55	6%
Chocolatines	2	0%
Chokis	3	0%
Crackets	39	4%
Emperador, chocolate	26	3%
Emperador, combination	16	2%
Emperador, lemon	40	4%
Emperador, pecan	16	2%
Emperador, vanilla	15	2%
Florentina	27	3%
Giro	15	2%
Grageas	18	2%
Hawaianas	34	4%
Lonchera	12	1%
Mamut	24	3%
Maravillas	44	5%
Marias	99	11%
Merengue	14	1%
Pan crema	22	2%
Populares	21	2%
Ricanelas	37	4%
Roscas	13	1%
Saladitas	97	10%
Surtido rico	43	5%
Swafer	2	0%
Swafer, chocolate	53	6%
Swafer, strawberry	42	4%
Swafer, vanilla	38	4%

Table A-13. Estimated palm oil content of PepsiCo products. Notes: Estimates are based on the products as listed in the USDA Food Central database (USDA, 2022).
Lipid content in products is assumed to be 100% palm oil.

Cookie Type	Estimated palm oil per 100 g product (g)
Arcoiris	9.62
Florentina	14.8
Animalitos	3.3
Barras de coco	12.5
Crackets	21.4
Chocolatines	17.9
Chokis	25.9
Mamut	17.2
Marias	12.9
Emperador, chocolate	17.6
Emperador, combination	17.6
Emperador, lemon	16.1
Emperador, pecan	17.6
Emperador, vanilla	20.6
Giro	20
Grageas	13.8
Hawaianas	15.5
Lonchera	9.62
Maravillas	14.3
Merengue	7.14
Pan crema	20.7
Populares	3.23
Ricanelas	14.1
Roscas	13.8
Saladitas	10.3
Surtido rico	26.5
Swafer	26.5
Swafer, chocolate	25
Swafer, strawberry	25
Swafer, vanilla	23.5

Table A-14. Estimated palm oil (PO) embodied in PepsiCo product shipments.

Product	Count	% of Shipments	Shipment weight (tons)	PO content per ton product (ton)	Estimated PO (tons)
Animalitos	36	4%	1,303.14	0.033	43.00
Arcoiris	37	4%	1,339.34	0.0962	128.84
Barras de coco	55	6%	1,990.91	0.125	248.86
Chocolatines	2	0%	72.40	0.179	12.96
Chokis	3	0%	108.59	0.259	28.13
Crackets	39	4%	1,411.73	0.214	302.11
Emperador, chocolate	26	3%	941.16	0.176	165.64
Emperador, combination	16	2%	579.17	0.176	101.93
Emperador, lemon	40	4%	1,447.93	0.161	233.12
Emperador, pecan	16	2%	579.17	0.176	101.93
Emperador, vanilla	15	2%	542.97	0.206	111.85
Florentina	27	3%	977.35	0.148	144.65
Giro	15	2%	542.97	0.2	108.59
Grageas	18	2%	651.57	0.138	89.92
Hawaianas	34	4%	1,230.74	0.155	190.77
Lonchera	12	1%	434.38	0.0962	41.79
Mamut	24	3%	868.76	0.172	149.43
Maravillas	44	5%	1,592.73	0.143	227.76
Marias	99	11%	3,583.63	0.129	462.29
Merengue	14	1%	506.78	0.0714	36.18
Pan crema	22	2%	796.36	0.207	164.85
Populares	21	2%	760.16	0.0323	24.55
Ricanelas	37	4%	1,339.34	0.141	188.85
Roscas	13	1%	470.58	0.138	64.94
Saladitas	97	10%	3,511.24	0.103	361.66
Surtido rico	43	5%	1,556.53	0.265	412.48
Swafer	2	0%	72.40	0.265	19.19
Swafer, chocolate	53	6%	1,918.51	0.25	479.63
Swafer, strawberry	42	4%	1,520.33	0.25	380.08
Swafer, vanilla	38	4%	1,375.54	0.235	323.25
Total	940		34,026.43		5,349.23

Calculation explanation: In 2019 Mexico produced 215 thousand tons of palm oil (Indexmundi, 2022) and imported an additional 3,030 thousand tons of palm oil from 21 countries (Chatham House, 2021). Palm oil from Guatemala comprises 41% of Mexico's combined total of domestically produced and imported palm oil. We assume 41% of the palm oil estimated to be embodied in Quaker products is of Guatemalan origin. This means that in 2019, 2,181.38 tons of Guatemalan palm oil flowed from Mexico to the U.S. via Quaker products.

Table A-15. Count of Mondelēz products included in shipments from Mexico to the U.S., 2019.
Data source: Panjiva (2021).

Product	Count	% of shipments
Barnums	1	0%
Belvita, blueberry	1	0%
Belvita, cinnamon	16	2%
Belvita, golden oat	3	0%
Chips ahoy	44	7%
Chips ahoy, mini	6	1%
Honey maid	27	4%
Honey maid, cinnamon	11	2%
Honey maid, low fat	11	2%
Nabisco cookies classic	5	1%
Nabisco cookies fun shapes	9	1%
Nabisco variety pack	22	3%
Newtons	6	1%
Newtons, blueberry	4	1%
Newtons, fat free	1	0%
Newtons, mixed berry	2	0%
Newtons, strawberry	4	1%
Newtons, whole grain	3	0%
Oreo	69	11%
Oreo, chocolate	8	1%
Oreo, chocolate crème	13	2%
Oreo, chocolate, mini	3	0%
Oreo, double stuf	52	8%
Oreo, golden	34	5%
Oreo, golden, mini	6	1%
Oreo, mini	60	9%
Oreo, mini, chocolate	1	0%
Oreo, mint	10	2%
Oreo, mint crème	8	1%
Oreo, thins	9	1%
Ritz	90	14%
Ritz, everything	3	0%
Ritz, fresh stacks	51	8%
Ritz, garlic butter	11	2%
Ritz, roasted veg	8	1%
Ritz, whole wheat	15	2%
Teddy grahams, honey	4	1%
Unspecified 'cookies'	21	3%

Table A-16. Estimated palm oil content of Mondelēz International products. Notes: Estimates are based on the products as listed in the USDA Food Central database (USDA, 2022).
Lipid content in products is assumed to be 100% palm oil. For "unspecified cookies" the palm oil estimate is based on the average of all cookie products.

Product	Estimated palm oil per 100 g product (g)
Unspecified 'cookies' *	17
Barnums	14.3
Chips ahoy	24.2
Chips ahoy, mini	23.3
Honey maid	14.3
Honey maid, cinnamon	11.3
Honey maid, low fat	5.71
Nabisco cookies classic*	17
Nabisco cookies fun shapes*	17
Nabisco variety pack	21
Newtons	7.14
Newtons, blueberry	5.17
Newtons, mixed berry	5.17
Newtons, strawberry	5.17
Newtons, whole grain	5.17
Oreo	20
Oreo, chocolate	34.5
Oreo, chocolate crème	20.7
Oreo, chocolate, mini	17.9
Oreo, double stuf	24.1
Oreo, golden	24.1
Oreo, golden, mini	21.4
Oreo, mini	20.7
Oreo, mini, chocolate	17.9
Oreo, mint	24.1
Oreo, mint crème	20.7
Oreo, thins	20.7
Ritz	28.1
Ritz, everything	25
Ritz, fresh stacks	28.1
Ritz, garlic butter	25
Ritz, roasted veg	21.9
Ritz, whole wheat	16.7
Teddy grahams, honey	15

Table A-17. Estimated palm oil (PO) embodied in Mondelēz International product shipments.

Product	Count	% of shipments	Shipment weight (tons)	PO content per ton product (ton)	Estimated PO (tons)
Barnums	1	0%	10.62	0.14	1.52
Chips ahoy	44	7%	467.36	0.24	113.10
Chips ahoy, mini	6	1%	63.73	0.23	14.85
Honey maid	27	4%	286.79	0.14	41.01
Honey maid, cinnamon	11	2%	116.84	0.11	13.20
Honey maid, low fat	11	2%	116.84	0.06	6.67
Nabisco cookies classic	5	1%	53.11	0.17	9.03
Nabisco cookies fun shapes	9	1%	95.60	0.17	16.25
Nabisco variety pack	22	3%	233.68	0.21	49.07
Newtons	6	1%	63.73	0.07	4.55
Newtons, blueberry	4	1%	42.49	0.05	2.20
Newtons, mixed berry	2	0%	21.24	0.05	1.10
Newtons, strawberry	4	1%	42.49	0.05	2.20
Newtons, whole grain	3	0%	31.87	0.05	1.65
Oreo	69	11%	732.91	0.20	146.58
Oreo, chocolate	8	1%	84.98	0.35	29.32
Oreo, chocolate crème	13	2%	138.08	0.21	28.58
Oreo, chocolate, mini	3	0%	31.87	0.18	5.70
Oreo, double stuf	52	8%	552.34	0.24	133.11
Oreo, golden	34	5%	361.14	0.24	87.04
Oreo, golden, mini	6	1%	63.73	0.21	13.64
Oreo, mini	60	9%	637.31	0.21	131.92
Oreo, mini, chocolate	1	0%	10.62	0.18	1.90

Product	Count	% of shipments	Shipment weight (tons)	PO content per ton product (ton)	Estimated PO (tons)
Oreo, mint	10	2%	106.22	0.24	25.60
Oreo, mint crème	8	1%	84.98	0.21	17.59
Oreo, thins	9	1%	95.60	0.21	19.79
Ritz	90	14%	955.97	0.28	268.63
Ritz, everything	3	0%	31.87	0.25	7.97
Ritz, fresh stacks	51	8%	541.72	0.28	152.22
Ritz, garlic butter	11	2%	116.84	0.25	29.21
Ritz, roasted veg	8	1%	84.98	0.22	18.61
Ritz, whole wheat	15	2%	159.33	0.17	26.61
Teddy grahams, honey	4	1%	42.49	0.15	6.37
Unspecified 'cookies'	21	3%	223.06	0.17	37.92
Total	**652**	**100%**	**6925.47**		**1464.71**

Calculation explanation: In 2019 Mexico produced 215 thousand tons of palm oil (Indexmundi, 2022) and imported an additional 3,030 thousand tons of palm oil from 21 countries (Chatham House, 2021). Palm oil from Guatemala comprises 41% of Mexico's combined total of domestically produced and imported palm oil. We assume 41% of the palm oil estimated to be embodied in Mondelēz International products is of Guatemalan origin. This means that in 2019, 597.30 tons of Guatemalan palm oil flowed from Mexico to the U.S. via Mondelēz International products.

Table A-18. Estimated palm oil content of Grupo Bimbo products by category. Notes: Estimates are based on the Grupo Bimbo products listed in the USDA Food Central database (USDA, 2022).
Lipid content in products is assumed to be 100% palm oil.

Product category	Estimated palm oil per 100 g product (g)
Assorted Pastries	20.17
Breads & Buns	6.34
Cookies & Biscuits	21.47
Stuffing	4.43

Table A-19. Count of Grupo Bimbo products included in shipments from Mexico to the U.S. 2019, by category. *Data source: Panjiva (2021). Note: Shipments are categorized based on product description provided as "goods shipped."*

Product description	Count	Percentage of shipments
Assorted Pastries	172	23%
Bread	148	19%
Cookies & Biscuits	381	50%
Stuffing	63	8%
Total	764	

Table A-20. Estimated palm oil (PO) embodied in Grupo Bimbo product shipments.

Product description	Weight (tons)	Estimated PO (tons)	Estimated PO from Guatemala (tons)
Assorted Pastries	24,670.89	4,976.12	2,029.23
Bread	21,228.44	1,346.41	549.06
Cookies & Biscuits	54,648.89	3,901.93	1,591.18
Stuffing	9,036.43	400.11	163.16
Total	109,584.66	10,624.58	4,332.63

Sample calculations:

109,584.66 tons * .23 = 24,670.89 tons

$$24{,}670.89 \text{ tons} \quad * \quad \frac{0.2017\text{g PO}}{1\text{g pastries}} \quad * \quad \frac{1{,}000{,}000\text{g pastries}}{1 \text{ ton pastries}} \quad * \quad \frac{1 \text{ ton PO}}{1{,}000{,}000 \text{ g PO}} = 4{,}976.12 \text{ ton PO}$$

In 2019 Mexico produced 215 thousand tons of palm oil (Indexmundi, 2022) and imported an additional 3,030 thousand tons of palm oil from 21 countries (Chatham House, 2021). Palm oil from Guatemala comprises 41% of Mexico's combined total of domestically produced and imported palm oil. We assume 41% of the palm oil estimated to be embodied in Bimbo Bakeries products is of Guatemalan origin. This means that in 2019, 4,332.63 tons of Guatemalan palm oil flowed from Mexico to the U.S. via Bimbo Bakeries products.

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Appendix B

Supplementary Information: Theorizing Certification-Driven Supply Chain Embeddedness

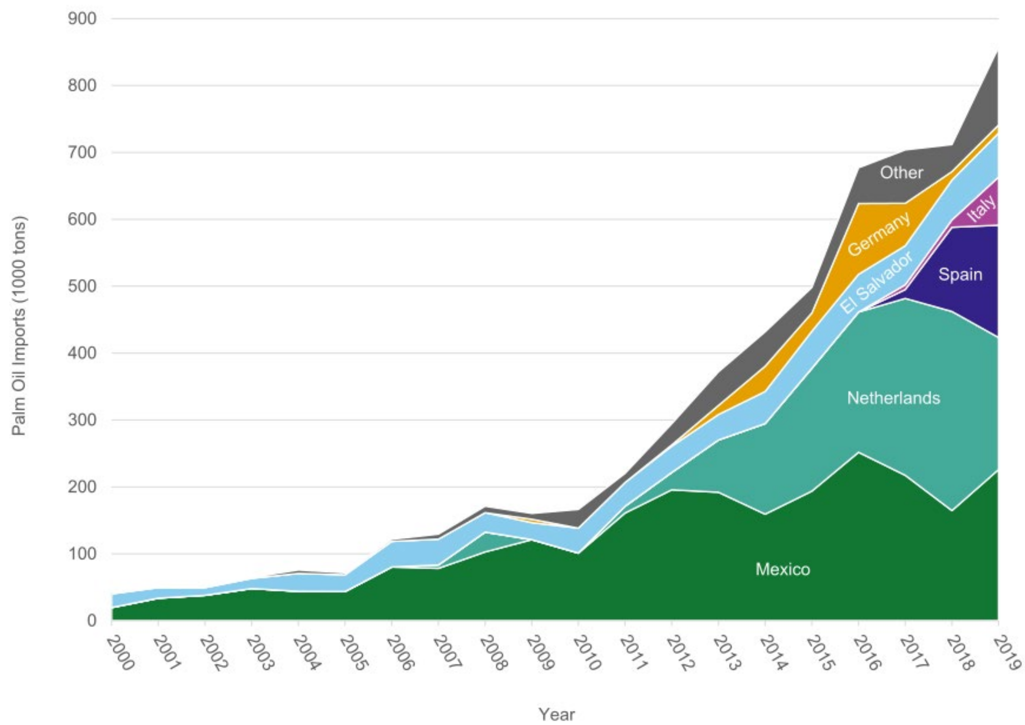
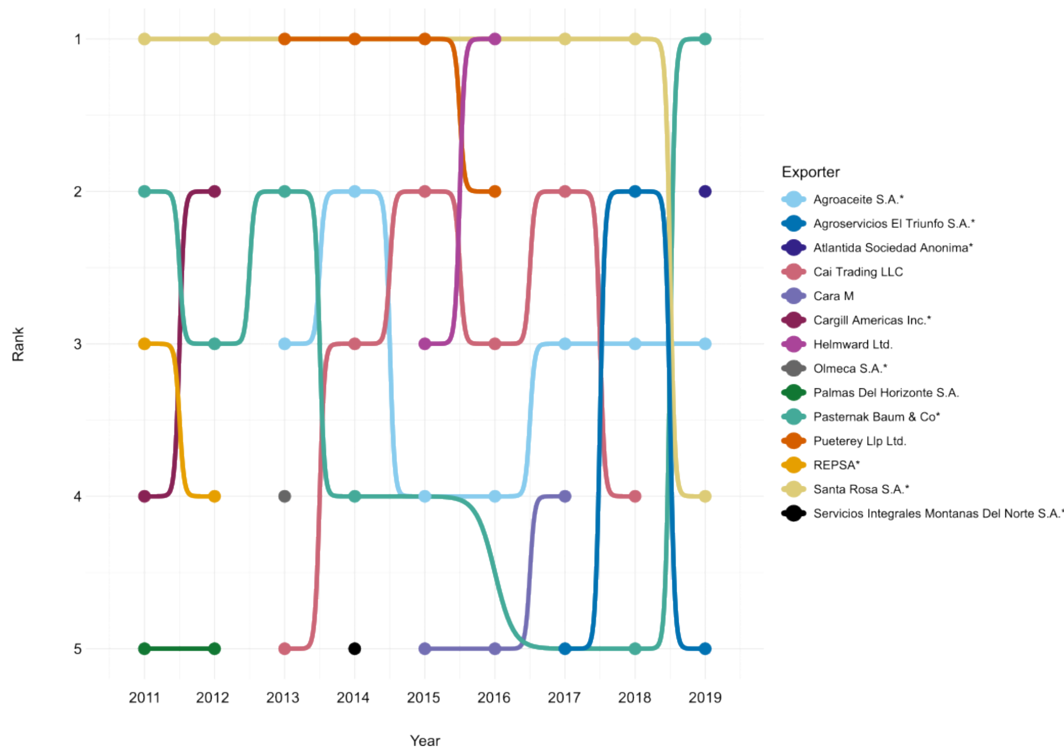


Figure B- 1. Top Importers of Palm Oil from Guatemala, 2000-2019.
Data are based on Harmonized System (HS) tariff codes for three primary palm oil products. Source: Chatham House (2021).

Figure B-2. Exports of RSPO-certified and non-certified palm oil from Guatemala to Mexico between 2011 and 2020.
Labels indicate the percentage of annual exports that were RSPO-certified palm oil by weight.
Source: Panjiva (2021).

(A)



(B)

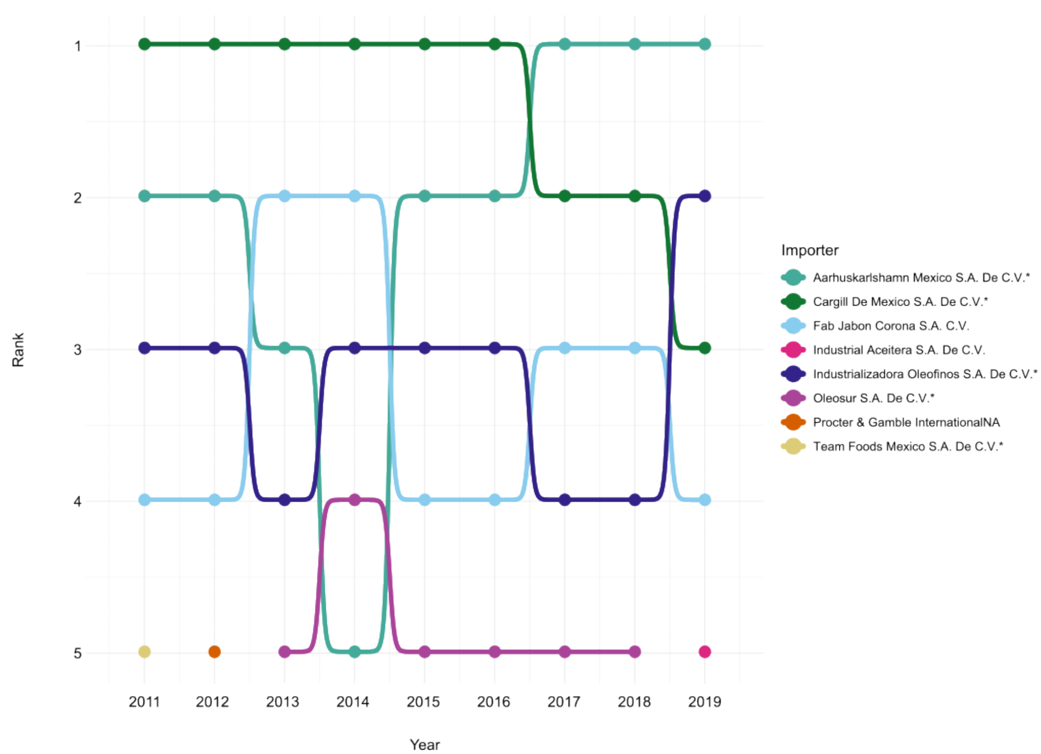


Figure B-3. Top ranking firms by trade volume, Guatemala-Mexico palm oil trade, 2011-2020. *Exporters are shown in (A), while importers are shown in (B). Note: An * indicates RSPO membership.*

Table B- 1. Themes from thematic analysis of company reports Annual Communications of Progress (ACOP) reports to the Roundtable on Sustainable Palm Oil (RSPO).

Theme	Explanation	Examples
Certification requirement	Buyers have established RSPO-certification as a precondition, or priority, for supplier selection	• "We require that all our suppliers are RSPO certified" • "We will promote by sourcing derivatives only from RSPO members" • "Maintain commercial ties with those certified suppliers and prioritize the creation of new certified suppliers"
Relational investment	Buyers invest (time, money, or expertise) in RSPO-certified suppliers	• "Continue to build relationships with our certified suppliers" • "Close coordination with suppliers of palm oil sourced materials to ensure the long term vision of RSPO is uphold and supported." • "Strict control of suppliers to provide relevant information"
Supplier certification	Buyers facilitate the certification of their existing suppliers. This includes capacity building, funding, and coordinated efforts	• "We plan to fund to our key suppliers in [order] to promote the RSPO. / with training program" • "We are preparing RSPO certificates with our suppliers " • "We will be directly involved to help suppliers to get RSPO certification"
Socializing certification	Buyers encourage RSPO certification to suppliers. However, they do not assist in the certification process or make certification a prerequisite for doing business	• "meetings and dialogues with our customers and suppliers explaining to them the benefits of RSPO certification and importance of CSPO" • "Encourage CPO suppliers who are not certified to implement RSPO P&C and go for certification" • "We will push our existing suppliers to participate in RSPO certification"
Certification neutral	Market demands determine whether the buyer partners with suppliers. Certification is not of primary concern	• "As traders, our business is dependent on supply and demand" • "As a trading company, [we rely] on offers from suppliers and manufacturers" • "Address the demand from our customers to our suppliers. If availability and demand meet requirements, we look forward to distributing more RSPO products"

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