IIIEE Theses 2020:06

Sustainability risks in multi-tier supply chains.

A dynamic capabilities perspective on integrating remote sensing technology into sustainable sourcing to manage sustainability risks in upstream supply chains.

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Thesis for the fulfilment of the
Master of Science in Environmental Management and Policy
Lund, Sweden, May 2020

LUND UNIVERSITY

iiiee
THE INTERNATIONAL INSTITUTE FOR INDUSTRIAL ENVIRONMENTAL ECONOMICS

Published in 2020 by IIIEE, Lund University, P.O. Box 196, S-221 00 LUND, Sweden,
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ISSN 1401-9191

Acknowledgements

This thesis marks a personal milestone and end of an inspiring two years with an extraordinary bunch of people at the IIIEE. It's been a challenging, at times frustrating, and overall very empowering experience and I want to thank anyone who has been part of this.

Thank you to my supervisor, Philip, for supporting my work with fast responses, critical feedback, and confidence in my abilities. I got valuable impulses and food for thought from our discussions and very much appreciate that I had a lot of freedom on how to pursue this work.

Thank you to my Tetra Pak supervisors, Julian and Johan, for trusting me with the topic. When we first started talking about this project, remote sensing and satellite technology were a black box to me. Looking back, I am impressed by how much one can learn from scratch in just four months and could not be happier with the topic choice. Thanks for the chance to step out of my box and explore supply chain sustainability from a novel angle.

Thanks to my peer reviewers, Roohi, Tamsin and Daniel, for going over this work again and again and again with patience and creativity. Thank you, Bea, for critical questions, full support and, specifically, for letting me tap your experience and ideas on supply chain related questions. Thanks, Håkan, for early-stage discussions on the topic and more generally for your honest feedback, advice and enthusiasm. I'll remember to have fun while 'saving the world'.

Thanks to friends and family for providing moral support, diversion and perspective. Special thanks to Henrik for always having my back whether it comes to the thesis, plietsch or life. Knowing you have full confidence in me pushes me to do what I do.

Thanks to my interviewees for taking some of your scarce time to share your experiences - this was vital input for my work. While a lot remains to be done about sustainability in supply chains, it was inspiring to see such a connected, action-oriented community and made me look forward to getting back into practice.

Finally, congratulations to Batch 25 for handling this thesis project under extraordinary circumstances. A big thank you for the last two years, I am excited for the futures ahead of us.

Malmö, 18 May 2020

Abstract

The raw material tier in companies' supply chains can be a hotspot for sustainability issues like deforestation and resulting legal, reputational and operational risks – yet companies' supply chain management efforts as well as research on sustainable supply chain management still focus on direct suppliers due to poor upstream transparency. With technical progress, remote sensing and satellite technology now allow companies to gain systematic, direct oversight of deforestation and related environmental change on the ground. This thesis addresses the research gap surrounding this largely practical phenomenon to synthesize lessons learned from current practice and contribute to better informed, data-driven supply chain sustainability risk management. This work draws on dynamic capabilities theory and multi-tier sustainable supply chain management theory to understand how a novel technical resource – remote sensing – connects to existing sustainable sourcing practices and governance mechanisms for managing sustainability across tiers. Empirical data is collected from 13 semi-structured expert interviews and 67 practitioner documents (reports, articles, websites, podcasts, webinars) and analyzed with a qualitative content analysis in NVivo. The results are synthesized into a conceptual framework and show that remote sensing requires integration into a mature sustainable sourcing approach that structures buyers' internal resources and skills to fulfill traceability, monitoring, follow-up and stakeholder accountability functions. The thesis further differentiates three governance mechanisms (working along the supply chain, across supply chains and across sectors) that buyers employ to compensate for internal weaknesses by gaining access to complementary external resources and skills. The conceptual framework highlights that remote sensing is no stand-alone or one-size-fits-all solution and specifies elements for companies to consider when adopting remote sensing or rethinking their sustainable sourcing. For research, it highlights the need for further insights into managing sustainability in opaque upstream supply chains.

Keywords: sustainable supply chain management; supply chain risk; remote sensing technology; deforestation; multi-tier supply chains; resilience; dynamic capabilities

Executive Summary

Distant upstream tiers like the raw material stage in companies' supply chains can be a hotspot for sustainability issues and resulting legal, reputational and operational risks. Companies acknowledge this growing exposure and seek to expand their sustainability efforts beyond own operations and direct suppliers. Yet, complex global supply chains severely limit the ability to reliably monitor and manage these risks on the ground at geographically and operationally distant raw material suppliers. This is particularly the case for forest-risk commodities like palm oil or wood products sourced from regions with vulnerable ecosystems and communities. Remote sensing leverages geospatial data to monitor environmental change like deforestation and is viewed as a potential solution for more direct, continuous insights into the situation on plantations, fields or forests. However, while remote sensing is no novel technology, its application by buyers for sustainable supply chain management (SSCM) is only emerging and to date remains a largely practical phenomenon that has not been systematically analyzed in research. Research on remote sensing in the commodity supply chain context focuses on the technology's use by actors other than buyers, while remote sensing technology receives limited attention in SSCM research, yielding a lack of interdisciplinary insights into the adoption process, capacities and limitations of remote sensing, as well as its potential for risk reduction and change on the ground. As adoption by multinational buyers in practice continues to grow, this thesis seeks to leverage empirical data to analyze current practice and synthesize the foundation for further research and improved use or uptake in practice.

The **research aim** is to produce empirical insights that contribute to better informed, data-driven management of sustainability risks across upstream supply chain tiers of forest-risk commodities in practice. The theoretical lens for analyzing the empirical data is based on Tachizawa and Wong's (2014, p. 657) framework on multi-tier SSCM and dynamic capabilities theory (Barreto, 2010; Teece, Pisano, & Shuen, 1997) to critically assess how a novel technical resource – in this case remote sensing – connects to existing sustainable sourcing practices and governance mechanisms to enable systematic sustainability risk monitoring, management and prevention across tiers. The addressed research questions are as follows:

RQ 1:	**Why are buyers implementing remote sensing technologies** to monitor deforestation-related sustainability impacts in their upstream supply chain?
RQ 2:	**How are remote sensing technologies** used by buyers for monitoring deforestation-related impacts in their upstream supply chain **integrated into other SSCM measures**?
RQ 3:	**What are the challenges and opportunities** related to using remote sensing technologies for monitoring deforestation-related impacts in the upstream supply chain?

The **research design** follows an exploratory, case-based approach to account for the novelty of applying remote sensing in sustainable sourcing and generate in-depth insights into current practices, address the corresponding research gap and synthesize lessons learned. The empirical basis encompasses data from 13 expert interviews conducted specifically for this research (see Appendix I and II) as well as 67 documents (28 websites and 21 practitioners reports, 11 news articles, 3 industry podcasts, 4 webinars; see Appendix V) by or featuring experts involved in the development, provision or use of remote sensing for supply chain monitoring, i.e. buyers, technology providers, NGOs and certification schemes. The data was systematically reviewed through qualitative content analysis in NVivo and subsequent in-depth analysis of identified themes. The initial coding framework (see Appendix III) for analyzing data in NVivo was based on SSCM literature, and specifically multi-tier SSCM and dynamic capabilities theory, and adjusted iteratively based on emerging findings during the coding (see Appendix IV).

The **research results** show that, in terms of the current application landscape, remote sensing tools are predominantly used in palm oil and cocoa supply chains (increasingly also pulp and paper, rubber and soy) for monitoring deforestation (increasingly also related and more granular impacts like forest degradation, forest conversion and reforestation or carbon stocks).

The **first research question** (see RQ1) can be answered as follows: Buyers are implementing remote sensing technologies because growing, diversifying business risks and stakeholder pressure increase the potential cost of business-as-usual, because existing certification schemes are unable to effectively mitigate these risks, because technological progress and declining costs make better technology more affordable, and because future opportunities and gains promised by operational efficiency improvements and proactive sourcing strategies increase. Overall, this study, thus, shows that the business case for remote sensing adoption is growing stronger.

For the **second research question** (see RQ2), it is concluded that buyers who adopt remote sensing tools already have a mature SSCM in place which enables the effective use of remote sensing by providing three connected functions: first, a traceability function that enables accurate monitoring by linking remote sensing data to supplier locations; second, a follow-up function that ensures remote sensing data is acted upon effectively to mitigate sustainability risk on the ground; third, an accountability function that harnesses remote sensing data to provide transparent assurance to stakeholders thereby mitigating reputational, financial, and legal risks. Buyers' ability to fulfill these functions internally can vary. To complement internal weaknesses with relevant external resources and skills, like geospatial analytics skills or staff for on-site verification, buyers draw on three collaboration types, i.e. along the supply chain, across supply chains/industries and across sectors. Jointly, internal SSCM skills and complementary external collaboration form a dynamic capability, enabling the buyer to systematically monitor issues, anticipate risks and opportunities, take timely action and continuously adjust the resource base.

The **third research question** (see RQ3) can be answered as follows: Challenges in the adoption and effective implementation of remote sensing emerge concerning technical limitations of different tools, data availability and ownership, buyers' internal capacities, collaboration and effective follow-up. Future opportunities were found to emerge regarding new use cases (such as pulp and paper or soy and forest conversion or aboveground biomass monitoring), broader monitoring across buyers' multiple commodity supply chains, moving beyond issue detection to prevention, as well as reforestation monitoring for carbon credits and offsetting.

The **contributions** of this thesis are fourfold: First, it investigates remote sensing tools available for the sustainable sourcing context as well as the drivers, process, challenges and opportunities of integrating them into existing SSCM practices. While acknowledging that no universal step-by-step manual for effective remote sensing adoption can be derived, the thesis identifies the critical elements that are relevant for buyers to consider, provides illustrations of how case companies have approached these challenges in their context, and outlines connected exercises that can support this process, thus supporting more informed, data-driven sustainable sourcing. Second, this thesis examines a largely practical phenomenon and condenses insights into a conceptual framework that lays the foundations for future inter- and transdisciplinary research across remote sensing research (where research in the commodity supply chain context focused on remote sensing use by actors other than buyers like governmental bodies, NGOs or research) and SSCM and sustainability risk research (where research on remote sensing is essentially non-existent and research into sustainability risks and their management at distant, indirect raw material suppliers is only emerging) to close the corresponding research gap. Third, this thesis suggests complementing the risk-focused approach in sustainable supply chain research with a more opportunity-oriented perspective by drawing on dynamic capabilities theory and validating this extension with empirical data, i.e. outlining an emergent focus on strategic opportunities in the context of volatile, dynamic sourcing environments in practice. Fourth, this thesis outlines why and how buyers adopt remote sensing and under which challenges, thus synthesizing insights for organizations like technology providers or NGOs working in the commodity supply chain context to better understand how they may be able to provide value or may need to adjust their approach to more effectively meet clients' needs or effect change on the ground.

The main **practical implications** deduced from the research results are: Buyers already using remote sensing tools can use the framework to analyze weaknesses and strengths in their approach, evaluate collaborations and the value of internalizing skills, and derive strategic conclusions considering risks, stakeholder pressures and opportunities. Buyers considering adopting remote sensing can use the framework to position their company by taking stock of internal resources and skills, drivers, stakeholders, existing supplier relations and collaborations. In essence, the framework suggests that: *Buyers need to have supply chain visibility. Buyers need to have the capacity to act (and thus manage sustainability risk on the ground). Buyers need to be able to credibly demonstrate their efforts to internal and external stakeholders (and thus manage resulting reputational, legal, operational or financial risk). Buyers need to understand our drivers (including their risk profile, their salient stakeholders and how the latter impact the former). Technology can help connect and achieve the above points in a more targeted, fact-based and efficient way.* Based on their positioning, buyers can evaluate if and how remote sensing is most suitable to their needs and what questions to discuss with potential partners like technology providers. Overall, remote sensing is no stand-alone solution but depends on a mature supporting SSCM and it is no one-size-fits-all solution but most effective when tailored to buyers' needs and context. Lastly, it does not have to be remote sensing if forest-risk commodities are a minor supply share or if a lack of SSCM expertise, budget, staff or power severely restricts buyers' ability to systematically use remote sensing.

In **conclusion**, remote sensing represents a potent technology for gaining more transparency over upstream supply chains and more control over hidden sustainability risks – yet its effectiveness, as for many technologies, depends on the companies using it, their commitment and their understanding of their own business, supply chain, materials and stakeholders. Perhaps the most essential underlying commitment is accepting that adopting remote sensing may uncover considerable upstream issues or traceability gaps that increase exposure to stakeholder scrutiny and require consequent sustainability leadership to prevent backfiring. It is encouraging to see that some companies are taking this step and driving results-oriented action towards mitigating sustainability risk in upstream supply chains. Taking a similar leap in SSCM research, to expand the focus from straightforward buyer-supplier relationships to the opaque area of managing upstream sustainability risk at distant raw material suppliers, is now up to future research. This thesis has taken the first step and outlined research pathways.

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Abbreviations

CDP - Carbon Disclosure Project

GFW - Global Forest Watch

NGO - non-governmental organization

RADD - Radar Alerts for Detecting Deforestation initiative

RSPO - Roundtable for Sustainable Palm Oil

SSCM - sustainable supply chain management

WRI - World Resource Institute

1 Introduction

The raw material tier in companies' supply chains can be a hotspot for sustainability issues and resulting legal, reputational and operational risks. Further, sustainability issues tend to be more likely and impactful, the further upstream they occur (Meinlschmidt, Schleper, & Foerstl, 2018). It is estimated that "more than half of supply chain risks lie with 2nd or 3rd tier suppliers" (Sourcemap, 2016) and "the further upstream an organization is the more impact it is likely to have on sustainability" (Mena, Humphries, & Choi, 2013, p. 72). This is particularly the case for issues like deforestation, illegal logging or resulting biodiversity loss in global supply chains of forest-risk commodities like palm oil, soy, beef or wood products (Thomson & Rogerson, 2020; Wolf, 2014). Climate change is the vital challenge of this generation and due to insufficient action has evolved in a vital threat to biodiversity and humankind. Besides cutting fossil fuel and meat consumption, two central leverage points for mitigating climate change are stopping deforestation and fostering reforestation of rainforest areas that serve as biodiversity hotspots and critical carbon sinks (Bastin et al., 2019; Falk et al., 2019).

Loss of forests aggravates climate change by releasing carbon dioxide and destroying important carbon storing biomass (Margono, Potapov, Turubanova, Stolle, & Hansen, 2014). Intact forests, on the other hand, provide crucial ecosystem services for local communities and globally (Newton, Agrawal, & Wollenberg, 2013; WWF, 2015). Thus, removing deforestation from the supply chains of everyday consumer products would yield substantial environmental and societal benefits and could reduce the legal, reputational and operational risks that buyers face from deforestation issues at their raw material suppliers.

In practice, however, poor transparency in supply chains represents a critical barrier. Most buyers lack visibility of raw material suppliers (Kashmanian, 2017), and thus focus on direct suppliers (Choi & Linton, 2011) where they have clear visibility, direct communication lines and influence via contractual relations (Seuring & Müller, 2008a). This focus on direct suppliers is reflected in sustainable supply chain management (SSCM) research where attention for explicit multi-tier SSCM is only emerging (Sauer & Seuring, 2019; Tachizawa & Wong, 2014). Concerning raw material suppliers, buyers have historically relied on certification to bridge the visibility gap and ensure responsible practices at the source – but trust in certification and their on-the-ground impact is challenged (Marin-Burgos, Clancy, & Lovett, 2015; Schepers, 2010).

Recent technological progress creates the opportunity to gain gaining more direct insights into the on-the-ground situation at raw material suppliers and providing additional assurance beyond certification. Environmental monitoring technologies, like remote sensing, i.e. "the use of aerial or satellite imagery to study features on Earth's surface" (Werner, Bebbington, & Gregory, 2019, p. 994) show substantial technological improvements and price drops (Guo et al., 2017) – making them intriguing for companies aiming to monitor issues that are related to land use change or deforestation in sourcing regions. A Swedish company facing this question of whether to adopt remote sensing is Tetra Pak who currently rely on third-party certification to ensure sustainable sourcing of their main materials and would like to go beyond that. Tetra Pak is therefore considering utilizing technologies to gain a more direct, continuous view of the forests, mines or plantations they source from and seeks to understand how other buyers have approached this, thus agreeing to host this thesis project.

This thesis investigates current applications of remote sensing technology by companies to monitor deforestation-related impacts at their raw material suppliers. Specifically, the thesis analyzes and condenses insights from pilot projects and broader roll-outs in practice to understand current patterns, challenges and opportunities in order to synthesize the critical factors necessary to enable the systematic monitoring, management and prevention of deforestation-related supply chain impacts at the raw material stage.

1.1 Problem definition

Companies perceive increased exposure to business risks resulting from sustainability issues at distant raw material suppliers. This is particularly the case for complex multi-tier supply chains of forest-risk commodities such as palm oil, cattle, soy and wood products that can often be associated with deforestation. Forests serve as vital carbon sinks and habitats, and thus are a critical element for mitigating climate change and biodiversity loss while 'business-as-usual' destruction can push global climate past its tipping points. In light of this urgency, stakeholders are pressuring buyers to halt deforestation and increase supply chain transparency.

Through stakeholder pressure, sustainability issues like deforestation that happen far upstream the supply chain translate into substantial business risks and repercussions for buyers. Yet, buyers currently lack the ability to transparently monitor and mitigate these issues on the ground. Certification schemes used to provide a greater extent of assurance but their legitimacy is challenged by recurring criticism concerning their ability to create lasting change on the ground, by new and less transparent labels entering the market and by resulting distrust from confused consumers. Technologies like remote sensing represent an opportunity for gaining more direct, continuous insights into the situation in suppliers' plantations, fields or forests and thus enable more accurate risk monitoring. In this sense, buyers who adopt remote sensing stand to gain transparency over the previous black box of deforestation-related impacts at distant suppliers (and looming stakeholder backlash). Yet, they also expose themselves to the accountability and need to respond to issues detected by these gains in transparency (and potentially stakeholder pressure). And while visibility across the supply chain may have increased, influence over raw material suppliers' practices may still be restricted, leaving buyers in a tricky situation.

The move from risk monitoring to more comprehensive risk management is a complex undertaking and may require companies to have additional measures in place: Complementary SSCM practices like supplier mapping exercises, certification or audit procedures could help standardize how remote sensing data is used internally and acted on. External collaboration with suppliers along the chain, or even industry peers and external stakeholders could support buyers' efforts and leverage additional knowledge or influence. Such internal and external support structures presumably affect how useful remote sensing tools are to buyers and how much they contribute to an improved risk oversight and management.

However, remote sensing use for monitoring sustainability risks in supply chains is a largely practical phenomenon driven by a handful industry leaders that has not been empirically or conceptually investigated in SSCM research. Systematic insights and guidance on how to navigate the above challenges and effectively leverage remote sensing's full potential for sustainability risk management are lacking.

1.2 Aim, research questions and contributions

The discussion above has highlighted a need for more data-driven supply chain sustainability management in practice and more scientific investigation of the topic in SSCM research. Pursuant to this, this thesis seeks to contribute to two areas:

First, the thesis aims to contribute to better informed, data-driven management of supply chain sustainability risks. Remote sensing technology is receiving growing interest for its potential to provide sound insights into developments on the ground – yet, to arrive at data-driven management and possibly prevention of deforestation-related supply chain risks, buyers need to be able (A) to select the suitable remote sensing tool, (B) to understand which factors determine what makes a tool 'suitable' to their needs, (C) to identify relevant organizational resources, skills or supply chain data that need to be in place for successful adoption of a tool,

(D) to be aware of challenges they may face during implementation, (E) to understand which skills, resources or measures are necessary to move from pure monitoring to management of issues, and finally (F) need to be able to consider and implement all these considerations. This thesis aims to shed light on these aspects and produce insights that contribute to a more effective use of remote sensing in SSCM and, overall, to better informed, data-driven management of deforestation-related supply chain impacts and resulting business risks.

Second, the thesis aims to provide substantiated insights into where more research on strategic, technology-assisted management of sustainability risk across supply chain tiers, and to facilitate research into this intersection by outlining future pathways for research. Since remote sensing research in the commodity supply chain context focuses on remote sensing use by actors other than buyers, and since remote sensing technology receives limited attention in SSCM research, while seeing adoption by major multinationals in practice, this thesis leverages empirical data to synthesize the foundation for future research of practical relevance. Applying multi-tier SSCM and dynamic capabilities theory, this thesis suggests that how buyers' complement remote sensing with other SSCM practices and how buyers engage with suppliers, industry peers or external actors determines whether buyers are able to tap remote sensing's full potential. The theoretical lens for analyzing the data, thus, draws on Tachizawa and Wong's (2014, p. 657) framework on mechanisms for multi-tier SSCM and dynamic capabilities theory (Barreto, 2010; Teece et al., 1997) to assess how a novel technical resource – like remote sensing – connects to existing SSCM practices and governance mechanisms to move from pure risk monitoring to more systematic risk management and prevention across tiers.

The **research questions** addressed in this thesis are the following:

RQ 1:	**Why are buyers implementing remote sensing technologies** to monitor deforestation-related sustainability impacts in their upstream supply chain?
RQ 2:	**How are remote sensing technologies** used by buyers for monitoring deforestation-related impacts in their upstream supply chain **integrated into other SSCM measures**?
RQ 3:	**What are the challenges and opportunities** related to using remote sensing technologies for monitoring deforestation-related impacts in the upstream supply chain?

1.3 Limitations and scope

This thesis' scope is defined as follows to allow for sufficiently comprehensive coverage and analytical depth while accounting for external restrictions such as time and resource constraints posed by the thesis project requirements. Taking these into consideration, the thesis focuses (1) on technologies for remote sensing and establishing transparency (vs. technologies for establishing tracking and traceability across the supply chain), (2) on environmental aspects observable via remote sensing (vs. economic or social aspects), (3) on buyers that source forest-risk commodities and use remote sensing, (4) on aspects linked to the activities of raw material suppliers (vs. direct suppliers only), (5) on a focal company's managerial perspective (vs. the perspective of governmental, non-governmental or other supply chain actors).

Central limitations emerging from this research scope relate to the relative novelty of applying remote sensing in sustainable sourcing. This thesis is positioned at the intersection of SSCM, sustainability risks and remote sensing. While there is substantial research on remote sensing in various disciplines, also related to supply chains, research in SSCM or general management journals or articles explicitly taking a buyer perspective are rare. At the same time, examples of practical uptake by companies are growing, as are remote sensing tools, yielding a dynamic field where research is perceived as currently lagging practice. Thus, the theoretical framework and coding structure guiding data collection and analysis are not directly derived from a single, remote-sensing or technology-specific framework but rather synthesized interdisciplinarily combining elements from dynamic capabilities and multi-tier SSCM theory and the literature review. This was deemed necessary to suit the research topic but may be less specific.

1.4 Ethical considerations

The research is supported by Tetra Pak and covers a subject relevant to Tetra Pak's operations. The thesis topic, scope and aims have been agreed upon with external supervisors from Tetra Pak and there is regular exchange on the thesis progress and relevant sources or interview partners to include. The thesis is exploratory and focuses on a field new to Tetra Pak, thus, there is no direction of results that is better or worse and may thus skew the research and integrity. For transparency, the collaboration is explicitly disclosed in this file and to interview partners. Participation in interviews for this thesis is voluntary and participants are informed about the research subject and aim, the collaboration with Tetra Pak and how data will be used beforehand for transparency. It is not expected that knowledge of the research interests will critically alter the participants' responses, trigger conformity with the researcher's expectations or socially desirable answers. Participants are given the option to have their organization anonymized in the publication to account for potential confidentiality concerns. Further, interviews are recorded and transcribed for practicality and reliability of the analysis. Before interviews, participants are informed about this, the right to opt out and asked for consent.

1.5 Audience

This thesis produces insights into current applications of remote sensing in SSCM, outlines drivers, internal structures and challenges for integrating it into existing SSCM practices. Thereby, this thesis expects to contribute to research and practice: By analyzing and positioning remote sensing tools in the context of SSCM and sustainability risk management, the thesis adds a **novel perspective to SSCM research** and outlines pathways for future research into data-driven supplier management as a means to deal with growing complexity of supply chains, sustainability issues and resulting business risks. By empirically investigating and outlining current practices, adoption drivers, challenges and opportunities, the thesis produces **practical guidance for buyers** concerning elements to consider for effective use of remote sensing to systematically monitor and manage deforestation-related impacts in upstream supply chains.

1.6 Outline

This thesis is organized as follows: **Chapter 1** introduces the topic by defining the research problem addressed in this thesis, the specific research questions guiding the analysis and the overarching aim driving the research interest. Further, it outlines necessary and deliberate limitations, the intended audience and makes explicit any ethical concerns. **Chapter 2** provides the broader theoretical background and disciplinary context of this thesis. Since the thesis is positioned at the intersection of the fields of SSCM, sustainability risk and remote sensing technology, chapter 2 introduces central theories and terms from these fields and develops the framework guiding data analysis. **Chapter 3** reviews the current state of research on remote sensing technology in the supply chain context to give a nuanced understanding of what this thesis builds on and contributes to. **Chapter 4** outlines the research design and logic underlying this thesis. It presents the methods chosen for data collection and analysis, the reasoning behind selecting these, their limitations, and approaches for mitigating these. **Chapter 5** presents the main findings and their analysis. The data retrieved from documents and interviews is analyzed and synthesized into a conceptual framework. **Chapter 6** discusses the findings regarding their significance and relevance, questions the methodology's soundness and limitations in terms of design, implementation, and interpretation, and critically reviews the thesis' practical implications and academic contributions. **Chapter 7** provides a conclusion by answering the research questions and outlining pathways and critical aspects for future research and practice.

2 Background and theoretical framework

The purpose of this chapter is twofold: First, it develops the background and disciplinary context of this thesis which is positioned at the intersection of the research fields of SSCM, sustainability risk and remote sensing technology. Thus, central concepts, definitions and terms are introduced in Sections 2.1 and 2.2. Second, it develops the thesis' theoretical framework based on multi-tier SSCM and dynamic capabilities theory (Section 2.3). The framework serves as the theoretical lens for analyzing empirical data and answering research questions.

2.1 Sustainable supply chain management

Companies' production and operations depend on a carefully organized inflow of resources, material and skills and further distribution of finished products to customers through logistics, warehouses and retailers, i.e. they depend on supply chains (Miles & Snow, 2007). A supply chain "encompasses organizations and flows of goods and information between organizations from raw materials to end-users" (Halldorsson, Kotzab, Mikkola, & Skjøtt-Larsen, 2007, p. 286). SSCM is defined as "management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements" (Seuring & Müller, 2008b, p. 1700). Increased scrutiny from these stakeholders, ranging from customers and business clients to NGOs, authorities, investors or employees (Freeman, 2010), has led business to adopt SSCM as a material part of their sustainability strategies. To what extent and which stakeholders shape companies' sustainability agendas depends on their salience, i.e. the "degree to which managers give priority to competing stakeholder claims" (Mitchell, Wood, & Agle, 1997, p. 869). Three criteria determine stakeholder salience: their power, their claim's urgency and their claim's legitimacy (Mitchell et al., 1997; Neville, Menguc, & Bell, 2003). Legitimacy depends on the surrounding social and institutional context and is defined as "a generalized perception of assumption that the actions of an entity are desirable, proper, or appropriate within some social constructed system of norms, values, beliefs, and definitions" (Suchman, 1995, p. 574). Going beyond stakeholder pressure, some companies have adopted "[p]roactive SSCM strategies recogniz[ing] that sustainability is an important strategic objective to an organization—independent of stakeholder claims. In the proactive approach, an organization understands its dependence upon the long-term sustainability of its resource supply" (Wolf, 2014, p. 319).

Supply chains have grown increasingly global and complex over the last decades, extending upstream via various supplier stages (so-called 'tiers', see Figure 2-1) towards the raw material source. Research seeks to understand approaches for managing these complexity and sustainability challenges in supply chains, usually from the perspective of the 'focal company'. The term 'focal company', in supply chain literature, is used in two ways, focusing their understanding more on the company's absolute or relative position in the supply chain. One understanding of 'focal company' uses the term to refer to the central, consumer-facing firm of a supply network that "usually (1) rule[s] or govern[s] the supply chain, (2) provide[s] the direct contact to the customer, and (3) design[s] the product or service offered." (Seuring & Müller, 2008b, p. 1699). In this understanding, focal companies are always business-to-consumer (B2C) companies, i.e. have an absolute positioning in the supply chain. In the sustainability context, these powerful consumer-facing buyers – focal companies as per the absolute-positioning-based definition – are particularly exposed to stakeholder pressure for more environmentally and socially responsible sourcing. They represent a common target for NGO campaigns seeking to harness their leverage over suppliers to improve conditions further upstream (Gosling, Jia, Gong, & Brown, 2017). Examples include the Greenpeace campaign against Nestlé's brand KitKat over rainforest deforestation (Khor, 2011; Wolf, 2014), or the public backlash against Apple when precarious working conditions at their supplier Foxconn erupted in a chain of suicides among workers (Lam, 2018). An alternative understanding of the 'focal company' puts more emphasis on aspect (1) and (3) of the aforementioned definition, i.e. the company's role in making decisions about suppliers and products, and puts less emphasis on relative positioning in the supply chain, i.e. stating that the focal company can be "positioned at various points in the supply process, i.e. on a path between raw material to end customer, including manufacturers, distributors and components suppliers" (Lamming, Johnsen, Zheng, & Harland, 2000, p. 682) as illustrated in Figure 2-1. This understanding operationalizes the term 'focal company' in terms of its managerial perspective on the supply chain, making it more tangible for analysis, and has been used in research (Beske, 2012; Kogg, 2009).

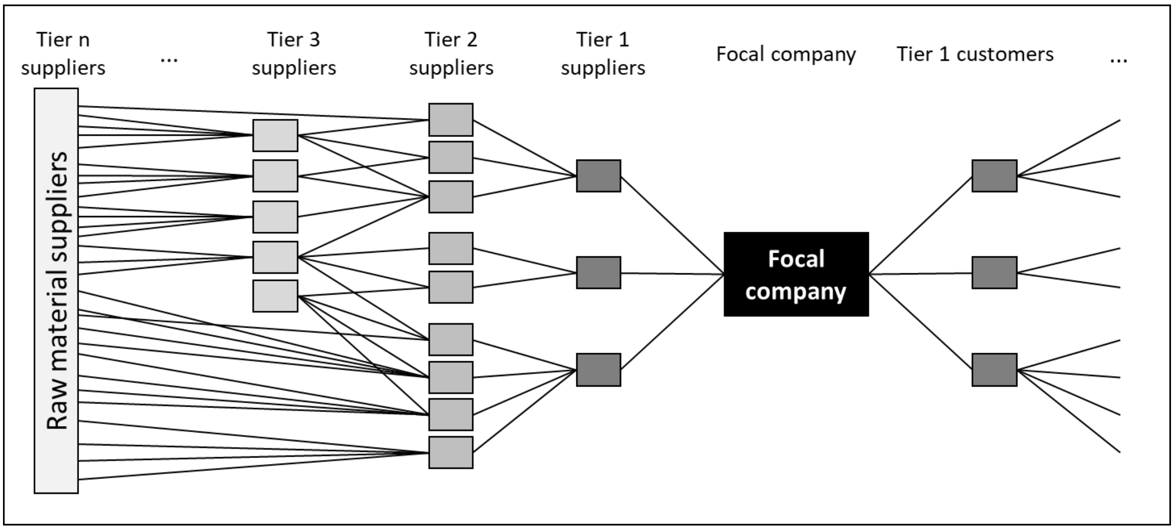

Figure 2-1 Supply chain structure

Source: Own illustration, based on Lambert et al. (1998, p. 3)

This thesis applies this second definition, arguing that in the sustainability context, B2B companies can face similar stakeholder pressure and risks as consumer: Some companies who are technically business-to-business (B2B) companies but have built well-known consumer brands, e.g. Tetra Pak, with considerable visibility and exposure to consumers, can experience similar public scrutiny. Further, in the sustainability context even companies that are almost unknown to the public – such as Wilmar, the world's largest palm oil trader, or Cargill – still face substantial reputational, financial and legal risks from stakeholders like NGOs, investors, regulators and, increasingly, clients (Greenpeace, 2019; Mighty Earth, 2019). Such repercussions illustrate how supply chains' interconnectedness can foster not just an optimized division of labor but also a re-distribution of liability to focal companies (Van Tulder, Van Wijk, & Kolk, 2009). As this thesis aims to investigate how companies approach supply chain sustainability risks, it uses the broader notion of 'focal companies' that emphasizes their relative positioning to include relevant B2B company cases. Further, 'focal company' is used interchangeably with the term 'buyer' in this thesis to highlight their role in comparison to 'suppliers'.

Supply chain management recognizes that supply chains are too complex for individual management of every supplier to be feasible or economical (Lambert & Cooper, 2000), instead strategic prioritization of relevant suppliers according to set criteria is vital. The same applies for SSCM (Meinlschmidt et al., 2018), thus companies typically focus on direct, first-tier suppliers (see Figure 2-1) where they have clear visibility, direct communication lines and influence through contractual relations (Meinlschmidt et al., 2018; Seuring & Müller, 2008a). Apart from practical difficulties of managing indirect suppliers or the full chain, complex supply chains (see Figure 2-1) facilitate a diffusion of responsibility where focal companies may neither feel responsible, nor be held accountable for issues at geographically and operationally distant suppliers (Zyglidopoulos & Fleming, 2011). However, from an environmental and social view, critical issues can be hidden upstream beyond direct suppliers and visibility (Sourcemap, 2016) where ecosystems, workers and communities can be more vulnerable to exploitative practices and repercussions of irresponsible behavior by buyers more scrutinized (Meinlschmidt et al., 2018; Mena et al., 2013). Thus, prioritizing suppliers based on the focal company's visibility and leverage may be misguided and essentially ineffective in reducing critical sustainability risks.

2.1.1 Supply chain sustainability issues as business risks

Research on supply chain risk is concerned with "the identification and management of risks for the supply chain, through a co-ordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole" (Jüttner, Peck, & Christopher, 2003, p. 201). It emerged out of necessity as "supply chains became more complex and consequently more vulnerable to disruptions" (Sodhi, Son, & Tang, 2012, p. 2). These disruptions are increasingly related to supply chain sustainability issues, although most supply chain risk frameworks do not explicitly recognize sustainability (Foerstl, Reuter, Hartmann, & Blome, 2010; Hofmann, Busse, Bode, & Henke, 2014). The emerging business risks are outlined in Table 2-1 below.

Table 2-1 Overview of business risks emerging from supply chain sustainability issues

Risk type	Explanation
Legal and regulatory risk	New regulations are increasingly seeking to make companies legally accountable for poor due diligence concerning illegal logging (Partzsch & Vlaskamp, 2016), conflict minerals (Hofmann, Schleper, & Blome, 2018; Sarfaty, 2015) or modern slavery (Fasterling & Demuijnck, 2013) in their upstream supply chain.
Reputational risk	Customers, NGOs and the public expect buyers to assume responsibility for mitigating issues like forced labor or deforestation associated with their products (Lozano, 2015; Roberts, 2003). That is, even when focal companies have outsourced production and processing steps to suppliers, the perceived responsibility for environmentally and socially sound production standards remains with them (Foerstl et al., 2010);
Operational risk	Environmental issues or extreme weather events can disrupt suppliers' operations and thereby cause supply bottlenecks, quality issues or price spikes (Hofmann et al., 2014). Under the influence of climate change, both the intensity and frequency of extreme natural events like floods or droughts is expected to increase, adding further pressure to operational planning, sound risk management and adaptation measures (Ghadge, Wurtmann, & Seuring, 2020; Haraguchi & Lall, 2015).
Financial risk	Investors and banks recognize that supply chain sustainability issues can threaten business performance and thus seek to remove these risks from their portfolios, which can limit access to capital (de Villiers, Venter, & Hsiao, 2017; EcoVadis, 2018b; Tropical Forest Alliance, 2017b). Likewise, clients of business-to-business firms increasingly seek to reduce risk in their own supply chains and therefore demand sound sustainability standards as a contractual condition (Beske, Land, & Seuring, 2014).

The risks above are driven by different stakeholder groups such as regulatory authorities, NGOs, clients or investors. While NGOs have a longer history of lobbying for stronger social or environmental protection, others like financial institutions or B2B firms' customers have only recently started to increase their scrutiny. At the same time, technological advances, publicly disclosed information and sustainability ratings have increased supply chain transparency to stakeholders. While it can be argued that the bulk of this information – from sustainability reports, to NGO investigations, to QR codes to trace a burger back to its origin – is only used regularly by a minority due to general information overload, it still provides stakeholders with the option to check up on companies – if they feel the need to. Essentially, this means that a broader group of stakeholders is interested in and has access to information that provides them with the leverage to substantiate their demands. This has the potential to reinforce or escalate the risks outlined above, further emphasizing the need for companies to be prepared.

As both sustainability issues in supply chains and their potential repercussions for business grow, a sound risk monitoring and management that reaches beyond direct suppliers is becoming critical. It is increasingly turning from a matter of good corporate conduct and stakeholder engagement into a matter of strategic and operational importance, particularly as the awareness of stakeholders, including clients, investors, NGOs and regulators, concerning supply chain issues and their ability to trace these issues is growing.

2.1.2 Strategies and measures for supply chain risk management

To understand, mitigate, manage and prevent these risks, companies have developed two broader supplier management strategies, supported by a spectrum of measures. The two core strategies are **supplier selection** and **supplier development** (Akhavan & Beckmann, 2017): The former screens suppliers against a set of sustainability requirements and systematically deselects non-compliant or low-performing suppliers, thus aiming to remove sustainability risk from the supply chain by default (Seuring & Müller, 2008b). The latter prioritizes capacity building and working with suppliers to improve their sustainability performance, thus aiming to reduce sustainability risk over time while building suppliers' capacities and potential business opportunities proactively (Harms, Hansen, & Schaltegger, 2013). In practice, these strategies are not mutually exclusive and often combined to some degree: A buyer may focus on supplier development where termination of supplier relationships is not a viable option like for suppliers of specialized components, with long-term relationships or high quality that is difficult to replace. However, supplier development is more resource intensive for both involved companies, so supplier screening and selection can be more efficient for eliminating sustainability risks for more readily replaceable suppliers or when the buyer has limited leverage due to, for instance, smaller sourcing volumes (Cox, 2004). Buyers also commonly apply a mixed approach where suppliers are audited against sustainability criteria at regular intervals but, in cases of non-compliances, are assigned corrective action plans and time to implement changes to meet the criteria (Foerstl et al., 2010). The choice for supplier selection or development, thus, largely depends on the supply chain structure, leverage of buyers, replaceability of suppliers, criticality of products, cost strategy, as well as internal resources available for SSCM.

The spectrum of measures available to buyers ranges from adopting sustainable sourcing policies and commitments, to establishing voluntary supplier codes of conduct or contractual obligations like including sustainability aspects in general terms and conditions (Harms et al., 2013) to the evaluation of suppliers through internal or third-party auditing, self-assessments, third-party assessments (Andersen & Skjoett-Larsen, 2009) or ratings (EcoVadis, 2018a). Approaches for managing sustainability risks at lower-tier suppliers include working with other organizations such as certification schemes to verify sustainable on-the-ground practices (Roberts, 2003; Seuring, 2011) or with NGOs, with peers in voluntary industry initiatives or with various stakeholders in multi-stakeholder initiatives (Foerstl et al., 2010; Lambin et al., 2018; Pagell & Wu, 2009) increasing companies' credibility and access to local knowledge (Orsato, Clegg, & Falcão, 2013). Collective approaches at industry level are a form of "self-regulation" (King & Lenox, 2000, p. 698) or "voluntary environmental initiative" (Orsato et al., 2013, p. 444) like the Roundtable for Sustainable Palm Oil (RSPO) that establish voluntary or informal sustainability standards that help align processes for efficiency and reduce the risk of tighter regulation or reputational harm by exerting collective pressure on laggards (Prakash & Potoski, 2012). These measures entail substantial time, budget and coordination requirements, particularly when employed across multiple tiers, and adopting a 'the more, the better' approach may only end in information overload on focal companies' side and audit fatigue on suppliers' side. Considering the spectrum of options, buyers benefit from consciously prioritizing and tailoring their approach for risk management, for instance, considering underlying drivers like responding to stakeholder pressures, securing future supply or preventing tighter regulation.

Certification schemes have long been the primary tool for buyers seeking to ensure sustainable practices at raw material suppliers. Certification schemes initially emerged as a governance alternative to government regulation which proved increasingly insufficient or unable to structure sustainable practices, particularly with growing complexity of supply chains (Cashore, Van Kooten, Vertinsky, Auld, & Affolderbach, 2005) However, certification schemes are facing recurring criticism concerning their stringency and legitimacy. This includes variations in enforcement (Smit, Mcnally, & Gijsenbergh, 2015) or their reliance on field audits which rely on 'snapshot' evaluations of a small, potentially unrepresentative sample and cause substantial cost, time and staff requirements for both the auditing and audited organizations (Marin-Burgos et al., 2015; Schepers, 2010). This has sparked interest in moving beyond certification schemes and towards information-technology-based solutions for providing assurance of sustainability performance (de Camargo Fiorini & Jabbour, 2017; Lopatin, Trishkin, & Gavrilova, 2016). Two focus areas for increased application of information technology are **traceability** across the supply chain and **transparency** of the situation on the ground.

Traceability-oriented approaches are concerned with solutions that enable actors to track (downstream; where is your package right now, where does it go) and trace (upstream; reverse flow and follow product back to its origin) a products' supply chain journey and have seen strong uptake after several food safety scandals to enable more targeted reactions and prevention (Mol & Oosterveer, 2015). Today, traceability in sustainability is defined more broadly as the "ability to identify and trace the history, distribution, location and application of products, parts and materials, to ensure the reliability of sustainability claims, in the areas of human rights, labor (including health and safety), the environment and anti-corruption" (Norton et al., 2014, p. 6). Traceability seeks to address the complexity challenge many focal companies face when trying to disentangle their global supply network in mapping exercises (Sourcemap, 2016). Achieving visibility into the chain, all the way upstream to the raw material producers requires substantial efforts (Saberi, Kouhizadeh, Sarkis, & Shen, 2019). Reliable traceability of a product's journey along this chain even more. Since the purpose of establishing traceability here is to provide assurance that the product actually comes from certified sources, schemes like FSC have developed 'chain of custody' approaches to simplify traceability by getting not just raw material producers but also intermediary actors certified (Mol & Oosterveer, 2015; Norton et al., 2014). By verifying that a product moved exclusively through certified actors at each supply tier, a simplified yet robust version of traceability is established that provides companies with assurance to back up sustainability claims and sourcing commitments.

Information technology can facilitate more nuanced traceability, allowing for tagging and tracing of single products throughout their individual supply chain journey (Mol & Oosterveer, 2015; Scholz et al., 2018). In light of growing stakeholder pressure and verification requirements, technologies like radio-frequency identification, Internet of Things, GPS tracking devices and recently blockchain are gaining attention (Björk et al., 2011; Francisco & Swanson, 2018; Saberi et al., 2019). However, a core challenge that blockchain and traceability face is reliably linking the physical and digital world, also known as the "garbage in, garbage out" (Blossey, Eisenhardt, & Hahn, 2019, p. 6891) problem: While establishing traceability provides data on actors along the chain, it provides limited insight, transparency and assurance concerning the on-the-ground conditions, e.g. in the field or forest. This is where transparency-oriented information technology like remote sensing comes in and adds data on environmental change on the ground.

2.2 Remote sensing technology

Technologies like remote sensing, "the use of aerial or satellite imagery to study features on Earth's surface" (Werner et al., 2019, p. 994) or geographical information systems (GIS) "by which geographical data are managed, analyzed and manipulated, usually to produce visualizations (2-D or 3-D), including maps" (Werner et al., 2019, p. 994) provide more direct, continuous observations of environmental change. These technologies, for instance, enable monitoring of deforestation frontiers in rainforest regions over time (Hansen et al., 2013). Remote sensing essentially consists of two parts: data collection and data analytics.

Data collection is conducted through spaceborne devices such as public or private satellites or through airborne devices such as small airplanes or drones that collect raw data on a specified area using different sensors. With technological progress, the **resolution** of remote sensing has improved substantially along several dimensions (see Table 2-2 below). Data collection's increasing sophistication produces vast amounts of data and enables more accurate, timely and continuous monitoring of land changes at lower costs (Guo et al., 2017). National space agencies' satellites play an important enabling role in this as they often provide satellite imagery that is free and publicly available, which is considered "paramount to accomplish the remote sensing monitoring" (Aguiar, Rudorff, Silva, Adami, & Mello, 2011, p. 2700) particularly for non-commercial projects. This includes, among others, satellites of NASA's Landsat program as well as the European Space Agency's Sentinel satellites (de Almeida et al., 2019), but increasingly also private commercial satellite providers (Starling, 2019). To make full use of the rich, often publicly and freely available images, sophisticated data processing capacities are required (de Almeida et al., 2019; Engtoft Larsen & Davis, 2019).

Table 2-2 Overview of remote sensing's resolution dimensions

Dimension	Explanation
Spectral resolution	**Spectral resolution** has increased and now enables more comprehensive and granular detection of surface structure. This is achieved by combining optical sensors with radar and lidar sensors that use radiation at different wavelengths along the electromagnetic spectrum. **Radar**, short for radar detection and ranging, sensors use longer, microwave wavelengths while lidar, short for light detection and ranging, sensors use visible to infrared wavelengths (Turner et al., 2003). lidar sensors are, for instance, able to see through forest canopy and to capture the underlying vegetation structure for three-dimensional models (de Almeida et al., 2019). **Lidar** data can thus circumvent some limitations of optical satellites such as obstruction by cloud cover, canopy or during nights, but at the same time has been restricted by the costs and limited range of using drones or airplanes (Csillik, Kumar, Mascaro, O'Shea, & Asner, 2019; de Almeida et al., 2019). Lidar data also presents the basis for biomass estimations and carbon stock accounting, for which demand can be expected to grow strongly in the future as zero-deforestation and reforestation ambitions become more central in climate change mitigation (Bastin et al., 2019; Pomeroy, 2020; Popkin, 2019). Here, the National Aeronautics and Space Agency (NASA)'s recent launch of their GEDI mission which produces the first satellite-based lidar data set covering the entire tropics represents a major milestone (Dubayah et al., 2020).
Spatial resolution	**Spatial resolution** of remote sensing is continuously improving with space- and airborne devices able to generate images that are both, more granular and covering a larger geographic area. For satellites, it is now possible to get daily images of every spot on Earth at a 3.7m or even 0.72m resolution (Planet, 2020) compared to a 30m resolution of NASA's Landsat data which is one of the longest running continuous programs (O'Shea, 2018). While coarser data can be more efficient for getting a broad overview and detecting where on the globe issues like forest fires are happening, fine-grained resolutions provide the basis for a more detailed investigation of the circumstances and potential intervention.
Temporal resolution	**Temporal resolution** describes "the time period between repeat passes over an object being remotely sensed" (Turner et al., 2003, p. 307) and has improved from annual monitoring to much more frequent intervals allowing for daily or sub-daily monitoring (Planet, 2020) which in earth observation terms can be considered near-real-time, near-continuous.

Data processing and analytics is commissioned through public platforms or private providers that use different methodologies and tools, like artificial intelligence algorithms including machine learning and deep learning algorithms (Sisodiya, Dube, & Thakkar, 2020), to turn raw data into actionable insights such as maps and automatic alerts. Previously, data analytics and change detection used to be conducted manually by individuals and although more efficient automated techniques are available manual analysis may still be employed if users are hesitant to adopt new technologies or if algorithms are not accurate enough for specific purposes (Sisodiya et al., 2020). The recent, unprecedented technological progress in various domains, including the development of new network standards like 5G and "availability of virtually unlimited storage and processing capabilities at low cost enabled the realization of a new computing model, in which virtualized resources can be leased in an on-demand fashion, being provided as general utilities" (Botta, De Donato, Persico, & Pescapé, 2016, p. 687). The rise of cloud computing has reduced barriers to data processing and contributed to better accessibility to a broader range of commercial and non-commercial users (Sisodiya et al., 2020), including open-source data processing platforms of which the Google Earth Engine may be the best-known example processing satellite imagery (Gorelick et al., 2017).

Despite the seeming match between remote sensing technologies' ability to provide transparency and objectiveness to SSCM's current challenges and needs, their application and applicability seem to have not been systematically assessed in SSCM research. This thesis thus pursues the following **research questions** (as introduced in Section 1.2):

RQ 1: **Why are buyers implementing remote sensing technologies** to monitor deforestation-related sustainability impacts in their upstream supply chain?

RQ 2: **How are remote sensing technologies** used by buyers for monitoring deforestation-related impacts in their upstream supply chain **integrated into other SSCM measures**?

RQ 3: **What are the challenges and opportunities** related to using remote sensing technologies for monitoring deforestation-related impacts in the upstream supply chain?

2.3 Theoretical framework

The previous sections substantiate the thesis' relevance and research questions by outlining the background, underlying problematization and rationale for why these questions are addressed. This section's purpose is to deductively develop the theoretical framework that provides the lens for addressing the research questions. Specifically, the framework is synthesized from multi-tier supply chain management and dynamic capabilities theory and their current application in SSCM research. The theoretical framework illustrates and makes explicit from which perspective the author is approaching the research questions and the role of remote sensing in sustainable sourcing and provides guidance for analyzing and interpreting the data.

2.3.1 Multi-tier sustainable supply chain management

Previous SSCM research has extensively investigated the dyadic relationship between buyers and direct suppliers (Sarkis, Santibanez Gonzalez, & Koh, 2019), the field is increasingly moving beyond the first tier towards explicitly addressing how supply chains and their sustainability are managed across multiple tiers (Mena et al., 2013; Sauer & Seuring, 2019; Tachizawa & Wong, 2014). Besides the fact that poor environmental or working conditions in upstream supply chains offer low hanging fruits, i.e. cheap and easy to implement sustainability improvements (Schmidt, Foerstl, & Schaltenbrand, 2017), and thus represent key levers for improving overall supply chain sustainability, the dyadic relationship focus has been criticized for poorly reflecting the complex supply networks found in reality (Mena et al., 2013). A recent special issue on multi-tier supply chain sustainability in the International Journal of Production Economics (Sarkis et al., 2019) implies that the topic gains traction beyond the sustainability field, yet a featured review finds substantial room for improvement concerning true multi-tier focus with "[o]nly 12% of the identified publications focused on joint sustainability efforts that included partners across more than two tiers" (Jabbour, de Sousa Jabbour, & Sarkis, 2019, p. 17).

As poor environmental or labor practices at distant upstream suppliers are becoming economic liabilities, companies are under pressure to monitor, manage and potentially prevent these risks (see Section 2.2), particularly since environmental destruction, labor and human rights violations tend to be more likely and more severe the more distant the supplier (Meinlschmidt et al., 2018; Wilhelm, Blome, Bhakoo, & Paulraj, 2016). However, managing lower-tier suppliers is typically characterized by limited transparency, complicating risk monitoring, and limited buyer influence, complicating risk management (Sancha, Josep, & Gimenez, 2019; Villena & Gioia, 2018): Lower-tier suppliers can be less inclined to implement sustainability demands from a distant buyer since they face limited stakeholder pressure (i.e. just as they may be unknown to the focal company, they are usually unknown to the public and thus less exposed), limited regulatory pressure (i.e. while lax regulation in sourcing regions is often an economic advantage of and argument for globalized supply chains, a weak legal context can hinder sustainability initiatives) and limited incentive to respond to such demands if sourcing relations are ad-hoc rather than long-term (Tachizawa & Wong, 2014). This results in a paradox situation where the interconnectivity of globalized supply chains makes focal firms vulnerable to the repercussions of sustainability breaches at distant suppliers while the complexity of globalized supply chains makes focal firms struggle to implement sound due diligence to prevent such breaches.

This thesis aims to address this dilemma by investigating the potential of remote sensing tools to support focal companies in their risk monitoring and management efforts. The thesis thereby ties in with an emerging research focus on supply chain management across tiers and the different mechanisms employed by focal companies to overcome these challenges and steer their supply chain towards sustainability. It, therefore, draws on Tachizawa and Wong's (2014, p. 657) conceptual framework of multi-tier SSCM (see Figure 2-2). The framework is synthesized based on a review of how scholars have applied organizational theories, ranging from institutional or stakeholder theory to the resource-based view, to explain the behavior of focal companies in multi-tier supply chains. The framework proposes four major **supply chain governance mechanisms** that focal companies can adopt (direct – indirect – work with third party – don't bother) to manage sustainability at lower-tier suppliers and seven contingency factors (power, stakeholder pressure, material criticality, industry, dependency, distance, knowledge resources) that affect mechanism choice and success (Tachizawa & Wong, 2014).

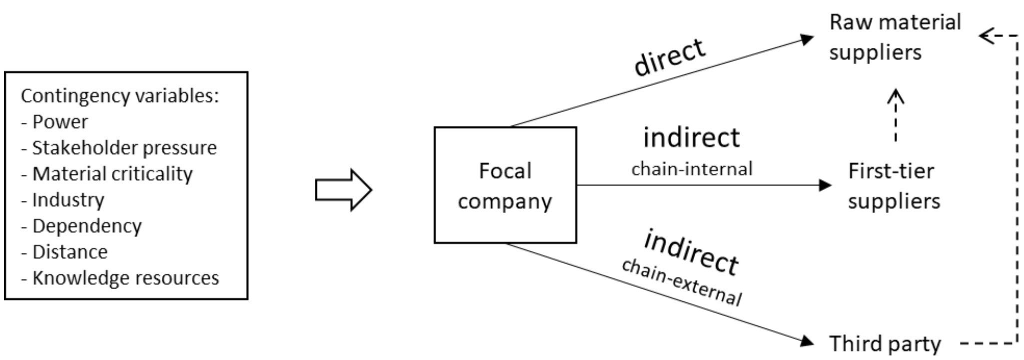

Figure 2-2: Conceptual framework of multi-tier supply chain sustainability management
Source: Tachizawa & Wong, 2014, p. 657

Working directly with lower-tier suppliers gives the focal company access to better, timelier information and promises more effective social or environmental improvement and reduced reputational risks than relying on trickle-down effects via pressure on intermediary suppliers (Tachizawa & Wong, 2014). However, this approach requires comparatively more resources and efforts on the focal company's side (Mena et al., 2013), meaning it is more costly, particularly with increasing distance to the tier and number of suppliers to be managed (Tachizawa & Wong, 2015). Working indirectly with lower-tier suppliers via first-tier suppliers is a more efficient way, but in practice is commonly targeting the passing-on of codes of conduct and certification requirements (Simpson, Power, & Klassen, 2012) rather than active engagement. The third mechanism of working with third party actors, such as NGOs, certification schemes or competitors and industry associations, to develop joint standards, increase leverage over lower-tier suppliers or get external assurance (Plambeck, 2012). Essentially, working with third parties provides focal companies with access to expertise, influence and resources they lack internally, but can entail substantial coordination efforts, depending on how close and specific the collaboration is. For instance, drawing on existing certification schemes for sustainable sourcing is less specific and effortful for the buyer than initiating a joint industry initiative with peers.

Basically, the three active mechanisms, i.e. all described in the framework except the 'don't bother' option, require additional efforts, time and budget from the buyer in exchange for – presumably – better sustainability performance of lower-tier suppliers and lower supply chain sustainability risks for the buyer. Buyers, essentially, have to decide whether it is worth dealing with the complexity and costs that lurk beyond supplier tier one, and weigh it against the sustainability risks and potential business repercussions associated with inaction. This equation, according to Tachizawa & Wong's (2014) analysis, is affected by various contextual contingencies amongst others including stakeholder and institutional pressures that pose various, sometimes conflicting, expectations on buyers (Oliver, 1991; Thornton & Ocasio, 2012), the buyer's dependency on materials and suppliers as well as resulting power structures (Mena et al., 2013; Pfeffer & Salancik, 1978), available knowledge resources and capabilities As buyers juggle internal resource constraints, competitive pressures and sustainability risks amplified by stakeholder pressure, identifying and prioritizing the most suitable approach is crucial to effectively navigate the complexity of multi-tier supply chains in practice.

Tachizawa and Wong's (2014, p. 657) framework has been used in the context of mineral supply chains (Hofmann et al., 2018; Sancha et al., 2019; Sauer & Seuring, 2019) which are particularly complex, difficult to trace and face specific risks for involve child and forced labor, conflict financing or illegal deforestation. Identified mechanisms target lower-tier "nexus suppliers" (Sancha et al., 2019, p. 468), i.e. smelters that combine raw material from a multitude of industrial and artisanal mines and have a central position in the supply chain's lower tiers, as proxies to deal with the complexity, thus suggesting that supply chain structure represents another important contingency. Hofmann et al. (2018) explore supply chain due diligence from a multi-tier SSCM perspective and find similar patterns as outlined earlier in this thesis that, both, the magnitude of sustainability risks and the complexity of gaining transparency and leverage increase with upstream distance. On a similar note, Sauer & Seuring (2019) find that current multi-tier SSCM frameworks insufficiently reflect upstream tiers and suggest that a cascaded view with two or more focal companies that each manage their closer tiers and interact to manage sustainability across the chain, may be more adequate to capture practical realities.

2.3.2 Dynamic capabilities theory

Dynamic capabilities theory is an organizational theory that emerged as an extension of the resource-based view of the firm and was first introduced by Teece et al. (1997). The resource-based view of the firm explains differentiation and competitive advantage as a result of a company's having identified internal resources that are valuable, rare, inimitable and non-substitutable (Barney, 1991) and selected a strategy that makes the best use of these resources in light of external opportunities (Grant, 1991).

The **resource-based view** suggests that internal strengths, like resources and capabilities, provide a more robust foundation for defining long-term strategy (Grant, 1991). In this sense, the resource-based view represents an important addition to the strategic management field (Mahoney & Pandian, 1992) as an alternative view to Porter's five forces model (Porter, 1980) which uses external factors to explain differentiation and corporate performance (Wernerfelt, 1984). Resources are understood as "anything which could be thought of as a strength or weakness of a given firm. More formally, a firm's resources at a given time could be defined as those (tangible and intangible) assets which are tied semipermanently to the firm" (Wernerfelt, 1984, p. 172). Resources are considered heterogeneously distributed between different companies and relatively stable over time (Mahoney & Pandian, 1992). Types of resources include financial, physical resources, human, technological, organizational and reputational assets, and their combination and use is then understood as a 'capability' (Grant, 1991).

The concept of **dynamic capabilities** criticizes and extends that the resource-based view's assumption of resources as stable and continuously valuable does not hold for cases where the context is characterized by frequent, non-linear and difficult to predict change, shifting market players and boundaries (Eisenhardt & Martin, 2000). Instead, the dynamic capabilities concept suggests that in fast-changing environments, it is not the resources per se, but the company's capability to dynamically modify and re-combine the existing resources as needed that creates the sustained competitive advantage (Teece et al., 1997). Teece et al. (1997, p. 516) define "dynamic capabilities as the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments". The definition emphasizes their' role and purpose of enabling the company to succeed in fast-changing contexts (Teece et al., 1997) and to identify and act on emerging opportunities swiftly (Teece, 2000).

Over time, however, scholars have tested the concept on a broader range of cases and found it most suitable for dynamic environments (Barrales-Molina, Bustinza, & Gutiérrez-Gutiérrez, 2013) but applicable – to a lesser extent – in less dynamic markets as well (Wang & Ahmed, 2007). They, thus, question whether the 'rapidly changing environment' should be part of the definition then if it is a sufficient, but not necessary condition for dynamic capabilities (Zahra, Sapienza, & Davidsson, 2006). Teece et al. (1997) who originally specified "rapidly changing environments" (Teece et al., 1997, p. 516) later generalized the understanding, acknowledging that dynamic contexts are the reality of most companies in globalized markets (Teece, 2007).

Further, research indicated that to be effective, it is not enough if a dynamic capability has the power to affect strategic decisions, i.e. affect how resources are used as per the definition but that the timing and the direction of the decisions, e.g. in terms of market orientation (Morgan, Vorhies, & Mason, 2009) are equally essential (Adner & Helfat, 2003). Consequently, scholars criticized aspects of the early dynamic capabilities definition as "conceptually vague" (Eisenhardt & Martin, 2000, p. 1106), with unclear boundaries (Arend & Bromiley, 2009; Zahra et al., 2006) and unclear mechanisms of how they turn resources into a competitive advantage (Wang & Ahmed, 2007), whether dynamic capabilities take the same form across industry actors, i.e. if heterogenous resource sets yield homogenous dynamic capabilities, or if DC are really able to create a long-term competitive advantage, considering that a lasting advantage in rapidly moving markets seems unlikely to begin with, and called for a more stringent, useful definition.

A revised definition proposed by Barreto (2010, p. 217), aiming to condense previous research and align the field's understanding, defines dynamic capabilities as "the firm's potential to systematically solve problems, formed by its propensity to sense opportunities and threats, to make timely and market-oriented decisions, and to change its resource base". Essentially, this definition breaks down the functionality of dynamic capabilities into four separate but essential elements (Barreto, 2010): (1) Identification of risks and opportunities, translation of these into (2) prompt and (3) economically relevant decisions, and (4) iterative review and adjustment of the underlying resource set (see Figure 2-3), while dropping the dynamic environment and 'long-term' competitive advantage as qualifiers due to the dynamic nature of essentially any market today. This thesis follows Barreto's (2010) definition as it seems more straightforward, less ambiguous for application to cases and has been applied in the supply chain context before to better understand focal companies' behavior in light of supply chain dynamics and complexity: Prior applications used this lens to empirically study the relation between firm innovativeness and supply chain resilience, finding a higher innovativeness linked to higher ability to recover from disruptions (Golgeci & Ponomarov, 2013), or to study the role of supply chain learning in helping firms from emerging economies enter developed markets (Golgeci & Arslan, 2014).

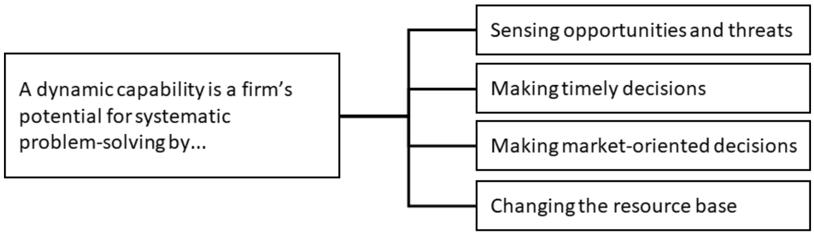

Figure 2-3 Visualization of Barreto's (2010) definition of dynamic capability and its four elements

Source: Own illustration, based on Barreto (2010)

Dynamic capabilities have been applied as a theoretical lens in a variety of studies in the sustainable supply chain context (Schilke, Hu, & Helfat, 2018), including for investigating how focal companies transition from traditional to green supply chain management (F. Bowen, Cousins, Lamming, & Farukt, 2001), how focal companies deal with fluctuating supply chain sustainability risks (Foerstl et al., 2010), how focal companies in the food industry meet evolving customer demands for traceability and transparency (Beske et al., 2014). Resources and skills that have been identified as important across studies range from environmental proactivity (Beske, 2012; F. Bowen et al., 2001) and technical knowledge, to internal organizational skills like cross-functional cooperation as well as external skills like collaborative approaches with suppliers (F. Bowen et al., 2001) and stakeholders (Foerstl et al., 2010) and potentially even competitors (Beske, 2012). The aforementioned elements are considered critical for focal companies' sustainable supply chain efforts through enabling early detection or anticipation of emerging stakeholder demands (Beske et al., 2014), timely and targeted responses (Reuter, Foerstl, Hartmann, & Blome, 2010) and risk management (Beske et al., 2014) including the "adaption of sustainability risk management processes" (Foerstl et al., 2010, p. 126). This thesis argues that the shift to more data-driven, technology-assisted decision-making, especially in the supply chain context, promises considerable support for the dynamic capability functions outlined above and thus could make companies' sustainability risk management more resilient to rapid changes. However, remote sensing technology as such has not been reviewed in the context of supply chain sustainability and dynamic capabilities yet and thus it remains unclear how it would need to be combined with other practices to unfold its potential.

2.3.3 Tech-based multi-tier SSCM as a dynamic capability

As problematized in Section 1.1, managing sustainability across multiple supply chain tiers is a complex endeavor and while remote sensing technology is celebrated as a transparency-opportunity, it is also clear that transparency alone does not ensure effective risk management and prevention. This thesis therefore argues that a dynamic capabilities perspective could provide novel insights into how focal companies can turn the technological resource 'remote sensing' into a part of a higher-level dynamic capability that enables them to not just react to detected issues, but further develop their measures and management approach in organizational, technical or collaborative terms to anticipate risks, and enable prompt and effective follow-up.

Rapidly and unpredictably developing environments represent the most relevant application context for dynamic capabilities theory (Eisenhardt & Martin, 2000; Wang & Ahmed, 2007). Beske (2012) suggests that these characteristics strongly overlap with those characterizing

SSCM, making dynamic capabilities theory a particularly suitable theoretical lens for understanding focal companies' behavior. Following this line of thought, this thesis argues that focal companies that explicitly aim for establishing (a) sustainability and (b) across multiple tiers' are particularly exposed to such rapidly and unpredictably changing environments: SSCM has long focused on simple dyadic relationship between buyers and suppliers. The reality however is more complex. Supply chain sustainability risks are diverse, fast changing and magnified based on the dynamic development of other stakeholder areas, e.g. changing customer preferences, new topics on the agenda of NGOs, increasing sustainability awareness among investors, regulatory action, as well as hard-to-predict natural events such as extreme weather resulting from climate change or disease outbreaks like Covid-19 (Choi, Rogers, & Vakil, 2020; Linton & Vakil, 2020; McGee & Edgecliffe-Johnson, 2020).

Technological resources, like remote sensing, could complement conventional risk management approaches by providing more accurate, frequent and actionable data to support responses to supply chain risks. In fact, Teece (2000) already 20 years ago explicitly emphasized the relevance of dynamic capabilities for making full use of available technology, like satellite imaging, for turning data into robust decision-making in the agricultural sector, stating that "[t]echnology has always been critical to agricultural productivity, but new information technology coupled with satellite surveillance and active futures market participation is enabling more astute decision-making" (Teece, 2000, p. 44). Yet, technology per se does not provide companies with a competitive edge as it is usually available on the market, i.e. to competitors, (Teece, 2000). Rather, it is how it is combined with other resources, e.g. human or organizational, and companies' core skills (Prahalad & Hamel, 1990) and how it is embedded into a company's broader SSCM practices, existing alliances and networks that makes the difference and equips companies for dealing with complexity (Aragón-Correa & Sharma, 2003). Since neither companies' external context, nor technological progress nor sustainability issues are static, companies need to develop the capability to continually adjust and adapt to this.

Barreto's (2010) definition specifies four elements that characterize a dynamic capability: (a) identifying risks and opportunities, taking (b) prompt and (c) economically relevant decisions and (d) deriving and implementing necessary changes to the resource set (see Figure 2-3). The technological monitoring of suppliers using remote sensing primarily relates to the first element, while the other three may – but need not – follow from pure information provision. Thus, remote sensing and automatic alerts about, e.g. detected deforestation in the supply chain, may provide transparency, but if a company has no means or procedures in place concerning how to follow up and manage or prevent these issues, the company's transparency ambitions will neither satisfy NGOs', nor customers' nor investors' concerns. Instead, it displays poor management and may even backfire or raise additional stakeholder concern. In this sense, taking the perspective of dynamic capabilities theory to review companies' use of remote sensing in sustainable sourcing may produce insights into which complementary resources or approaches beyond the pure technological monitoring are relevant for successful implementation.

As the adoption of remote sensing and related technology, as well as the development of a corresponding dynamic capability requires a substantial investment of time, money and organizational capacity, it is relevant to take a step back and consider the opportunity cost and alternatives like more "ad hoc problem solving" (Winter, 2003, p. 992). Taking the example of remote sensing, its detection of issues is limited to specific environmental changes. If these represent the main source of risk in a focal company' supply chain, e.g. affecting a critical material or main stakeholder concern, if the company has access to relevant other resources, e.g. technical knowledge or collaborations with peers, and if these risks can be expected to only become more material and volatile in the future, it may be valuable to develop the dynamic capability to identify, anticipate and respond to such risk. Here Tachizawa & Wong's (2014, p.

657) framework provides a theoretical lens on mechanisms for managing sustainability risk across multiple tiers in supply chains. It provides a basis for, first, analyzing how a novel technical resource – like remote sensing – fits into these mechanisms and existing tools and, second, critically reviewing how these need to be adapted or extended. Tachizawa & Wong's (2014, p. 657) contingency variables like stakeholder pressure, material criticality or knowledge provide insights into, first, whether a focal company is in a situation that benefits from building a dynamic capability and, second, how the company can best leverage its resources to form one. The resulting theoretical framework, based on multi-tier SSCM and dynamic capabilities theory, is presented below in Figure 2-4.

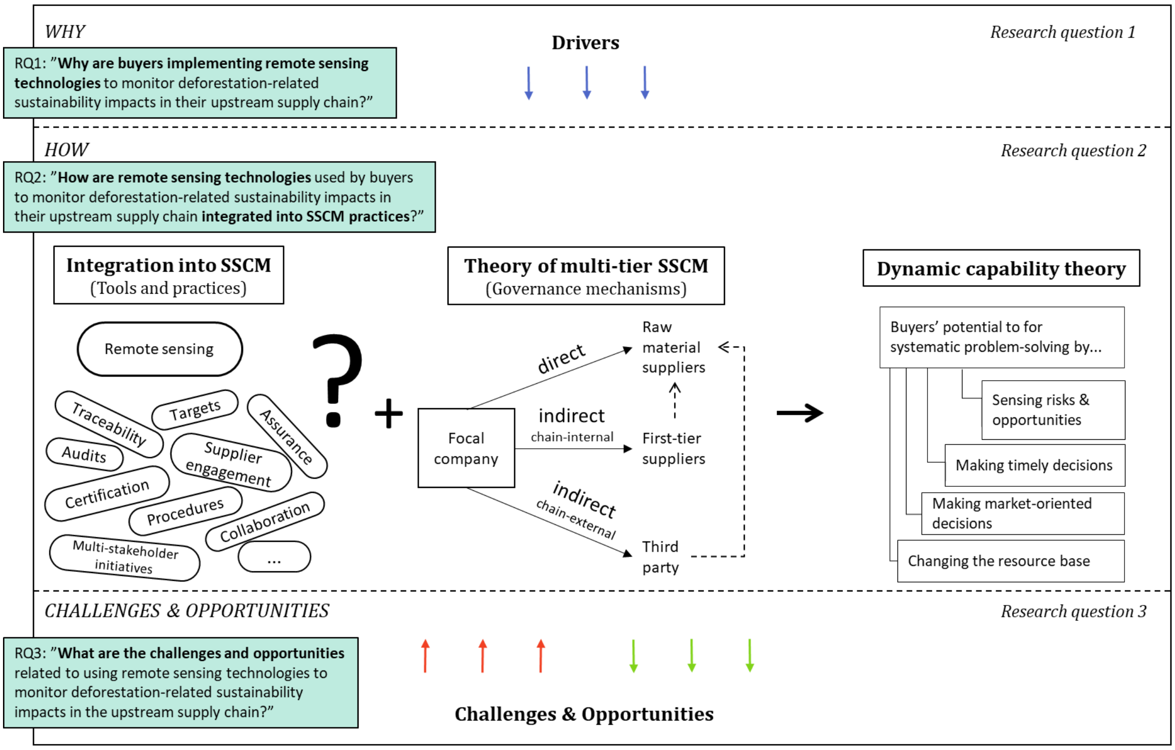

Figure 2-4 Theoretical framework synthesizing dynamic capabilities and multi-tier supply chain sustainability management theory in the context of remote sensing of deforestation-related supply chain risks

Source: Own elaboration, in part based on Tachizawa & Wong (2014), Barreto (2010) and Teece (2007)

This thesis proposes plugging remote sensing tools (as a transparency-oriented technology that has not received attention in SSCM literature but is already used in practice by major companies) into the framework (see Figure 2-4) to empirically assess how it is used in practice. Drawing on multi-tier SSCM theory and dynamic capabilities theory, this thesis analyzes how focal companies are applying remote sensing tools for better informed supply chain sustainability risk management, which additional supply chain management or sustainability practices they need to put in place in order to make full use of monitoring technology, which (supply chain-internal or external) actors they may want to collaborate with, and investigate to what extent the proficient use of tech in multi-tier supply chain management can be considered a dynamic capability. Based on the analysis of the empirical data the thesis synthesizes an updated framework (Chapter 5) and then proceeds to discuss how this relates to the literature and which implications can be derived – for theory and practice (Chapter 6).

3 Literature review on remote sensing in the supply chain context

This chapter reviews the current state of academic research on remote sensing technology in the broader supply chain context to give a differentiated, nuanced understanding of the extant research that this thesis builds on and contributes to. Grey literature is not included at this stage.

Research on remote sensing technologies is characterized by **interdisciplinarity** and has been conducted across a spectrum of disciplines. These range from earth observation and geography where remote sensing enables large-scale geospatial mapping of landscapes and their changes over time e.g. regarding tropical deforestation and land use change (Hansen et al., 2013; Margono et al., 2014) to information technology where machine learning, artificial intelligence and cloud computing open up new opportunities for data analytics and coping with the vast amounts of available raw data, e.g. through self-training deep learning systems that automatically detect and recognize patterns in raw data (Gilbertson & van Niekerk, 2017; Sisodiya et al., 2020; Zhang, Xia, Wu, Lin, & Tai, 2016) Further, remote sensing has a longer history in biodiversity and environmental conservation research where it supports monitoring of habitats (Rose et al., 2015; Turner et al., 2003), reforestation monitoring (de Almeida et al., 2019; White, Wulder, Hermosilla, & Coops, 2019) and wildlife populations (Stephenson, 2019) and also emerging topics like quantifying ecosystem services (Huang, Cao, Xu, Fan, & Wang, 2018). Likewise, it has been supporting urban and spatial planning in monitoring and managing urban development and sprawl (Katyambo & Ngigi, 2017) or identifying heat islands and pollution zones for more targeted interventions (Meerow & Newell, 2017). Remote sensing is further relevant for the monitoring of operations and efficiencies in various economic sectors including in mining for exploration or monitoring subsidence, tailings or water and soil pollution (Jade & Jade, 2017; Werner et al., 2019), in forestry for harvest planning and monitoring fires or pests (Athanasiadis, Anastasiadou, Koulinas, & Kiourtsis, 2013; Müller, Jaeger, & Hanewinkel, 2019), in agriculture for optimizing irrigation, fertilizer use or harvesting (Aguiar et al., 2011; Godar, Suavet, Gardner, Dawkins, & Meyfroidt, 2016) and water management where satellite imagery provides insights into the ecological quality of water bodies and potential agricultural or industrial pollution (Sharaf El Din, Zhang, & Suliman, 2017). While these examples show strong interdisciplinary aspects, scholars explicitly highlight the need and value of research and collaboration across disciplines to further broaden the use of available methods in research and improve their applicability to the challenges at hand (de Almeida et al., 2019). A common theme is the potential of remote sensing and related technologies for improving the **monitoring and management of natural resources** – for efficiency improvements or sustainability, depending on the disciplinary background.

Coordination and governance across different actors represents a frequently discussed concept with regard to environmental conservation (Schleicher, Peres, Amano, Llactayo, & Leader-Williams, 2017), disaster risk management (Fekete et al., 2015) or supply chains (Gardner et al., 2019; Godar et al., 2016). Remote sensing is viewed as a means to bring objective, robust data into complex decision-making and governance processes that involve, interest or potentially affect a variety of stakeholders (Godar et al., 2016; Newton et al., 2013; Werner et al., 2019). **Supply chain governance** is addressed in several articles which focus on the role of NGOs, governmental authorities, certification schemes and their use purpose or use potential for remote sensing while buyers are rarely addressed centrally (Godar et al., 2016; Newton et al., 2013). While several articles discuss commodity supply chains and their impacts implicitly (Hansen et al., 2013; Margono et al., 2014) or explicitly (Gardner et al., 2019; Newton et al., 2013), it is surprising that none of the reviewed articles were published in supply chain or general management journals or taking the perspective of the focal company – as the arguably most influential actor and driving force in commodity supply chains.

The purpose of using remote sensing technologies is often to support some form of governance (Fuller, 2006; Gardner et al., 2019; Newton et al., 2013) by providing more objective insights to enable **data-driven decision-making**, but the specific use purpose varies depending on the user: Companies in agriculture, forestry or mining use remote sensing to monitor their own operations to optimize inventories (Müller et al., 2019) and harvesting (Aguiar et al., 2011) or pest management or compliance with legal requirements, e.g. concerning water pollution (Jade & Jade, 2017) or overlap of concessions and protected areas or indigenous land (Werner et al., 2019). Regulatory authorities and governmental agencies use remote sensing to monitor compliance from their side and support enforcement activities by allowing more targeted checks (Aguiar et al., 2011; Newton et al., 2013), for instance in Peru (Weisse, Nogueron, Vivanco Vicencio, & Castillo Soto, 2019). Similarly, NGOs increasingly rely on remote sensing to detect and call-out irresponsible behavior and put pressure on companies or governments to act (Rothe & Shim, 2018). Certification bodies consider using remote sensing to complement audits of certified areas since it "could substantially reduce the costs associated with field audits" (Lopatin et al., 2016, p. 1) while providing unbiased, accurate assessments of large, remote or dispersed areas (Lopatin et al., 2016). Articles addressing the application of remote sensing by buyers, however, are limited. This **limited coverage of buyers' perspective** in academic literature compared to grey literature (Gardner et al., 2019; Proforest, 2017; PwC, 2019) is striking considering their focal role in supply chains but may signal that buyers' engagement in supply chain governance across multiple tiers and self-regulation has been limited in the past. As buyers' accountability for upstream sustainability issues is expanding – and as a consequence their stake in controlling these, too – they may be required to take on a more central role in supply chain governance in the future.

The review suggests that the major driver of the adoption of remote sensing technologies is **risk monitoring and management** (Kashmanian, 2017). In sectors and regions where the risk for environmental destruction, and resulting legal fines, lawsuits, stakeholder pressure, reputational harm and financial loss are higher, remote sensing technology is more frequently adopted by any involved actor (Gardner et al., 2019; Werner et al., 2019). For instance as the countries facing the highest deforestation rates globally, there is a particular focus on Indonesia (Margono et al., 2014) and Brazil (Hansen et al., 2013). Similarly, the application in the palm oil sector is increasing due to continuous, severe environmental destruction and resulting public and NGO criticism (Kashmanian, 2017). However, the monitoring object or unit of analysis of remote sensing technologies in the supply chain context is not specific to distinct commodities or sectors, but rather centered around specific issues, particularly deforestation (Hansen et al., 2013), land-use change, illegal logging (Athanasiadis et al., 2013), pre-harvest burning (Aguiar et al., 2011) or water pollution (Werner et al., 2019), i.e. visually detectable changes. This means, remote sensing technology is used for various crops, commodities, regions and supply chains with the specific unit of analysis depending on the user, but focuses on those were risks for negative environmental impacts are highest or where positive environmental changes (e.g. outcomes of conservation programs) can be expected.

Another central driver or enabler of remote sensing uptake is the substantial **technological progress** and rapidly **declining costs** for technology and data processing capacities which remote sensing like other technologies has undergone (Hansen et al., 2013; Müller et al., 2019). By making remote sensing technologies more sophisticated, accessible and affordable over the last years, this can reduce the barriers to adoption considerably. The capacities of machine learning and similar approaches determine the usefulness of the insights that can be retrieved from raw data. With increasing sophistication (and declining costs of processing massive amounts of raw images), algorithms make it possible to differentiate degrees of deforestation or forest degradation. Further, feeding in other types of information, such as national data on commodity production and trade flows or cadastral information, can detect correlations and patterns that may help understand underlying causes, resulting implications or general trends

(Godar et al., 2016), e.g. which countries are the main importers of commodities from endangered regions or to what extent deforestation happens outside concessions or inside protected areas. The resulting information can provide insights into potential leverage points for intervention and governance. Crowd-sourced information, i.e. insights collected and/or provided by local actors, and more participation-based approaches are also discussed for remote sensing, although predominantly in the spatial planning context (Meerow & Newell, 2017). Participatory governance approaches, however, may also provide valuable qualitative insights into the **drivers and underlying dynamics** of deforestation or land use change in supply chains and help connect the dots and provide the basis for turning remote-sensing-based insights into actual change on the ground. Simultaneously, questions of data ownership, methodological transparency and information accessibility as well as "interpretation bias" (Rothe & Shim, 2018, p. 431) emerge as the rise of remote sensing is followed by a rise in private monitoring platforms and commercial software providers (Newton et al., 2013). Considering the combination of increasing risks, on the one hand, and declining costs for increasingly sophisticated tools, on the other hand, it can be expected that adoption of remote sensing continues to rise. This may particularly be expected for buyers for whom sustainability risks and their business repercussions are growing and potentially outweighing the cost of adopting remote sensing.

Overall, in the supply chain context, research has focused on remote sensing technology application for improving the broader governance of environmental risks connected to commodity supply chains. In this context, it is striking that buyers and suppliers – being the ones who set up, drive, profit from global commodity trade – have rarely been investigated. Neither have scholars in the supply chain and general management literature investigated the topic from the perspective of buyers and/or suppliers, nor have other disciplines comprehensively addressed the role and potential leverage of buyers using remote sensing (Godar et al., 2016). However, as outlined in Section 2.1, the tide is shifting and environmental risks at distant raw material suppliers increasingly mean business risks for buyers. The resulting interest and uptake of remote sensing tools in practice may trickle down into academic research.

Looking forward, the review suggests that the substantial momentum around remote sensing technologies can be expected to further pick up pace rather than slow down: Global challenges like climate change, forest fires and biodiversity loss create an increasing (sense of) urgency of combatting issues like deforestation (Ferretti-Gallon & Busch, 2014; Hansen et al., 2013). Certification schemes and industry self-commitments face declining trust and increasing criticism concerning their transparency, effectiveness and change on the ground, which is aggravated by new, less strict or transparent schemes entering the market (Gardner et al., 2019; Lopatin et al., 2016; Werner et al., 2019). The trends of increasing technological sophistication, particularly regarding AI and machine learning, and plummeting costs for sensing technology and data processing capacities can be expected to continue (Gardner et al., 2019; Hansen et al., 2013). While research is currently lagging practice in this regard, these recent developments are opening up an intriguing new research area at the intersection of supply chain management, remote sensing technologies and supply chain governance. A corresponding expansion of the already interdisciplinary research to include the supply chain and management discipline and practitioner perspective for a more transdisciplinary approach is deemed valuable.

With this chapter reviewing and structuring the existing literature on remote sensing in the broader supply chain context around identified themes and frontiers that this thesis aims to contribute to, the next chapter outlines the methodology and research logic of how the thesis aims to produce these contributions.

4 Research design, material and methods

This chapter outlines the research design and logic underlying this thesis. It presents the methods chosen for data collection and data analysis, the reasoning behind selecting these methods, their limitations and approaches for mitigating these limitations.

4.1 Research design

The research design is shaped critically by three characteristics of the underlying research problem: First, the application of remote sensing in the sustainable sourcing context is relatively novel. Second, the literature review revealed a research gap in the supply chain and general sustainability management research concerning remote sensing. Third, at the same time, practical examples exist of buyers adopting remote sensing to complement their sustainable sourcing efforts in, for instance the palm oil context, in initial trials or pilot projects and full-scale roll-outs. This suggests that research as well as practitioners could benefit from a transdisciplinary thesis project that analyzes and condenses empirical insights to explore and understand drivers, current practices as well as challenges and opportunities faced when adopting remote sensing to monitor, manage and possibly prevent deforestation-related risk. The gap in management research and its discrepancy from what is already the reality in practice, suggests that an exploratory case-based approach would be useful. Studying cases is considered particularly suitable for such novel situations where prior research is limited, complexity is high (Verschuren, 2003) but settings exist where the phenomenon can be analyzed in the real world (Yin, 2014), as is the case for examining remote sensing use across multi-tier supply chains.

This thesis follows Verschuren's (2003, p. 137) of case-based research as "*research strategy that can be qualified as holistic in nature, following an iterative-parallel way of preceding, looking at only a few strategically selected cases, observed in their natural context in an open-ended way, explicitly avoiding (all variants of) tunnel vision, making use of analytical comparison of cases or sub-cases, and aimed at description and explanation of complex and entangled group attributes, patterns, structures or processes*". By acknowledging this complexity and need for an in-depth, nuanced analysis of the problem, it underlying and contextual factors, case studies' findings are considered more valuable for practitioners than generic insights (Flyvbjerg, 2006), especially for complex contexts like supply chains (Pagell & Shevchenko, 2014). Further, case-based research is considered more relevant for studying dynamic capabilities since other methods may face difficulties capturing the full picture and context (Barreto, 2010). The research design, thus, takes an **exploratory case-based approach**: Multi-tier supply chain sustainability management is an emerging field where practices, particularly around remote sensing technology, are driven by a handful of pioneering companies – thus strategic sampling is employed in order to specifically capture specifically those 'outliers' and be able to understand how and why they are driving novel practices. Interviews and documents analysis are used to extract insights from current use cases of remote sensing for monitoring of deforestation risks in, for instance, palm oil or cocoa supply chains and to develop a conceptual model about its applicability to support monitoring, management and prevention of sustainability impacts in forest-risk commodity supply chains.

Case selection in exploratory case studies aims to carefully identify cases that provide valuable insights into new or underresearched phenomena (Verschuren, 2003). From this viewpoint, cases that reflect novel challenges, extreme circumstances or are otherwise outstanding promise insightful findings. Research and practice around buyers' use of remote sensing for risk monitoring and potentially broader supply chain governance is continuously emerging, yet application cases are still rather limited, thus this thesis treats all identified cases as potentially 'outstanding' as they promise novel insights for research. From the multi-tier supply chain perspective, it is difficult to view a single buyer as a distinct case due to their behavior's interconnection with other involved actors including competitors, suppliers, remote sensing providers and NGOs, certification schemes or local actors. Thus, the unit of use cases refers to the application of remote sensing in a particular commodity supply chain. Expert views of actors along these commodity supply chains, as expressed in documents or interviews, are treated as sub-cases of how different actors perceive the application of remote sensing. While the term 'supply chain' evokes the image of a linear source-to-customer chain, in literature and practice it is equally used to describe today's complex supply structures which more closely resemble networks than chains. Likewise, this thesis' use cases can be viewed as 'hypothetical' in the sense that not all organizations represented by the experts are necessarily linked by direct or indirect supply relationships – rather they are all involved in forest-risk commodities' larger supply network. While not as clear-cut as other scientific case studies, this approach is considered necessary and relevant in order to accurately reflect the reality and complexity of actors.

4.2 Data collection

For data collection, this thesis draws on interviews and documents. To ensure a comprehensive understanding based on diverse perspectives (Flyvbjerg, 2006), data was collected from interviews with and documents of different practitioner organizations (e.g. buyers, suppliers, NGOs, technology providers (see Figure 4.1)) that are involved in the development, provision or use of remote sensing tools for supply chain monitoring. These data sources complement the literature review with emerging information since the field and practice is rapidly developing and new grey literature continuously published. The data sources (21 reports, 28 websites, 11 news articles, 4 webinars, 3 podcasts and 13 interviews; see Appendix I for list of interviewees and Appendix V for full list of documents) were triangulated, i.e. combined, to reduce bias and increase the results' validity (G. A. Bowen, 2009; Verschuren, 2003).

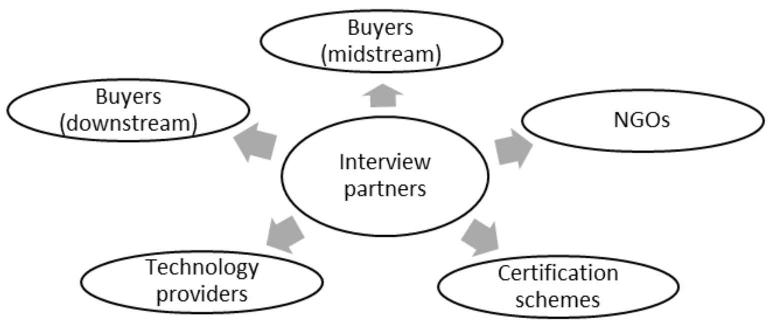

Figure 4-1 Relevant practitioner organizations for interviews

Documents, specifically reports and websites of the relevant practitioner organizations as well as news articles covering their activities are considered a useful foundation and complement for the practitioner interviews. Industry podcasts and webinars by or with the relevant practitioner organizations were included as further relevant documents for more in-depth insights on ongoing activities and industry discussions. The document review was conducted before the interviews to gain a robust understanding and answer fundamental questions to thereby enable more effective and efficient interviews with more time for more specific questions. Further, the review was used to refine the coding framework for the subsequent analysis.

Interviews are considered valuable for collecting comprehensive, differentiated data on complex, internal processes such as strategic decisions that may be difficult to capture through methods like observations or surveys (Eisenhardt & Graebner, 2007). Expert interviews serve to generate insights that reflect the perspective of the expert's position or function rather than their personal views (Flick, von Kardorff, & Steinke, 2004). As this thesis focuses on exploring a rather novel use case of remote sensing from the buyer perspective while taking into account other stakeholders' perspectives, the expert interview was deemed the most suitable approach.

13 interviews with experts from relevant organization types (see Figure 4.1) were conducted for this thesis (see Appendix I for an overview of the interviewees' roles and organizations). The selection of specific experts was guided by three criteria: First, the thesis scope defined in Section 1.4; Second, experts' exposure to the application of remote sensing in supply chains as a user, provider, consultant or in a similar function; Third, the aim to cover expert perspectives representing all relevant practitioner organization types (see Figure 4.1), with the aim to include more than one expert per organization type to reduce the weight of potentially biased opinions.

Interviews were conducted in semi-structured form for comparability and reliability (Walliman, 2006) while ensuring some flexibility for additional questions. The questions were adjusted when necessary. Information from the document review was used, where possible, to ask more specific questions, e.g. concerning a specific tool. Likewise, certain questions were adjusted based on the experts' background, such as including questions regarding technical possibilities for technology providers. Interview lengths varied between 30-60 minutes depending on experts' availability, so key questions were prioritized for interviews with shorter durations. Questions were phrased in an objective, non-leading way, for instance, instead of using 'drivers' or 'barriers', i.e. terms that may suggest that remote sensing is desirable, more neutral terms like 'reasons' were used in open-ended questions. The original set of questions was discussed with the academic and external supervisors, and pre-tested with two participants who had no prior knowledge of remote sensing in order to test whether the questions were comprehensible and whether the questions were adequate for the planned interview duration. In line with this thesis' exploratory approach, the interview questions were adjusted based on emerging knowledge from earlier interviews. A full consolidated version of the interview guide is provided in Appendix II. Subsequently, interviews or interview notes, depending on interviewee consent and interview length, were recorded and transcribed for data analysis. Transcription software was used to facilitate the transcription process and a systematic subsequent data analysis.

4.3 Data analysis

For data analysis, the thesis conducted a qualitative content analysis using the software NVivo. The qualitative content analysis followed the process proposed by Mayring (2000) illustrated in Figure 4-2 that has been used in the sustainability and supply chain management context before (Beske et al., 2014; Engert, Rauter, & Baumgartner, 2016; Seuring & Müller, 2008b). The coding framework (see Appendix III) was developed deductively based on coding categories that emerged as relevant from the academic literature review and background while taking into account the research questions of this thesis. The coding framework was piloted on the first documents where particular attention was paid to whether the deductive coding categories were relevant to the content of practitioner documents and whether they were able to fully capture the document comment or which additional coding categories may be necessary. Subsequently, the transcribed interviews and grey literature were read and the content was coded according to the initial framework. Additional coding categories were identified inductively when new codes emerged as relevant during the coding process. These were added to the initial coding framework. The coding categories were reviewed iteratively for overlaps, redundancy or needed restructuring. When useful, codes were merged or removed, yielding a consolidated version of the revised coding framework (see Appendix IV). Based on the findings, a conceptual framework of the relations between the identified elements was synthesized.

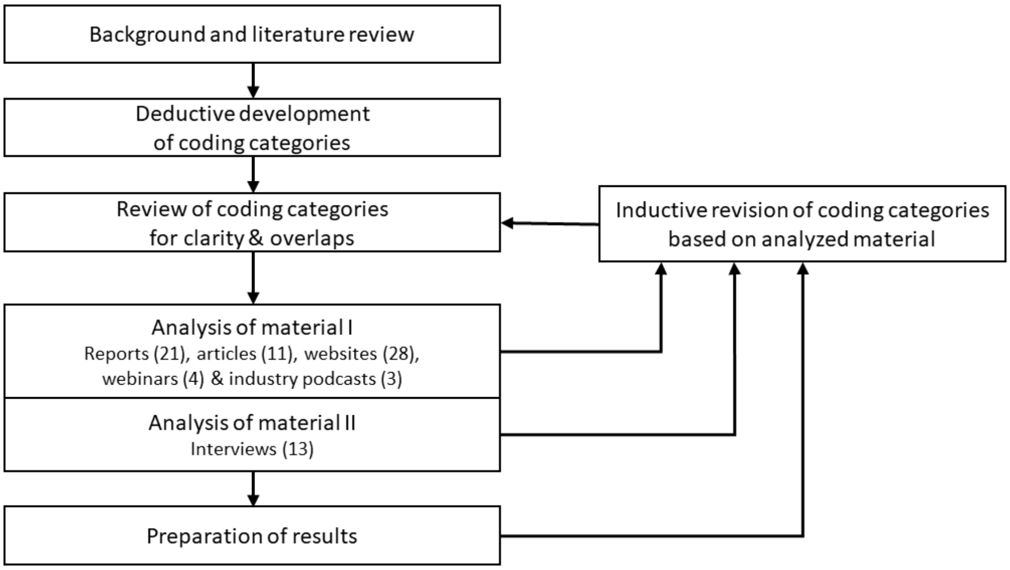

Figure 4-2 Qualitative content analysis process

Source: Own illustration, adapted to this thesis, based on Mayring (2000)

4.4 Limitations

Limitations of these methods include that it can be difficult to find relevant persons who are willing to be interviewed, particularly within the time constraints of a master's thesis. Extending data collection to interviews <u>and</u> grey literature is expected to provide a broader data base and to some extent compensate for a potential lack of interviewees. However, while grey literature may provide broader insights, it may also be more superficial, particularly regarding the implementation process and organizational challenges. Available industry podcasts featuring relevant practitioners and webinars held by relevant organizations were thus included to get more direct, less formalized views compared to, for instance, edited company reports and press releases. Negative aspects like challenges or sensitive information like internal drivers may, however, be less present in the document sample. They may also be more difficult to elicit during interviews depending on how much the participant is willing to share. To mitigate this, information concerning how the data is stored, anonymized, used and published is provided at the beginning of each interview. Further, it needs to be taken into account that interviewees – and humans generally – are subject to cognitive limitations such as hindsight bias, also called retrospective sensemaking which causes individuals' memory of a given situation to adjust over time in line with new information, beliefs and expectations (Christensen-Szalanski & Willham, 1991; Harley, 2007). That is, an individual may remember a process, like starting a business, more positively than they actually experienced it if the process outcome is positive or successful for them and vice versa (Cassar & Craig, 2009). This can be mitigated by focusing interviews on recent situations or combining interviews of both retrospective and current accounts (Eisenhardt & Graebner, 2007) as well as through triangulation with other data sources. Thus, cognitive bias is considered important to consider since this thesis is particularly interested in drivers, internal processes, challenges or opportunities which may be affected by positively or negatively skewed memory. However, the recency of events is deemed sufficient since the application of remote sensing in the supply chain context is a recent phenomenon where most tools and pilot projects have emerged within the last years. Further, interviewed practitioners are expected to be at different stages (considering adoption – deployment of pilot project – evaluation of pilot – implementation of full roll-out to one commodity – extension to other commodities) while all currently engaged in the topic thus providing a comprehensive picture.

5 Findings and analysis

This section investigates the results from the qualitative content analysis conducted in NVivo by providing a richer, in-depth analysis of the themes that emerged (see Appendix IV for final coding framework). As outlined in the method chapter, the practitioner community surveyed includes buyers and raw material suppliers, but also actors like NGOs or technology and data analytics companies (see Appendix I for the list of interviewees). Specifically, the data was triangulated from 13 interviews conducted for this thesis, 4 webinars and 4 industry podcasts as well as 28 websites, 11 news articles and 21 reports by or featuring relevant practitioners (see Appendix V for full overview). Information from interviews is referenced in square brackets.

This chapter is structured as follows: Section 5.1 introduces the current application landscape of remote sensing in the supply chain context by mapping the key tools used by practitioners and their main use cases in terms of monitored commodities and environmental impacts. This lays the foundation for understanding the subsequent sections that – following the thesis' research questions – review underlying drivers that explain this pattern of use cases and why buyers increasingly adopt remote sensing (Section 5.2), that investigate how remote sensing is embedded in existing sustainable sourcing practices to ensure effective use (Section 5.3) and that analyze current challenges and future opportunities faced by buyers (Section 5.4 and 5.5). The raw structure of how the research questions and following sections relate is illustrated in Figure 5-1 below and is gradually populated with more detailed content through the next pages.

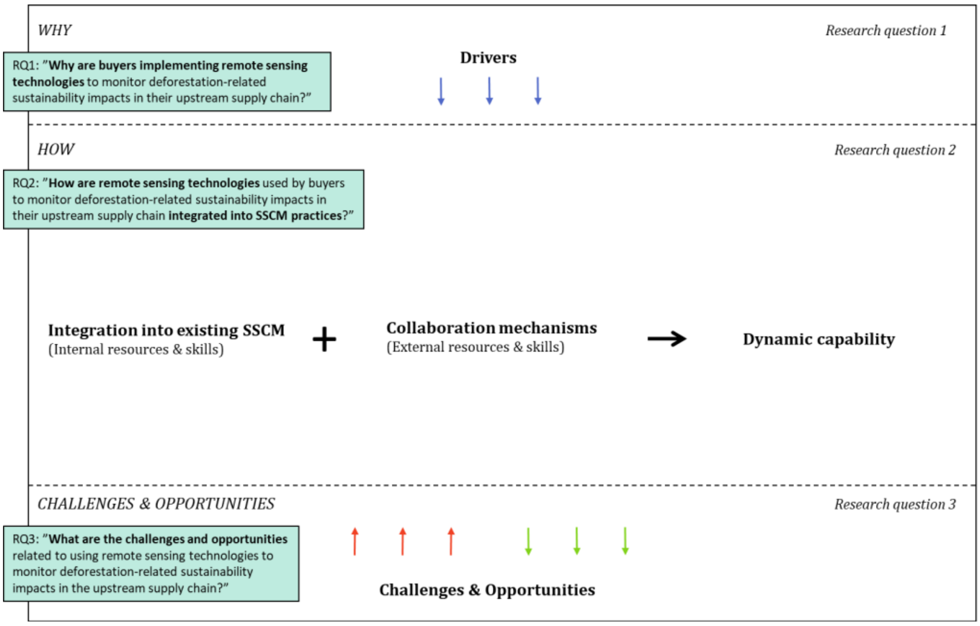

Figure 5-1 Illustration of conceptual framework structure and research questions

5.1 Current applications of remote sensing in SSCM

This section provides an overview of how remote sensing technologies are currently used by buyers for monitoring deforestation-related impacts associated with activities of suppliers.

5.1.1 Technologies and tools

This section introduces the key tools for monitoring deforestation-related impacts that turned up as the most frequently discussed and used in the document sample and interviews. The most widely applied and discussed tools are based on, particularly satellite-based, remote sensing and introduced below. The list does not aim or claim to be exhaustive but focuses on approaches that emerged as well-known and applied in the supply chain context. Most of these solutions were developed through collaborations between technology companies, research institutions, think tanks or NGOs, and partly co-developed in pilot studies with companies. They provide high resolution images and/or the necessary data processing capacities to produce actionable results that enable monitoring of forest or land use change. As outlined in Chapter 2.2 on remote sensing, the essential process consists of two steps, data collection and data analysis. Similarly, technology providers differ along this spectrum, from providers that specialize in imagery collection and have their own very high resolution satellite constellations but offer only basic in-house analytics (Planet, 2020), to providers that rely on publicly available imagery but have developed sophisticated algorithms for data processing (Satelligence, 2020c).

From the customer perspective, the existing tools differ in various aspects including if they are publicly available or commercial, which environmental changes they are able to monitor, which commodities they cover, how tailored vs. generic the insights are, how much support is provided, and what it costs. From a more technical perspective, these former factors are determined by underlying technical differences concerning if the tool is based on open public imagery like NASA's Landsat imagery or proprietary imagery, which temporal resolution or revisit time these datasets offer, which type of data (optical, radar, lidar) is included, how advanced the algorithm and its detection accuracy is. Table 5-1 below provides an overview of the reviewed tools and summarizes the following, more detailed, elaboration on the tools.

Table 5-1 Overview of reviewed remote sensing tools' characteristics

	Global Forest Watch (Pro)	**Starling Verification**	**Satelligence**	**RADD** (in progress)	**Planet**
Developed by	WRI	Airbus & Earthworm Foundation	Satelligence, founded out of Wageningen Uni. spin-off SarVision	WRI, Satelligence, Wageningen University	Planet
Access	Public	Commercial	Commercial	Public	Commercial
Monitored impacts	Forest cover, Forest loss, Forest gain, Forest fires	Deforestation, Forest degradation, Forest conversion	Deforestation, Forest fires, Reforestation, Aboveground biomass	Deforestation	Deforestation Forest health Land use change
Commodity use cases	Not restricted or specific to certain cases	Palm oil, cocoa, pulp & paper	Palm oil, cocoa, soy	Palm oil	-
Specific for use by buyers?	No; possible to upload & analyze own data in GFW Pro	Yes	Yes	Yes	No
Imagery & resolution	Rather coarse, Public datasets (optical)	Higher, Proprietary & public data (optical + radar)	Higher, Public data (optical + radar)	Higher, Public data (radar)	Very high resolution; proprietary data (optical)
Tailored algorithms?	No, GLAD & Terra-i alerts	Yes	Yes	Yes, to palm oil sector	No, algorithms not built inhouse, need for partner
Future	Integration of RADD	Extension to other commodities	Extension to pulp & paper, rubber, coffee	Integration into GFW	Piloting of supply chain solution

Source: (Earthworm, 2019; GFW, 2019b, 2020b; O'Shea, 2018; Planet, 2020; Satelligence, 2019a, 2020b; Starling, 2019; Wageningen University, 2019)

Global Forest Watch and Global Forest Watch Pro

Global Forest Watch (GFW) is an open-source online platform for monitoring forests based on open satellite imagery that was established by the World Resource Institutes (WRI). Essentially, GFW provides a global map, similar to Google Earth, that users can interactively populate with forest-related information to explore, e.g., deforestation patterns (GFW, 2020a).

GFW includes the so-called 'Hansen' dataset (Hansen et al., 2013) on tree cover, tree cover gain and tree cover loss and other datasets that can be activated as additional layers to be displayed on the interactive online map. These additional layers include datasets on protected areas such as national parks, land rights of indigenous peoples, palm oil mill locations or boundaries for concessions (logging, oil palm or certified oil palm concessions etc.) for select countries (GFW, 2020c). By selectively activating dataset layers, the user can see how factors correlate, like forest cover loss in proximity to palm oil mills but outside of palm concessions. GFW now also include a layer on global tree cover loss by dominant drivers developed by Curtis et al. (2018) that differentiates commodity-driven deforestation, shifting agriculture, wildfire, urbanization and forestry. This model aims to address the "*common misperception that any tree cover loss shown on the [GFW] map represents deforestation*" (Curtis et al., 2018, p. 1111) by differentiating permanent loss due to land use change, e.g. from forest to agriculture, from temporary tree cover loss in managed forests. However, this provides few insights into how sustainable the forest management is and thus needs to be complemented with audits [E].

For monitoring of recent deforestation events, the GFW includes weekly Global Land Analysis & Discovery (GLAD) alerts and monthly Terra-i deforestation alerts for tropical regions (Weisse et al., 2019). The GLAD algorithm developed by Hansen et al. (2016) and the Terra-i algorithm developed by Reymondin et al. (2010) are based on open, optical NASA imagery at a resolution of 30m and 250m respectively, i.e. with a relatively coarser detection accuracy. Proprietary data from Planet (see below) is integrated selectively to investigate deforestation alerts and retrain algorithms (GFW, 2020b). To increase the usefulness of the GFW platform for companies, the GFW Pro extension was launched in 2019. It allows buyers, traders and producers to securely upload own data like supplier locations, share data with suppliers or buyers and customize it to their needs (GFW, 2019b, 2020d). This is viewed as helpful for making the alerts more actionable and operational for further investigation (Cargill, 2020; Ng, 2019).

Starling Verification

Starling Verification is a commercial platform set up in a collaboration between aerospace company Airbus and the environmental NGO Earthworm [A]. It provides companies who are interested in monitoring their operations or supply chains with the relevant data and analytics on parameters like deforestation (Earthworm, 2019; Sachet, 2019). The platform and capabilities were piloted with Nestlé and Ferrero in 2016 for their palm oil supply chains in Indonesia and Malaysia to develop the functionalities, alerts and dashboard elements (Welsh, Houdry, & McWilliam, 2020). Starling generally runs on publicly available satellite imagery from Sentinel, the European Space Agency's satellite program. Airbus' own constellations provide complementary, higher resolution data (optical data at 50m or 25m resolution and radar data at 3m resolution) that can be used to supplement Sentinel imagery depending on customer needs, for instance for monitoring forest regrowth and activities below forest canopy. Monitored commodities include mainly palm oil, cocoa and pulp and paper, for clients including buyers as well as governmental bodies (Welsh et al., 2020). Starling's system is able to detect deforestation as well as different levels of forest degradation and can be adjusted based on clients' needs [A].

Satelligence

Satelligence is a commercial provider of data analytics for forest monitoring based on open satellite imagery from Sentinel and Landsat (Satelligence, 2020c). Satelligence was founded by a former member of Wageningen University spin-off SarVision that develops satellite monitoring and mapping systems to support sustainable development in tropical forest landscapes (SarVision, 2020). Satelligence views its agenda as bridging the gap between business and research by making these monitoring systems more operational and relevant to practitioners' reality and thereby address tropical deforestation more effectively [K]. Therefore, the company developed a sophisticated algorithm that is intended to detect deforestation early and accurately and provides prioritized deforestation alerts tailored to clients' needs (Satelligence, 2020a). Geographically, Satelligence focuses on tropical regions where deforestation rates are highest and the consequences of deforestation most severe [K]. Beyond deforestation, Satelligence is able to monitor aspects like aboveground biomass and estimated carbon stocks as well as forest fires, water stress, droughts and flooding (Welsh & Wielaard, 2019). Commodity-wise, Satelligence currently focuses on palm oil, cocoa and soy with increasing activity in pulp and paper, rubber and coffee. Their customers include buyers, financial institutions and they are also working with governments and certification schemes to an extent (Satelligence, 2020b). Satelligence is also contributing their expertise to the development of a radar-based joint monitoring scheme, RADD, for the palm oil industry introduced below (Satelligence, 2019a).

Radar Alerts for Detecting Deforestation (RADD) system

In the palm oil sector, a new system for radar-based alerts for detecting deforestation, the RADD system, is on the way, funded and developed by a cross-industry coalition including WRI, Satelligence, Wageningen University as well as major palm oil buyers, traders and producers including Mondelez, Nestlé, Pepsico, Unilever, Cargill, Wilmar, Bunge, Musim Mas, Golden Agri-Resources and Sime Darby (Selby, 2019; Wageningen University, 2019). The coalition aims to develop a joint system based on public Sentinel radar imagery to increase the accuracy of available insights, remote sensing uptake in the sector and the effectiveness of follow-up action (Wageningen University, 2019). For this purpose, the RADD alerts are going to be included in the GFW platform, i.e. made publicly available (Slavin, 2020). Likewise, the methodology behind the alerts is to be made public for transparency (Satelligence, 2019a). Interviewed buyers and NGOs described the initiative as action-oriented and explained that the goal is to collaborate not just for developing the tool but also for acting on the alerts [G,K].

Planet

Planet is a commercial satellite provider that has its own micro satellite fleet and can provide daily or sub-daily images of every spot on Earth at a 3.7m or even 0.72m resolution (O'Shea, 2018; Planet, 2020). Planet's specialty, thus, lies in providing very-high resolution imagery. They offer basic analytics services like object detection but for the most part work with data analytics partners or supply high resolution datasets directly [H]. For instance, GFW draws on Planet datasets to gain high-resolution insights into select areas like deforestation frontiers or for baseline maps [H], but due to the data's proprietary nature and associated costs, it is not fully integrated, but selectively into the GFW platform (GFW, 2020b). Planet's data has strong potential for use in the sustainable sourcing and sustainable finance context [H].

5.1.2 Monitored impacts

In terms of monitored impacts, remote sensing is inherently restricted to observable **environmental changes** such as forest cover changes, land use change or water levels. In the supply chain context, remote sensing tools have been pioneered for **deforestation** monitoring and this continues to represent the primary focus according to analyzed empirical data.

The general approach is to layer satellite imagery of the current situation against datasets such as the baseline level of forest cover or land use in a region in order to detect changes using specialized algorithms. For a buyer to then understand if suspected deforestation is linked to their supply chain, additional data is needed. Ideally, concession boundaries and polygons of suppliers' plantation or farm boundaries are available that can be contrasted with the detected forest cover change to understand which specific supplier may be associated with this to be able to follow up, investigate the situation and determine actions (Petersen, Davis, Herold, & Sy, 2018). If such granular datasets are not available or upstream suppliers are unknown, coarser estimates can be used depending on the commodity like taking the radius around mills as a proxy [A,G,N]. This narrows down the list of suppliers possibly linked to the deforestation alert and enables more targeted conversations with suppliers and follow-up activities. Further dataset layers can be added to provide a richer, more nuanced basis for understanding the situation and context: Such datasets range from protected areas like national parks, areas of high conservation value or high carbon stock, peatlands, or datasets to bring in social aspects such as land rights and cadastral information (Proforest, 2017). These can then be contrasted with maps of the suppliers' plots and deforestation events to ensure there is no violation of land rights or deforestation outside concessions. Which datasets are used depends on the dynamics of the commodity and regions as well as their availability and possible integration into the different tools. While it may seem that more datasets are always better, interviewees brought up that some layers can be rather 'heavy' and slow down the tool [E]. Knowing which layers are key for the buyer's specific purpose and prioritizing accordingly is thus crucial to ensure actionable insights.

Other environmental impacts that are monitored using remote sensing include forest degradation, forest fires as well as the emerging use cases of aboveground biomass, carbon stocks and reforestation (analyzed in Section 5.5 on future opportunities). These more granular observations become feasible with better remote sensing and data analytics capabilities. Forest degradation refers to "*[c]hanges within forests that negatively affect the structure or function of the stand or site over many decades, and thereby lower the capacity to supply products and/or ecosystem services*" (WWF, 2015, p. 2). This can deteriorate forest and make it vulnerable to deforestation. Monitoring of forest degradation is considered particularly relevant in commodity contexts like cocoa where there is the risk of cocoa being planted in intact forests which is then gradually deforested, or pulp and paper where poor forest management practices can cause degradation [A,I]. In these cases, detecting deforestation at an early stage is critical for buyers to be able to step in and prevent further or permanent damage. However, forest degradation requires high resolution and especially trained algorithms that recognize small-scale events and thinning canopy [A,K].

The overarching pattern is that technologically speaking many things are possible and technology providers offer a spectrum of solutions that vary in their comprehensiveness, accuracy, cost and required effort on the buyers' side. Overall, buyers need to decide what they need out of a tool, which level of accuracy is needed, if they need a tailored solution, how much assistance the buyer needs and how much they are willing to spend. The result show that there is a trade-off between granularity and cost. Increasing uptake in industry and technological progress could, however, shift this balance and make more granular monitoring and more accurate algorithms available at lower costs in the future. Considerations concerning which tool is best suited depend on a range of factors explored in more detail in the following sections.

5.1.3 Monitored commodities

Remote monitoring of deforestation-related impacts is mostly conducted or commissioned by multinational consumer brands in food & beverage or personal care industries. The commodities for which remote sensing tools are currently applied include palm oil, cocoa as well as pulp and paper which are analyzed below. As outlined for the different tools (Section 5.1.1), there is growing interest in monitoring soy and cattle, rubber or coffee, but these use cases did not emerge much from the empirical data collected for this thesis. Thus, the following sections focus on experiences and insights from the established use cases.

Palm oil supply chains represent the primary use case of remote sensing-based deforestation monitoring in the supply chain context. Technology-assisted deforestation monitoring is rather common and advanced in palm oil (Welsh & Wielaard, 2019) and interviewees outlined that this capacity has grown historically as palm oil was one of the first sectors to adopt this, particularly in response to its association with tropical deforestation, ease of detecting clear-cut deforestation and because the drivers for adopting it are particularly condensed here (see the next Section 5.2 on drivers) [A,B,G,I,M,N]. Global palm oil production is concentrated in Indonesia and Malaysia with some production spread over tropical countries around the globe. Palm oil plantations have been associated with deforestation of tropical forests, peatland drainage, violation of land and human rights of workers and communities (Orsato et al., 2013). Palm oil supply chains move from large plantations or smallholder plots to mills, to refineries, to traders, to consumer-facing brands (Amaral & Lloyd, 2019). The palm oil sector's concentration around a few large producers and traders who process palm oil from own plantations and source from third-party suppliers or third-party mills (Khor, 2011), makes it easier for NGOs but also buyers to apply targeted pressure (Ng, 2019). In turn, these intermediaries can exert pressure at larger suppliers upstream to improve practices. Deforestation has long been driven by large-scale clearing events for industrial palm oil plantations. To date, these events have come under better control while small-scale deforestation by smallholder farmers for palm oil or for subsistence activities like farming or firewood persists (Earthworm, Mars, Tropical Forest Alliance, & Mas, 2020).

Cocoa is the second larger use case of remote sensing tools. Similar to palm oil, cocoa has a rather concentrated production region with a lot of cocoa originating from West Africa, particularly Ivory Coast (>40% of total global production (IDH, 2020b)) and Ghana, which are heavily affected by deforestation. While not the only cause, cocoa is viewed as a key contributor besides timber and firewood, mining or infrastructure. While demand for chocolate and cocoa is growing and cocoa represents a key export commodity, poor agricultural practices, limited productivity, soil erosion and climate risks threaten the sustainability of cocoa production while driving the need for deforestation for more productive land (Smit et al., 2015). To break this spiral, the Cocoa & Forests Initiative has been initiated with support from IDH and includes 34 companies covering 80% of global cocoa use, various stakeholder groups and the governments of Ivory Coast and Ghana (GFW, 2019c) committing to "*working together, pre-competitively, to end deforestation and forest degradation in the cocoa supply chain*" (IDH, 2020a, p. 1). Compared to palm oil, smallholder farming plays a larger role in cocoa. From farmers, often organized in cooperatives, the supply chain flows via traders, domestic exporters, grinders and other intermediaries to consumer brands (Kroeger, Bakhtary, Haupt, & Streck, 2017). From a supply chain context, this further complicates upstream visibility and traceability of cocoa to specific cooperatives or farms which have an average size of only 2-5ha in West Africa (GFW, 2019c; van de Put, 2020). Further, deforestation is characterized by smaller-scale events like in the palm context, although in cocoa gradual forest degradation is more prevalent than clear-cutting. While cocoa's ability to grow in shade in agroforestry as a more sustainable, soil-friendly option compared to growing cocoa in monoculture in full sun, this ability also makes it more difficult to detect from space and easier to grow protected forests which are than step-by-step deforested (Welsh et al., 2020). On a similar note, practitioners highlighted the need to detect forest degradation and prevent encroachment early on since the final cutting of canopy trees that can be detected with optical satellites only takes place once the forest is already severely destroyed [B,R,K].

Pulp and paper represents another use case for some of the tools introduced above such as Starling or Satelligence. What is different here is that plantations stretch across the globe with productive forests found in tropical and temperate regions. For other forest-risk commodities like palm oil or cocoa, production regions are much more concentrated, on the tropics or even on specific countries. Further, forest conversion from natural forests to forests under (more or less responsible) management is not limited to tropical regions but also an area of concern in, for instance, Russia or the United States (Welsh et al., 2020). Another difference is the level of granularity necessary for detecting forest degradation or conversion that can require higher resolution data or specifically trained algorithms. Starling, for instance, can differentiate between coniferous, deciduous and mixed forests, but a related challenge is that identifying which type regrows is only possible once the trees have a sufficient size [A].

Interest in **cross-commodity landscape monitoring** is another emerging use case. There is increasing interest in broader and collaborative monitoring solutions that better reflect the reality that deforestation and its underlying causes are complex and often spanning different commodities and industries in the same region (Welsh et al., 2020). While addressing and overcoming these underlying issues is often necessary to achieve more fundamental and lasting improvements on the ground and thereby effectively prevent future deforestation, it can involve considerable goal conflicts between affected actors and is basically unrealistic to be achieved by any actor alone [K]. The trend towards landscape approaches analyzed in detail in Section 5.3.

Overall, the focus on specific environmental impacts and commodities can be summarized as centrally shaped by two factors – tools' current capabilities and buyers' needs. Technology providers in interviews were positive that the necessary technological adjustments, such as retraining algorithms, for extending their solutions to novel contexts are feasible and primarily a matter of their clients' needs. Expanding on this topic, the next section investigates why buyers are using remote sensing and what the core drivers behind their decision to adopt are.

5.2 Drivers of remote sensing adoption

After the previous section outlined how and which remote sensing tools are currently used in the supply chain context, for which monitored aspects and which commodities, this section analyzes why these tools are used and which factors drive buyers to adopt remote sensing tools. Based on the empirical data, the key drivers behind the uptake of remote sensing for sustainable sourcing are: Risks, stakeholder pressures, certification's limitations, operational improvements, proactive sustainability management as well as declining technology costs and technological progress. Detailed insights into each of these factors and their interlinkages are provided below.

5.2.1 Risks

Deforestation risk (IDH, 2020b; Unilever, 2019) and the resulting business consequences were mentioned as critical factors for the adoption of remote sensing in practitioner documents. The key risks identified include reputational risks (SCTN, 2017) but also legal (CDP, 2015; Weisse et al., 2019) or operational risks (Nestlé, 2019) as well as the financial risk of losing access to capital from banks who increasingly "*seek to avoid deforestation risk in their own portfolios"(CDP, 2015, p. 6)*. These findings were reflected in the interviews. Particularly, interviewees pointed to remote sensing's potential to provide buyers with a more continuous view of what is happening on the ground [B,G,H,N] and thus to identify deforestation risks early on and allow action before they evolve into larger business risks. From both the documents (Greenpeace, 2018) and interviews, reputational risks which threaten to affect sales or brand value emerged as the key factor that triggered the initial uptake and continues to strengthen the broader diffusion of remote sensing technology. Early sensing of potential issues puts companies in a position to react and be prepared before issues grow to their full size. From a company perspective, operational risks related to unsustainable practices that threaten the long-term supply of commodities were also considered relevant, particularly when remote sensing for environmental monitoring was coupled with operational monitoring of yields and productivity [N]. In interviews, legal risks were not named explicitly as a key factor for remote sensing. The risk-driven adoption of remote sensing is reflected in its rather early and broad adoption in palm oil supply chains as well as the more recent uptake in cocoa where sourcing regions are also affected by large-scale deforestation [F,I,K]. Likewise, technology providers like Satelligence focus their work on the tropics where deforestation risk and the need to act are highest (Welsh & Wielaard, 2019).

5.2.2 Stakeholder pressures

The magnitude of business risk – besides for operational risks caused by natural causes like extreme weather or drought – resulting from issues like deforestation is critically determined by whether stakeholders find out about and act upon the issue. Thus, stakeholder pressure can act as an exacerbating factor on sustainability issues in supply chains and stakeholders' demand for more transparency is identified as a driver of remote sensing adoption throughout interviews.

NGO pressure – Pressure from campaigning NGOs like Rainforest Action Network (Neslen, 2017) or Greenpeace, for instance on Wilmar to adopt satellite-based monitoring of their suppliers (Greenpeace, 2018; Hicks, 2019), emerged as an essential driver of the adoption of satellite imagery in palm oil sourcing, especially in the early days. Interviewees mirrored this view and emphasized that this is particularly the case for palm oil where the dynamics make it easier for NGOs to target their campaigns: The concentration of sourcing on a handful consumer brands as well as large traders and producers, which have relatively high public visibility and thus reputational vulnerability although they are not technically consumer-facing, provides NGOs with more leverage to target them [F,G,K]. Interestingly, interviewees also pointed out that these same dynamics can also increase buyers' leverage over (direct) suppliers to act on issues at plantations further upstream and if needed suspend suppliers[G,M]. On the other hand, the situation can be more challenging in cocoa where smallholder farming is accounting for a larger share of production and thus makes traceability to specific sources more difficult and can inhibit the leverage of both, NGOs and buyers (see Section 5.4.5 for details) [B,F,I]. NGOs are increasingly using remote sensing themselves, e.g. Mighty Earth (Mighty Earth, 2018), to reveal deforestation associated with companies' supply chains and build pressure (Slavin, 2020) [I]. Running their own remote sensing analytics provides companies with a means to double-check such NGO findings either themselves or through technology partners, and follow-up on the ground if necessary to act timely and prevent reputational damage that can harm brand value, sales and entail scrutiny over companies' future sourcing decisions [K]. Another aspect that emerged from documents (Hicks, 2019; Ng, 2019) and interviews [B,F] (taken up in detail in Section 5.4) is that pressure tends to be put on the companies that are more present in public debate, for deforestation issues or for other reasons, while less proactive, less consumer-facing competitors may get away from the scrutiny by selling to less scrutinizing markets. This situation has over time led to increased industry pressure from their peers and – in the case of large B2B traders and producers – customers. At the same time, this might deter buyers from being more transparent publicly due to concerns about being singled out in the future despite their efforts.

Industry pressure – Industry pressure from peers or clients can be observed as a driver particularly in concentrated cases like palm oil where there are a few central consumer brands and traders involved with a comparatively long experience with remote sensing and deforestation activities. While not a core driver for the interviewees, it was brought up as several times as a 'collaborative pressure' that they are actively engaging in to raise the bar [B,G,K,N]. This is considered crucial for improvements on the ground since tackling deforestation causes is often a complex challenge requiring wider industry collaborations or landscape approaches (Proforest, 2017). On the other hand, industry pressure can also take the shape of 'competitive pressure' where the use of satellite imagery to ensure zero-deforestation supply is used for competitive differentiation and marketing to consumers, for instance by chocolate brands [B,I].

Investor demands – The document review showed that the financial sector is aiming to remove deforestation risks from portfolios (Proforest, 2017) and therefore increasing pressure on companies to avoid deforestation and provide reliable data on their performance (CDP, 2015). Norway's pension fund, for instance, takes this approach, leading to "*more than 60 divestments [made] due to deforestation risks, including 33 palm oil firms, since 2012*" (Reuters, 2019). Good performance regarding no-deforestation commitments in turn can give companies access to better financing conditions and lower capital costs (Olam, 2019; Welsh & Wielaard, 2019). In this sense, stakeholder pressure from investor is unique in that it creates a clear incentive beyond risk reduction by enabling proactive companies to reduce their costs. This mechanism of applying pressure while linking it to concrete financial opportunities for sustainability leaders was reiterated in interviews. Technology providers are seeing an increasing interest by banks and rating agencies (Robeco, 2019) to start using remote sensing themselves to tap robust data on deforestation-related issues directly without relying on firm's self-reporting [H]. Yet, this was not brought up as a major driver of adoption by companies, possibly because this development has not been around for long and thus may not have affected adoption decision a few years ago and because the pressure by financial institutions differs between listed and private companies.

Other stakeholder pressure – While interviewees acknowledged some pressure from consumers and the public, particularly concerning certified products, this was not discussed as a critical factor, possibly because these aspects are taken up and amplified by NGOs with the critical pressure then coming from NGOs. Pressure from governments was brought up as relevant in the cocoa context where the Cocoa & Forests Initiative has been instrumental in driving broader diffusion of actions across the industry and has set requirements for satellite monitoring (GFW, 2019c). So, while the choice of which remote sensing approach to use is up to the companies, alignment with government views and exchange is rather close, while in palm oil campaigning NGOs take the lead where government action, at best, is lacking. Similarly, regulatory pressure did not come up as a driver. Pressure from the public and consumers was mentioned but not as a key factor, presumably because these pressures are represented and amplified by NGOs and thus acting indirectly. While awareness for deforestation-free products is perceived as growing, particularly in the European market, this does not necessarily translate into corresponding demand for sustainable products and varies strongly in other markets [F].

Overall, the emerging pattern is that perceived stakeholder pressure is intensifying and diversifying, but which stakeholders are most salient depends on the industry and commodity dynamics. These pressures push companies towards transparent monitoring by exacerbating the potential business consequences of inaction.

5.2.3 Certification system limitations

A central function of certification schemes is to provide buyers with assurance that the sourced materials were sustainably produced. And while certification is still perceived as a critical tool, there are also limits to it. These range from limitations inherent to audits like their snapshot nature of only capturing a limited scope at one point in time that is not necessarily representative but rather costly, to increasing questions regarding certification's legitimacy (Smit et al., 2015). As certification schemes are facing public scrutiny regarding their transparency, mixed findings concerning their effectiveness (Context, 2018), or as Mondelez' CEO put it "*schemes haven't always trickled down to drive real change on the ground*" (van de Put, 2020, p. 2), buyers are turning to remote sensing as a means to complement the credibility of certification and measure impact.

A recurring point made in interviews was that for companies that are sustainability leaders in their industries, certification schemes do not fully meet their needs because they tend to move slowly [N,B,G,K,L], e.g. relying on paper-based rather than digital records or because their multi-stakeholder nature inherently entails slower decision-making processes for consensus. A response by some is to take initiative and pioneer novel promising approaches like remote sensing to get a more continuous, measurable understanding of conditions on the ground and then take the experiences back to discussions at certification level [K,N]. Further, on a more practical level, while large buyers cover parts of their sourcing volumes from certified sources, there can also be uncertified suppliers in their chain that are typically subject to at least basic sustainability requirements [I,N]. For buyers aiming to eliminate deforestation from their supply chain, they need a verification mechanism for the uncertified volumes – like remote sensing.

5.2.4 Operational improvements

Gaining access to more 'direct', objective insights into what is happening on the ground emerged as a key theme and driver of adopting remote sensing. Based on the reviewed documents (FSC, 2020; IDH, 2020b) and interviews, organizations across the spectrum from companies to NGOs and certification schemes are experiencing the need to move towards more data-driven decision-making and management [A,D,E,I,K,M,N]: Robust data is considered a valuable basis for effectively engaging at-risk suppliers and allocating resources efficiently for audits or capacity building as well as the basis for internal assurance (goal setting, performance measurement, accounting) and external assurance (stakeholder communication, reporting).

Effectiveness and efficiency gains – Reliable, real-time data promises better operational effectiveness and efficiency through more systematic approaches to prioritizing audits and supplier engagement activities (Proforest, 2017) and, in relation to the previous section, also more systematic approaches to overall risk monitoring and management. Remote sensing is viewed as useful for pinpointing suspected deforestation of at-risk suppliers and, thus, selecting suppliers for engagement in a more targeted way [E,K]. Likewise, it provides a reliable data basis for confronting suppliers with suspected deforestation and for having that conversation. Audits are inherently limited in their coverage and frequency, especially for vast and remote plantations (Selby, 2019), and typically costly (Proforest, 2017). Remote sensing is viewed as a means to gain more continuous insights into the situation at suppliers that – while not replacing audits – helps to develop a more streamlined, targeted auditing process that leads verification activities to the high-risk areas where their in-depth nature provides most value. FSC is piloting a GIS platform [E] based on the datasets used by GFW to prioritize areas for auditing to select forest areas to specifically check during an audit (Dalgaard Worm, 2019) or even to leave more time during the actual audit for factors that cannot be monitored remotely like social aspects (FSC, 2019, 2020).

Performance measurement and management – Remote sensing also provides a more robust foundation for companies to track the performance of their sustainability activities and progress against no-deforestation targets. Capturing and quantifying progress on sustainability aspects can be tricky, making it challenging to assess if the resources poured into sustainability work in fact translate into improvements on the ground. Similar to NGOs adopting remote sensing to pressure companies, buyers rely on accurate information on where deforestation is happening to be able to put according pressure on relevant suppliers. Without an accurate understanding of the status quo performance, responses to deforestation risks are reduced to generic 'blanket' approaches rather than specific measures tailored to the circumstances and underlying causes [K,M]. While remote sensing does not automatically translate into effective deforestation mitigation, it is seen as an important step towards overcoming data-related limitations [A,I]. More robust information can also be crucial for internal communication and obtaining buy-in, e.g. by the procurement department, to more systematically act on deforestation connected to suppliers and streamline departments' actions [K,G]. In this sense, remote sensing's ability to turn sustainability topics into quantitative figures that are more readily understood – and potentially viewed as more credible – may facilitate cross-functional cooperation internally.

Transparency towards stakeholders – In response to external stakeholder pressures outlined previously, robust data on companies' progress towards deforestation commitments is critical to engage in fact-based conversations with stakeholders and to demonstrate transparency: Trust in company-provided data can be limited (CDP, 2015), particularly if it is based on less standardized sources such as supplier self-assessment questionnaires or intention-based or activity-based information around the commitments and initiatives put into place. Remote sensing data, on the other hand, is viewed as useful for increasing transparency and for facilitating discussions with stakeholders as it is usually accepted as an objective and performance-based data source (Dekker, 2020) [A,E,F]. Interviewees pointed out that this can strengthen the credibility of certification and companies' communication on targets and policies and, quite simply, supports messages by creating a powerful visualization [K]. Interviewees, both from company and NGO sides, outlined that satellite-based data had also proven helpful for establishing common ground in multi-stakeholder initiatives, which was also reflected in documents for initiatives at landscape level (Welsh & Wielaard, 2019; WWF & ISEAL, 2019). Data that is externally collected through technology rather than provided by any involved actor with vested interests is particularly needed for discussions around targets or progress [F]. Linked to this, however, are questions regarding data ownership that are covered in Section 5.4.2.

Overall, the availability of more robust data through remote sensing emerged as a core driver due to its central role for enabling fact-based decision-making, responses and risk management.

5.2.5 Proactive sourcing strategies

Beyond reacting to risks and stakeholder pressures or reacting in a more effective and efficient way thanks to data, some buyers are also adopting remote sensing without immediate need to act and respond to stakeholder pressure. Proactivity as a driver of remote sensing adoption seems to be based on longer-term projections of sustainability becoming only more critical to business in the future and of the need to secure important resource supply. As demand for forest-risk commodities – for consumer goods, renewable fuels or plastics – is continuing to grow, a corresponding increase in competition, in pressure on already vulnerable forest ecosystem and in resulting stakeholder scrutiny can be expected. Climate change is adding another dimension of volatility. Proactively building resilient supply chains can thus be a strategy to not just prevent risks but put the buyer in a better position to realize future opportunities.

The empirical data suggests that this is accompanied by a more fundamental reorientation towards data-driven decisions and digital tools to optimize operations, including sustainability aspects and their integration into sourcing decisions. Unilever is, e.g., creating a 'digital twin' of the supply chain that integrates deforestation aspects into supply chain data: "*We have quite a lot of factories that have a digital twin which is connected to real-time data. Essentially, it allows you to manage your stock, your production, everything through your datasets on a real-time basis. And we aim to do that also for our supply chain. We want to create a digital twin for our supply chain, so that you do not face a delay in interpreting how your supply chain is functioning but that you are able to see the performance in real-time, also in the areas of deforestation, carbon and natural capital*" (Interview, Unilever, Global Head Sustainable Sourcing). Setting up such systematic infrastructures equips buyers with a unique resource that builds on internal data, knowledge and supplier relations and thus hard to imitate. At the same time, it provides the necessary structure to use remote sensing data to its full potential (see Section 5.3). With proactivity, buyers that are recognized as sustainability leaders ensure they stay ahead while laying the foundation for using future commercial opportunities related to sustainability.

5.2.6 Technology progress and costs

Remote sensing technology and data processing have undergone rapid progress in the last years as outlined in Section 2.2 on remote sensing, accompanied with declining costs. The points and developments raised in documents (Engtoft Larsen & Davis, 2019; Ng, 2019; Proforest, 2017) and interviews largely correspond to the information in 2.2 and were discussed as key enablers.

For deforestation monitoring, the trend is to add radar imagery to optical imagery which can be obstructed by clouds that are common throughout the year for tropical areas: If optical satellites at a revisit rate of 7 days happens to only capture cloud-covered images several revisits in a row for an area undergoing deforestation, its detection – and possible interventions – can be severely delayed (Weisse et al., 2019). Combining spectral resolutions can thus provide more accurate, consistent imagery that is key for timely detection [A,K]. Beyond deforestation, a recent milestone in technology progress is NASA's launch of the lidar satellite 'GEDI' mission (Dubayah et al., 2020). Lidar sees through clouds and forest cover and capture 3D aspects like tree heights or vegetation structures, thus enabling to quantify vegetation and stored carbon content (see Section 5.5). Likewise, substantial progress and dropping costs for cloud computing and imagery processing as well as more sophisticated algorithms were pointed out as important developments that are expected to continue [A,K]. Emerging possibilities with data analytics progress, include using expensive datasets to train algorithms to detect environmental changes and then calibrate it to detect these same changes in less costly optical datasets [H].

Among technology providers, views differ – in line with business models – regarding what level of (optical) imagery resolution is necessary and to what extent coarser imagery can be (over-)compensated for by capable algorithms, integration of radar imagery and other datasets. What became clear during interviews was that technologically, there is much more possible than what buyers may need or understand. So while it may feel like the more data the better and the more granular the better, the larger question seems to be how is this embedded, which additional datasets are available for demarcation, and how the tool and technology provider's profile match buyers' goals and internal capacities. This was echoed by the head of Earthworm, co-developer of Starling, stating that "*we see various satellite platforms competing over accuracy, the number of sensors mobilized to establish maps (radar or not radar), the resolution of the satellite used, the frequency, availability and, more often, cost. (…) Actually, what we have found is that the success of any platform is really about who is using it and for what*" (Sachet, 2019, p. 1). Technological progress and declining costs, thus, are not drivers per se but key enablers of a broader uptake of remote sensing in sustainable sourcing.

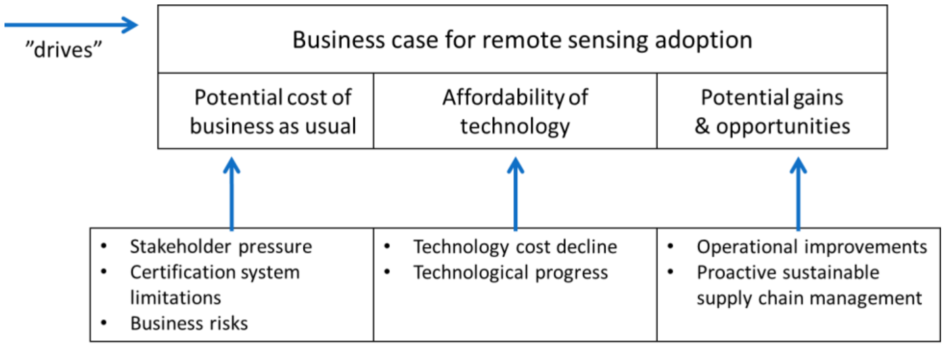

Figure 5-2 Drivers of remote sensing adoption

Overall, the drivers (business risks, stakeholder pressure, certification limitations, technological progress, technology cost decline, operational improvements, proactive sourcing strategies) identified from the empirical data, suggest that the business case for remote sensing-based monitoring is strengthening, as outlined in Figure 5-2 above: Better technology and analytics capacities are available at declining costs – making solutions more affordable – while the magnitude of business risks resulting from supply chain sustainability issues is growing and exacerbated by diversifying stakeholder pressures – making inaction more costly. Further, perceived opportunities of what could be gained through more robust data range from operational efficiencies and cost reductions to more credible and proactive sustainability leadership. Figure 5-3 below positions these results in the conceptual framework and connects to the next section on remote sensing's integration into existing sustainable sourcing practices.

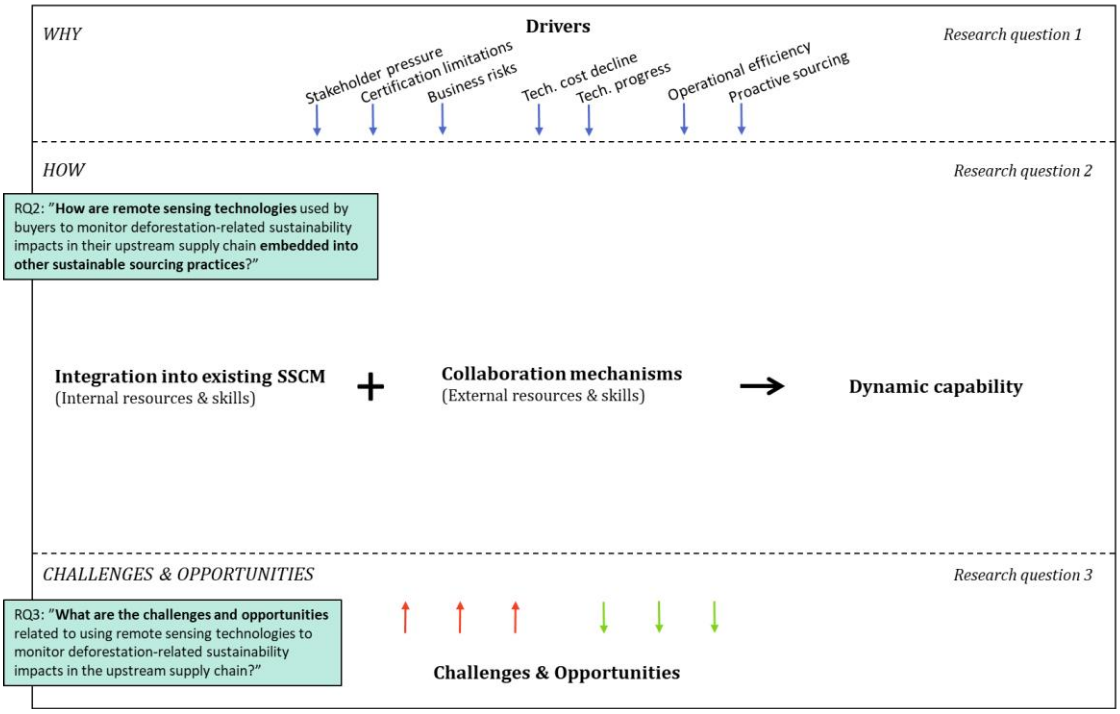

Figure 5-3 Preliminary conceptual framework of remote sensing adoption, including drivers

5.3 Integration of remote sensing into sustainable sourcing practices

After the previous section investigated the drivers that explain why buyers are increasingly adopting remote sensing solutions, this section analyzes how buyers embed these remote sensing solutions into their sustainable sourcing approaches. The next section is then putting these findings into context by assessing challenges and opportunities identified from the data. The conversations with practitioners suggest that to be effective, remote sensing needs to be carefully embedded into existing SSCM structures. The pattern emerging from the empirical data is that remote sensing relies on buyers' existing SSCM structure for three functions: for traceability to the supplier, for effective follow-up and for assurance to stakeholders (see Figure 5-4 further below in Section 5.3.3). Traceability enables monitoring, which in turn enables effective follow-up, i.e. management of deforestation risks on the ground, and accountability to internal and external stakeholders, i.e. management of stakeholder perceptions and resulting reputational, financial, operational or legal risks. The results suggest that tools' effectiveness is restricted by weaknesses in the connected practices and improved through complementary external collaborations. These empirical findings are elaborated on in the next sections.

5.3.1 Visibility and traceability

Visibility and traceability to upstream suppliers were identified by practitioners as a critical precondition for effectively linking remote sensing data and suspected deforestation to specific suppliers. The more details are available, the more targeted, granular and actionable the insights, as "*the effectiveness of forest data hinges upon the ability of companies to have visibility into their supply chains*" (SCTN, 2017, p. 26). For instance, detecting that deforestation is occurring in a sourcing region is useful knowledge, but insights that link deforestation to a specific plantation location is more actionable for effective follow-up and risk management [A,B,G,H,K,N]. Essentially, as outlined by Wilmar's conservation advisor in a commentary on their use of remote sensing (2019, p. 2) "*Without these reference points, further investigation, intervention or action related to deforestation alerts or data received from satellite monitoring platforms (…) cannot be carried out, regardless how precise the satellite imagery is*". Therefore, practices like supply chain mapping help to understand how much upstream visibility the focal company has, for instance only to direct suppliers or up to intermediaries like domestic exporters in cocoa, up to the mill-level in palm oil, or even to plantations. Available information on mill locations, concession boundaries, GPS points of smallholder plot locations or plantation boundaries can be integrated into the remote sensing tools introduced in Section 5.1 and contrasted with deforestation and land use activities to identify potential involvement.

Gaining visibility up to the supply chain's "*first mile*" (Ferrero, 2018, p. 150), i.e. raw material producers, their locations and plantation boundaries, is a major challenge in multi-tier supply chains. This is further aggravated for commodities like palm oil, cocoa or pulp and paper because they flow through processing facilities that mix supply from a multitude of sources and may not be willing or able to disclose where they source from due to e.g. proprietary data (IDH, 2020b). Further, the effort for identifying raw material suppliers can differ vastly depending on commodity dynamics and supply chain structures, e.g. concerning the number of intermediary supplier tiers or the share of supply volume – of a specific company or a sector more generally – produced by smallholders [B,I]. For certified producers, certification schemes usually have some location information available like a GPS point and plot size for MSPO-certified plantations (SGS, 2019), that buyers can work with [G]. In cocoa, where smallholder farmers make up the bulk of production, this multiplies the difficulty – and quite simply the efforts and costs – involved in collecting GPS coordinates of farm boundaries (Dekker, 2020): Based on interviews and reviewed documents, this can range from using phones or apps to collect GPS polygons, to drawing on certification schemes traceability data for certified producers, to "*train[ing] 35 technicians from cooperatives and six representatives from the participating mill on geolocation and mapping, enabling the mill involved to obtain 100% traceability to plantation, with geolocation of 4000 farmers, and full mapping of 221 of those farms*" (Nestlé, 2020, p. 13). The resulting detailed data is valuable for delineating supplier plots in remote sensing tools but scaling such efforts for supply chains of several tenthousands individual farms, few hectares in size, remains a massive task.

Practitioners outlined that risk-based approaches can help get a better grasp of where to focus attention. Knowing how the material reaches the buyer, i.e. via which mills and intermediary suppliers, can be a starting point for identifying who to approach for upstream data and who to involve in follow-up action and pressure to change sourcing practices. One common approach, particularly for palm oil but also for pulp and paper, is to start from the mills where raw materials are processed [A,G,K,N]: Depending on the commodity and region, raw material can only be transported a certain distance before it needs to be processed or before transport becomes uneconomical. Thus, based on the maximum transportation radius, it is possible to draw a circle around mills to get a rough estimate of possible sourcing region. This provides no sound basis for actionable alerts but narrows the options and enables buyers to identify at-risk mills. If more datasets are available, e.g. concession boundaries or national parks, these can give further insights and delineations, for instance, allowing the buyer to focus on suppliers and mills in proximity to national parks and protected areas and prioritizing these in efforts to gain more visibility further up the chain. One practitioner explained how they use an opt-in traceability system for transportation providers who can agree to have their trucks' location GPS-tracked to provide the buyer with information on where the raw material is coming from [N]. An alternative way for narrowing the scope is to start from the country level and move gradually towards tracing supply to specific provinces or districts and prioritize the deforestation monitoring and engagement with suppliers according to the deforestation risk of the provinces, e.g. based on past deforestation rates and vulnerability to further deforestation [B]. This was discussed as useful when intermediaries are not disclosing their sub-suppliers but can indicate what part of their volume is coming from which areas. Thus, remote sensing can even enable buyers to obtain better visibility into their supply chain, step-by-step, yet it is crucial to have basic data or a plan on how to compensate for a lack of more granular data to begin with.

5.3.2 Follow-up and collaboration

Follow-up and collaboration practices that ensure buyers are capable to act on deforestation alerts emerged as the second major support function that buyers' sustainable sourcing approach needs to provide to ensure remote sensing can be used effectively. Having transparency and near-real-time alerts about where deforestation is happening is considered pointless if it is not backed up by the capacities to act on it: "*Receiving information about high risk deforestation areas, in the comfort of your office alone is not stopping deforestation from happening. How the information is used is what makes the difference*" (Dekker, 2020, p. 2). Follow-up determines whether or not deforestation is stopped. Thinking back to Section 5.2.1 on drivers, 'ending deforestation' can be viewed as the meta-driver while remote sensing presents a better tool for juggling intermediate drivers like stakeholder needs, limitations of certification and the need for more actionable data on the way to ending deforestation. Empirical data yielded that practices center around collaboration with suppliers, local governments, NGOs and communities to verify issues, identify drivers and implement solutions. Practitioners emphasized that follow-up capacity is crucial for lasting change on the ground and maintaining credibility towards internal or external stakeholders.

Follow-up on remote sensing tools' deforestation alerts typically starts with supplier engagement (Nestlé, 2020), with the buyer reaching out to the supplier to understand the situation, investigate the suspected deforestation case, potentially verify it on the ground and develop measures such as corrective action plans (Cargill, 2020). A systematic approach to this, including established procedures (Tropical Forest Alliance, 2017a; Weisse et al., 2019), relevant supplier contacts (Ng, 2019) or having both the buyer's sustainability and procurement functions on board emerged as key from the empirical data. Practitioners outlined that in palm oil where supply is concentrated through a few large producers and traders, follow-up on suspected issues at plantation or mill-level can be a joint exercise by consumer brands and their direct suppliers. Here, satellite imagery provides an important data source and robust basis for dialogues with suppliers and orchestration of further measures like ground verification, potential suspension of the suppliers and work with NGOs or local governments: "*The palm oil sector is really leading the pack here. For instance, Bunge has been using for 3 years now information on high deforestation risk areas and also for investigating what that means on the ground and calling their employees and suppliers to identify what happened, making decisions on stop-work-orders, or where changes have been detected in national park areas, alerting the local governments or WWF to urge them to take action"* (Welsh & Wielaard, 2019). Practitioners further outlined that adopting remote sensing helps uncover where existing tools like audit procedures have weaknesses and to improve them accordingly (SCTN, 2017) [G].

Underlying supplier management strategies (see Section 2.1.2) tend to focus on engagement and supplier development while **supplier (de)selection** represents a last resort if a supplier is unwilling to change practices. In the palm oil context, suspending suppliers was mentioned as useful to some extent, particularly when large plantations are concerned, but generally the last option [G,N]. Due to the 'historic' scrutiny from campaigning NGOs, the public exposure of upstream suppliers is considerably higher than for other commodities and they are more wary of being singled out. Understanding the local context, deforestation drivers and incentive structures of suppliers was highlighted as essential knowledge. Being suspended by a buyer based on satellite-detected deforestation can create unwanted attention for the supplier which in turn gives buyers more leverage to exert pressure via supplier selection [K]. However, as pointed out earlier, deselection is usually the last resort due to the risk of 'leakage', i.e. the risk that the deselected supplier continues deforesting since there are sufficient buyers that are less environmentally concerned, more cost-driven and willing to buy the material anyways. As the Supply Chain Transparency Network points out, if buyers "*simply divest from problematic areas, less scrupulous actors may continue to invest in deforestation and agricultural expansion into forests*" (SCTN, 2017, p. 21). Supplier (de)selection, while seemingly more consequent and effective at removing deforestation from supply chains, can be ineffective from a sustainability view (WRI, 2017), leaving the situation on the ground unchanged or even worse than before [F]. This is particularly the case when drivers of deforestation are unclear, complex and intertwined with social issues surrounding land rights, smallholders' or communities' livelihoods (van de Put, 2020).

Supplier engagement and **supplier development** was outlined as important, particularly in the smallholder context in palm oil (Hicks, 2019; Wilmar, 2018) and cocoa, but also with larger suppliers. Based on conversations with experts from buyers, as well as NGOs and certification schemes [E,F,G,H], the overall trend with increasing remote sensing use seems to be towards more honest, meaningful and action-oriented engagement with suppliers. This starts with acknowledging that there may be issues, to more openly raising challenges and working towards change (Dekker, 2020). It needs to be kept in mind that even if deforestation is detected and verified as violating buyers' policies, the deforestation can still be legal (Olam, 2019). The supplier may not see the point of halting deforestation and expansion, and buyers have varying leverage, particularly the further removed the tier is. It can be argued that committing to supplier development and longer-term sourcing relations is the basis for constructive dialogue. Along the same lines, the practitioner review yielded examples of collaboration along supply chains, of how consumer brands work with direct suppliers (Nestlé, 2020) who have closer connections to upstream suppliers, local knowledge or more capacities for following up on the ground.

The challenge of achieving lasting change on the ground often requires understanding the underlying causes and dynamics of deforestation and typically extends beyond the single supplier or even commodity. As a result, **collaboration across supply chains**, i.e. between potential competitors, as well as across sectors in so-called jurisdictional or landscape approaches is increasing. This way, buyers are able to draw on more comprehensive, nuanced set of knowledge resources concerning local context as well as follow-up capacities and relations to relevant local suppliers and external actors. Further, it enables buyers to share follow-up activities based on strategic relevance and take a joint approach to create higher leverage over suppliers and increase pressure on laggard competitors to minimize the risk of leakage, i.e. less sustainability-oriented buyers purchasing deforestation-associated supply anyway thereby creating an outlet for deforesting suppliers. The RADD initiative (see Section 5.1) is one recent example where ten major consumer brands, traders and producers in the palm oil sector join forces to fund and develop a tool for industry-wide radar-based deforestation monitoring with WRI and Satelligence. While similar alliances and initiatives across supply chains exist, this one is special because competitors join forces also for the follow-up which is seen as "a real game-changer" (Welsh & Wielaard, 2019, p. 2). "*In palm oil, pretty universally everyone feels that this is precompetitive and that they just can't do it on their own. There's a very high eagerness to collaborate and there's also frustration among companies and the feeling that over the last 10 years of working in this space, they didn't achieve the results that they had hoped. And these collaborations are really speeding up and becoming more action-oriented or new ones are forming that are more action-oriented because companies are just tired of waiting for slow-moving things*" (Interview, Buyer B). Some of the involved companies like Nestlé already work with advanced commercial systems and do not rely on the RADD system per se, yet still drive funding and development to increase industry pressure and unify and improve publicly available data [G,K]. The overarching pattern seems to be that collaborative action is very much driven by what is needed to take action and effectively change the situation on the ground, recognizing that deforestation is difficult to tackle by a one actor alone. But practitioners also discussed that 'deforestation-free' is also a way for consumer brands to differentiate themselves in the market which can hinder more collective approaches, for instance in cocoa, where the recent start of the CFI may drive more constructive collaboration at landscape level (Welsh et al., 2020) [B].

Multi-stakeholder initiatives or landscape approaches follow an even broader approach, acknowledging that deforestation in a region is usually driven by various commodities or deforestation drivers and/or their interplay, which in turn are driven by dynamic underlying economic, environmental, political or subsistence interests, and often spans national or jurisdictional borders in regions where governmental institutions may be weak to begin with (WWF & ISEAL, 2019). To address sustainability issues and goal conflicts affecting larger regions, landscape approaches aim to bring involved stakeholders together and work towards a joint roadmap (Proforest & Daemeter, 2019). Particularly when deforestation is linked to smallholders, as is typically the case in cocoa and increasingly in palm oil as large-scale deforestation comes under control, causes can quickly extend into the social sustainability domain where poverty can drive deforestation for subsistence farming and firewood or where unclear land rights and overlaps between community land and protected areas cause tensions (Earthworm et al., 2020; Tropical Forest Alliance, 2017a) [F,M]. For such situations, practitioners shared experiences that remote sensing data is considered 'objective' or 'neutral' and viewed as useful to bring actors together and establish common ground in landscape approaches (Welsh et al., 2020). Starling satellite data is, for instance, used to support land-use planning in two landscape approaches in Indonesia with Earthworm (Nestlé, 2020).

5.3.3 Assurance and accountability

Demonstrating assurance and **accountability to stakeholders** is a critical element of managing supply chain sustainability risks – and using remote sensing – effectively. As outlined above, follow-up activities are about ending deforestation. But then again, most drivers that motivate buyers – including accountability, stakeholder pressure, environmental proactivity – have an external side to them that requires that, beyond ending deforestation on the ground, buyers are also able to credibly communicate this to relevant groups. This latter aspect determines if buyers are able to manage not just deforestation risks, but also ensuing reputational, legal, operational or financial risks that result from stakeholder pressure. The consequences, both, on the ground and in stakeholders' perceptions, can differ strongly between complying with zero-deforestation commitments by terminating relationship with all suppliers involved in deforestation – and risking leakage of their produce onto the market through other buyers – on the one hand, and complying by engaging with suppliers and getting them to stop deforesting – while continuing to source deforestation-associated material during the transition – on the other hand. Demonstrating accountability and a robust SSCM approach to stakeholders is, thus, crucial.

Certification represents the 'classic' way for a company aiming to ensure they are sourcing sustainable produced products and communicating it to stakeholders. As outlined previously, certification schemes are battling with criticism concerning their ability to create positive change on the ground (Context, 2018). By taking verification into their own hands using remote sensing, buyers are building a 'second layer of defense' and gain access to insights into what is happening on the ground [GN] which presumably also lets them anticipate media or stakeholder backlash. Further, 'no deforestation' is usually a precondition for obtaining certification and an exclusion criterion. For buyers who also source from uncertified suppliers, this means they may face stakeholder pressure relating to their uncertified supply. Some companies adopt 'no-harm' approaches where they remove specific fundamental issues, for instance, deforestation or forced labor from their entire supply chain for both certified and uncertified materials – in contrast to focusing on direct suppliers and certified suppliers [I]. For deforestation and land-use change related risks, remote sensing represents an increasingly important technology.

Remote sensing, further, emerged as an important basis for reporting on progress towards zero-deforestation commitments (Earthworm, 2019), sustainable sourcing goals and the effectiveness of various measures implemented towards achieving these commitments [G]. Thus, it supports activities that serve to demonstrate accountability, ranging from public communication, marketing to consumers or to B2B customers respectively, annual reporting, disclosures to investors and external ratings (CDP, 2015; EcoVadis, 2018a; Robeco, 2019) as well as responses to NGO reports and, if necessary, accusations. Remote sensing data enables buyers to respond to these stakeholder pressures and, potentially, engage in further dialogue based on a clear understanding of what is happening on the ground since satellite-based data seems to be accepted as more legitimate than information from supplier self-assessments or internal audits (see Section 5.3.2). A technology provider explained how their data is used to provide a second opinion as NGOs increasingly use geospatial data themselves and approach buyers about suspected deforestation, where buyers using remote sensing tools are usually more prepared and often have followed up on the incident already [K]. Thus, corresponding reputational, operational, legal or financial risks can be mitigated and – as remote sensing tools are more systematically embedded into SSCM structures and reporting over time – prevented by demonstrating transparency and proactivity. Practitioners further highlighted that stakeholder concerns around deforestation often generalize the entire industry or single out companies that are not even the worst but more public-facing (Ng, 2019). Thus, being transparent can provide secondary benefits in terms of reduced exposure to business risks by increasing the pressure on industry laggards to improve their practice which otherwise would fall back on the entire sector.

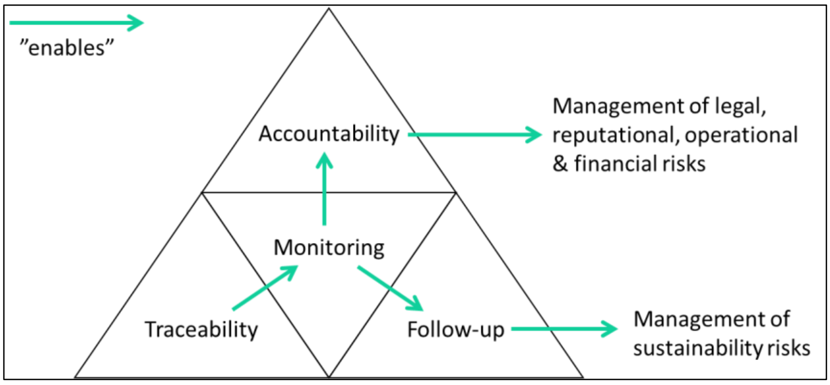

Figure 5-4 Functional integration of remote sensing-based monitoring into existing SSCM practices

The framework above (see Figure 5.4) synthesizes the empirical findings as analyzed above and provides a model of the essential building blocks that a supply chain sustainability risk management approach needs to provide, based on buyers' internal resources and skills, in order to make effective use of a remote sensing tool. The **monitoring function**, driven by remote sensing data in this case, is located at the center of a data-driven approach to managing supply chain sustainability risks. As the shapes signify, it is fundamentally supported by the traceability function and the follow-up function. The **traceability function** provides vital information to be fed into the remote sensing tool, e.g. mill locations, concession or plantation boundaries, to operationalize the alerts and ensure that remote sensing data is actionable to the buyer, i.e. links deforestation to specific suppliers. The **follow-up function** provides the second support pillar, namely the capacity to act on the remote sensing insights and effectively manage **sustainability risk** by following up on suspected deforestation with suppliers, reviewing the issue and implementing a solution, e.g. through standardized procedures, supplier engagement, audits or landscape approaches. The three functions together form a solid base for supply chain sustainability risk management – knowing where to look, detecting issues and taking action to remove the issue. Yet, supply chain sustainability risks extend beyond the pure environmental risk occurring on the ground and instead entail additional reputational, financial, operational and legal risks that emerge from stakeholder pressures. Consequently, the three basic functions are complemented by an **accountability function** that draws on remote sensing data to respond to stakeholder concerns and expectations in a credible, transparent, data-driven way.

5.3.4 Governance mechanisms

The previous sections outlined that effective use of remote sensing depends on the ability of the buyers' SSCM to provide essential traceability, follow-up and accountability functions.

Whether these functions are fulfilled primarily depends on the buyers' internal resources, skills and experience. Collaborative skills emerged as critical from the empirical data as they enable buyers to build constructive relations with internal or external stakeholders and thus compensate and overcome internal weaknesses in terms of supplier visibility, monitoring, follow-up or accountability capacities by leveraging partners' resources, skills and networks.

Based on the empirical data, three types of mechanisms emerged (see Figure 5-4 below): first, working **along the supply chain** (directly with lower-tier suppliers or indirectly via first-tier suppliers), second, working **across supply chains** with competitors in the same industry or peers in other industries like food and beverages or personal care, and third, working **across sectors** with third parties like technology providers, NGOs, governments or certification schemes. Working directly with lower-tier suppliers represents the most direct approach if buyers have full upstream visibility and contacts to raw material suppliers. However, if the raw material tier consists of large numbers of fragmented suppliers or smallholders, this approach can be quite complex, requiring knowledge resources as well as substantial budget and time for onsite audits or follow-up (Dekker, 2020). Consumer brands that are relatively further removed from the raw material stage often work with direct suppliers to gain visibility or follow-up via direct suppliers that are in closer proximity and have more direct sourcing relationship and thus influence, as well as often better capacity for follow-up activities with staff on the ground. Interviews [K] and the reviewed documents (Hicks, 2019; Ng, 2019; Olam, 2019) suggest that intermediaries like large palm oil producers also have more internal experience working with geospatial data for productivity analyses and the necessary skills to run own data analytics.

The empirical data suggests that working with competitors or peers from other industries that source the same commodity or other commodities from the same region and are thus similarly affected by deforestation-related risk plays an increasing role (Earthworm et al., 2020). As uptake of remote sensing across industries is broadening, loose exchange on best practices, supplier lists, follow-up activities and more formalized initiatives aiming to further drive uptake in the industry are growing (Proforest, 2017; Sachet, 2019; Slavin, 2020). "*GAR has started to monitor forest areas outside supplier concessions areas but inside critical landscapes. Specifically, GAR, together with Nestle, Ferrero and other buyers, are trialing Starling services to monitor forest cover change in the Leuser Ecosystem in Aceh*" (GAR, 2019, p. 1), thus increasing pressure on other actors. Concerted alliances like RADD aim to increase the efficiency of monitoring, align imagery quality and definitions and streamline follow-up activities (Selby, 2019), to facilitate uptake by further peers and increase pressure on laggards to up their standards and close the market for deforestation-associated produce (Nestlé, 2019). Reputational, financial and regulatory risks relating to a commodity's image are typically generalized across an industry and can hit public-facing firms harder than actual laggards, thus pressuring low-performing competitors can allow sustainability leaders to reduce their own risk exposure while reaping benefits from demonstrating proactivity.

Working across sectors with external stakeholders can provide buyers with credibility, local knowledge resources and more timely risk detection and management. Maintaining close relationships with NGOs and bringing them in for projects can provide buyers with expert knowledge on specific issues, contacts to or representation of local communities' views, can increase buyers' credibility and perceived legitimacy and, by providing a platform for voicing concerns early on, can prevent later reputational risks. As outlined before, landscape approaches promise more holistic, lasting solutions and enable buyers to somewhat spread the responsibility and are advocated for by buyers and NGOs alike, but as multi-stakeholder processes, landscape approaches run the risk of becoming lengthy and ineffective at finding consensus (WWF & ISEAL, 2019). Technology providers are grouped as another example of buyers working across sectors as the reviewed tools are based on collaboration between a hard- or software company and environmental NGOs, thinktank or research and, thus cross-sector inherently. As outlined in Section 5.3.2, buyers' internal technical capacities vary and by outsourcing geospatial data collection and analytics to technology providers, buyers are able to more systematically leverage their strengths and focus on practices like supplier engagement or communication [A,G,K].

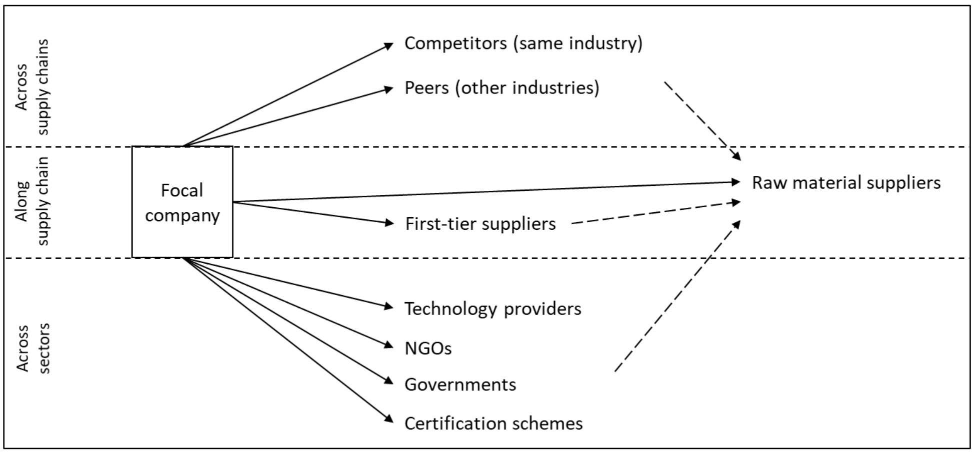

Figure 5-5 Governance mechanisms in remote sensing-based multi-tier supply chain management

Based on the empirical data, the rationale or pattern behind buyers collaborating with external partners seems to be the selective choice of partners with complementary skills, resources, knowledge or experience that are not available internally. This enables buyers to systematically focus on their core competencies. This, in turn, frees up resources for further developing skills of strategic relevance like building supplier relations that secure long-term resource availability. Figure 5-6 below illustrates the results on the integration of remote sensing into existing SSCM and governance mechanisms that together form – and are formed by – a dynamic capability.

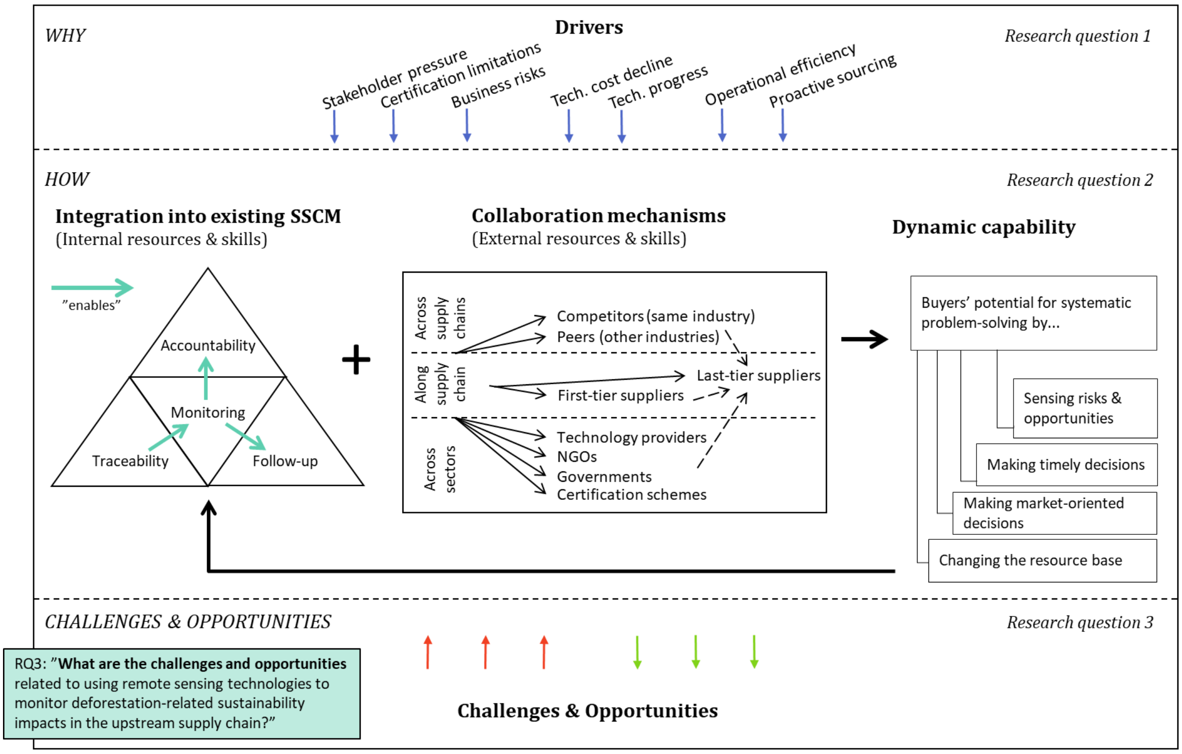

Figure 5-6 Preliminary conceptual framework of remote sensing adoption, incl. drivers and integration process

Overall, the pattern emerging from empirical data is that mature SSCM structures are typically in place before the adoption of remote sensing, and, while remote sensing has enabled leveraging existing structures and practices to a greater extent, it is no replacement, but a valuable complement, for a systematic SSCM approach. If buyers do not have these 'safety systems' in place or the necessary external collaborations that can compensate for internal weaknesses, remote sensing provides limited insights and on the contrary, may even create accountability to stakeholders that the buyer cannot live up to: If a buyer detects an issue but does not have the systems in place to know if it is their supplier, which supplier it is, how to address this and how to communicate externally, than remote sensing can actually backfire, increasing their reputational, legal, operational and financial risks by exposing their unpreparedness. The next section investigates the emerging challenges with remote sensing.

5.4 Challenges

After analyzing how and why buyers are adopting remote sensing tools to manage sustainability risks in their supply chain, this section investigates the challenges that emerge during this task.

5.4.1 Technical limitations

Concerning technical challenges, practitioners brought up various aspects such as optical satellites' limitation that "cloud cover increases the time lag between the date deforestation happens and the date it is detected" (Weisse et al., 2019, p. 18) which can be mitigated by combining optical and radar technology (Müller et al., 2019) or having to balance 'resolution vs. reach' under budget constraints (SCTN, 2017) or the general limitation to visually detectable changes, making it challenging to capture social impacts with human or labor rights or drivers of land-use-change. Combining remote sensing with tools that help survey social aspects, like smallholders' perceptions and needs, was brought up as a useful complement to better understand underlying dynamics, incentive structures and leverage points for effective supplier engagement [M]. Further, while high-quality images can be freely available, data processing for turning images into digestible, actionable insights or automatic alerts represent a challenge and explain the frequent collaboration with technology providers (GFW, 2019a; Starling, 2019).

Interviewees echoed these concerns but pointed out that the tools are continuously developing as imagery and algorithms are becoming increasingly accurate [A,K]. Follow-up with activities on site were, anyways, considered critical for verifying alerts [E]. Collaboration with technology providers was highlighted as a way to continuously improve the accuracy of deforestation detection and advance the analytics for both partners [G]. The trade-off between costs and accuracy of tools was highlighted as another challenge [H]. As proprietary high resolution satellite data is available but rather costly for large-scale monitoring, the training of capable algorithms is viewed as a promising way to compensate, particularly with expected advances in artificial intelligence and cloud computing (Satelligence, 2020c). Regardless of whether accuracy is pursued primarily through better imagery or algorithms, there is usually a trade-off between increased accuracy and costs of the service. To what extent a buyer is able and willing to work with free public tools like the GFW with comparatively coarser data and less tailored alerts or support was seen as largely depending on how much internal skill and experience with remote sensing and data analytics the buyer has, i.e. how much of that needs to be outsourced [K].

A related challenge, for commodities like cocoa and rubber, is the need for granular data to detect forest degradation and prevent the move into protected areas (Satelligence, 2019b): Illegal deforestation and encroachment in protected areas is typically started by gradually clearing of understory forests, while the final cutting of canopy trees that can be detected with optical satellites only takes place once the forest is already severely destroyed (Welsh et al., 2020). Thus, complementing optical imagery with radar or lidar imagery and applying specifically trained algorithms is necessary to detect forest degradation and thereby enable timely intervention [A]. Interviewees across organization types [A,B,F,I,M] emphasized the importance of considering the bigger picture and context of satellite data and alerts: The described gradual deforestation leads to situations where cocoa farmers and families are settling in the degrading forests with their livelihoods depending on the grown cocoa and cut wood. Late detection and follow-up can, thus, confront companies (or governments) with a social dilemma and added responsibility.

Further, buyers that already use remote sensing tools for certain commodities increasingly seek to broaden it to further impacts and commodities (see Section 5.5 for details), but limitations in imagery resolution or the detection accuracy of algorithms can challenge transfer. At the same time, technology providers pointed out that it is not so much a permanent technical limitation but rather a temporary one driven by (lack of) demand [A,H,K]: As the tools are still relatively new and were developed specifically for certain commodities most relevant to buyers, they were positive that a shift in buyer demand, an interest to co-develop and pilot a new use case and the continuing technological progress would like drive new applications in the future.

5.4.2 Data availability, ownership and sharing

Data-related challenges affect how useful the generated geospatial insights are for buyers' supply chain risk monitoring. Here, the aforementioned lack of visibility or traceability of raw material suppliers and their locations can be constraining, leaving buyers unable to link deforestation alerts with particular suppliers and lacking a granular foundation for monitoring and follow-up. Further challenges emerge from questions around data ownership and data sharing with buyers.

As outlined before, buyers may have varying levels of **upstream supplier visibility** concerning who their raw material suppliers are and where they produce. Obtaining this data represents a multidimensional challenge, aggravated by large numbers of suppliers, geographical or operational distance, the need for suppliers to agree on data sharing. The granularity of obtained data ranges from exact plantation boundary polygons to GPS points of farm, plantation or broader mill locations, and can pose secondary challenges when it comes to targeted follow-up. Working with nexus suppliers like mills in palm oil and pulp and paper or domestic exporters in cocoa can provide buyers with insights into where they are (roughly) sourcing from and in which quantities, narrowing it down geographically to certain provinces or districts [A,B,G]. This regional focus can then be used to operationalize remote sensing tools, even public ones with coarser deforestation alerts like GFW, and survey the deforestation rates and alerts in different areas to understand the overall situation and prioritize action based on where risks are assumed to be highest [B]. Yet, this only provides a rather rough estimate and provides little insights concerning which supplier's activities may be related to the deforestation or whether deforestation is even linked to the supplied commodity.

Beyond data on supplier locations, obtaining accurate **baseline data** on previous land-use is seen as critical to understand potential deforestation in the past and delineate which commodities drive deforestation, but also as challenging [A,H,K]. Older imagery may be coarser and more granular changes like planting cocoa or rubber into primary forests, thus, harder to distinguish (Ng, 2019). Technology providers typically support with baseline maps (Starling, 2019), but buyers may need to be aware which aspects they need to have. Additional – proprietary or public – datasets on topics like community and indigenous peoples' land rights, protected areas, peat land and assessments of high conservation value and high carbon stock areas can provide valuable additional layers, depending on the context. On a related, more operational note, handling all these datasets represents another challenge. While more granular information and multiple data layers can allow for more targeted insights, they can also require considerable processing capacities, thus slowing down tools, and need to be kept updated in regular intervals (Proforest, 2017) [E]. For certification schemes moving towards remote sensing tools, a connected challenge can be to digitalizing paper-based registers and information on farm locations [I]. At the same time, the tool and buyer still need to be able to process and use the data. Thus, while more accuracy (see Section 5.4.1) and more datasets can make the insights more actionable, this effect can level off after a certain point and become overwhelming instead.

Questions around **data ownership, confidentiality and data sharing** emerged from the empirical data as further challenges that can inhibit buyers' ability to access and use more granular data. While buyers can upload their own supply chain data into commercial tools as well as public tools like GFW Pro, sharing of data between buyers and external actors can be restricted by questions of data ownership and privacy [F,H]. This limits tools' efficiency and can lead to duplication of efforts for data collection among buyers (SCTN, 2017). Interviewees pointed out that governmental or legal restrictions can be a challenge here too, making sharing of concession boundaries illegal in some jurisdictions (Hicks, 2019) but Indonesia and Malaysia have changed their approach to this. To date, voluntary location sharing with downstream buyers, sharing and publication of supplier mills is becoming more common practice (GAR, 2019; Nestlé, 2020; Slavin, 2020) and also FSC is publishing a map of their certified forests, at least those for which boundaries were voluntarily disclosed, on their website (Dalgaard Worm, 2019). Yet, as outlined previously, the fact that deforestation is typically driven, not by a single commodity or actor, but by complex dynamics between different actors, commodities and land uses present in a region makes it necessary to tackle the issue cross-sectorally, i.e. share data "*at a higher landscape or jurisdictional level*" (Proforest, 2017, p. 34). Essentially, this means that data sharing, not just along supply chains, but across commodity supply chains and industries would be needed to verify that, e.g., deforestation is not just shifting between commodities. Beyond necessary data sharing, this would require standardization or compatibility between tools, methodologies and definitions used. Approaches like the RADD initiative in palm oil seek to bridge these by developing a joint alert system from scratch with the relevant involved parties.

5.4.3 Limited internal capacities

Buyers' internal capacities, like how mature their SSCM is, play a critical role in determining how effective remote sensing technology can be used. As outlined in Section 5.3, buyers may have upstream visibility or existing relationships with suppliers. However, the skills related to geospatial analytics or the development and training of algorithms are typically not among the core competencies of consumer-facing buyers. Thus, a key challenge that emerged from the empirical data is understanding which internal resources and skills the buyer has and how these affect the choice of remote sensing tool and how these may need to be complemented.

Practitioners agreed that while internal experience with geospatial analytics may seem necessary, it is not a critical precondition but will likely affect the choice of technology provider and required budget because the buyer will presumably need or want more support [G,I,K]. But as the founder and CEO of Satelligence put it "*[w]ell, the first thing is not a technical thing, but it's the* **commitment** *to really want to change stuff*". Thus, it is critical to have internal clarity on objectives and purpose, and to obtain internal buy-in from management to secure the necessary budget and support to enable consequent action after adoption such as the suspension of suppliers if necessary. Interviewees discussed that knowledge exchange and communication within the company, particularly between sustainability and procurement functions but in large companies also between business divisions, represent a key challenge [B,G,K]. The (lack of) internal communication affects if internal knowledge resources are fragmented or accessible to the relevant teams and it affects follow-up (Proforest, 2017). It can ensure or hinder alignment on questions like how to proceed with suppliers once deforestation is detected or who is responsible for leading follow-up activities. Again, the company's ability to share work and selectively leverage team's core competencies as well as speaking to suppliers with one voice determines how effectively risks are managed. One technology provider [K] explained that they see the dynamics shifting here and that procurement managers are increasingly involved or even reaching out in the first place suggesting that sustainability concerns are becoming more central.

In terms of **geospatial skills**, pattern emerging from the interviews is that companies closer to the raw material tier, like large traders that are also involved in production and processing, often have been working with remote sensing for a longer time also for monitoring their own operations, e.g. agricultural productivity, and often have internal experts and GIS departments. These companies may thus use freely available data or purchase the datasets and run their own analytics and prepare their own dashboards. Consumer-facing buyers that are further removed from the raw material stage on the other hand may lack the technical capacity and thus benefit from technology providers that combine satellite imagery and data analytics and further functionalities. "*So, you could of course say that a company should have a hundred people and should have their own GIS experts, but that's probably not where most companies are going. But it's definitely good to have some of that internally in the company and then you need a good partner that complements and supplements your skills*" (Interview, Buyer B). Nestlé, for instance, uses Starling with partner Earthworm for the technical support and focus their strengths on supplier engagement activities, while being actively involved in the sector-wide RADD initiative to drive remote sensing uptake in industry (Nestlé, 2020). In a sense, basic understanding of remote sensing may be more relevant to enable buyers, first, to have remote sensing on their radar and realize that there is a need or opportunity to adopt it, and second, to navigate the spectrum of available solutions and technical jargon.

Working with technology providers can support buyers' internal capacities, not just with the relevant imagery and data analytics, but also other resources like in-depth knowledge on how to prioritize alerts according to the local context or support with traceability. Selecting a technology provider comes back to the question of what the buyers' drivers and objectives with the remote sensing adoption are, which tools are available for a specific commodity or impact, which skills they have internally or need support with, if they seek to adopt the same system their peers and/or suppliers use, if they want an off-the-shelf or tailored system and what the budget is. The empirical data shows that buyers do not necessarily have the skills for "*time-consuming analyses, but they need to spend their time working with suppliers and farmers instead of having to sift through satellite images*" (Welsh & Wielaard, 2019, p. 2). But then again, it depends on the buyers' internal strengths and experience with remote sensing, and the choice can more generally be summarized as 'identifying what you, as a buyer, are good at and choosing the provider that allows you to do more of that while they take care of the rest', potentially in combination with other partners.

Further challenges relate to potential weaknesses in buyers' SSCM and associated resources and skills. For instance, a lack of knowledge resources concerning local context, deforestation dynamics and drivers in sourcing regions restricts buyers' visibility and effectiveness of follow-up action; a lack of local presence or resources for follow-up field activities limits buyers' ability to consequently follow through on alerts, thereby harming credibility (see Section 5.4.5); lack of negotiation or relation skills can limit buyers' ability to understand suppliers' incentive structures and convince suppliers to halt legal deforestation or to recruit direct suppliers to support them.

Overall, companies tend to stick to their core competencies – and may opt to further develop those of strategic relevance – but otherwise bring in external partners like technology providers and collaborations with other actors to supplement lacking skills. Thus, the challenge is more to prioritize and strategically complement existing internal skillsets than to diversify internally.

5.4.4 Governance challenges

The complexity of global supply chains as well as the monitored impacts does not allow individual actors to solve the issue by themselves, thus collaboration emerged as a critical requirement but also challenge from the empirical data. In Section 5.3, three governance mechanisms were identified from the data: collaboration along the supply chain, across supply chains and across sectors. While these can enable buyers to implement remote sensing and manage risks more effectively by providing access to external skills, bringing in external partners introduces additional variables, dependencies and challenges that are analyzed in the following.

Buyers rely on their relations with and leverage over direct and indirect suppliers for better upstream supplier visibility, more efficient follow-up processes for verifying alerts and getting raw material suppliers to comply with zero-deforestation requirements. Particularly for the latter, practitioners highlighted that even if deforestation is detected and verified as violating buyers' policies, the deforestation may still be legal in that jurisdiction and the supplier may not see the point of halting it (Olam, 2019) [F]. Achieving and maintaining influence across supply chain tiers, thus, represents a core challenge, particularly in complex supply structures.

Precompetitive collaborations across supply chains, i.e. governance activities involving peers from the same or different industries, for instance to share information, tools and follow-up like in RADD (Welsh & Wielaard, 2020), emerged in response to this challenge. Described as action-oriented and pragmatic, particularly in palm oil [F,G,K], these approaches help when individual buyers cannot solve the issue alone or with standard tools like certification and present an extension to working 'along supply chains' when working with suppliers is not yielding the expected results. This exchange enables more efficient resource use and helps to align supplier engagement in a concentrated industry like palm oil where consumer brands share supply chains via the large traders and producers (Satelligence, 2019a). However, a lack of this perceived 'pre-competitiveness' can pose a challenge. An interviewed buyer expressed frustration over the fact that 'deforestation-free' claims are viewed as a means for differentiation by some consumer brands in the cocoa context which hindered constructive collaboration beyond the multi-stakeholder CFI []. A related challenge at industry-level is that, on the one hand, industry laggards and free-riders can get away with deforestation and benefit from the overall improved industry image, while on the other hand, demonstrated transparency and actual progress on the ground by a few leading buyers do not necessarily translate into reduced reputational risks for these: The situation that stakeholder, particularly NGOs, pressure in the palm oil context may not necessarily target the industry laggards but focuses on more publicly present companies or brand names instead to trigger them to exert their influence creates this dilemma. "*It was demoralising for us in Wilmar, and to me personally, having been constantly singled out despite all our ongoing work to meet our sustainability commitments while other industry players with lesser or even no commitments continue to slip through the cracks*" (Ng, 2019, p. 4). In a sector where there is limited enforcement, either because deforestation is legal or because weak institutional capacities and corruption hinder enforcement of consequences for illegal deforestation (Weisse et al., 2019), the industry collaborations mentioned before become a form of voluntary self-regulation. Demonstrating voluntary standards or methods, for instance the RADD system, that companies employ to tackle deforestation, is thought to raise the bar for lagging competitors and – in a highly concentrated industry – call out the ones who are not part of the initiative.

Working across sectors represents a way to increase pressure on laggards with NGOs and address systemic issues and underlying drivers of deforestation at the root by bringing in local governmental actors and communities. On their website, palm oil producer GAR states that they "*would like to explore the development of an industry supply chain mapping platform. Together with other companies, we can input data from our mill and grievance lists and the platform would report on the cumulative transformation of the industry. It would also shine a spotlight on leakage buyers who source from rogue suppliers. NGOs and buyers can then initiate grievances against these buyers to close the leakage*" (GAR, 2019, p. 1). Collaboration with buyers and NGOs can thus enable 'soft' enforcement of higher sustainability standards. The CFI works similarly, with the support of two governments, although practitioners explained that the limited upstream visibility and limited public exposure of intermediaries like domestic exporters restrict the ability to exert influence and make it easier for less scrupulous actors to continue buying from opaque sources. At the same time, interviewed NGO and certification practitioners pointed out that sometimes governmental interests can be counterintuitive and support deforestation as a means for economic development or, if smallholder-driven deforestation is essentially caused by weak governments [F,I]. In such cases, remote sensing can help increase the public pressure not just on buyers and suppliers but also on governmental actors and working with local NGOs and communities can provide local knowledge. Landscape approaches can also be the basis for better local governance and over time reducing the involvement of companies and shifting responsibility to local actors.

So overall, while collaborations can provide buyers with access to complementary external skills and resources, managing these collaborations comes with its own challenges and transaction costs for communicating expectations and tasks, handling potentially conflicting interests or understandings. Thus, it can make sense to internalize these skills over time.

5.4.5 Leakage and on-the-ground challenges

Follow-up challenges that emerge from the data relate to how to move from risk monitoring and detection to effective **risk management** and actual **on-the-ground improvements** and was considered a critical factor for the success and usefulness of technology. Overall, it was pointed out that environmental monitoring provides limited value as a stand-alone measure but rather should be complemented with management of detected issues (see Section 5.3 for details).

One strategy for follow-up, supplier de-selection, would be to stop sourcing from raw material suppliers or regions after issue detection. However, supplier de-selection can lead to situations "*where the "good guys" move out of "bad areas" and leave a vacuum of good governance in the places where such investment is most sorely needed*" (SCTN, 2017, p. 88). As Musim Mas' General Manager of Programmes explained in a webinar "*We could of course just draw out of the high-risk areas. That would be easier. But that does not get us anywhere as an industry and will only increase scrutiny*" (Earthworm et al., 2020). Buyers' decision to stop sourcing from non-compliant suppliers risks can cause a challenge with leakage and "*only lead to a diversion of products originating from that place to other buyers, or to a displacement of undesired impacts (e.g. deforestation) to other locations (i.e. leakage), thus limiting or negating any overall net benefit*" (Godar et al., 2016, p. 10). This situation is driven by suppliers that are unwilling to forego revenues by stopping to legally deforest their land, on the one hand, and buyers that have no internal sustainability standards and are selling to markets where consumers do not require sustainability aspects. An alternative would instead focus on supplier development and engagement of local stakeholders to address the underlying causes and prevent new issues (Earthworm, 2019; Nestlé, 2019; Smit et al., 2015). The underlying challenge here links back to Figure 5-4 and to the decision between being seemingly consequent by removing deforesting suppliers and moving out of at-risk areas, demonstrating accountability to stakeholders and commitments and thus reducing reputational risks, on the one hand, and, on the other hand, accepting the messy reality and working with existing suppliers and local stakeholders to address underlying deforestation drivers and work towards lasting improvements on the ground. The former leaves the region even more vulnerable and at risk of further deforestation while the latter leaves buyers 'stuck' with capacity-building and community engagement tasks that are not part of companies' typical sphere of responsibility or expertise.

Similarly, interviewed NGO and certification practitioners pointed out that sometimes governmental interests can be hindering, for instance, supporting deforestation as a means for economic development or tolerate it through lack of enforcement by weak governments and institutions [F,I]. "*Because maybe companies don't want to be associated with any deforestation even if it's legal. But governments or smallholders who live on the land there have the right to convert it, so in this case if remote sensing detects deforestation but it's technically legal deforestation and the company then says 'ok, we don't want to source from you any longer' then this can create social and political issues. And these situations and interest conflicts you need to take into account when thinking about remote sensing*" (Interview, NGO A, Program Officer). Navigating such situations and conflicting interests – although not specific to the remote sensing context – without aggravating the situation and sparking reputational harm represents a challenge that may be mitigated or diffused by taking issue and responsibility to a collective level, similar to industry initiatives to pressure laggards.

Follow-up and its effectiveness depend to a large extent on whether the buyer sufficiently understands the **underlying dynamics, deforestation drivers and incentive structures** in different commodity supply chains and regions. Tackling ongoing deforestation and taking action to prevent recurrence requires understanding what led the specific supplier to deforest, what their incentive structure is and what gets them to change their behavior lastingly [M]. This challenge of having in-depth local knowledge and corresponding tactics means that follow-up activities by the same buyer may differ for different commodities, suppliers or regions [K]. Thus, knowing the supply chain structure and dynamics is important. Technology providers like Satelligence (2020a) explicitly consider this challenge and aim to support their clients through local offices and networks. In palm oil, deforestation has shifted from large-scale clearing to smaller, fragmented events by smallholders for palm oil or subsistence activities. Globally, smallholder farming produces more than a third of palm oil (Tropical Forest Alliance, 2017b), thus representing a considerable share of supply. However, mitigating deforestation by smallholders is also a more complex challenge due to larger numbers of individual actors and interdependency with other factors (including poverty, limited productivity, or country-level path dependencies from unsustainable land-use policies, infrastructure extension, urbanization, growing demand, or effects of events like war, economic trends and large-scale migration) (Kroeger et al., 2017; Smit et al., 2015). Further, smallholders continue to face barriers like comparatively high costs for obtaining sustainability certification (Khor, 2011). These challenges raise the risk of stakeholder exclusion from supply chains as buyers strive for 100%-certified or no-deforestation (Earthworm et al., 2020). Interviewed buyers brought up smallholder inclusion as an important connected challenge [B,D,G,N]. Similarly, as analyzed earlier (Section 5.4.1), remote sensing data may need to be complemented with other tools for surveying, for instance, social factors: "*By looking at it more holistically, you can also start to understand and change behaviors. Of course, deforestation is influenced macro-economic trends and policies, but in the end, you cannot change it without changing the behavior of companies or of smallholders, for instance in the palm sector. But you also have a lever there where greater awareness around what is the behavior, what are the perceptions, what is at stake for the people, what are their and your risks, that can also be an important lever for action*" (Interview, Ulula, CEO).

Overall, buyers' understanding of their specific context – in terms of supply chain structure, commodity dynamics, deforestation drivers, incentive structures, levers and contextual factors – is a challenge that affects traceability and follow-up and thus risk management effectiveness.

5.5 Future opportunities

The previous sections provided a comprehensive, nuanced overview of the current state of application of remote sensing technology in forest-risk commodity supply chains and its interrelation with other supply chain measures. In this context, the previous sections provided insights into patterns emerging from the empirical data with regard to current applications and connections to other sourcing practices. This section builds on the previous findings and serves to outline opportunities for future practical application and observed development pathways.

Transfer to other commodities and environmental impacts

As technological improvements are advancing rapidly and commercial interest in environmental monitoring is continuing to expand, an expansion of current tools to new commodity sectors is in the pipeline [A,K]. As outlined above, each commodity sector comes with particular dynamics and requirements for the technology. While monitoring of deforestation for palm oil plantations may be rather straightforward due to the clear cut differences observable in imagery, other materials like pulp and paper or rubber require more granular imagery and more advanced algorithms to be able to, first, differentiate regular harvesting from unwanted deforestation, and, second, detect more nuanced degrees of forest degradation. Moreover, the geographical range of forestry monitoring for pulp and paper is broader, ranging across temperate and tropical areas while both palm oil and cocoa growth is rather locally constricted with more condensed monitoring (Welsh et al., 2020). However, technical capabilities for pulp and paper-relevant imagery exist and will see broader use as buyers' interest increases [A,K]. One expert explained that some commodities entail again other challenges like the risk of secondary deforestation [A]: Sugar cane, for instance, would be relatively straightforward to monitor technically due to its growing pattern, but may require a more sophisticated methodology that can capture and detect when sugar cane grown on non-deforested land in fact pushed other land uses into vulnerable areas, causing secondary deforestation. However, as tool development is primarily determined by technical possibilities and buyer needs, future extension into new contexts seems likely.

Broadening scope across supply chains

Some of the early movers are now drawing on the experience gained during pilots (and full roll-outs) in high risk commodity supply chains for palm oil and/or cocoa, to broaden the monitoring scope in supply chains [G,N]. Again, this takes place in close collaboration with technology providers for adjusting analytics solutions to the new dynamics. Nestlé, having co-developed the Starling system, is now working with them to extend to commodities like pulp and paper or cocoa and potentially reforestation [A]. Unilever is developing a "*digital twin*" (Interview, Unilever) of their supply chain to be able to track commodity flows and sustainability aspects in real-time, linking their tailored blockchain-based chain of custody solution with other technologies. Both, with Cargill and others, are also involved in RADD to fund and develop an industry-wide system to be made available publicly in the GFW tool. At the same time, the field is constantly evolving, with new technology providers entering the market as well as new use cases and new users. This diversification is accompanied by a consolidation where new solutions like RADD are developed by and integrated into Satelligence's and GFW's services and made publicly available, where proprietary data from Planet is integrated into tools to increase granularity and where pioneer users fund additional, public, industry-wide solutions. These trends suggest that accuracy, standardization and compatibility of tools will increase.

From detection alerts to prediction and prevention

Moving beyond tackling already ongoing deforestation to also prevent future deforestation emerged as an overarching longer-term objective or motivation for buyers and other practitioners alike [F,K,N]. Approaches could include developing "*predictive models reflecting likely hotspots of future deforestation (risk) based, e.g. on patterns of infrastructure development and expansion, to encourage actors (e.g. investors) to adopt preventive measures*" (SCTN, 2017, p. 93). In a way, buyers' current use of remote sensing data for more risk-based selection of suppliers for audits or capacity building represents a simplified version of this. Practitioners argued that before prevention, there are various open tasks concerning ongoing deforestation, raising the playing field for entire industry, leakage of deforestation-linked supply onto the market and concerning cross-industry collaboration to avoid shift of deforestation pressure from one commodity to another in the same area [K]. Yet, with growing market demand for forest-risk commodities, e.g. for biofuels and bio-based plastics, and pressure from other land uses on forests, it will become only more relevant to reliably assess deforestation risk accurately and prioritize action.

Reforestation monitoring for carbon credits and offsetting

Monitoring of aboveground biomass, carbon stocks and reforestation projects receives growing interest as companies strengthen their climate targets [A,H]. On the road to becoming a carbon-neutral company, carbon offsetting for instance via reforestation projects, can complement internal emission reduction efforts. Lidar sensors provide a basis for estimating aboveground biomass and stored carbon content. While lidar sensing used to be restricted to rather costly monitoring via drones or airplanes, NASA's 2018 GEDI satellite mission (Dubayah et al., 2020) enables larger coverage and cheaper monitoring, albeit at a coarser granularity. Technology providers pointed out that it is a promising area for future application where they experience strong interest by a range of companies [A,H,K]. There are still certain inherent limitations, for instance, the time until the planted trees have grown large enough for remote sensing to be able to distinguish and classify forest types (Petersen et al., 2018). However, high resolution imagery combined with ground surveys can address this. As technology continues to improve and buyer interest is high, new solutions targeting reforestation monitoring can be expected.

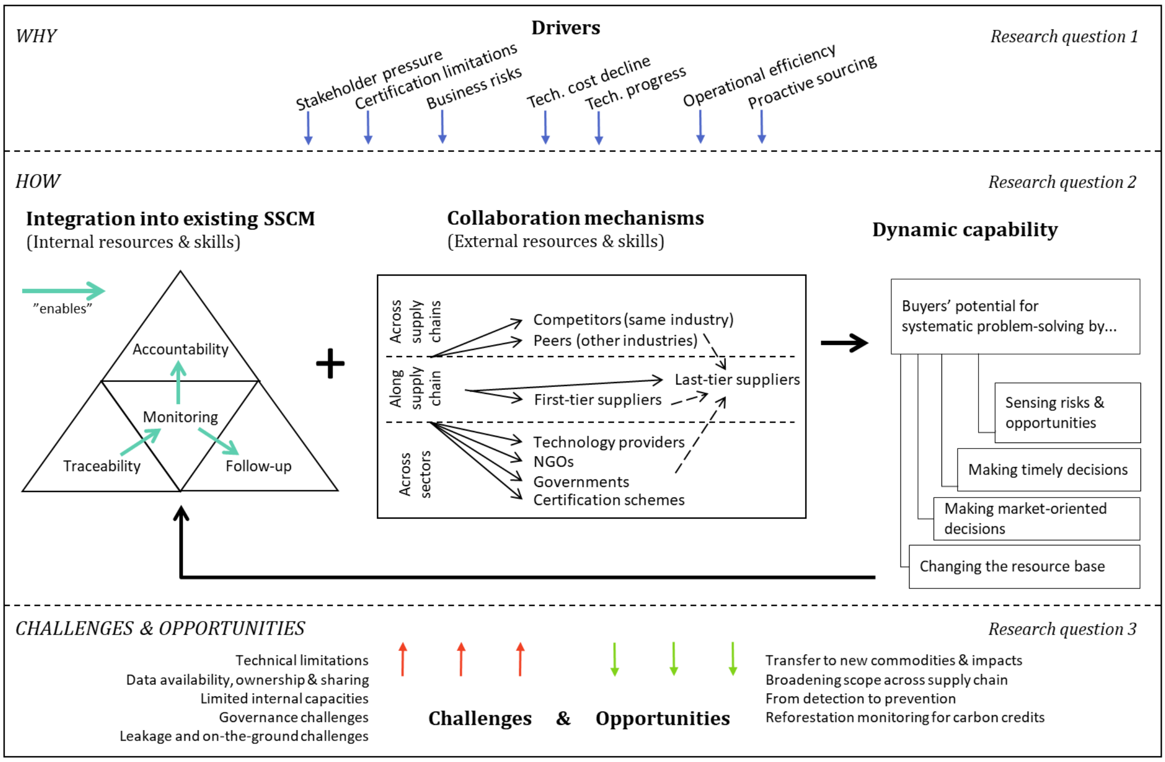

Figure 5-7 Conceptual framework of remote sensing adoption for systematic management of supply chain sustainability risks

Figure 5-7 above synthesizes the results from the previous sections and illustrates how, at the core, remote sensing tools are embedded into buyers' existing SSCM and complemented with external resources and skills through governance mechanisms to form a dynamic capability that enables the buyers to systematically solve current and future problems and harness emerging opportunities through continuous adaptation. Contingent drivers as well as challenges and opportunities affect which configuration and combination of internal and external resources and skills is most suitable to the specific buyer's case. These results, their significance, relevance as well as limitations and implications for practice and research are discussed in the next chapter.

6 Discussion

This chapter serves to review the findings of this thesis critically, thereby building the basis for the subsequent conclusion. First, the results are put into context and discussed regarding their significance and relevance for the thesis' research questions and aims. Second, the research methods' suitability, in terms of design as well as implementation and validity, reliability and generalizability, is scrutinized and limitations made explicit. Finally, after the findings' contributions and limitations have been discussed explicitly, implications for research and practice are deduced and starting points for further research and application outlined.

This thesis aims to contribute to more informed, data-driven management of supply chain sustainability risks across supply chain tiers. The application of remote sensing to monitor deforestation-related risks in supply chains has previously been a largely practical phenomenon that had not been investigated empirically or conceptually in the sustainable supply chain or general management research (see Chapter 2). The literature review of prior research on remote sensing in the context of sustainability and commodity supply chains, on the other hand, yielded mostly articles on application by actors other than buyers like NGOs or governmental bodies (see Chapter 3). This thesis has connected the two fields and draws on multi-tier supply chain management and dynamic capabilities theory to argue and provide evidence that the integration of remote sensing into existing sustainable sourcing strategies increases buyers' capacity to systematically solve problems, manage risks and harness opportunities related to upstream commodity supply chains. The research questions addressed in this thesis are as follows:

RQ 1: **Why are buyers implementing remote sensing technologies** to monitor deforestation-related sustainability impacts in their upstream supply chain?

RQ 2: **How are remote sensing technologies** used by buyers for monitoring deforestation-related impacts in their upstream supply chain **integrated into other SSCM measures**?

RQ 3: **What are the challenges and opportunities** related to using remote sensing technologies for monitoring deforestation-related impacts in the upstream supply chain?

6.1 Findings, significance and relevance

Comparing the empirical results with the academic literature review, which mainly reviewed articles on the use of remote sensing by other actors such as governmental bodies, research or NGOs due to the limited coverage from the buyers' perspective, it becomes clear that the underlying patterns are very similar. In line with the empirical results, the literature review suggested a strong focus on the palm oil sector (Kashmanian, 2017) and on tropical regions where deforestation risk is high and governance weak (Hansen et al., 2013; Müller et al., 2019).

What remains striking about reviewed literature on remote sensing (see Chapter 3) is the stark contrast between the substantial interest in remote sensing's role in sustainable governance of commodity supply chains and their environmental implications, on one hand, and an apparent absence of research on application or applicability by buyers and suppliers – being the ones who set up, drive, profit from global commodity trade – on the other hand. The latter was found reciprocally as a gap on the buyer's perspective in remote sensing-focused research and a gap on remote sensing technology in supply chain and general management research. Potential reasons for this limited interest include that interdisciplinary research between supply chain management and disciplines more traditionally using remote sensing like environmental conservation may be limited in the first place, suggesting a lack of awareness of remote sensing's potential value and a lack of sufficient commercial pressure or expected strategic advantage for buyers to proactively assume responsibility for deforestation issues and sustainability risks far upstream the supply chain and take corresponding monitoring and mitigation action.

Interestingly, the empirical data suggests that these disciplines' practical counterparts are a step ahead, have moved beyond traditional sectoral boundaries with buyers adopting remote sensing tools, co-developed with technology providers and environmental NGOs, and are currently at a stage of broadening the diffusion across industries.

RQ 1: **Why are buyers implementing remote sensing technologies** to monitor deforestation-related sustainability impacts in their upstream supply chain?

After exploring the current landscape of remote sensing use cases, centered around palm oil and cocoa supply chains, this thesis investigated the underlying drivers that explain why buyers are adopting remote sensing in the first place to answer RQ1. The drivers identified in empirical data range from business risks and stakeholder pressure, limitations of certification schemes, to technological progress and declining technology cost to leveraging more robust data for internal operational improvements and proactive sustainable sourcing strategies. Taken together, these suggest that the business case for adopting remote sensing is strengthening, as the potential costs associated with business-as-usual and not responding to stakeholder pressure and risks increase, as potential gains and future opportunities enabled through remote sensing increase and as better technology becomes available at declining prices. These results are consistent with the literature review which suggested risk monitoring (Gardner et al., 2019; Godar et al., 2016), declining trust in certification (Lopatin et al., 2016; Werner et al., 2019) as well as technological progress and technology costs (Hansen et al., 2013; Müller et al., 2019) as central drivers.

Different **risks** that buyers face – exacerbated by **stakeholder pressures** – emerged as the core driving force, particularly of the initial decision to adopt remote sensing. The early and by now comparatively broad adoption of remote sensing in the palm oil sector is driven by NGO pressure, together with the resulting reputational harm and scrutiny from other stakeholders like consumers and investors that threaten to entail boycotts, reduced sales and higher costs of capital. This particular emphasis on broader stakeholder pressure did not appear as centrally in the literature review (see Section 3), presumably because the reviewed literature focused on remote sensing use by stakeholders, like NGOs, who are driven by environmental risk on the ground rather than the resulting, stakeholder-exacerbated business risks. This is congruent with literature on supply chain sustainability risks and SSCM in two ways: First, companies act on supply chain sustainability issues when these become the subject of stakeholder pressure (Hofmann et al., 2014), as reflected in Seuring & Müller's (2008b, p. 1700) seminal definition of SSCM as the "*management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements*". Second, as companies' scope of ethical and legal accountability extends upstream, companies are facing larger business consequences from reputational, legal, operational and financial risks and thus incentives to take action and "reduce supply chain vulnerability as a whole" (Jüttner et al., 2003, p. 201) (Sodhi et al., 2012). Thus, literature suggests that uptake of technologies to gain transparency and management control over upstream sustainability risks should occur first in industries (A) where the particular sustainability risks on the ground are highest and (B) where stakeholders are sufficiently salient to exert pressure and thus operationalize sustainability risks into business risks, i.e. reputational, legal, operational or financial risks. This pattern is reflected in the predominant adoption in palm oil and increasingly cocoa supply chains.

However, **legal or regulatory risks** did not emerge as central from the empirical data although typically discussed as key in the background literature (Lozano, 2015; Reuter et al., 2010). Drawing on research on voluntary environmental initiatives, it can be argued that remote sensing adoption as well as the interviewed companies' overall sustainability efforts can be viewed as "beyond compliance" (Prakash & Potoski, 2012, p. 125): Legal frames are lagging behind stakeholder expectations in this area since transparency-oriented technology like remote sensing's use in supply chains is comparatively new, thus stakeholder demands play a larger role than legal demands. On the other hand, regulation targeting buyers' due diligence efforts and establishing the legal basis for holding them accountable for distant upstream sustainability issues has been increasing over the last years: Due diligence laws are now in place across major consumer markets, tackling supply chain risks like human rights violations and funding of armed conflict (Hofmann et al., 2018; Kim & Davis, 2016; Sarfaty, 2015). While these do not encompass deforestation-related risks – except the French Due Diligence Law that cover environmental impacts (LeBaron & Rühmkorf, 2017) – future regulation of deforestation due diligence does not seem farfetched. However, the empirical results suggest that, particularly in palm oil, the industry has shown more initiative, precompetitive efforts and ability to gradually get a hold of deforestation than for other sustainability issues. This is consistent with research on voluntary environmental initiatives, suggesting that companies engage in 'beyond compliance' activities to prevent tighter regulation or to manage competitors through increased pressure (Aragón-Correa & Sharma, 2003; Orsato et al., 2013). While industry-level efforts, including the recent moves towards industry-wide remote monitoring systems (Selby, 2019), are substantial, practitioners acknowledged the trend towards landscape level approach as necessary due to deforestation's complexity and interdependency of industries. In fact, due diligence regulation for forest-risk commodities was reviewed as an option in a recent feasibility study commissioned by the European Commission but – while promising strong contributions to tackling deforestation – found difficult to implement technically and politically (COWI, 2018). Further, regulation by select consumer markets, even if large, would be unable to close the leakage market which would require more uniform action across consumer markets or legal change within producing jurisdictions. Concerning the latter, practitioners even pointed out that current local governments in fact obstruct anti-deforestation efforts, for instance discouraging disclosure of concession maps or lacking enforcement. Empirical data suggests industry leaders are forming alliances to overcome such barriers, establish informal sustainability standards beyond legal requirements and thus raise the bar and pressure on laggards (further discussed below in the context of industry collaboration). In this sense, legal risks may not be primary drivers of buyers' current activities but do exist in the form of looming regulatory risks if voluntary industry action fails to bring about progress. Further, observing the general trend towards extended accountability for upstream sustainability issues in other sectors, buyers of forest-risk commodities may view it as a precautionary step to implement measures now that will in the future give them a critical edge over unprepared competitors.

Similarly, proactive sustainable sourcing strategies that **focus on emerging opportunities** emerged as a new key driver, beyond risks and beyond external enabling factors like technology's improving value-for-money equation. This focus on opportunities, i.e. 'positive' risks, is not explicitly discussed in SSCM research (Villena & Gioia, 2018) where 'negative' risk and stakeholder pressure dominate the seminal definitions (Seuring & Müller, 2008b). Where opportunities have been analyzed in the supply chain sustainability context, they have been operationalized as "*what may be solutions to existing sustainability problems*" (Schaltegger & Burritt, 2014) with potential "*positive spill over benefits*" (Pagell & Wu, 2017, p. 341) rather than as 'what may be business opportunities arising from solving sustainability problems'. However, the empirical data suggest that remote sensing adoption is not pursued by companies purely seeking to cut actual and potential costs or trial novel sustainability solutions. Approaches like Unilever's "*digital twin of the supply chain*" (Interview, Unilever) inherently build on a tight integration of sustainability data into business processes and proactively pursue a joint performance management. The companies interviewed can be seen as sustainability pioneers and while a majority of them have been targets of NGO campaigns in the past, their more recent activities suggest that these companies work towards taking sustainability seriously and integrating tools like remote sensing strategically offers benefits beyond risk mitigation such as ensuring resources supply or differentiation based on superior supplier relations. In that sense, the results on business opportunities as drivers are closer to strategic sustainability management literature (Engert et al., 2016) than the risk-focused SSCM research. These empirical patterns suggest that extending research and models on (supply chain) sustainability risks to also account for 'positive' risks could yield a better understanding of what firms get when pursuing SSCM that is systematically supported by technology (see Section 6.3 for future research suggestions).

While the focus on anticipating future opportunities and building the capacity to act on them is novel for the sustainability risk field, it strongly resonates with this thesis' second theoretical pillar of dynamic capabilities. This thesis initially argued (see Section 2.3.3) that tech-based multi-tier supply chain management of sustainability issues may represent a critical dynamic capability of the 21st century that not only enables companies to steer clear of reputational, legal, financial or operational risks resulting from sustainability issues but provides the basis for proactive anticipation of and adaptation to emerging opportunities. Both these elements, risk management and opportunity sensing, emerged empirically as core drivers of remote sensing adoption for systematically dealing with the dynamic context of stakeholder expectations, sustainability issues and supply chain complexities. Research on voluntary environmental initiatives provides an interesting, alternative perspective on the role of strategic proactivity, suggesting that the line between managing risk and harnessing opportunity is blurring in the future context: Taking proactive measures, like pushing the entire industry considerably beyond compliance as discussed above can thus prevent looming regulatory risks (Orsato et al., 2013; Prakash & Potoski, 2012). Yet, from a dynamic capability and resource-based view perspective, this form of proactivity can have limited strategic value if it does not specifically strengthen the buyer's internal resources and capabilities and, thereby, build a hard to imitate competitive advantage (Aragón-Correa & Sharma, 2003). This is further discussed below for RQ2.

RQ 2:	**How are remote sensing technologies** used by buyers for monitoring deforestation-related impacts in their upstream supply chain **integrated into other SSCM measures**?

RQ2 seeks to make a novel contribution, both, to practice and research by exploring buyers' internal processes and structures for remote sensing adoption. This serves to supplement prior research on remote sensing in commodity supply chains, which interestingly did not cover buyers' perspective, and prior research on SSCM, which did not cover remote sensing, and to connect these fields for future research. Elucidating the elements that determine effective remote sensing use for supply chain monitoring, further, is supposed to enable practitioners to ask themselves the right questions and make informed decisions about remote sensing.

The empirical data suggests that the effective use of remote sensing depends on its integration into a mature SSCM approach that provides certain support functions: first, a traceability function that enables accurate monitoring by linking remote sensing data to supplier locations; second, a follow-up function that ensures remote sensing data is acted upon effectively to mitigate sustainability risk on the ground; third, an accountability function that harnesses remote sensing data to provide transparent assurance to stakeholders thereby mitigating reputational, financial, and legal risks. These functions depend primarily on buyers' internal resources, skills and experience. Collaborative skills that enable buyers to build constructive relationships with internal and external partners, thus, emerged as critical from the empirical data: They enable buyers to compensate internal weaknesses (in terms of supplier visibility, monitoring, follow-up or accountability functions) by leveraging external partners' resources, skills and networks via three governance mechanisms: along the supply chain, across supply chains and across sectors. Together, the internal sustainable sourcing approach and external governance mechanisms form a dynamic capability that allows the buyer to systematically address emerging risks and opportunities, act on them in a timely and effective manner and continuously adjust their resource base to be prepared for future risks and opportunities.

These results are consistent with theory on dynamic capabilities as a "*firm's potential to systematically solve problems, formed by its propensity to sense opportunities and threats, to make timely and market-oriented decisions, and to change its resource base*" (Barreto, 2010, p. 217). Following this understanding, the results are consistent with theory: This thesis argued (see Section 2.3.2) that remote sensing can be viewed as the technological core of a dynamic capability. As a technical resource, remote sensing cannot fulfill these functions alone, but would – theoretically – have to be integrated into other practices and skills. Evidence for this was found in the empirical data with remote sensing relying on practices that ensure traceability to the supplier, effective follow-up and accountability to stakeholders (see Figure 5-7). The empirical data clearly suggests that remote sensing relies on a comprehensive SSCM being in place and can provide support and synergies as a data-driven component to existing sustainability efforts. This raises the question **whether a dynamic capability is result or also starting point** of remote sensing adoption. Thinking back to Figure 5.4 visualizing a buyer's SSCM elements as a large triangle consisting of four smaller ones, without the central small triangle of remote sensing-based monitoring, the figure or SSCM is still standing but is not as robust. Remote sensing provides additional stability against disruptions in dynamic environments, emerging risks and stakeholder pressures, but is no standalone solution or silver bullet. It could be argued that buyers' recognition of remote sensing as a new technical resource that could strengthen their SSCM suggests them to have an existing dynamic capability to begin with. However, buyers adopt remote sensing to gain on-the-ground transparency, i.e. precisely because their current approach lacks two of dynamic capabilities' defining elements that enable **timely** and **actionable** decisions. Thus, they seem to have a partial dynamic capability and good basis for extending it, rather than a full one to begin with.

Yet, by itself remote sensing remains a simple technical resource. From a resource-based perspective, the entire challenge thus essentially is about how to turn this technical resource, remote sensing, that is accessible to the entire industry and often for free into a distinct advantage that cannot be copied (Grant, 1991). This is consistent with research finding that certain resources need not be unique and can actually be quite common across competitors (Eisenhardt & Martin, 2000) but that it is that resource's integration with other resources and specific operationalization that is idiosyncratic (Gibbert, 2006). The buyers analyzed appear to be aware or expect that access to geospatial insights will inevitably become more universal soon and that to maintain their advantage, using remote sensing by itself is not sufficient differentiation. Instead, they need to make it hard to imitate by integrating it into their system, e.g. through co-developed tools as in Nestlé and Starling's case with tailored functionalities or the internal analytics of Unilever and Cargill. This concentration on internal core skills as the basis for distinct remote sensing use is consistent with literature (Prahalad & Hamel, 1990). This is further consistent with the emergence of pre-competitive initiatives: Buyers seem to have recognized that it is **not remote sensing data per se that provides the superior skillset, but rather how it is integrated** with other key data and worked with. Thus, early movers may just as well promote wider industry-initiative because A) it reduces industry stakeholder pressure by pressuring laggards and B) others will not be able to imitate their approach anyways. Further, remote sensing is associated with the dilemma of increased transparency outlined before: Buyers who already have a sound SSCM approach in place tend to benefit from the gained transparency while buyers with less mature support functions may find themselves unable to adequately work with remote sensing data and the additional transparency and resulting stakeholder scrutiny.

Concerning governance mechanisms, the most direct and basic one identified is buyers work along their supply chain with raw material suppliers, if possible, or intermediary suppliers to gain visibility and effectiveness. In line with prior research which identified nexus suppliers that aggregate supply from large numbers of upstream suppliers such as smelter in mineral supply chains (Sancha et al., 2019) as important steppingstones, a similar pattern emerged empirically for mills in palm oil or pulp and paper. While providing rather coarse proxies for where the material originates from, remote sensing of nexus suppliers' radius provides estimates of associated risks and enables buyers to prioritize high-risk suppliers for traceability efforts. This trend towards risk-based approaches in auditing is consistent with research (Hofmann et al., 2018). Sauer & Seuring (2019) take this a step further and suggest a two-step cascaded approach where nexus suppliers represent not just consumer-facing buyers' go-to point for traceability but also for managing and acting on issues further upstream, yielding essentially two focal companies with more targeted knowledge and leverage. This is reflected in remote sensing use by both, consumer brands and large traders like Cargill, i.e. consumer brands' suppliers.

Beyond governance along supply chains, working across supply chains, i.e. with peers from the same or different industries, and working across sectors, i.e. with technology providers, NGOs, governmental actors or certification, were important complementary governance mechanisms. This is consistent with multi-tier SSCM literature (see Section 2.3.1) that finds that buyers employ different governance mechanisms to bridge the complexity and distance of working with raw material suppliers (Mena et al., 2013; Tachizawa & Wong, 2014). The empirical data implies that **governance mechanisms and collaborations diversify and intensify** beyond certification as precompetitive initiatives and landscape approaches assume more central roles.

Certification schemes have long been the classic go-to third-party provider for assurance of sustainable sourcing in complex supply chains (Tachizawa & Wong, 2014). Yet, the empirical data suggests that the recent uptake of remote sensing was, among others, driven by certification somewhat losing its relevance. Central limitations include, first, inability to keep up with buyers' assurance needs in the face of the dynamic nature of complex supply chains, sustainability issues and stakeholder pressures, caused by second, the slow pace of digitalization and adoption of available technologies to increase transparency and traceability, reinforced by the inherently lengthier decision-making processes in multi-stakeholder settings. Buyers' choice to take things into their own hands by adopting remote sensing to enable more direct, timely, actionable insights is consistent with dynamic capabilities theory: It can be argued that, fundamentally, the growing discrepancy between what buyers need and what certification offers is caused by their increasingly dynamic, volatile context and the **path-dependencies of certification schemes**: In a sense, certification schemes are locked into a resource base that used to be advantageous and is now outdated – but is difficult to adjust due to the nature of multi-stakeholder decision processes. At the same time, it can be questioned whether adopting a parallel system, not just for assurance but with landscape approaches also for supplier development, is an efficient approach. Moving into this thesis project, it was unexpected to see large buyers adopting or co-developing own tools, rather than driving a joint approach at certification level. During data collection, however, it became apparent that remote sensing has long been on the agenda for established certification schemes, with more or less successful pilots, and with FSC launching a pilot remote sensing-based platform this year for more targeted audit planning (FSC, 2020). As discussed with buyers, the pattern seems to be that buyers pilot remote sensing and aim to take insights back to certification schemes. How effective this is and if this is the way forward for certification to stay relevant (see 6.3 for future research opportunities) remains to be seen.

Empirical data further suggests a **trend towards pre-competitive industry initiatives** seeking to address the issue at industry-level, raise the playing field and diffuse higher informal standards, such as the use of the RADD monitoring system, is consistent with literature. Pre-competitive collaboration has been discussed as common in cases where legal frameworks are substantially lagging stakeholder demands and companies are taking things into their own hands. In such cases, sustainability leaders in the industry who go beyond legal requirements and help improve the industry's reputation, may face disadvantages over freeriding industry laggards, who benefit from the reduced stakeholder and regulatory scrutiny that results from strong voluntary action, while increasing the risk for a major backlash. This frustration over free-riders aligns with research which further suggests that industry initiatives can have limited effectiveness if lacking sanctions (King & Lenox, 2000). This comes back to the question of how to deal with a lack of enforcement capacities (on industry- or on governmental level if institutions are weak). While it did not come up in interviews, the circumstances, as discussed earlier for RQ1, suggest that industry leaders may in fact be supportive of due diligence regulation, e.g. by the EU, as it could further institutionalize the pressure on laggards. Likewise, this would shift the quasi-governmental role of establishing and enforcing standards from buyers to regulators and, thus, would allow buyers to focus on their actual business again rather than on governance. As discussed earlier, theory suggests that buyers use their dynamic capability to gradually internalize strategically crucial resources and skills (Eisenhardt & Martin, 2000; Prahalad & Hamel, 1990). Taking this argumentation a step further, it implies that buyers also gradually externalize non-essential tasks to free up resources and sharpen their strategic profile. Shifting responsibility back to regulators can, thus, be understood as externalizing governance tasks and skills that are outside of companies' scope and were only acquired out of necessity to begin with.

Tachizawa & Wong (2014) argue that the **choice of governance mechanisms** is affected by contingencies such as the industry, the commodity's criticality to the buyer, stakeholder pressure or knowledge resources. This thesis did not investigate contingencies explicitly but analyzed and discussed these factors within the identified elements, for instance a buyer's traceability function being affected by their industry and particularly supply chain structure. The remote sensing use cases analyzed in this thesis are characterized by high criticality of the monitored commodity to the buyer, high stakeholder pressure, high corresponding business risks as well as considerable complexity of both monitored environmental impacts and supply chain structure. Essentially, this emerging contingency set substantiates the strategic relevance of the given sustainability risks and, thus, the need for investing in dynamic capability that enables better management of associated risks and opportunities. Theory argues, however, that building dynamic capabilities is not always necessary but that in fact "**ad hoc problem solving**" (Winter, 2003, p. 993) can suffice or even be superior when not targeting or building strategically critical, frequently used skillsets (Schilke et al., 2018). Thus, for buyers to whom the above contingencies do not apply (i.e. buyers with low material criticality of forest-risk commodities, low stakeholder pressure, low corresponding business risks, less complex environmental impacts and supply chain structures) remote sensing and the associated systematic SSCM structures may be overly complex and costly considering they promise relatively lower added benefits.

Buyers' observed **reliance on external partners** for accessing additional skills and compensating for internal weakness to build dynamic capabilities is consistent with research by Eisenhardt & Martin (2000, p. 1113) arguing that *"[d]ynamic capabilities also rely more on real-time information, cross-functional relationships and intensive communication among those involved in the process and with the external market*". At the same time, while investing in longer-term strategic collaboration is valid and in a way required to cope with the complexity of sustainability risks in global supply chains, it seems less suited to accommodate their volatility, and seem to contradict the very nature of dynamic capabilities theory: Having been developed to overcome the resource-based view's tendency to proactively establish path-dependencies by building strategic advantage on fixed resources which tends to lock companies in and hinder necessary fundamental innovation in more dynamic markets – establishing intensive collaborations with external actors seems contradictory. Further, as discussed for certification, democratic multi-stakeholder processes can slow down decision-making, innovation and create lock-in effects – and essentially created the need for buyers to adopt remote sensing to begin with. Thus, while engagement of suppliers and external partners can be crucial as discussed earlier, it needs to be chosen and managed carefully to avoid setting up a parallel system to certification with parallel weaknesses, but high operational and sunk costs invested in a capability that is outside the buyers' core business. This can be assessed as another argument for selectively prioritizing collaborations and for gradually internalizing strategically critical skills, rather than taking a 'the more, the better'-approach.

While external partners' ability to strengthen buyer credibility and accountability to stakeholders is identified as a core function, it was surprising that this **perceived trustworthiness** did not specifically emerge for the choice of technology provider. It seems that, on the contrary, satellite data is perceived as objective or neutral by stakeholders and more reliable than data reported by actors with vested interests. However, it can be expected that stakeholder scrutiny and buyer concerns around credibility are going to increase in the future as new remote sensing providers and buyers who are less ambitious about actual change on the ground and more interested in convenient assurance, enter the market. As for technology providers and tools reviewed in this work, it can be argued that they draw accountability from having roots in environmental NGOs, thinktanks or in research. In the future, calls for transparency and published methodologies, as for GFW and RADD, could grow. This could be a challenge for commercial providers like Starling whose business model is structured around their proprietary algorithm while commercial providers like Satelligence who intentionally publish their algorithm and instead rely on their longstanding expertise in client-centered, actionable insights seem better prepared.

RQ 3: **What are the challenges and opportunities** related to using remote sensing technologies for monitoring deforestation-related impacts in the upstream supply chain?

RQ3 addressed the concrete challenges and opportunities of the application and applicability of remote sensing in the sustainable sourcing context. Specifically, the empirical data suggested key challenges with technical limitations, with the availability, ownership and sharing of data, with limited internal capacities, with governance and with leakage and on-the-ground follow-up. Emerging opportunities identified relate to new use cases for additional commodities and environmental impacts, buyers seeking to monitor multiple supply chains, a shift towards prevention and an extension to reforestation monitoring for carbon credits and offsetting.

The empirically identified challenges resonate with those identified in the literature review. Technical limitations such as obstruction of optical data by cloud coverage affects buyers and non-commercial users alike, although a reliance on coarser but free, public imagery featured more centrally in the literature review. Likewise, the lack of visibility and data (Kashmanian, 2017), specifically access to confidential buyer and supplier data by external actors (Gardner et al., 2019), and the challenge of follow-up enforcement and leakage emerged (Godar et al., 2016). Expectedly, challenges related to buyers' internal capacities and role in governance mechanisms were not covered in literature which, as discussed earlier, did not cover the buyer's perspective.

Overall, these challenges reemphasize the need for a mature SSCM approach to provide supporting functions – while technical limitations and further developing tools according to buyers' needs is a challenge for technology providers, the remaining challenges essentially restate that buyers' need to have internal resources and skills to put the remote sensing data into context and into action: Data-related challenges essentially emerge from a lack of upstream traceability. Challenges of follow-up and understanding local dynamics result from a weak follow-up function and ability to act on deforestation alerts. The challenges with internal capacities and collaboration, then, on a higher level outline the difficulty of mapping and prioritizing what can and should be conducted internally and identifying which external collaboration mechanisms to engage in to compensate for weakness and build a strategic advantage. Leaving the remote-sensing-specific thesis subject for a moment to return to the broader supply chain research background, these challenges all fundamentally resemble the challenges that have kept supply chain practitioners and researchers for a long time from approaching sustainability risks at distant upstream suppliers (see Chapter 2). The lack of visibility, data and predictable dynamics, the difficulty of enforcing standards via geographical and operational distance, the resource-intensive, lengthy nature of working with stakeholders, the lack of local laws requiring companies to take on quasi-governmental functions – these aspects are inherent to a lot of sustainability issues ranging from climate impacts to forced labor in complex global supply chains. Coming back to the remote sensing and deforestation, here it becomes apparent that practitioners start to accept these dynamics and are moving towards action-oriented efforts. Likewise, the triangle of SSCM functions resembles the plan-do-check-act cycle of any management system. So, this is essentially no new information. Likewise, the monitoring function – in this thesis operationalized to focus on remote sensing – is covered by other practices like audits in normal SSCM. What is novel, however, is the need to plan-do-check-act across multiple supply chain tiers, to bring in other actors, be it other internal teams, suppliers or external actors, and to gain more accurate, real-time, spatially explicit monitoring skills.

The nature of the future directions that emerged from the empirical data suggest that the uptake and diffusion of remote sensing in the sustainable sourcing context is going to continue: While starting with high-risk commodities and regions, the future patterns point towards broader, deeper and timelier or even predictive monitoring of supply chains. Moreover, they are extending to not exclusively supply-related areas like reforestation projects that promise to turn into considerable economic opportunities when the world eventually turns climate commitments into actions or else as backup supply to meet growing demand for forest-risk commodities. Anyway, remote sensing in sustainable sourcing seems here to stay, along with an overall trend towards data-driven decision-making and supply chain transparency.

6.2 Methodology and limitations

This section discusses the suitability of the research design, methodological rigor and limitations. The research design was influenced by three key characteristics of the research problem: The application of remote sensing in the SSCM context is relatively new. Research at the intersection of remote sensing and SSCM is limited, particularly research taking the buyer's, i.e. management, perspective, as is research on managing sustainability risk at distant raw material suppliers. Simultaneously, in practice, examples of buyers adopting remote sensing to complement their sustainable sourcing efforts in, for instance, the palm oil context, range from initial trials to pilot projects and even full-scale rollouts are growing. This thesis' research design thus followed an exploratory case-based approach to investigate this emerging phenomenon by collecting qualitative empirical data on the experiences of these pioneering practitioners and analyzing the drivers, current practices, challenges and opportunities. The findings were synthesized to form a foundation for future research targeting the research gap at the intersection of remote sensing and sustainable sourcing literature as well as a foundation for further practitioners aiming to venture into this field to monitor, manage and possibly prevent deforestation-related risk.

The research design was not a priori restricted to a specific industry, commodity or buyer since use cases of remote sensing in sustainable sourcing are only emerging and still rather limited. This not having a clear-cut case can be seen as a limitation due to less specific results, less clear delineation from other cases and thus potentially impaired generalizability to a particular group. Yet, this approach was deemed necessary within the thesis' scope to ensure a sufficiently broad and detailed set of interviews and documents. Limiting the scope to a specific industry or buyer beforehand would have posed the risk of finding limited reports or available interviewees and having to retrofit the scope later on. Further, the very purpose of this thesis, among others, is to understand how, including by whom and for which commodities, remote sensing is applied – thus it was deemed necessary and more valuable to take a broader approach.

In terms of **validity**, the results would have benefitted from a larger sample (than 13 interviews) and more overlap: Interviews with several experts from the same organization or organization types to reduce the impact of individual, potentially biased viewpoints could have increased the internal validity (Verschuren, 2003). Interviews were conducted with experts from focal companies, certification schemes, NGOs and consultants. Including raw material suppliers or local actors could have added a valuable perspective by those who are close to deforestation-related impacts and drivers, remote sensing and local dynamic on the ground. This could have yielded a more comprehensive, nuanced picture, particularly since these groups tend to be the most vulnerable actors in supply chains, but data collection in the field was not feasible within the thesis scope. Interviews with experts from NGOs and certification were included to capture this perspective to some extent via a third party. To further account for potential gaps and to complement interviews, the thesis included 21 practitioner reports, 28 websites, 11, news articles, 3 industry podcasts and 4 webinars held by or featuring experts from relevant organizations. Overall, the data sample and validity seem adequate and realistic, particularly when assessing this in the context of a four-month thesis with limited time for data collection.

Concerning the results' **reliability**, qualitative methods like interviews are inherently more prone to variation both in data collection and analysis (Walliman, 2006). To counteract this, interviewees were given the same introduction, interviews were conducted in semi-structured form and the qualitative content analysis was conducted systematically in NVivo. Structured interviews could have led to more reliable results but would likely also have compromised the richness of data gathered and led to more superficial insights. All interviews were conducted online, thus limiting situational influences. Further, a high degree of overlap between the empirical results and concepts and patterns found in literature was found.

Besides these anticipated limitations and difficulties, the outbreak of **Covid-19** added an unexpected constraint to the situation. From a data collection perspective, the chaotic situation faced by practitioners – from cancelled meetings, work from home and extra workload – made it more difficult to schedule calls with experts, with three practitioners explicitly declining interviews referring to Corona. Most of the data collection and thesis write-up, however, progressed as planned. While the Corona outbreak specifically could not have been anticipated, the author planned for contingencies and potential delays more generally when scoping the thesis and project plan. Reaching out to practitioners ahead of time to accommodate their schedules, supplementing primary data with podcasts and webinars that featured intended interviewees, and scheduling buffer times helped compensating for Corona-related disruptions.

Concerning **generalizability**, the results do not offer a one-size-fits-all manual of how to integrate remote sensing into sustainable sourcing to conquer risks and opportunities. The thesis also never aimed to do this, and qualitative case-based research is typically not the most suited research approach for producing universal rules based on statistical averages. Instead, cases are "aimed at [the] description and explanation of complex and entangled group attributes, patterns, structures or processes" (Verschuren, 2003, p. 137). The thesis followed this approach and, thus, scrutinized empirical data to extract core elements – like drivers, sourcing structures, governance mechanisms and challenges – that, in one form or another, are characteristic of remote sensing adoption for SSCM for forest-risk commodities and possibly mining as multi-tier SSCM literature suggests similar supply chain structure, traceability challenges, lack of oversight and stakeholder pressure (Hofmann et al., 2018; Sancha et al., 2019; Sauer & Seuring, 2019).

Inherently, remote sensing tools come with the limitation or specialization on environmental impacts like forest conversion rather than social issues. In this sense, the thesis topic itself reinforces the existing tendency in research on sustainability, sustainability management and SSCM to – explicitly or implicitly – **focus on environmental over social** sustainability aspects that has been reiterated over the years without entailing much change in research (Pagell & Wu, 2009). And while datasets on indigenous or community lands are aiming to bring the social dimension into satellite imagery, it is still difficult to systematically capture such impacts. Yet, many environmental changes like deforestation are closely connected to underlying causes like poverty, weak institutions, vested interests of elites and secondary impacts like increased inequality and vulnerability of communities. This thesis deliberately decided to limit its scope to environmental deforestation-related aspects, yet in the future, these transparency ambitions need to be brought together more strongly with human and labor rights transparency. With a growing focus on data-driven decision-making and transparency, this merging of data can be expected to become more feasible. Likewise, information on workers' perceptions and situations also provide a more nuanced, holistic understanding of drivers and consequences of deforestation, particularly on smallholders, and thus the basis for lasting change on the ground.

Dynamic capabilities theory is at the core of this thesis and has been instrumental in complementing and extending the narrower risk-perspective of sustainable supply chain literature to also encompass the potential of future opportunities. However, dynamic capabilities theory has been criticized for being vague, difficult to operationalize and tautological, prone to circular explanations (Williamson, 1999; Winter, 2003). To address these concerns, the thesis followed Barreto's (2010) definition that was developed more narrowly to limit precisely these criticisms. However, it needs to be critically acknowledged that prior knowledge of a theory introduces availability bias in the sense that the author is at risk of more easily identifying the theory's same familiar patterns in a given dataset than without prior theory knowledge. This is a particularly valid concern for a theory like dynamic capabilities that has been criticized as a 'catch-all'. While having another researcher independently analyze the data and then triangulate the findings would be a useful countermeasure under different circumstance, this was not an option in the setting of an independent thesis project. However, to partly compensate for this, the findings and analysis were iteratively discussed with the academic supervisor, peers and the feedback group supervisor to assess how substantiated the results and conclusions were.

As discussed previously, the focus on specific use cases, commodities, industries and monitored impacts emerged – within the predefined scope (Section 1.3) and practitioner selection criteria (Section 4.2) – inductively from the empirical research. This yielded a focus on deforestation-related impacts, palm oil and cocoa and specific tools. The overall thesis subject is highly inter- and transdisciplinary, connecting – beyond supply chain management, sustainability risks and remote sensing – to forest management, development studies, government failures, certification schemes, sustainability governance, stakeholder management or smallholder inclusion. Readers will – depending on their backgrounds and interests – be drawn towards different elements within this thesis, recognizing the inherent connections, and be prompted to identify relevant related aspects that could have been addressed in this thesis – but were not. These may range from mapping power structures to discussing achievements or issues with multi-stakeholder-governance processes in general, to surveying how stakeholders perceive different remote sensing tools' credibility. Yet, while the thesis could have tried to provide more background or in-depth analysis of select topics, this was never the aim and defined scope of this work and would have blurred the analysis. Rather, this thesis aimed to spark precisely these thought processes and discussions, by venturing into a novel area at the intersection of SSCM, sustainability risks and remote sensing technology, where research was apparently lagging practice and where practical lessons learned had not been analyzed and structured in a way that enables further systematic research and application. The developed framework synthesizes current empirical knowledge and builds the foundation for scholars and practitioners to locate where this work connects to their research discipline or company background, interests or needs and take it from there. The next section develops these thoughts and implications in more detail.

6.3 Implications for practice and research

As outlined in the last section, this thesis critically reviewed the emerging practice of remote sensing for sustainable sourcing of forest-risk commodities and, by synthesizing lessons learned from empirical data provides implications for practice and research. Concerning **research implications**, the results suggest several pathways for research opportunities that either expand on and deepen the investigations of this work or complement it with additional perspectives.

More comprehensive **understanding and operationalization of the risk-opportunity spectrum** in supply chain sustainability risks and management research. Extending and critically reviewing existing frameworks as well as definitions that only account for negative risks, i.e. potential costs, to also encompass positive risks, i.e. potential opportunities or gains. Working towards a more holistic mindset in SSCM can reveal previously overlooked business opportunities and thereby increase the strategic relevance of responsible sourcing. This is reflected in a systematic literature review in the field that identifies a future research opportunity in the inclusion of positive aspects (Beske-Janssen, Johnson, & Schaltegger, 2015). A recent Delphi study of 35 SSCM practitioners and academics on future research areas did not identify strategic business opportunities explicitly as a future research area, other than "*Long-term SSCM results, i.e. potentials and resulting benefits*" (Reefke & Sundaram, 2017, p. 204) ranked 13th, thus reinforcing the need for a more fundamental mindset shift. Investigating and redefining SSCM, not just in terms of its ability to avoid environmental or social harm and stakeholder pressure (Seuring & Müller, 2008b), but also potential opportunities to ensure future resource supply, market access and differentiation are deemed relevant based on this thesis. Particularly the role of technology, like remote sensing, in enabling timelier insights and responsiveness may be crucial to review as, both, sustainability issues and global supply chains are dynamically evolving and characterized by complex interdependencies that are not fully understood.

As brought up in Chapter 2, there remains a need for "[t]ruly **multi-tiered supply chain research**" (Jabbour et al., 2019, p. 19) beyond dyadic or triadic (Mena et al., 2013) buyer-supplier relations. As Sauer & Seuring (2019, p. 31) conclude for mineral supply chains, "*the most impactful tiers lie outside the reach of current MT-SSCM concepts"*, a finding that emerged also in this thesis. A move towards all-tier SSCM includes developing more differentiated understanding of different supply chain structures – beyond generic categorization as *"closed", "transitional"* or *"open"* (Mena et al., 2013, p. 61) configurations – and their implications for sustainable sourcing and risk management. As companies move towards a more targeted, risk-based auditing of direct suppliers, this may need to be expanded to prioritize the highest risk suppliers across tiers to reflect the impact of upstream issues more adequately. Investigating the role of technology and data-driven risk assessment for complex supply chains could be relevant to support practical operationalization. A related research opportunity is investigating not just effects of supply chain structure on SSCM, but also effects of SSCM strategies on future supply chain structures. While supply chain structures may change in response to sustainability and supply chain resilience becoming more critical to business performance in general, the recent supply disruptions triggered by Covid-19 lockdowns have sparked discussions around the value of shorter, more regional supply chains or planned redundancies and higher flexibility to ensure resilience. Research examining existing 'conventional' supply chain management tools and how to align and improve them with, e.g. remote sensing-based, sustainability data – similar to the 'digital twin of the supply chain' that Unilever is developing – could advance practical value.

Related to this last point, this work provides evidence that there is a substantial need for **more inter- and transdisciplinary research** in order to tap remote sensing's full potential. Practitioners with a research background in remote sensing outlined that there is a substantial gap between what is researched in the labs and what is relevant in practice. High-level research is considered too detached from the practical realities (and even other disciplines' application needs) to provide full value. The lack of coverage by SSCM literature further suggests that scholars on remote sensing technology have been equally unable to demonstrate the potential use and value to other research fields. Similarly, insights from practice need to better find their way back into research to inform further development of technologies and processing capabilities to build user-friendly practically relevant tools. This implies that applied, transdisciplinary research that gets its research problems and data from practice and develops scientific solutions for practice could be valuable. Similarly, interdisciplinary research bringing in fields like forest management, development studies, sustainability governance or stakeholder management could provide deeper insights into the individual elements of the framework and its implications. Further, transdisciplinary research with practitioners involved in commodity supply chains can improve knowledge on underlying dynamics and deforestation drivers and allow for better informed follow-up and landscape approaches and prevention of unintended consequences. As suggested by empirical data, deforestation or degradation is often linked to poor agricultural practices, social aspects like poverty, perverse government incentives, lack of enforcement of laws or certification requirements, conflicts of interest, and leakage markets. Increased transdisciplinary research may allow more targeted, effective programs and encourage buyers to dare to work towards long-term improvements in risky areas rather than divesting to stay formally on track for no-deforestation goals. Likewise, research into how to avoid path dependencies of governance schemes that rely too strongly on private companies is deemed relevant and in the interest of companies, communities and governments alike.

Related to the future of certification is future research into **stakeholders** and the role of **legitimacy** which becomes increasingly relevant with the ongoing more data-driven decision-making: Based on the empirical data, remote sensing to date faces surprisingly little discussion around methodological transparency and data interpretation, but is rather seen as a source of objective, reliable and neutral information to inform stakeholder dialogues and landscape approaches. As with other information technologies, it can be expected that stakeholder scrutiny concerning legitimacy of remote sensing providers, tools, methodologies and data and how it affects the legitimacy of buyers using these is going to grow with further uptake.

Research into the **role of certification schemes** and how to update them to better meet the needs of buyers as well as certified suppliers and smallholders seeking certification. One of the empirically identified drivers of remote sensing adoption is buyers' dissatisfaction with certification schemes concerning their effectiveness to induce change on the ground, their perceived legitimacy and thus their value for effectively reducing environmental and business risk. The diversification of stakeholder pressure and diversification of assurance mechanisms – for instance, from the financial sector scrutinizing companies' sustainability reporting and considering remote sensing data to leapfrog companies' self-reporting – challenges certification schemes as the formerly primary providers of independent assurance. Research could investigate how certification's two-edged role as assurance and development mechanism is developing and how business model innovation based on digitalization of services, traceability, new data sources like remote sensing and development-oriented activities enable certification to stay relevant.

Practical implications of the thesis relate to how the developed conceptual framework can assist companies who already use remote sensing and companies who are considering adopting remote sensing to navigate their decisions and prioritize how to further improve their use. While acknowledging that no universal step-by-step manual for effective remote sensing adoption can be derived, the thesis identifies the critical elements and questions that are relevant for buyers to consider, provides illustrations of how others have addressed challenges, and outlines connected exercises that can support the process. For practitioners, relevant considerations that can be drawn from this study and framework include: *We need to have supply chain visibility. We need to have the capacity to act (and thus manage sustainability risk on the ground). We need to be able to credibly* *demonstrate our efforts to internal and external stakeholders (and thus manage resulting reputational, legal, operational or financial risk). We need to understand our drivers (including our risk profile, our salient stakeholders and how the latter impact the former). Technology can help connect and achieve the aforementioned points in a more targeted, fact-based and efficient way*. These insights are explained in more detail below.

Remote sensing is **no stand-alone solution**. Rather, it requires careful consideration, preparation and integration into a mature sustainability management system, providing traceability, follow-up and accountability functions, to enable the buyer to make the most of it by linking remote sensing data to suppliers to make it actionable, acting effectively on the data, and communicating the achievements credibly to stakeholders.

Remote sensing is **no one-size-fits-all solution**. Remote sensing solutions are providing more relevant insights, the better they are tailored to the specific challenges a company is facing. For this reason, considerations concerning the purpose and objectives of adopting remote sensing, the particular supply regions and aspects to monitor are critical. The better a company knows their drivers and risk profile, their internal resources and skills, their supply chain structure and dynamics, the more value they can get out of the remote sensing tool. Large producers with internal GIS capacities may require less analytics and follow-up support but more external expertise to establish stakeholder accountability. Consumer brands may be stronger in terms of stakeholder engagement and demonstrating accountability, while they may lack geospatial skills and follow-up on the ground. For the latter, focusing on core skills could mean outsourcing tailored data analytics to a commercial provider who provides necessary support, and instead focusing on building strong relations to direct suppliers who could take over follow-up tasks.

It can make sense to decide **against remote sensing adoption**. Remote sensing data is clearly a potent tool for getting a better understanding of what is happening on the ground in supply chains, monitoring risks, taking timely targeted actions and communicating transparently about it. Yet, it also requires resources in terms of staff, budget and time, beyond the functional sustainable sourcing approach discussed above. Adopting remote sensing means continuously engaging with the data and with suppliers (or other actors depending on the governance mechanisms) and the added external transparency can raise expectations of stakeholders – thus increasing the risks associated with not delivering. Consistent with literature, sometimes sticking with 'ad hoc problem-solving' is more useful than investing in building a dynamic capability. If forest-risk commodities represent minor sourcing volumes, if deforestation or other remotely sensible impacts are no material sustainability issues, if staff capacities simply do not suffice, if there is no stakeholder pressure, if you are a small company, etc., it may make sense to reject or postpone the idea of remote sensing and resort to alternative methods like sourcing certified or selecting suppliers based on proxies like suitable (!) country-risk indicators.

Adoption considerations that can be useful to ask and clarify internally to assess if and how remote sensing can provide value: *What are our main drivers for considering adoption? Who are our stakeholders? Which are most salient and what are their expectations? Have we mapped them? How do we expect drivers and stakeholder expectations to develop in the future? What are our objectives with remote sensing adoption? Which opportunities do we see? How mature is our SSCM? What are weaknesses? How much time, staff and budget are we willing to allocate for this on a continuous basis? What are our technical skills? How are our supplier relationships? How far upstream can we get data? How is our supply chain structured? Which nexus suppliers might we use as proxies? Which existing external collaborations or partners do we have? How can they help gain better upstream visibility/follow-up/credibility towards stakeholders? Which of these aspects do we need support with? Etc.* While it may not be possible to answer all these questions, they enable the buyer to get a clearer picture of where their strengths and gaps are, where they may need external support and where additional exercises, like stakeholder mapping, could help specify what a remote sensing tool should deliver.

7 Conclusion

This thesis set out to investigate how remote sensing tools are currently used by buyers to monitor deforestation-related sustainability risks in supply chains, how it connects to other sourcing practices and organizational skills and what the critical factors are that allows buyers to systematically monitor, manage and sense (and act on) new deforestation-related supply chain risks and opportunities. Thereby, this thesis hoped to contribute to better informed, data-driven monitoring and management of sustainability risks across upstream supply chain tiers in practice. As research is still predominantly concerned with direct buyer-supplier relationships than sustainability risks further upstream, while companies are forging ahead and piloting tools like remote sensing to gain upstream transparency, this thesis aims to synthesize what has so far been learned in practice to build a foundation for researchers as well as further practitioners seeking to venture into this field. For this purpose, qualitative empirical data, consisting of 13 interviews conducted for this thesis, 4 webinars, 3 industry podcasts, 28 websites, 21 practitioner reports and 11 news articles, was collected and analyzed through a qualitative content analysis in NVivo and subsequent in-depth analysis to answer the following research questions:

RQ 1: **Why are buyers implementing remote sensing technologies** to monitor deforestation-related sustainability impacts in their upstream supply chain?

RQ 2: **How are remote sensing technologies** used by buyers for monitoring deforestation-related impacts in their upstream supply chain **integrated into other SSCM measures**?

RQ 3: **What are the challenges and opportunities** related to using remote sensing technologies for monitoring deforestation-related impacts in the upstream supply chain?

Concerning the current application landscape, the empirical data yields that remote sensing tools are predominantly used in palm oil and cocoa supply chains (increasingly also pulp and paper, rubber and soy) for monitoring deforestation (increasingly also related and more granular impacts like forest degradation, forest conversion and reforestation or carbon stocks).

The **first research question** (see RQ1) can be answered as follows: Buyers are implementing remote sensing technologies because growing, diversifying business risks and stakeholder pressure increase the potential cost of business-as-usual, because existing certification schemes are unable to effectively mitigate these risks, because technological progress and declining costs make better technology more affordable, and because future opportunities and gains promised by operational efficiency improvements and proactive sourcing strategies increase. Overall, this study, thus, shows that the business case for remote sensing adoption is growing stronger.

For the **second research question** (see RQ2), it is concluded that buyers who adopt remote sensing tools already have a mature SSCM in place which enables the effective use of remote sensing by providing three connected functions: first, a traceability function that enables accurate monitoring by linking remote sensing data to supplier locations; second, a follow-up function that ensures remote sensing data is acted upon effectively to mitigate sustainability risk on the ground; third, an accountability function that harnesses remote sensing data to provide transparent assurance to stakeholders thereby mitigating reputational, financial, and legal risks. Buyers are typically able to internally fulfill these functions to varying degrees. To complement weaknesses in internal capacities with relevant external resources and skills, like local knowledge or analytics skills, buyers draw on three collaboration types, i.e. along the supply chain, across supply chains/industries and across sectors, to achieve better traceability, monitoring, follow-up and accountability functions. Together, the internal SSCM skills and complementary external collaboration form a dynamic capability, enabling the buyer to systematically monitor issues, anticipate emerging risks and opportunities, take timely action and continuously adjust the resource base, e.g. by internalizing skills previously access through external collaboration.

The **third research question** (see RQ3) can be answered as follows: Challenges in the adoption and effective implementation of remote sensing emerge concerning technical limitations of different tools, data availability and ownership, buyers' internal capacities, collaboration and effective follow-up. Future opportunities were found to emerge regarding new use cases (such as pulp and paper or soy and forest conversion or aboveground biomass), broader monitoring across buyers' multiple commodity supply chains, moving beyond issue detection to prevention, as well as reforestation monitoring for carbon credits and offsetting.

The **contributions** of this thesis are fourfold: First, it investigates remote sensing tools available for the sustainable sourcing context as well as the drivers, process, challenges and opportunities of integrating them into existing SSCM practices. While acknowledging that no universal step-by-step manual for effective remote sensing adoption can be derived, the thesis identifies the critical elements and questions that are relevant for buyers to consider, provides illustrations of how case companies have approached these challenges in their context, and outlines connected exercises that can support this process (see implications below), thus supporting more informed, data-driven sustainable sourcing. Second, this thesis examines a largely practical phenomenon and condenses insights into a conceptual framework that lays the foundations for future inter- and transdisciplinary research across remote sensing research (where research in the commodity supply chain context focused on remote sensing use by actors other than buyers such as governmental bodies, NGOs or research) and SSCM and sustainability risk research (where research on remote sensing is essentially non-existent and research into sustainability risks and their management at distant, indirect raw material suppliers is only emerging) to close the corresponding research gap. Third, this thesis suggests complementing the risk-focused approach in sustainable supply chain research with a more strategic, opportunity-oriented perspective by drawing on dynamic capabilities theory and validating this extension with empirical data, i.e. outlining an emergent focus on strategic opportunities in the context of volatile, dynamic sourcing environments in practice. Fourth, this thesis outlines why and how buyers adopt remote sensing and under which challenges, thus synthesizing relevant insights for organizations like technology providers or NGOs working in the commodity supply chain context to better understand how they may be able to provide value or how they may need to adjust their approach to more effectively meet clients' needs or effect change on the ground.

This thesis largely achieved what it set out to do, yet there are also some limitations that have to be acknowledged. The major limitation of this thesis is the relatively broad scope which was adopted as a conscious decision to account for the limited number of available use cases due to the novelty of the technology – or at least its application in sustainable sourcing – and to allow inductively emerging information to guide the data collection and sample towards the most fruitful cases. Yet, a focus on a single or comparative case study of a particular commodity, industry, impact or company could have provided more specific insights – assuming that a sufficient amount of documents and interviewees had been accessible. Thus, the synthesized conceptual framework delineates the critical elements that affect remote sensing adoption and effectiveness, and the elements' interrelations. Investigating the particular configuration of these elements for specific cases and exploring prescriptive recommendations or connections to different research fields remains open for further research.

The key **research implications and opportunities** derived from this thesis are: First, an extension of the risk-oriented focus of SSCM research to explicitly cover business opportunities emerging from SSCM and, thus, increase the strategic relevance of SSCM. Second, future research should expand prior multi-tier SSCM research to truly account for all upstream tiers to increase the usefulness for complex supply chains and sustainability issues. Research into how to identify, prioritize and manage sustainability across the full chain, how to adjust current tools to operationalize these insights, and to study buyers who venture into this novel area seems crucial. Third, more inter- and transdisciplinary research across SSCM and remote sensing research to increase the practical value of technology solutions and across SSCM and disciplines like forest management, development or human rights studies to better represent the complexity of sustainability governance in upstream supply chains and understand underlying dynamics, potential side-effects and effective, lasting risk mitigation. Fourth, with technology's rise and growing stakeholder scrutiny, it is relevant to assess the perceived legitimacy of remote sensing providers, tools and data and its effects on buyers' legitimacy. Fifth, research is needed into the challenges faced by certification schemes as buyers feel they are unable to meet their needs and thus adopt parallel approaches. Research can analyze certification's two-edged role as assurance and development mechanism and how business model innovation based on digitalization of services, traceability, new data sources like remote sensing and capacity building may enable certification to stay relevant. Overall, the identified research implications are not novel or ground-breaking. Rather, they reiterate persistent tendencies in SSCM research like focusing on environmental over social topics or direct suppliers over the full chain. It seems that SSCM research may need a more fundamental mindset shift, from what is straightforward and feasible to research, towards what is challenging but meaningful for practice and society to research.

The main **practical implications** that can be deduced from this thesis' findings are: Buyers already using remote sensing tools can use the framework to analyze weaknesses and strengths in their approach, evaluate collaborations and the value of internalizing skills, and derive strategic conclusions for developing the resource base considering risks, stakeholder pressures and opportunities. Buyers considering adopting remote sensing can use the framework to position their company by taking stock of internal resources and skills, drivers, stakeholders, existing supplier relations and collaborations. In essence, the framework suggests that: *Buyers need to have supply chain visibility. Buyers need to have the capacity to act (and thus manage sustainability risk on the ground). Buyers need to be able to credibly demonstrate their efforts to internal and external stakeholders (and thus manage resulting reputational, legal, operational or financial risk). Buyers need to understand our drivers (including their risk profile, their salient stakeholders and how the latter impact the former). Technology can help connect and achieve the above points in a more targeted, fact-based and efficient way*. Based on their positioning, buyers can evaluate if and how remote sensing is most suitable to their needs and what questions they need to discuss with potential partners like technology providers. Overall, remote sensing is no stand-alone solution but depends on a mature, supporting SSCM. Remote sensing is no one-size-fits-all solution but is most effective when tailored to buyers' needs and supply chain context. Lastly, it does not have to be remote sensing if forest-risk commodities play a minor supply role or if a lack of SSCM expertise, budget, staff, time or power severely limits buyers' chances of systematically using remote sensing.

In **conclusion**, remote sensing represents a potent technology for gaining more transparency over upstream supply chains and more control over hidden sustainability risks – yet its effectiveness, as for many technologies, depends on the companies using it, their commitment and their understanding of their own business, supply chain, materials and stakeholders. Perhaps the most essential underlying commitment is accepting that adopting remote sensing may uncover considerable upstream issues or traceability gaps that increase exposure to stakeholder scrutiny and require consequent sustainability leadership to prevent backfiring. It is encouraging to see that leading companies are taking this step and driving results-oriented action towards mitigating sustainability risk in upstream supply chains. Taking a similar leap in SSCM research, to expand the focus from straightforward buyer-supplier relationships to the opaque area of managing upstream sustainability risk at distant raw material suppliers, is now up to future research. This thesis has taken the first step and outlined research pathways.

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Appendix

7.1 Appendix I – List of interviewees

Organization	**Interviewee role**	**Organization type in thesis context**	**Code for in-text reference**
Buyer A (Multinational Food & Beverage company)	Project Manager	Buyer	D
Buyer B (Multinational Food & Beverage company)	Global Responsible Sourcing Leader	Buyer	G
Cargill	Forest Advisor	Buyer	B
Tetra Pak	Environmental Sourcing Coordinator	Buyer	L
Unilever	Global Head Sustainable Sourcing	Buyer	N
Airbus Defence and Space – Intelligence	Head of Sales, Agriculture and Forest Solutions	Technology provider	A
Ericsson	Program Manager, Sustainability and Corporate Responsibility	Technology provider	C
Planet	Director of Forest Programs	Technology provider	H
Satelligence	CEO	Technology provider	K
Ulula	CEO	Technology provider	M
FSC (Forest Stewardship Council International)	GIS and Earth Observation Officer	Certification scheme	E
Rainforest Alliance	(former) Chief Innovation and Technology Officer; Independent Sustainability Advisor	Certification scheme; Consultant	I
NGO A	Program Officer, Soy, Palm Oil and Tropical Timber	NGO	F

7.2 Appendix II – List of interview questions

The following list provides a consolidated overview of interview questions. The specific questions were adapted based on the list below to account for the organizational background of the interviewee, experience with remote sensing and interview duration. The question list was adjusted during the interview process based on emerging topics from previous interviews.

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1. How is your organization working with remote sensing technology in the supply chain context?
2. Which environmental impacts, related to which commodities are you monitoring?
3. Remote sensing technology has been applied in other contexts, like spatial planning, for a comparatively long time. What do you see as the reasons for its more recent uptake in the supply chain context?
4. Which challenges does remote sensing help to overcome?
5. What do you consider the main reasons that keep companies from adopting remote sensing technology in their supply chain?
6. Which factors do you consider crucial for the successful implementation (both, regarding the tool's capabilities and the company's internal capabilities)?
7. How does remote monitoring of suppliers by buyers relate to environmental certification and the role of certification schemes? How do you expect that to develop in the future?
8. How does remote sensing for environmental monitoring tie in with (depend on/support) other sustainable sourcing practices? What do you consider necessary to have in place to make full use of remote sensing tools?
9. How does your organization (for non-buyers: suggest to) use the monitoring data (e.g. alerts, insights into deforestation patterns)? How does your organization (for non-buyers: suggest to) respond to detected/suspected issues?
10. Which challenges do you see concerning the implementation of remote sensing?
11. What role do you see for collaboration (e.g. between companies along supply chains or with stakeholders across sectors)?
12. How do you expect this field (remote sensing for monitoring environmental impacts at raw material suppliers) to develop in the future (in terms of monitored impacts, commodities, new practices or coalitions etc.)? Which opportunities and future applications do you see?

7.3 Appendix III – Initial coding framework

This backbone of the coding framework was developed deductively based on the background and literature review. Besides the parent codes, several sub-codes were also identified prior to the data collection. It was adjusted and extended during the reading and coding of documents as well as the coding of interviews.

- Drivers
  - Certification limitations
  - Proactive sustainability management
  - Risks
  - Stakeholder pressure
  - Technology costs (declining)
  - Technology progress
- Implementation – How is it embedded?
  - Audits
  - Certification
  - Commitments, targets
  - Traceability & supply chain mapping
  - Multi-stakeholder approaches
  - Supplier engagement & capacity building
- Collaboration
  - Direct, with lower-tier suppliers
  - Indirect, with direct suppliers
  - Indirect, with third parties
- Implementation – Challenges
  - Collaboration
  - Data availability
  - Follow-up
  - Supplier visibility
  - Technical limitations
- Future opportunities
  - Transfer to other commodities
  - Transfer to other impacts

7.4 Appendix IV – Revised coding framework

This initial coding framework was adjusted and extended (marked in blue) during the reading and coding of documents and interviews in NVivo. The final version is provided below.

Drivers
- Certification limitations
- Efficiency gains
- More robust data
- Proactive sustainability management
- Risks
- Stakeholder pressure
- Technology costs (declining)
- Technology progress

Implementation – How is it embedded?
- Audits
- Certification
- Commitments, targets & reporting
- Multi-stakeholder & landscape approaches
- Due diligence & other risk assessments
- Policies & supplier codes of conduct
- Procedures
- Publication of supplier lists
- Supplier engagement & capacity building
- Supplier (de)selection
- Traceability & supply chain mapping

Implementation – Emerging themes and challenges
- Data availability
- Data ownership & sharing
- Internal capacities
- Collaboration
- Follow-up activities
- Supplier visibility
- Technical limitations
- Understanding of underlying dynamics and deforestation drivers

Collaboration
- Along the supply chain
- Across supply chains
- Across sectors

Future opportunities and applications
- Transfer to other commodities and/or impacts
- Broader scope in supply chains
- Carbon credits and offsetting
- Certification scheme level
- From monitoring to prevention

Tools & initiatives
- Global Forest Watch
- Planet
- RADD
- Satelligence
- Starling Verification

Impacts monitored

Commodities

7.5 Appendix V – List of practitioner documents

The list below includes all documents (4 webinars, 3 industry podcasts, 21 reports, 28 websites and 11 news articles) that – besides the 13 expert interviews, see Appendix I – make up the empirical data collected and analyzed for this thesis.

Amaral, L., & Lloyd, J. (2019). A new tool can root out deforestation from complex supply chains. Retrieved from https://blog.globalforestwatch.org/commodities/a-new-tool-can-help-root-out-deforestation-from-complex-supply-chains

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