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Summary

Chocolate manufacturers are increasingly investing in sustainable cocoa sourcing. Nonetheless, following two decades of sustainability initiatives in the cocoa sector, numerous severe, intractable, and often interrelated environmental, social, and economic sustainability challenges remain. For sustainable sourcing practices to succeed and generate the desired changes in cocoa growing communities, two "basic understandings" are crucial. First, it requires understanding the sustainability challenges faced by cocoa producers. Second, it requires a good understanding of factors that influence farmers' decisions to implement or adopt sustainable cocoa farming practices. Currently, many questions remain regarding the sustainability issues on cocoa farms when assessed in a comprehensive way, and the influence of numerous factors on the adoption of sustainable practices remain poorly understood. This dissertation seeks to address these knowledge gaps.

The research is guided by two lead questions. The first research question: "What are the main sustainability challenges for cocoa farms?" aims to capture the multi-dimensionality and interrelatedness of farm-level sustainability among predominantly smallholder cocoa producers in Ecuador and Uganda. Within the second research question: "Which factors influence practice implementation in cocoa farming systems?" the focus is placed on the role of value chain factors and household labour for sustainable cocoa production. Combining multi-criteria sustainability assessment and econometric modelling, this dissertation shows that major sustainability issues lie in the social and governance dimensions and that the continuous focus on environmentally-friendly cocoa production demands economic trade-offs from farmers. This work additionally shows that downstream companies have various levers to improve the sustainability performance of their suppliers; for example, through capacity building and stable, long-term relationships. Furthermore, household labour plays an essential role in the future of sustainable cocoa production. While agro-environmental decisions are mainly taken at farm level, social and governance issues, including farmer organisation or rural out-migration, are rather influenced by the socio-cultural setting in which farmers operate. Generating the necessary changes thus requires interventions beyond the farm level, in strong collaboration with diverse actors.

Chapter 1: Introduction

Cocoa (Theobroma cacao) is a crop with a long-standing history in Latin America, which has gained in importance throughout the world. Today, cocoa is grown by millions of, mainly smallholder, farmers throughout the tropics (Voora et al., 2019). Chocolate, with cocoa beans as its main ingredient, is mostly consumed in Europe and the USA (Fountain & Huetz-Adams, 2020). Cocoa beans are thus traded in global value chains with a clear South to North direction. With sustainability becoming a guiding principle for global development ambitions (UN, 2015), increasing attention is being paid to the sustainability issues related to cocoa production (Fountain & Huetz-Adams, 2020; Thorlakson, 2018). Thus, consumer-oriented chocolate manufacturers are increasingly held accountable for the sustainability impacts of their entire value chains and pressure is mounting to address these impacts (Fountain & Huetz-Adams, 2020; Thorlakson, 2018). As a consequence, and to safeguard future cocoa supplies, chocolate manufacturers have started sourcing cocoa through value chains that apply sustainable sourcing practices (SSP) (Thorlakson, 2018). Many SSP contribute to the strategy of promoting sustainable farming practices among their upstream producers.

Sustainable cocoa production is believed to have the potential to reconcile the essential goals of environmental preservation, social well-being, and economic prosperity in productive landscapes and communities. The numerous SSP in the cocoa sector have been working in the past two decades towards achieving these goals (Fountain & Huetz-Adams, 2020), but sustainability challenges and goal conflicts are still widespread. Cocoa production is known for numerous severe, intractable, and often interrelated environmental, social, and economic sustainability challenges. Furthermore, climate change is expected to severely influence global cocoa growing patterns (Bunn et al., 2017; Läderach et al., 2013). This will potentially exacerbate sustainability challenges in the future, especially for farmers who highly depend on cocoa incomes. Many sustainability issues have been reported in West African countries, where the vast majority of cocoa is produced (FAO, 2022a), but these issues are also relevant for cocoa production systems globally (Huetz-Adams et al., 2022).

Two "basic understandings" are crucial to inform companies' sustainable sourcing ambitions and to increase their return on investment in sustainable cocoa production. First, it requires understanding the sustainability challenges faced by cocoa producers. So far, we have an overview of sustainability issues on cocoa farms, yet mostly regarding single topics of current public interest like child labour or deforestation. Sustainability, however, is a multi-dimensional concept and deserves a comprehensive assessment in order to generate a full picture, but we know little about the sustainability performance when assessed in a comprehensive way and the trade-offs or synergies between individual sustainability dimensions (Eichler Inwood et al., 2018; Martin et al., 2018). Second, it requires an understanding of the processes that influence cocoa farmers' decisions to implement or adopt sustainable farming practices (SFP), which is necessary to enable the strategy, followed by most SSP initiatives, of promoting such adoption by farmers. Currently, the influence of many factors on practice adoption remains poorly understood, including the diverse company levers within value chains (Mozzato et al., 2018) or the role of labour constraints (Adolph et al., 2020; Dahlin & Rusinamhodzi, 2019).

This context provides the starting point for this dissertation, as I draw on land system sciences to inform my scientific interest. Starting from a broad and comprehensive point of view, I aim to capture the multi-dimensionality and interrelatedness of farm-level sustainability among cocoa producers in Ecuador and Uganda. This provides answers to the first research question: "What are the main sustainability challenges for cocoa farms?" The focus then narrows to contribute to closing research gaps in our understanding of sustainable practice adoption by asking: "Which factors influence practice implementation in cocoa farming systems?" This question is broken down to first spotlight the role of value chain factors for the implementation of sustainable cocoa farming practices before shifting focus to the role of household labour for sustainable cocoa production.

This introductory chapter first provides an overview of cocoa production and value chains as well as a description of SSP in the cocoa sector. I then summarise the literature on sustainability assessments at farm level and interrelations between sustainability dimensions; highlighting the need for comprehensive assessment approaches. Reviewing the literature on agricultural technology adoption among

smallholder farmers, I focus on the role of value chains in promoting sustainable cocoa farming practices among farmers as well as on the relationship between farm labour availability and sustainable cocoa production. Next, I describe the motivation and objectives of my dissertation and include my two overarching research questions before positioning my work conceptually and empirically. I then present the two alue chains that serve as case studies throughout the empirical work of this dissertation, spanning from producer groups in Ecuador and Uganda to Swiss chocolate manufacturers. Finally, I outline the structure of the remaining document.

1.1Background

1.1.1 Cocoa production systems and value chains

Cocoa is a sensitive tropical understory tree that requires specific ranges in temperature, precipitation, humidity, and shade to thrive (Lahive et al., 2018). Hence, it can only be grown in a belt between 10 degrees latitude north and south of the equator (ICCO, n.d.). Today, cocoa is mainly cultivated by millions of smallholder farmers (Voora et al., 2019) and is of great economic importance for several countries, especially in West Africa. For the world's two largest producers Côte d'Ivoire and Ghana, cocoa beans and derivate products represented almost 50% and over 16% of respective export values in 2020 (OEC, 2020a, 2020c). Ecuador, Cameroon, and Indonesia are also important producer countries (FAO, 2022a). Global production volumes have more than doubled in the past 30 years (Figure 1) from 2.5 million tonnes in 1990 to 5.8 million tonnes in 2020 (FAO, 2022b). This is attributed to beneficial weather conditions in major producer countries and an increasing number of cocoa farms (Fountain & Huetz-Adams, 2018). Farmer programs promoting productivity have also been proposed as a reason for increased production (Fountain & Huetz-Adams, 2018). Yet yields, which increased globally until around 1990, have rather stagnated with average values between 1990 and 2020, controlled for yearly weather-related fluctuation, at 0.459 tonnes/hectare (FAO, 2022b).

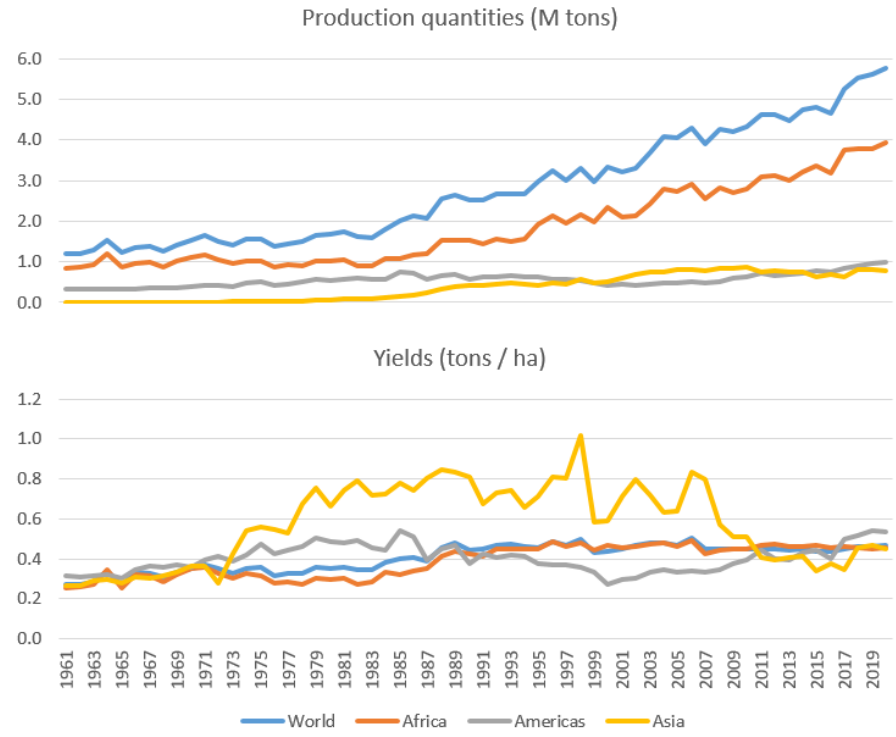

Figure 1: Overview of cocoa production and yields development over time. (Source: (FAO, 2022b))

As a cash crop, cocoa provides an important source of livelihood for millions of smallholder farming households (Bermudez et al., 2022), yet reports have shown that cocoa farmers often live below the poverty threshold (van Vliet et al., 2021). One important reason is low cocoa yields, resulting in the inability to invest in proper soil fertility and pest and disease management or renovate plantations (Kongor et al., 2018). This consequently motivates farmers in some regions to expand their cocoa plantations into new and fertile areas of tropical rainforest, causing deforestation and forest degradation (Barima et al., 2016). Cocoa is often grown in full-sun monoculture systems despite thriving in shaded agroforestry systems, which are considered to be able to reconcile the environmental and economic outcomes (Armengot et al., 2016; Niether et al., 2020). A further important reason for high poverty rates are low and highly volatile market prices for cocoa (Bermudez et al., 2022), which is traded on global commodity markets. Multiple consequences of poverty among cocoa farmers are known, including food insecurity (Bymolt et al., 2018), lower ability to generate

off-farm income (van Vliet et al., 2021), and lack of input and labour investment into agriculture (Kongor et al., 2018). This often results in cocoa farmers resorting to child labour (Berlan, 2013) and hiring labourers to work under poor working conditions (Meemken et al., 2019).

While cocoa can only be grown in the tropics, the consumption of cocoa and chocolate mostly takes place in industrialised nations. Thus, most cocoa is traded in global value chains with a clear South to North direction. A "typical" cocoa-chocolate value chain is described as follows: After cultivation and primary processing (fermentation and drying) on farms, cocoa beans are sold through intermediaries to export companies. A smaller share of mostly specialty cocoa farmers sell their cocoa through farmer organisations; either directly to exporters or to their final buyers (Middendorp et al., 2020). Export companies then ship cocoa beans to consumer countries to be processed into cocoa liquor, butter, and powder. These are used by manufacturers to produce chocolate. Finally, chocolate is sold to consumers through retailers. (World Cocoa Foundation, n.d.) With millions of mostly independent farmers, and thus a highly diffuse producer base, the downstream cocoa-chocolate value chain is much more concentrated. Trading and processing is dominated by six companies, which handle the vast majority of all cocoa on the world market (Fountain & Huetz-Adams, 2020). Eight confectionary manufacturers controlled about 41% of the market in 2021 (Candy Industry, 2021). This consolidates power at the trading, processing, and manufacturing levels of the global cocoa value chains (Thorlakson, 2018) and gives great power to few actors in a global chocolate market worth over 100 million USD in 2021 (Bermudez et al., 2022). The chocolate market is expected to grow in the future. Demand for cocoa beans has been steadily increasing and is projected to continue at 7.3% annually until 2025, partly due to increasing consumption in emerging economies such as China and India (Grand View Research, 2019).

1.1.2 Sustainable cocoa sourcing practices

Public attention by diverse stakeholders including NGOs and consumers has increased pressure on consumer-oriented chocolate companies to address the sustainability issues within their own value chains (Thorlakson, 2018). As a result, a dynamically

changing range of responses has been developed and implemented throughout the sector.

Initially, these responses included mostly sourcing cocoa beans that have been certified under a voluntary sustainability standard (Thorlakson, 2018) such as Fairtrade, organic, or UTZ. These certification systems are market mechanisms aimed at changing production and trading practices to generate consumer, producer, and environmental benefits (Ruben & Zuniga, 2011). They contain a clear set of standards that producers and traders have to comply with. Compliance is controlled through a third-party audit and group certification is common to avoid high costs for individual farms (Ansah et al., 2020). In addition, the certification process is often organised by farmer groups and cooperatives, or other value chain actors who seek to source certified produce. The area under certified cocoa production has increased by 53% between 2015 and 2019 (FiBL-ICT-SSI Survey, 2021). In 2019, between 23% and 42% of the production area was certified (FiBL-ICT-SSI Survey, 2021).

With a continuous prevalence of sustainability challenges, projections of future cocoa supply shortages, and calls for greater private accountability and traceability, chocolate manufacturers diversified their SSP. They introduced add-ons to existing certification systems or started company-own in-house sustainability programs (Fountain & Huetz-Adams, 2020; Krauss & Barrientos, 2021; Thorlakson, 2018). These are "a form of corporate social responsibility and self-regulation, whereby a business monitors and ensures active compliance with the spirit of the law, ethical standards, and national or international norms" (Ingram et al., 2018). This gave rise to the role of multinational trading companies in reaching sustainable cocoa production goals, as they connect producing communities and chocolate manufacturers and initiated their own sustainability programs (Ingram et al., 2018; Thorlakson, 2018). In comparison to third-party certification, in-house programs follow individual companies' priorities and theories of change without independent oversight (Krauss & Barrientos, 2021; Thorlakson, 2018). This generates a significant shift in the credibility of sustainability claims.

The impacts on humans and nature of certification of tropical agricultural commodities have been widely studied, as several recent reviews have shown (deFries et al., 2017; Ingram et al., 2018; Meemken, 2020; Oya et al., 2018). These conclude

that impacts are generally moderate, heterogeneous, and highly context specific. The impact of in-house sustainability programs is mainly shared through company-own sustainability reports instead of objective scientific studies (e.g. Bitzer et al., 2020), which is possibly due to their shorter lifetime and lack of publically accessible data. Yet, monitoring of impacts of SSP and reporting by chocolate manufacturers is increasing, which is partly attributed to a standardised framework developed by the World Cocoa Foundation's CocoaAction initiative (Thorlakson, 2018).

Regardless of the, albeit moderate, positive impacts of voluntary sustainability certification, opponents highlight high non-compliance rates by farmers (Ansah et al., 2020), their limited coverage among producers, especially in least developed countries (Tayleur et al., 2017), and low demand of certified products in consumer countries (Meemken et al., 2021). Similarly, in-house sustainability programs attract criticism, including fears that power asymmetries within cocoa value chains are exacerbated (Amuzu et al., 2022; Krauss & Barrientos, 2021; Odijie, 2018) as farmers are locked in to specific value chains. The tendency of programs to focus on cocoa productivity is viewed as a way to secure future supplies and create benefits for buyers instead of farmers (Odijie, 2018). What most SSP have in common is that they follow top-down or North to South approaches; rarely including producers' priorities and interests in the definition of sustainability, the design of SSP, or in value chain decision-making processes (Meemken et al., 2021; Mithöfer et al., 2017a; Thorlakson, 2018).

In addition to these private cocoa initiatives, public-private and multi-stakeholder initiatives have evolved and efforts were reoriented from farm to landscape or sector level (Nelson & Phillips, 2018). Public actors in both producer and consumer countries are playing an increasing role in cocoa sustainability (Krauss & Barrientos, 2021). Examples include: jurisdictional approaches that aim to increase sustainability within administrative boundaries that apply to all stakeholders (von Essen & Lambin, 2021); targeted public interventions addressing farmer livelihoods like the Living Income Differential in Ghana and Côte d'Ivoire (van Vliet et al., 2021); consumer country regulations, such as propositions on deforestation-free products and a directive on corporate sustainability due diligence by the European Commission (Grumiller & Grohs, 2022); and the Living Income Community of Practice as a multi-

stakeholder alliance aiming to support activities to improve smallholder farmer incomes (Living Income Community of Practice, 2021). Ingram et al. (2018) furthermore highlight the role of civil society in advancing sustainability initiatives in the sector. Examples include the Cocoa barometers, a biannual report on the cocoa sector and related sustainability challenges published by the Voice Network (Fountain & Huetz-Adams, 2020, 2022). Lately, multi-stakeholder cocoa platforms in diverse consumer countries, such as the "ISCOs" in Germany, Belgium, and Switzerland have formed with the aim of coordinating stakeholder sustainability initiatives.The hope is that, through broadening stakeholder involvement and geographic focus, sustainability initiatives are coordinated better and can be scaled up (Nelson & Phillips, 2018). Furthermore, voluntary initiatives are combined with binding measures (Grumiller & Grohs, 2022) and governments regain partial control over sustainability governance (Lambin & Thorlakson, 2018). So far, little knowledge exists about the impacts of these policy mixes as impact studies have mostly evaluated the effectiveness of single interventions (Lambin & Thorlakson, 2018).

Despite increased engagement by diverse actors, the Voice network (Fountain & Huetz-Adams, 2020) criticises the current levels of alignment of sustainability strategies, continuous focus on productivity, and absence of higher farm gate prices by pointing out that these create an environment that is unable to generate the radical change that the sector needs to tackle intractable issues.

1.1.3 Sustainable food systems

Food systems are characterised by a complex network of interacting actors, resources, and activities and involves all steps from production to consumption of food (FAO, 2018). The global trade of food products has been growing rapidly with a 270% increase in export value of food products from 2000 to 2020 alone (WITS, 2023), increasing the complexity of global food systems. This has contributing to the decoupling of production and consumption, with environmental and socio-economic impacts of food production geographically distant from consumption (Kummu et al., 2020). Expectations of the global food systems to provide "a growing global population with healthy diets" (Willett et al., 2019) are rising, despite environmental and socio-economic challenges related to a changing climate, resource depletion, and

social and economic inequality (FAO, 2018). In order to achieve the Sustainable Development Goals, calls emerged for a transformation of food systems towards sustainability, food security, soverainity, and justice while staying within the safe operation space (IPCC, 2022; Rockström et al., 2009; Webb et al., 2020; Willett et al., 2019).

Diverse pathways have been suggested to reach this transformation. At the food systems level, these include agroecology. This describes an "integrated approach that simultaneously applies ecological and social concepts and principles to the design and management of sustainable agriculture and food systems" (FAO, 2023). At the farm level, sustainable agricultural intensification (SI) is proposed as a pathway for transformation and has become a leading strategy for agricultural development (Pretty, 2018; Rasmussen et al., 2018; Rockström et al., 2017). SI comprises practices or processes "in which production is maintained or increased while progressing toward substantial enhancement of environmental outcomes […] without the cultivation of more land and loss of unfarmed habitats" (Pretty, 2018).

The transformation of food systems follows multiple goals. Each pathway towards sustainable food systems generates trade-offs in which improvements towards one goal come at the expense of another goal. A transition towards a food systems with a greater share of organic products, for example, could reduce the environmental impact of production but increase costs for consumers (Frehner et al., 2022). Environmentally-friendly farming practices can also hold social trade-offs, such as food security (Ingram, 2011). Developments towards sustainable food systems should thus to aim to minimise trade-offs and invest in maximising synergies.

1.1.4 Assessing farm-level sustainability

Designing targeted and impactful SSP requires a thorough understanding of sustainability challenges on cocoa farms. Nevertheless, its appraisal is challenging given the complex and multidimensional nature of sustainability and the multifunctionality of farming systems. Diverse concepts of sustainability have found widespread use in decision-making at societal and political level in recent decades and their development evolved along the broader societal sustainability discourse, albeit

more prominent in industrialised nations. The initial 'limiting' discourse (Hugé et al., 2013) centred on environmental protection and avoided resource depletion. This resulted in early sustainability assessment methods based on energy and material flows (Ness et al., 2007). The 'integration' discourse integrates environmental and development objectives, nominating the market as problem solver through monetary valuation as an addition to biophysical analysis (Hugé et al., 2013). This discourse integrates environmental, social, and economic goals (Purvis et al., 2019) and follows a win-win paradigm aiming at achieving different goals simultaneously while also acknowledging trade-offs (Hahn et al., 2010). The 'transformative' discourse (Hugé et al., 2013) views sustainability as a process of changing societal values and social systems, rather than a strict endpoint. This requires a deep understanding of social systems and their dynamics (Janker & Mann, 2018; Janker et al., 2019).

Parallel to the general sustainability discourses, sustainability assessment approaches in agriculture have initially rather focused on technical aspects and environmental issues, prior to integrating economic and eventually social aspects (Binder et al., 2010). Numerous and highly diverse assessment frameworks and tools exist, which inhibits the comparison and generalisation of results (Schader et al., 2014). The developed assessment frameworks and tools range from single topics assessments, such as farm economics assessments, to multi-criteria assessment frameworks that cover diverse topics (Alaoui et al., 2022; Arulnathan et al., 2020; Coteur et al., 2020). The great number of farm-level sustainability assessment tools indicate a broad diversity of measurement schemes that show trade-offs between scope and precision, have different aims and end users, make use of different theoretical reference frameworks and thus apply different sets of indicators, which inhibits the comparison and generalisation of results (Coteur et al., 2020; de Olde et al., 2017; Schader et al., 2014). The majority of assessment tools follow top-down approaches, i.e. have predefined impact categories and indicators. Those approaches that follow participatory, bottom-up pathways rather focus on system boundaries beyond the farm-level (Binder et al., 2010). Examples include the Multiscale Methodological Framework (lópez-ridaura et al., 2005) and implementations of transdisciplinary assessments of food sustainability (Jacobi et al., 2020).

As highlighted in Section 1.1.3, generating simultaneous benefits across sustainability dimension and creating win-win situations is not always possible. Despite being considered essential for sustainability assessments (Hahn et al., 2010), it remains poorly understood to date how sustainability dimensions and indicators interrelate (Eichler Inwood et al., 2018; Martin et al., 2018). To identify potential sustainability trade-offs or synergies, sustainability assessments need to include diverse topics across the environmental, social, and economic dimensions.

Research on the sustainability performance of cocoa production systems has mostly focused on single sustainability indicators or dimensions, including profitability and farmer income (Kongor et al., 2018; Viteri Salazar et al., 2018), deforestation and forest degradation (Barima et al., 2016), and child labour (de Buhr & Gordon, 2018; NORC, 2020). Only few studies have looked at cocoa farm sustainability from a comprehensive point of view, and these have included only few indicators (Jacobi et al., 2015). Regarding trade-offs and synergies between sustainability dimensions, past research has looked at environmental-economic synergies (Blaser et al., 2018; Middendorp et al., 2018; Schroth et al., 2016b; Tothmihaly et al., 2019) and much less at environmental-social synergies. This mirrors a more general research gap in understanding potential social-ecological trade-offs or synergies in agriculture (Jia et al., 2018; Rasmussen et al., 2018; Schader et al., 2016). A better understanding of general farm-level sustainability performance, and trade-offs and synergies between practices, will be necessary to promote sustainable cocoa farming practices among producer communities.

1.1.5 Adoption of sustainable farming practices

The adoption of SFP is considered a first step towards reducing the impact of agricultural production and increasing sustainability outcomes. The determinants of adoption of environmentally-friendly agricultural technologies, innovations, and practices by farmers have been subject to intensive scientific studies. This is showcased by the large number of microeconomic review articles in recent years that have developed diverse adoption frameworks (Candemir et al., 2021; de Oca Munguia & Llewellyn, 2020; Foguesatto et al., 2020; Liu et al., 2018; Meijer et al., 2015; Mozzato et al., 2018). Determinants for practice adoption within the social and

economic dimensions of sustainability have been much less studied (e.g. Nkamleu & Kielland, 2006; Okoffo et al., 2016).

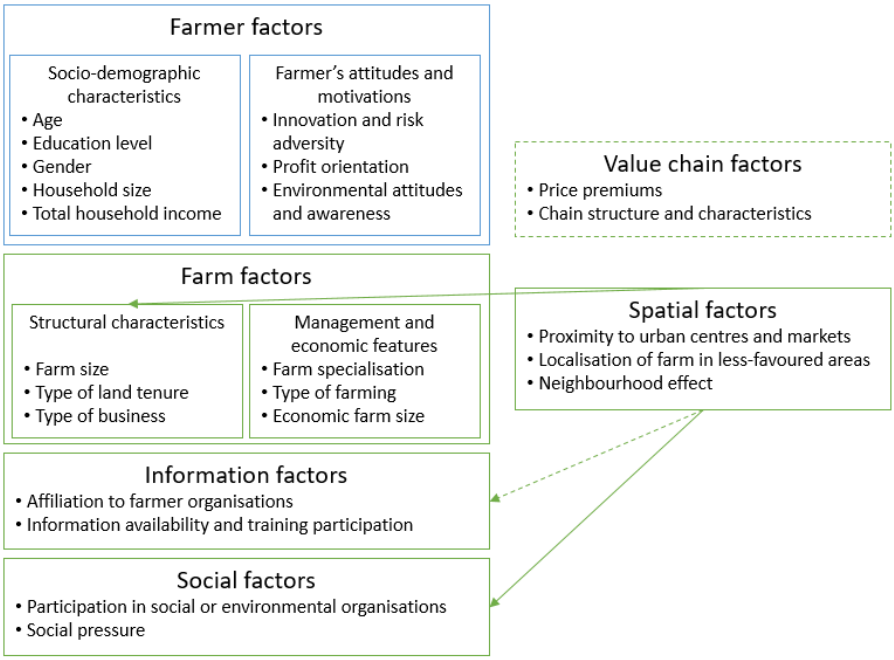

Figure 2: Overview of intrinsic (blue) and extrinsic factors (green) influencing environmental practice adoption. (Source: adapted from (Mozzato et al., 2018))

Existing reviews show a great number of indicators that potentially influence farmers' decisions to implement or adopt (or not) a specific practice on their farm. One exemplary framework for farmer adoption of SFP is provided in Figure 2, which shows a clear differentiation between intrinsic farmer factors and extrinsic farm and environmental factors, as is common in adoption frameworks. Existing reviews have also identified a great contextual heterogeneity in factors influencing environmental practice adoption, including in cocoa (Sellare et al., 2020b). This is likely a result of the complex interplay between individual behaviour, social and traditional institutions, public governance, the practice itself, and market settings (Foster & Rosenzweig, 2010). As a result, adoption studies are increasingly expanding knowledge about factors beyond the traditional set of predictors, for instance looking into farmer psychology through knowledge and attitude (Meijer et al., 2015).

However, the importance of certain specific, and groups of factors, remain poorly understood, including the influence of value chain factors and labour restrictions.

There is increasing evidence that market-based policies in value chain governance influence farmers, including smallholder farmers in the tropics, in their decisions to adopt certain farming practices or to comply with specific sustainability requirements. Past studies have looked into the role of direct buyers, including farmer cooperatives (Candemir et al., 2021), small to medium-size intermediaries, and large-scale buyers (Liverpool-Tasie et al., 2020). Furthermore, the role of price structures and incentives (Piñeiro et al., 2020), and the strength and quality of buyer-supplier relationships (Lazzarini et al., (forthcoming); Reis et al., 2020) have been investigated. A comprehensive overview of how value chains influence environmental practice adoption by smallholder farmers (Liverpool-Tasie et al., 2020) or how they influence the benefits farmers derive from SSP like sustainability certification (Meemken, 2020) has not yet been published.

Labour is an important agricultural input. Smallholder production systems with low mechanisation, such as cocoa production, heavily rely on household labour (Voora et al., 2019). Current demographic trends, such as an increasing urbanisation rate in major cocoa producing countries (Ritchie & Rosner, 2019), more attractive income sources for landless labourers (Bymolt et al., 2018), growing pressure on land resources (Chiarella et al., 2022), and the lack of perspectives for young people in cocoa production (Kongor et al., 2018) influence the availability of household and hired labour in cocoa growing communities. Research into smallholder production systems has shown that household labour availability highly influences which practices farmers adopt; especially when the practice is labour-saving (Arslan et al., 2020; de Oca Munguia & Llewellyn, 2020). First indications exist that household labour availability positively influences cocoa yields and revenues (Juhrbandt et al., 2010) and that cocoa farmers perceive certain practices to be sufficiently beneficial to invest in hired labour (Martínez & Martínez Pachón, 2021). Yet, large research gaps exist in this regard, as it is difficult to change (household) labour availability in experimental settings and existing studies rely on one-time observations. Knowing how farmers invest limited labour resources, and which practices they consider

worthwhile to carry out, can be of high value in the design of SSP to increase sustainability outcomes.

Few agricultural practices are as controversial as synthetic pesticide use. On the one hand, synthetic pesticides can secure cocoa yields and are considered important for increasing (climate) resilience (Denkyirah et al., 2017). On the other hand, they have high human and environmental impacts (Rani et al., 2021) and reducing their use can benefit human and environmental health. Furthermore, private and public sustainability governance, such as organic certification or import regulation of the European Union (The European Parliament and the Council of the European Union, 2005), aim at reducing or eliminating (highly toxic) synthetic pesticide use in cocoa production. In general, a relationship between pesticide use and farm labour availability is expected, as both pesticide application as well as alternative pest and disease management measures are labour intensive (Armengot et al., 2016; Folefack et al., 2021; Scudder et al., 2022). Examination of these relationships appears to be a fruitful line of inquiry to inform ambitions of pesticide-free cocoa production.

1.2 Research framework

1.2.1 Broader project setting

This thesis was carried out within the framework of, and funded through, the research project "Enhancing supply chain stability, resilience and sustainability through improved sub-supplier management – chocolate and cotton apparel case studies". The project was funded by the Swiss National Science Foundation through the National Research Program "Sustainable Economy" (NRP73) and implemented by the Research Institute of Organic Agriculture (FiBL) in Switzerland. This project was transdisciplinary with close collaboration with Swiss chocolate manufacturers. The project and with it my dissertation initially followed the main aim of evaluating the impact of targeted interventions that address sustainability issues in cocoa production through a randomised controlled trial. This was planned in three steps: 1) identification of sustainability issues among cocoa producers within specific cocoa value chains that supply Swiss chocolate manufacturers, 2) joint development of a

treatment that targets at least one of the identified sustainability issues among cocoa producers and implementation of the treatment through the Swiss chocolate manufacturers, and 3) evaluation of the treatment's impact in improving targeted sustainability issues. The main aim of the project, and of this dissertation, had to be adapted as a result of the Covid-19 pandemic, since industry partners were not able to implement interventions as planned and in a scientifically-sound way. This adaptation had to be done creatively, flexibly, and partly opportunistically during the course of the pandemic. The adjusted aims and methods of this dissertation are described in the remainder of this chapter.

1.2.2 Motivation and objectives

Sustainable cocoa farming has the potential to reconcile the important goals of environmental preservation, social fairness, and economic well-being of productive landscapes. Numerous sustainability initiatives in the cocoa sector work towards achieving these targets; many of which follow the strategy of promoting sustainable cocoa farming practices among farmers. Achieving these complex and sometimes competing goals in the most efficient way requires knowledge about the actual sustainability performance of the cocoa supplying farms and identifying pathways for the adoption of (new) practices by cocoa farmers based on scientific findings. Currently, there are shortcomings in the scientific understanding of the sustainability performance on cocoa farms when assessed in a comprehensive way and of the interrelations between sustainability dimensions and indicators. Moreover, there is a lack of scientific insight into the role of important factors that influence farmers' decisions to implement a specific practice, including value chains and farm labour availability.

This dissertation begins from the broad starting point of comprehensive farm-level sustainability, before continuously narrowing the focus to sustainable cocoa farming practices and the factors that influence their adoption (Figure 3). It follows the main aim of identifying key sustainability challenges among cocoa growing communities and the factors that influence the implementation of sustainable cocoa farming practices. This dissertation specifically addresses the poorly understood role of value

chains and household labour for the promotion of sustainable cocoa farming practices. Two research questions summarise the objective:

1. What are the main sustainability challenges on cocoa farms?
2. Which factors influence practice implementation in cocoa farming systems?

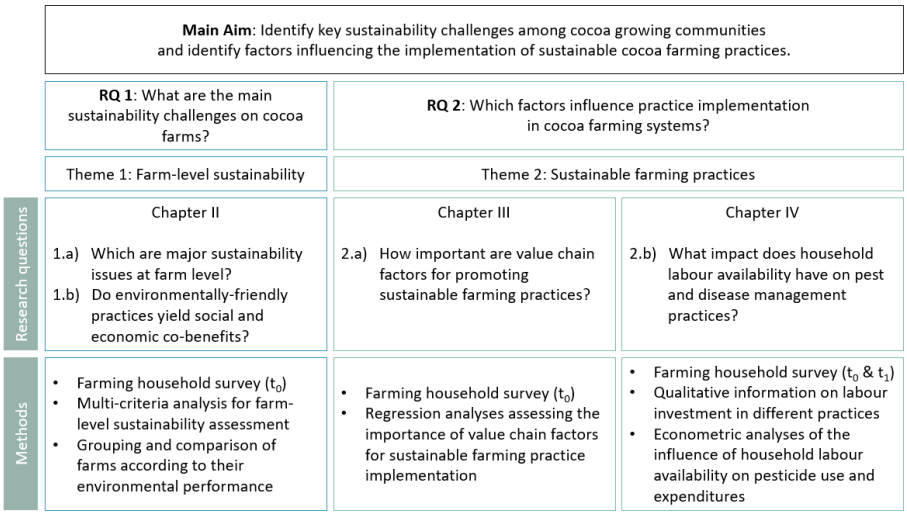

Figure 3: Outline highlighting research questions and methods of the individual chapters and showing how they feed into this dissertation's main research questions and aim.

1.2.3 Conceptual framework

The concept of sustainable cocoa farming systems lies at the heart of this work. This dissertation integrates factors that influence the implementation of sustainable cocoa farming practices and the consequent sustainability impacts of farm management for cocoa producers and society (Figure 4). Past studies have integrated factors influencing practice adoption with sustainability outcomes. For example, Nakawuka et al. (2017) assessed factors influencing irrigation technology adoption in East Africa and related outcomes across sustainability dimensions. Within this dissertation, I go beyond single practices, considering the farming system as a wholistic entity. My work is of interdisciplinary nature, positioned within land system science and relying upon concepts and approaches from different disciplines in the individual empirical chapters.

Positioning within land system sciences: Land systems are the "result of human interactions with the natural environment" (Verburg et al., 2015) and are thus socio-ecological systems. With a cover of 36.5% of global land area in 2020 (The World Bank, 2023), agricultural production dominates human activity on land. Human decision-making drives local to global changes in land systems, such as effects of global trade on local farming decisions (Meyfroidt et al., 2022; Verburg et al., 2015). Changes in land systems can be both a cause for global environmental change and a source of solutions for mitigation and adaptation (Verburg et al., 2015). As such, cocoa production has generated substantial land system change, for example through deforestation in West Africa (Higonnet et al., 2017; Renier et al., 2022). At the same time, sustainable cocoa farming can be an opportunity for reforestation of previously cleared and degraded land, while generating socio-economic benefits for humans (Schroth et al., 2016a). A transition towards sustainability through land use requires an equitable distribution of benefits from land use, potentially through fair trade-off solutions (Meyfroidt et al., 2022). Thereby, the cocoa sector is representative of a wider, emerging trend in land systems in which private or private-public governance with strong corporate actors promote the adoption of sustainable sourcing practices along commodity value chains as well as the adoption of sustainable farming practices by farmers, to some extent also driven by conscious consumers demanding a higher level of sustainability (Lambin et al., 2018; Rueda et al., 2017; Thorlakson, 2018).

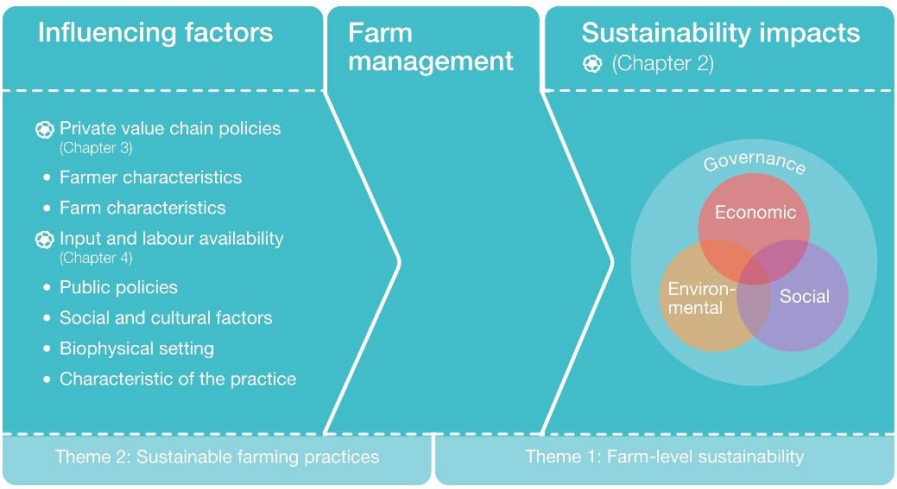

Figure 4: Conceptual framework of this dissertation.

Farm-level sustainability: Sustainability has become a guiding principle for global development and with the Sustainable Development Goals (SDGs), the United Nations has provided a comprehensive framework that encompasses ecological, social, and economic goals (UN, 2015). Sustainability is thus a multidimensional term. There are numerous concepts and tools for assessing the sustainability of farming systems (see Section 1.1.4). These concepts and tools vary conceptually: in scope from single topics to multi-criteria assessments; in application from single sectors to global relevance; in applicability from single countries to global reach; and/or in stakeholder inclusion from top-down to inclusive approaches (Arulnathan et al., 2020; Coteur et al., 2020). The common denominator of these approaches is a clear trade-off between scope and precision as well as site-specificity and comparability of results across regions (Binder et al., 2010; Schader et al., 2014). Despite numerous studies, there is no consensus on what sustainable agriculture actually means, when it is "accomplished", what aspects need to be considered, and which perspective must be adopted when evaluating sustainability.

Assessing the multidimensional sustainability impacts of farm management on farms and society requires a) a clear definition of farm-level sustainability and b) knowledge of which practices influence farm-level sustainability and in which ways. Chapter 2 of this dissertation aimed at generating in-depth insights into the farm-level sustainability performance of two producer groups in Ecuador and Uganda. This required an approach that covered sustainability in the most comprehensive way, would make it possible to identify key sustainability issues, would allow for comparability across cases and regions, and would provide results for consequent scientific analyses. Based on these needs, this dissertation makes reference to the Sustainability Assessment of Food and Agriculture Systems (SAFA Guidelines) (FAO, 2014). The SAFA Guidelines represent a comprehensive global reference framework for sustainability assessment along agricultural value chains. They were developed in a participatory process with civil society and private sector, and build on various existing sustainability standards, protocols, frameworks, and tools. These include the planetary boundaries (Rockström et al., 2009), the GRI Sustainability Reporting Guidelines (GRI, 2023), and the ILO Declaration on Fundamental Principles and Rights at Work (ILO, 1998), among many. The SAFA Guidelines include the three sustainability dimensions of environmental integrity, social well-

being, and economic resilience in addition to a fourth, overarching dimension of good governance (Figure 5). Within these four dimensions, the SAFA Guidelines outline universally agreed elements that are essential to sustainability, so-called sustainability themes and sub-themes. For each of the 21 sustainability themes and 58 subthemes, the SAFA Guidelines offer a clear goal definition, which again enables the measurement of goal achievement through indicators.

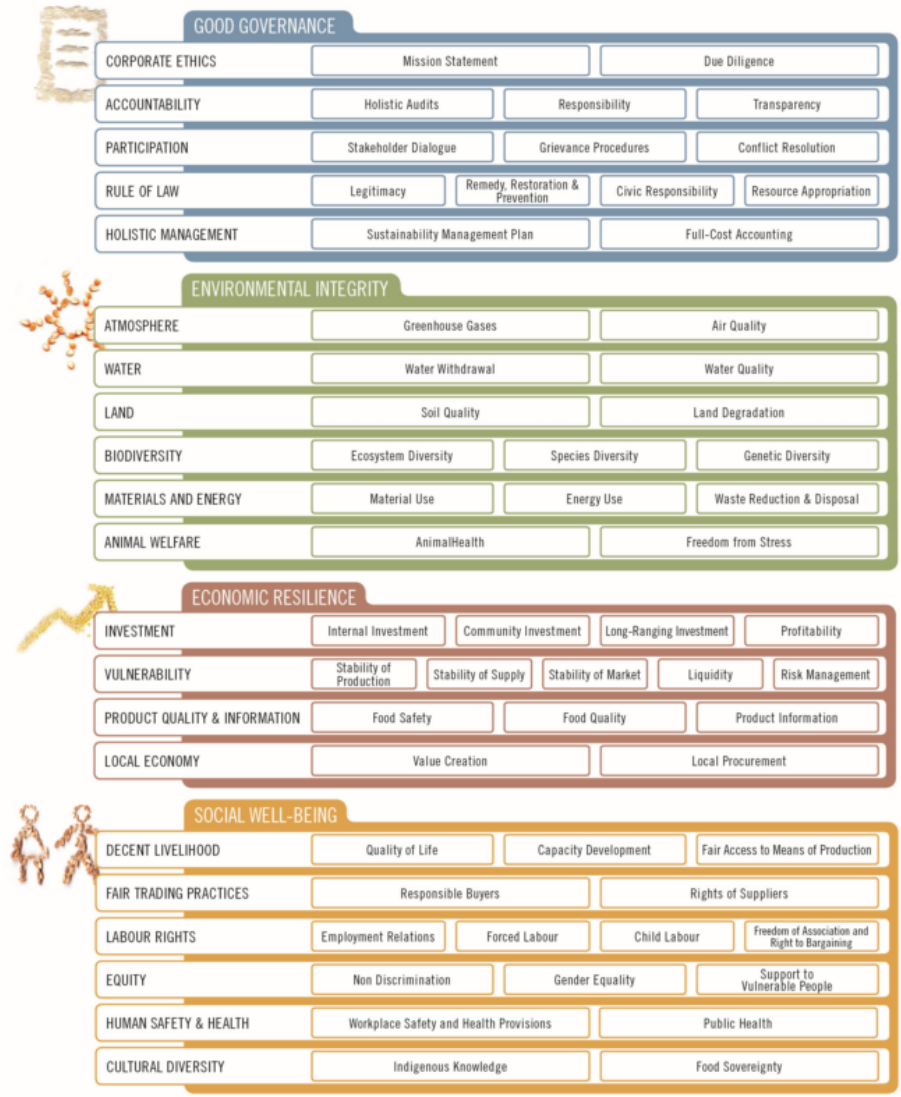

Figure 5: Dimensions, themes, and sub-themes of the Sustainability Assessment of Food and Agriculture Systems (SAFA) guidelines. (Source: FAO (2014))

Sustainable farming practices (SFP): The way in which farms are managed and which SFP are implemented on farms largely depends on farm managers' decisions. In this dissertation, SFP are defined as practices that aim to protect the environment, ensure the economic viability of the farm, and promote the well-being of farming households, workers, and communities. Various disciplines have attempted to make sense of farmer decision-making from different perspectives, such as economic, psychological, and sociological. Within (agricultural) economics, several theories for decision-making have been proposed. These include the expected utility theory, which predicts outcomes of decision-making based on the greatest expected utility of different choices (Schoemaker, 1982). This is considered especially important in the context of economically-constrained farmers who need to manage risk to secure their livelihoods (Meijer et al., 2015). The theory of planned behaviour (Ajzen, 1991) represents one of the most common theories addressing the social-psychological level of decision-making. According to this theory, attitude, subjective norms, and perceived behavioural control shape an individual's behavioural intentions through a reasoned process, which again is the most proximal determination of behaviour. Behavioural economics adds more nuances, acknowledging that farmer decision-making is not always rational and that a range of psychological biases and social factors can influence it, for example in situations of uncertainty or risk (Dessart et al., 2019). Hence, farmers' decision-making is a complex and often non-linear process that is influenced by multiple factors, questioning the sufficiency of a single theory to explain decision-making (Meijer et al., 2015).

In this dissertation, I do not refer to any particular theory, but to the literature on sustainable practice adoption and sustainable supply chain management. Past research has mostly considered agri-environmental practices when assessing factors influencing farmer adoption. Numerous recent review studies have each proposed distinct frameworks that identify important factors for adoption (Foguesatto et al., 2020; Liu et al., 2018; Meijer et al., 2015; Mozzato et al., 2018; Takahashi et al., 2020). In Figure 4, I summarise the factor groups identified by these frameworks. This dissertation does not aim to shed light on all groups, but focusses on two, namely value chains and labour availability. This is due to substantial research gaps as well as a growing importance of these factor groups as value chain actors become increasingly engaged in cocoa farming and demographic changes will lead to changes

in labour availability. By focussing on these two specific groups of factors, I examine three implicit and common theories of change in the cocoa sector: a) Farmers lack knowledge about SFP and offering capacity building through the value chain would increase knowledge and consequently change farm management; b) Dependency, information transfer, and stability of relationships, among others, can influence suppliers' compliance with buyers' codes of conduct; and c) Greater (household) labour availability leads to increased adoption of sustainable farming practices.

1.2.4 Empirical framework

Figure 6 shows the methodological approaches that are used in each research theme of this dissertation. As a consequence of disruptions by the Covid-19 pandemic, the aims and research questions of this dissertation needed to be adapted. With this adaptation, the methodological approach presented below also had to be modified, and only parts of it were foreseen and planned for at the beginning of this work.

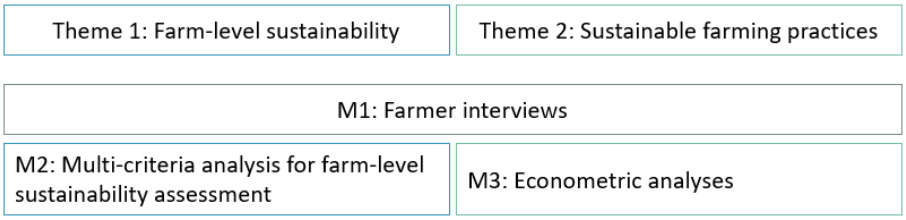

Figure 6: Overview of methodological approaches used in each Theme of this dissertation.

In parallel to the main research questions, my empirical approach starts broadly, to capture the multi-dimensionality of farm-level sustainability using a multi-criteria sustainability assessment tool (Theme 1, Chapter 2). I then build on methodological approaches from econometrics and impact assessment to understand the relationships between value chain settings, as well as household labour availability and farmers' implementation of sustainable cocoa farming practices (Theme 2, Chapters 3 and 4). All empirical research in this dissertation relies on primary data, collected from farmers and other value chain actors within two specific cocoa value chains. Sections 1.2.5 and 1.2.6 respectively include a description of the case studies and data

collection. Chapters 2 to 4 include a detailed description of the individual analytical approaches.

Farmer interviews

Most data used in this dissertation was collected during farmer interviews and is thus contingent on farmers' accurate reporting. Thus, quality control was of utmost importance and was done in two ways: through the interview setup and through the mode of data collection. First, the interviews were set up in a structured way. In structured interviews, questions are formulated uniformly and appear in a predefined order. This minimises the risk of enumerator bias and increases the comparability of the collected data (Flick, 2018). During enumerator training and test interviews, great emphasis was placed on generating a common understanding of the questions and how to rate farmers' responses. To verify collected information and avoid omitting qualitative insights, all quantitative and semi-qualitative indicators had a comment field for qualitative insights. Furthermore, interviews were conducted on-farm, which allowed the immediate validation of farmers' responses to certain indicators during a farm tour. If discrepancies occurred between farmer statements and observations, they were cautiously discussed with the respondent and if discrepancies remained, noted in the comments section. Moreover, all data for this dissertation was collected using electronic devices, which simplified data collection. For example, parts without relevance for a respondent could simply be skipped. Also, a certain automated data quality control was possible by regulating the input and the digital data collection avoided potential errors that could have occurred when digitising paper-based questionnaires.

Farmer interviews have the benefit of generating information directly from the researched community, including their experiences and perspectives. The validity of data from interviews can be affected by bias (Bhattacherjee, 2012). For example, farmers might be biased to provide socially-desired responses to critical questions, such as child labour. Respondents might also be subject to recall bias, which can be especially pronounced in systems without bookkeeping and requires triangulation of data where possible (e.g. comparison of yields with the amount of cocoa sold to buyer, verification of input quantities through packaging).

Data collection for this dissertation was performed in accordance with all relevant institutional and national ethical guidelines. It followed free and informed consent by farmers. Participation was voluntary and we ensured that all respondents had a clear understanding of the implications of their participation. The purpose of the research and the use of personal information was verbally explained to all participants. Informed consent for the collection and processing of personal data was obtained verbally from respondents, and documented by a signature in a participation list. This dissertation followed a data management plan, which clearly states the ownership of the data with FiBL to ensure confidentiality, protection, and the safe storage.

Farm-level sustainability assessment

So far, no single universal definition of sustainable farming systems exists. While it is important to acknowledge the views of diverse actors in global food systems on sustainability, this has the drawback of generating uncountable definitions of this term and multiple assessment frameworks. As highlighted in Section 1.1.4, numerous frameworks and tools for farm-level sustainability assessment have been developed. Based on the conceptual framework of this dissertation, referring to the SAFA Guidelines (Section 1.2.3), I selected the SMART- Farm Tool (Schader et al., 2016) as a suitable method to answer Research Question 1. This tool operationalises the SAFA Guidelines through a multi-criteria assessment approach that allows an estimate of an individual farm's level of achievement of each SAFA goal. The SMART-Farm Tool fulfils the requirement of data comparability across cases and regions, which represents one aim within this dissertation. Using >300 qualitative and quantitative indicators (depending on farm complexity), a farm's performance within each indicator is translated into an indicator score from 0-1. Sets of weighted indicator scores are then aggregated for each subtheme, in which the weight reflects an indicator's relative importance for achieving the subtheme goal (0-100%). The tool aggregates a farm's sustainability performance up to the theme-level without providing a single sustainability score, which is common among sustainability assessment tools (Arulnathan et al., 2020). A detailed description of the SMART-Farm Tool is provided in Section 2.2.1.

Applied econometrics

Applied econometrics follows a research process of combining real-world data, i.e. something that needs explaining, with statistical analyses, i.e. ways to explain it, and comparing the results to theory, i.e. making sense of the results. This can either be done to study relationships between variables, or to establish causality between variables and disentangle the effect of a treatment on an outcome from other variables. Causal effects are best identified through randomised experiments, although quasi-experimental designs paired with a sound analysis of the data can have sufficient rigor when randomised experiments are not possible or unethical (Kim & Steiner, 2016).

In this dissertation, I used applied econometrics to the baseline cross-sectional data to identify relationships between explanatory variables and diverse outcome variables, representing different sustainable cocoa farming practices. This allowed to study differences and similarities within groups. Controlling for the village in which farmers were located ensured that any differences between farmers were not due to factors that were specific to a village and unrelated to the variables of interest. Using cross-sectional data, nonetheless, often suffers of endogeneity bias (Hill et al., 2020) and does not allow to establish causality between variables. I then applied quasi-experimental approaches to identify causal relationships between changes in household labour and pesticide use using two-period panel data, making use of a quasi-experimental setting. It follows the theory of change that with greater household labour availability and thus seemingly free labour, more time would be invested in labour-intensive farming practices, such as manual weeding, rather than resorting to chemical pesticides (more details in Chapter 4). The overall study design was developed in a rather flexible manner based on observations in our case study regions following the Covid-19 pandemic. Quasi-experimental designs also have some limitations that might affect causal claims. These include a potential selection bias when randomisation is not possible and observed and/or unobserved confounding factors remain (Hill et al., 2020). The baseline data collection in this dissertation had followed a randomised farmer selection approach, which reduced the selection bias in this quasi-experimental design. Nonetheless, data that was not collected at baseline was missing, potentially contributing to some bias in the study design.

1.2.5 Case study description

The research questions were addressed with a case study approach. The selection of case study value chains was done jointly with the two Swiss chocolate brands that were project partners in the larger research project (Section 1.2.1). Few other countries are as associated with chocolate as Switzerland, for whom chocolate is a national branding product and of high emotional value. The Swiss led the global statistics of chocolate consumption with 11.3 kg per capita in 2021 (Chocosuisse, 2021). The selection was informed by the suitability of the value chain to participate in a 4-year project and the chocolate brands' interest. Each selected case represents one value chain from one producer country to each Swiss chocolate brand with at least one intermediary and one sustainability mechanism in place. The two producing communities within case study value chains are located in Ecuador and Uganda. Most cocoa is produced in West African countries, specifically Côte d'Ivoire and Ghana (FAO, 2022a), and most sustainability challenges are reported from these countries. Good indication exists that small-scale cocoa farmers globally face substantial challenges (Huetz-Adams et al., 2022). Studying sustainable cocoa farming in other countries and regions can provide important insights into global sustainability challenges of the sector and contribute to closing research gaps. While acknowledging that a large part of cocoa is still traded outside of sustainable value chain mechanisms, choosing two very different value chains with distinct sustainability mechanisms in place provides comprehensive insights into the sustainable cocoa segment. The selection of farmers from only the sustainable cocoa segment might be source of bias in this dissertation, however was initially done to assess the impact of specific interventions within value chains with a sustainable sourcing mechanism in place (see initial objectives in Section 1.2.1). Given the focus of this study, the following case study descriptions mainly address the upstream end of the value chain, i.e. the farm level, as well as sustainability mechanisms in place for farmers.

Farmer samples in both case studies were smallholder-dominated. We define smallholder farms as farming systems that "are characterized by family-focused motives such as favouring the stability of the farm household system, using mainly family labour for production and using part of the produce for family consumption" in addition to managing land areas of up to 10 hectares (FAO, 2012).

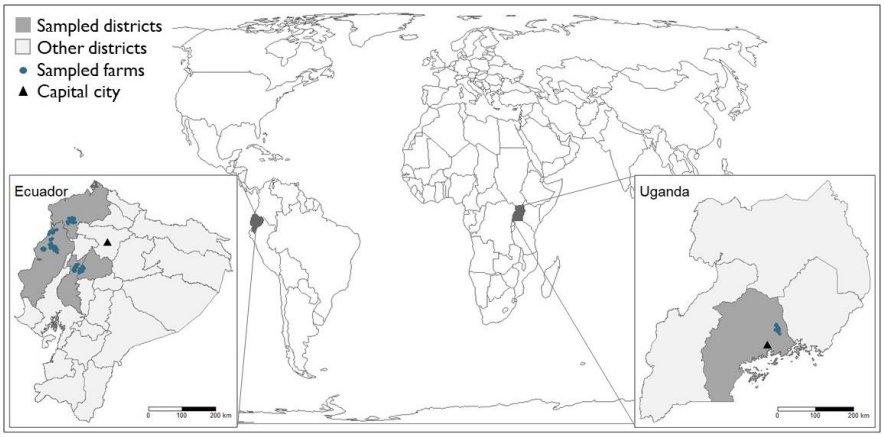

Figure 7: Map with study sites in Ecuador (Manabí, Esmeraldas, Los Ríos, and Cotopaxi Provinces; Ecuador shown here without the Galapagos Islands) (farm sample n = 190) and Uganda (Central Province) (farm sample n = 204). Map based on Open Street Map and geoBoundaries data, developed with Tmap and rgeoboundaries packages in RStudio. (Source: Tennhardt et al. (2022))

Ecuador

Cocoa production has a long history in Ecuador and as the "pepa de oro" or golden seed, it has historically brought economic prosperity to the country (Paguay Ortiz, 2012). Until today, cocoa represents an important export commodity for Ecuador, accounting for 4% of the national export value in 2020 (OEC, 2020b). Ecuador has a liberalised cocoa market. Ecuador is the world's fifth largest producer of cocoa, with almost 330,000 tonnes produced in 2020 (FAO, 2022a), and is the largest producer of fine flavour cocoa, known in Ecuador as Cacao Nacional (Anecacao, n.d.). While Ecuadorian fine flavour cocoa still enjoys a high reputation globally, the hybrid cocoa variety CCN-51 has become the dominant variety and is often mixed with fine flavour cocoa, with negative effects on quality premium prices (Huetz-Adams et al., 2022). Historically, the United States were the biggest export market for Ecuadorian cocoa, yet Indonesia and Malaysia have become equally important customers (OEC, 2020b).

In 2007, a new government embedded social and ecological goals of the "buen vivir" or good life into the national constitution and economy. This also influenced the development of the cocoa sector (UNCTAD, 2015). The consequent public assistance was mainly directed at smallholder farmers and poverty alleviation, for example

through capacity building, breading improved cocoa varieties, or infrastructure development (UNCTAD, 2015). In 2018, Ecuador put in place the PMC Cacao (Plan de Mejora Competitiva para el Desarrollo Agroindustrial de la Cadena de Cacao-Chocolate - Competitive Improvement Plan for the Agro-industrial Development of the Cocoa-Chocolate Chain) that aimed at doubling cocoa and derivate exports by 2030 and made available 600 M USD of public funds, with a call on the private sector to contribute a similar amount (Presidencia de la República del Ecuador, n.d.).

Exact data on the share of Ecuadorian cocoa grown under any SSP is not known. However, almost 30% of the 2019 national production (105,800 tonnes) were certified under the labels organic, Fairtrade, Rainforest Alliance, and UTZ (FiBL-ICT-SSI Survey, 2021). Cocoa yields in Ecuador differ strongly between provinces and cocoa varieties, with CCN-51 dominated areas reporting averages of >1 ton/hectare compared to National-dominated areas reporting averages of <200 kg/hectare (Huetz-Adams et al., 2022). The majority of the 527,347 ha of land used for cocoa cultivation in Ecuador in 2020 (FAO, 2022b) was located in the coastal area (INEC, 2020), which is also the location of the sampled farmers in this case study (Figure 7).

In this case study value chain, the majority of farmers sell their cocoa to middlemen in nearby towns, who in turn sell to a large multinational trader as an export company, which then exports cocoa to a large Swiss chocolate company (Figure 8). Farmers, middlemen, and the export company form part of the chocolate company's in-house sustainability program for fine flavour cocoa, which was initiated in 2014, is implemented by the export company, and has grown to over 7,000 participating farmers in 2020. Farmers in the program are grouped around intermediaries in the closest town to facilitate cocoa transportation logistics and sustainability program activities.

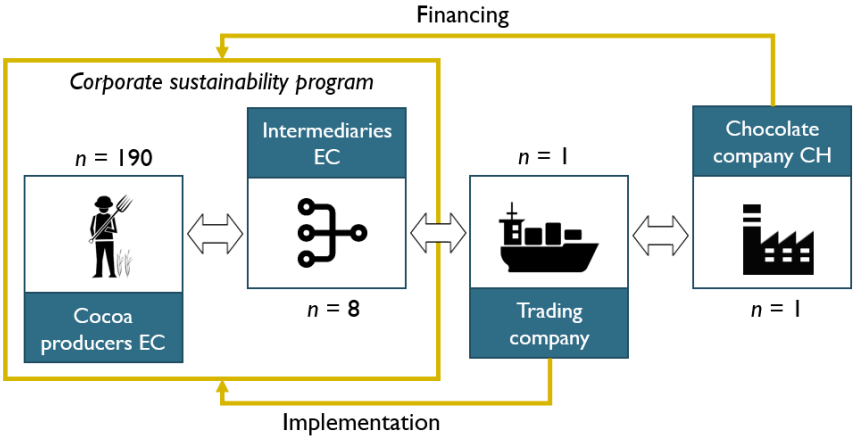

Figure 8: Sketch of the first case study value chain, spanning from Ecuador (EC) to Switzerland (CH). (Source: own graph)

The sustainability program focusses on cocoa traceability, farmer training, in-kind premium distribution, and community development. Each farmer group, ranging in size from 100 to 600 farmers, is supported by one extension officer and farmers undergo several modules of training with a focus on good agricultural practices and environmental protection. Most training sessions are held at the intermediary shop in the town and farmer trainers rarely pay additional visits on individual farms because of the high number of farmers. The program does not provide price premiums for fine flavour cocoa yet pays "normal" market prices, which are dependent on quality and humidity content. Instead, farmers receive in-kind premiums, such as fertilisers, fungicides, or small machinery (e.g. motorised grass cutters for a group of 4-5 farmers). Additionally, the program started some community development projects. There are no minimum requirements or contracts for farmers to join the program. As participants of the program, farmers are expected to separate fine flavour and hybrid cocoa at the time of sales and to regularly sell to program intermediaries, otherwise they no longer receive in-kind premiums. Anecdotal evidence suggests that participating farmers highly valued the sustainability program, which is mainly due to the continuous support since 2014, the in-kind premiums they receive, and because, for many, it is the only source of training and advisory service available.

Uganda

Until recently, cocoa was of minor importance in Uganda (Jones & Gibbon, 2011). In comparison to Ecuador, Uganda had a much smaller cocoa production in 2020 of 35,000 tonnes, harvested from 70,809 ha (FAO, 2022b). National production quantities and export values, however, have been increasing steadily (FAO, 2022b). In 2020, cocoa beans represented the third most exported product from Uganda worth 101 M USD and the second most important agricultural product following coffee (OEC, 2020d). This increase in cocoa production has also been supported by national and international policies. One of seven major projects by the Ugandan Ministry for Agriculture, Animal Industry and Fisheries provides cocoa seelings to farmers in traditional and new cocoa growing areas to increase farmers' incomes and increase foreign exchange revenues through exports (Ugandan Ministry of Trade Industry and Cooperatives, 2015) The National Coffee Research Institute now also carries out research into cocoa variety improvements and plant health (National Coffee Research Institute, 2022). Furthermore, the European Union (EU) through the Market Access Upgrade Programme (MARKUP) supported the Ugandan cocoa and coffee sector in 2018 with 14.6 billion UGX (almost 4 M Euro) to increase exports mainly to the EU (European Union External Action, 2018). This supported the National Export Development strategy from 2016-2020, which identified cocoa as one of 20 priority products (Ugandan Ministry of Trade Industry and Cooperatives, 2015). Just as in Ecuador, the Ugandan cocoa market is liberalised.

Around 10,240 tonnes were certified under the organic, Fairtrade, Rainforest Alliance, or UTZ standard in 2019 (FiBL-ICT-SSI Survey, 2021). While Uganda is not a major cocoa producer today, the suitability for cocoa production in Central and East Africa is predicted to increase due to climate change (Bunn et al., 2017). Major cocoa producing areas in Uganda are Bundibugyo in the Western Region and Mukono in the Central Region, with the latter corresponding to the location of sampled farmers in our case study value chain (Figure 7).

Mukono farmers in this case study (Figure 9) currently sell their cocoa to different local intermediaries and international traders. However, the group of almost 500 independent farmers has been undergoing conversion to organic certification since 2017. That year, a national export company seeking to increase its supplier base in

Mukono District recruited farmers based on a door-to-door campaign asking for their willingness to comply with organic regulation in exchange for higher cocoa prices. Since then, the national export company has been organising the conversion process and plans to buy farmers' cocoa and vanilla with a price premium once it has been certified. The first external audit took place in 2021, but high levels of non-compliance by farmers in the application of synthetic pesticides were identified so the certifier demanded improvements before being able to certify the group. Thus, farmers' cocoa cannot yet be sold as certified organic with price premiums (status September 2022).

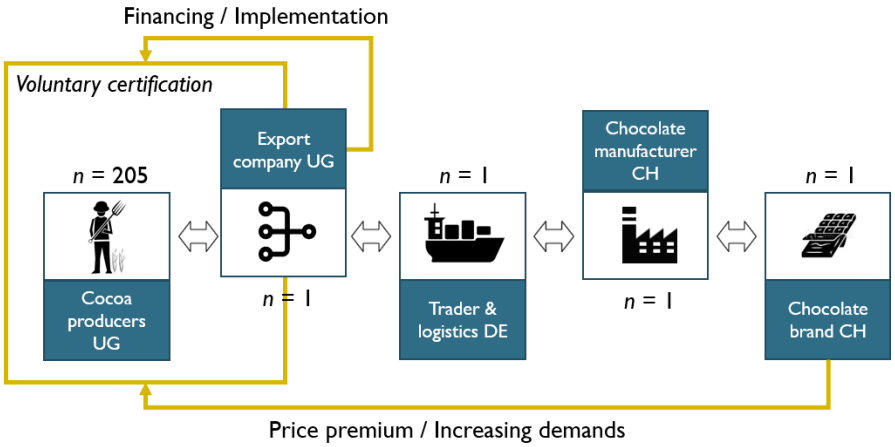

Figure 9: Sketch of the second case study value chain, spanning from Uganda (UG) to Switzerland (CH). (Source: own graph)

Additionally, no contractual relationships were in place between farmers and buyer and none had been planned. During the conversion process, the export company established an internal control system to assure that the participating farmers comply with organic regulations. Furthermore, a training program comprising several modules on organic farming and certification was offered, yet not mandatory, for participating farmers. The export company hired two trainers to manage and provide training to the group of farmers in Mukono District and to control compliance. The small Swiss chocolate brand currently buys organic and Fair for Life certified cocoa from the same trader but this is sourced in Western Uganda and caters to a niche market of consumers of sustainable chocolate. The brand owners personally know the lead farmer and the conditions in which farmers in Mukono District live and operate, have expressed the intention to source cocoa from Mukono farmers once they are

certified, and intends to pay organic as well as additional voluntary living income price premiums.

1.2.6 Farmer sampling and data collection

Farmer sampling followed a randomised approach in both case studies, targeting sample sizes of around 200 farmers that were feasible within the project framework. Due to the very high number of farmers (>6,000) and wide geographical distribution across coastal Ecuador, north-western Ecuador was selected as a wider region to reduce regional differences within the sample. Then, eight intermediary groups in four provinces were selected. From a list of participating farmers in each intermediary group, which was provided by the export company, random subsamples of 25 farmers per group were drawn, to give a final sample of 190 farmers. All supplying farmers in Uganda were located in Mukono district in Central province with a group size of around 450. The export company provided a list of participating cocoa farmers, from which a random sample of 204 farmers was selected.

Data collection took place at two points in time to provide data for the impact evaluation initially planned within this thesis. A first data collection round took place from July to September 2019 in Ecuador and from February to March 2020 in Uganda. The aim of this data collection was to collect general farmer and farming household information, as well as data on farm management, inputs, and farm-level sustainability (Chapters 2, 3, and 4). All information was collected for the reference years 2018 for Ecuador and 2019 for Uganda. Selected farms were visited for a face-to-face interview with farm managers, including a farm tour, which lasted around 3 hours each. In Ecuador, these interviews were carried out by two trained enumerators and myself. Due to the language barrier in Uganda, trained enumerators carried out the farm interviews while I accompanied a part of the interviews. A second data collection round took place between February and March 2022 in Uganda for the reference year 2021. This farm manager interview focussed on farm management and inputs as well as experienced changes since the beginning of the Covid-19 pandemic (Chapter 4). A second data collection also took place in Ecuador to evaluate the treatment implemented within the larger research project. These results, nonetheless, were not used in this dissertation as the treatment had not been implemented in a way that

allowed for a clean scientific evaluation. Most farmers that we approached were willing to participate in this study, with few farmers (4 in Ecuador, 6 in Uganda) refusing participation.

1.3Outline

This dissertation has one main aim and two overarching research questions (Figure 3), which are addressed by following a case study approach that includes two specific cocoa value chains and producer communities in Ecuador and Uganda.

Chapter 2 comprehensively explores sustainability challenges and trade-offs between sustainability dimensions on smallholder cocoa farms to provide answers to Research Question 1. This chapter follows the specific objectives of a) detecting key sustainability challenges faced by two cocoa growing communities, and b) identifying the social and economic co-benefits and trade-offs associated with environmentally-friendly cocoa production. To achieve these objectives, a survey of farming households was carried out using the SMART-Farm Tool to collect comprehensive farmer, farm management, and sustainability data. A multi-criteria approach was then used to assess farm-level sustainability performance in the environmental, social, economic, and governance dimensions. By grouping farms according to their environmental performance and comparing social and economic indicators, the co-benefits and trade-offs of environmentally-friendly production are identified.

In Chapter 3, I contribute to answering Research Question 2 by studying the relationships between the value chain into which farmers sell their cocoa and the implementation of SFP. I estimated the relative importance of value chain factors for sustainable farming practice implementation and identify mechanisms or levers through which focal companies, through their value chains, can influence their implementation. This chapter uses a selection of sustainable cocoa farming practices and influencing factors, with data from the same farm household survey that was used in Chapter 2, to model on-farm practice implementation using mixed regression models.

Interactions between household labour availability and pest and disease management on smallholder cocoa farms are assessed in Chapter 4, which provides further insights

for Research Question 2. The objectives of this chapter are to a) explore the relationship between changes in household labour availability and pest and disease management, and b) test whether changes in pest and disease management influence farmers' use of synthetic pesticides. To achieve these aims, a second survey of the same farming households in Uganda was carried out after changes in household labour availability had taken place as a result of the Covid-19 pandemic. Different regression models were paired with qualitative information to provide insights into how increased household labour was allocated and how this influenced pesticide use and expenditures. This chapter concludes by highlighting the importance of household labour for the sustainable intensification of labour-intensive cash crop production in smallholder farming systems.

Finally, in Chapter 5, I summarise the empirical findings for each research question, reflect on methodological choices, and provide an overview of the main contributions of this dissertation. I furthermore include a positionality statement before closing with more general limitations of this work and highlighting directions for future research.

Chapter 2: Sustainability performance of cocoa farms

This chapter is based on the following paper:

L.M. Tennhardt, G. Lazzarini, R. Weisshaidinger, C. Schader (2022). Do environmentally-friendly cocoa farms yield social and economic co-benefits? *Ecological Economics* (197) 107428, DOI: https://doi.org/10.1016/j.ecolecon.2022.107428

Abstract

Downstream companies in chocolate value chains are increasingly engaged in improving the sustainability of cocoa production, which requires a multidimensional understanding of cocoa farms' sustainability performance. However, prior research has insufficiently addressed the multiple sustainability dimensions of cocoa production or the interrelationships between dimensions. This study explores farm sustainability using our comprehensive data set of 395 cocoa farms in Ecuador and Uganda and identifies social and economic co-benefits and trade-offs of environmentally-friendly cocoa production. For this, farms were grouped according to environmental performance and then compared. This approach revealed lowest sustainability performance in the social and governance dimension. We identified important social and economic co-benefits of environmentally-friendly cocoa production regarding human health benefits from reduced pesticide use and resource conservation for farms' long-term productivity, although at the expense of farm investments and profitability. Future interventions require approaches that target underrepresented sustainability issues and enable synergistic effects between environmental, social, and economic sustainability for cocoa farms.

2.1 Introduction

Cocoa (*Theobroma cacao*) is an important agricultural commodity traded globally and with continuously increasing demand (Voora et al., 2019). Cocoa cultivation, however, is associated with numerous environmental, social, and economic issues, including deforestation, child labour, or farmer poverty (Fountain & Huetz-Adams, 2020; Lambin et al., 2018). This leads to public and consumer pressure (Mithöfer et al., 2017b) and an increasing demand for sustainably-produced cocoa (FiBL-ICT-SSI Survey, 2021). Consequently, cocoa traders/processors and chocolate companies have started addressing farm-level sustainability through value chain mechanisms, such as voluntary certification or in-house schemes (Barrientos, 2011; Grabs & Carodenuto, 2021; Thorlakson et al., 2018). These sustainability mechanisms, nonetheless, have also received criticism. For example as certification schemes lack farmer inclusion in decision-making and the ability to trigger large-scale transformation (Glasbergen, 2018; Mithöfer et al., 2017a; Mithöfer et al., 2017b). Sustainability mechanisms in cocoa focus on – with differing degrees – agronomic, environmental, and social aspects (Grabs & Carodenuto, 2021; Thorlakson, 2018) and have largely relied on farmer trainings or input provision to increase productivity. Economic deficiencies for cocoa farmers have lately been highlighted within the living income debate, resulting in the creation of the Living Income Community of Practice. Despite these efforts, cocoa farming's environmental, social, and economic challenges remain (Fountain & Huetz-Adams, 2020).

Past research on cocoa sustainability has mostly focused on only a few topics. These include salient issues like child labour (Berlan, 2013; Busquet et al., 2021), the environmental impact of cocoa farms, and the relationship between environmentally-friendly farming practices and profitability. Within the latter, ecosystem services provided by agroforestry systems and the economic outcomes for farmers in terms of cocoa yields have been at the centre of research: identifying both trade-offs (Blaser et al., 2018; Middendorp et al., 2018; Tothmihaly et al., 2019) and synergies (Schroth et al., 2016b; Somarriba et al., 2013). Economic co-benefits of cocoa agroforests through income diversification have also received some scientific attention (Blare & Useche, 2013; Cerda et al., 2014; Niether et al., 2020; Tschora & Cherubini, 2020).

Environmentally-friendly production practices, such as agroforestry systems and phytosanitary measures, increase farm labour demand but can generate economic co-benefits due to higher system and cocoa yields (Armengot et al., 2016; Armengot et al., 2019). Compared to the economic co-benefits of environmentally-friendly cocoa production practices, very little research has addressed social co-benefits, mirroring a more general research gap in understanding potential social-ecological trade-offs and synergies in agriculture (Rasmussen et al., 2018). This might be influenced by the lack of a common understanding of social sustainability in agriculture and conceptual frameworks as well as difficulties in their operationalization (Janker & Mann, 2018). Beneficial effects of lower pesticide use include the reduced health risk for farm workers (Franzen & Borgerhoff Mulder, 2007), while agroforestry systems appear to result in social benefits such as food security (Cerda et al., 2014; Mbow et al., 2014) or fuelwood self-sufficiency (Tschora & Cherubini, 2020). Few qualitative studies paint a more nuanced picture of trade-offs and co-benefits in cocoa systems (Rueda et al., 2018).

The perspectives of existing research have tended to be rather narrowly focused on single sustainability dimensions or topics, yet a broader perspective is needed to get a comprehensive sense of sustainability issues in cocoa production systems. Furthermore, interrelations between agronomic, environmental, social, and economic sustainability remain poorly understood (Eichler Inwood et al., 2018; Martin et al., 2018). Understanding these relationships, however, can provide critical information for the future development of both public and private interventions to promote sustainable cocoa production by taking co-benefits and trade-offs into account.

In this study, we therefore aim to identify which major sustainability issues exist in cocoa systems when viewed under a comprehensive sustainability lens. Furthermore, we aim to evaluate whether measures to improve the environmental sustainability of cocoa farms also lead to social and economic co-benefits. We hypothesised that economic co-benefits would be evident on environmentally-friendly cocoa farms due to diverse income (Armengot et al., 2016; Niether et al., 2020) but that there would be few social co-benefits, such as women's access to land or credit (Ingram et al., 2016), as these are highly influenced by the social and cultural setting in which

farmers operate and are less commonly addressed by cocoa value chain mechanisms (Thorlakson, 2018).

To test our hypotheses, we first examine the general sustainability performance of cocoa farms within two case studies using a comprehensive sustainability assessment tool. Then, we explore specific trade-offs between the environmental dimension and the social and economic dimensions of sustainability. As all sampled farms form part of a certification and in-house sustainability program, we do not aim at drawing general conclusions about the impact of these value chain mechanisms on cocoa farm sustainability. We hope to identify co-benefits and trade-offs arising from environmentally-friendly production practices within our samples and thus draw more general conclusions. For this, we group farms within our sample based on their environmental performance and test for simultaneous performance in the other dimensions. This approach allows us to cover a large number of social and economic sustainability topics and to test for co-benefits across diverse indicators.

2.2 Materials and methods

2.2.1 Sustainability analysis tool and data collection

To measure sustainability in a meaningful way, numerous analytical frameworks have been developed (Eichler Inwood et al., 2018; Hák et al., 2016; Singh et al., 2012), with great disagreement among experts of how to do this best (de Olde et al., 2017). The developed frameworks for farm-level sustainability assessment range from single-unit (e.g. greenhouse gas emissions) to diverse indicator and dimension approaches, each following a unique purpose with different scopes and precision that inhibits the comparison of results between approaches (Schader et al., 2014). As a response to this situation, the Food and Agriculture Organization (FAO) developed the SAFA Guidelines (Sustainability Assessment of Food and Agriculture systems) as a comprehensive and universally relevant framework to guide sustainability assessments of agricultural systems (FAO, 2014). Within the four sustainability dimensions of Good Governance, Environmental Integrity, Economic Resilience, and Social Well-Being (in the following referred to as governance, environmental,

economic, and social dimensions), the SAFA Guidelines address 21 themes and 58 subthemes (FAO, 2014). For each subtheme, SAFA defines a corresponding goal, considering farms' areas of influence via decisions in procurement, management, and sales.

The Sustainability Monitoring and Assessment RouTine (SMART) Farm Tool operationalizes the SAFA Guidelines through indicators that influence each of the 21 SAFA themes and 58 subthemes (Schader et al., 2016) and thus enables farm-level sustainability assessments. So far, the SMART-Farm Tool has been applied on over 5,000 farms across different regions and farm types (Curran et al., 2020; Ssebunya et al., 2019; Winter et al., 2020). Based on both qualitative and quantitative indicators, a farm's performance within each indicator is translated into an indicator score, expressed as a percentage based on pre-defined levels. For example, the indicator "Does the farm have a professional agricultural accounting procedure that is also used for the farm management?" is answered in a qualitative way (No, Partly, Yes) and then translated into a percentage rating (0, 50, 100%). The number of indicators assessed per farm ranged from 188 to 266 in Ecuador and 182 to 263 in Uganda, depending on the number of farm enterprises and complexity of farm activities. Using a multi-criteria approach and following the standardized use of the SMART-Farm Tool, sets of weighted indicators are aggregated for each subtheme, in which the weight reflects an indicator's relative importance ("impact") in achieving the subtheme goal. Each indicator may interact with multiple subthemes simultaneously based on a weight scale from -1 to +1 (e.g. non-use of pesticides has a positive impact on species diversity and a negative impact on stability of production). Individual indicators weights were developed in an expert-based Delphi process (Schader et al., 2019) and form part of every sustainability analysis using the SMART-Farm Tool. Based on the scores of indicators aggregated into subthemes and themes, the "degree of goal achievement" for each theme and subtheme is calculated in the SMART-Farm Tool, expressed as a percentage of the goal defined in SAFA (0% = no achievement and 100% = full goal achievement). For the analysis of this study and in order to identify topics with the most urgent need for improvement, each subtheme with a mean goal achievement in the Unacceptable (0-20%) or Limited (20-40%) ranges was defined as a major sustainability issue. We used a one-sample t-test to test whether

the mean goal achievements in each case study and subtheme were significantly lower than the defined threshold of 40%.

2.2.2 Analysis of co-benefits and trade-offs

Grouping farms based on environmental performance: Similar to clustering techniques, latent profile analysis (LPA) is a mixture model approach that identifies discrete subgroups within a population based on a set of continuous variables (Oberski, 2016). LPA does this by assuming that observations can be classified with varying degrees of probabilities into categories with different profile attributes. We aimed at identifying farms within our Ecuadorian and Ugandan data sets with a relatively higher and lower environmental performance than other sampled farms, thus without fixed cut-off points of high or low environmental performance. We used LPA to identify these subgroups of farms within our data sets based on their level of goal achievement in five environmental themes Atmosphere, Biodiversity, Land, Materials and Energy, and Water. The SAFA theme Animal Welfare was excluded for LPA as it was considered less important for the sustainability of cocoa production. To identify the best latent profile model and thus the most suitable number of subgroups, we used the general model selection and comparison approach Bayesian information criterion (BIC) (Schwarz, 1978). BIC is used to avoid overfitting models by penalizing the addition of parameters and preference is given to models with lower BIC.

Comparison between high and low environmental performers: After allocating sampled farms to subgroups according to their environmental performance, the farms with high environmental performance and low environmental performance (hereafter referred to as HEP and LEP) were selected for further analysis. This division into subgroups was carried out purely for this research and does not reflect distinct treatment of subgroups through the value chain (e.g. through performance-based price premiums). Certain trade-offs and synergies between (sub)themes are inherent within the SMART-Farm Tool, as single indicators can positively and/or negatively influence different (sub)themes at the same time. Therefore, we assessed differences between the HEP and LEP at indicator level, comparing indicator scores between the two subgroups.

As mentioned above, the selection of indicators that are relevant for each sustainability subtheme as well as their individual weights in the SMART-Farm tool was established in an expert Delphi process (Schader et al., 2019). To distinguish between those indicators that influence the environmental dimension and thus had an effect on the division of environmental performance subgroups and those indicators that do not, the former were marked with a superscript one in the following section. We defined co-benefits as the simultaneous existence of high performance in the environmental dimension and high performance at indicator level in one of the other sustainability dimensions. Conversely, high performance in the environmental dimension with simultaneous low performance at indicator level within the other sustainability dimensions was defined as a trade-off.

All comparisons between HEP and LEP were carried out using non-parametric statistics (Wilcoxon rank-sum test for continuous variables). All statistical analyses were performed in R (vers. 3.6.3, R Project for Statistical Computing, RRID:SCR_001905), via RStudio (vers. 1.2.5033, RStudio, Q19 RRID:SCR_000432). The analysis was implemented in RStudio's RMarkdown script format, which integrates analysis, reporting, and export functions for highly reproducible research reports (Baumer & Udwin, 2015). Data and code are available here: https://shorturl.at/ikoH3.

2.3Results

2.3.1 Agronomic characteristics

Most of the surveyed farms were small, with areas below 4 ha (55%) with few farms of medium to large sizes above 10 ha (16%). However, there were significant differences between case studies: The median farm size in Ecuador was 7.0 ha and in Uganda 2.02 ha. In general, farmers in both countries differed in most demographic and farm characteristics, as shown in Table 1. Similarities existed only in farmers' age, land ownership, ability to hire workers, application of fungicides, and irrigation. Despite largely similar median yields of 0.181 t/ha in Ecuador and 0.210 t/ha in Uganda (compared to national averages of 0.540 t/ha in Ecuador and 0.484 t/ha in

Uganda for 2019 (FAO, 2022b)), Ecuadorian farmers had significantly higher incomes from cocoa production (median of 1,295 USD/year) than Ugandan farmers (median of 272 USD/year). This can be attributed to cocoa production areas (median of 4 ha in Ecuadorian sample and 1 ha in Ugandan) but also to producer prices, as Ecuadorian farmers received on average 1.91 USD/kg of dry cocoa and 0.76 USD/kg of fresh cocoa in 2018, and Ugandan farmers 5,940 UGX/kg of dry cocoa (=1.61 USD/kg) and 2,277 UGX/kg of fresh cocoa (=0.62 USD/kg) in 2019. Average world market prices in 2019 and 2020 were 2.34 USD/kg and 2.37 USD/kg, respectively (ICCO, 2021).

Table 1: Median values (standard deviation) and percentages of farm characteristics in both case studies. Statistical comparison between case studies using a Wilcoxon rank-sum test and Chi-square test.

Farm characteristics	Ecuador (n = 190)	Uganda (n = 204)	p-value
Farm manager male (% farmers)	80.0	68.3	0.008
Farm manager age (years)	53.0 (14.1)	53.0 (12.9)	0.424
Highest degree rewarded (% farmers)			< 0.001
No degree	4.3	35.8	
Primary	62.3	40.6	
Lower Secondary	21.0	16.0	
Higher Secondary	6.8	2.1	
Other (university EC/training UG)	5.6	5.3	
Total farm area (ha)	7.0 (16.3)	2.02 (2.9)	< 0.001
Share cocoa (% farm area)	70.0 (31.1)	51.9 (24.0)	< 0.001
Share arable land (% farm area)	0.0 (13.3)	25.0 (19.3)	< 0.001
Share permanent grassland (% farm area)	0.0 (28.8)	0.0 (7.6)	< 0.001
Cocoa cropping density (% of cocoa area)	80.0 (25.8)	50.0 (23.2)	< 0.001
Cocoa yields (t/ha)	0.181 (0.338)	0.210 (0.455)	0.249
Cocoa revenue (USD/year)	1,295 (9,181)	272 (979)	< 0.001
Secure land tenure rights (% farmers)	90.5	87.3	0.311
Employment of hired workers (% farmers)	74.2	66.8	0.108
Access to credit (% farmers)	68.4	96.1	< 0.001
Livestock ownership (% farmers)	100.0	67.0	< 0.001
Use of synthetic pesticides (% farmers)	83.0	62.0	< 0.001
Use of organic fertilisers (% farmers)	14.2	65.9	< 0.001
Use of mineral fertilisers (% farmers)	85.8	37.1	< 0.001
Irrigation system in place (% farmers)	14.7	19.5	0.209

2.3.2 Overall sustainability performance

Here, we present the overall sustainability results for the farms in the two case studies and major sustainability issues at subtheme level including selected indicators that contribute to the poor performances. Unless indicated otherwise, all values presented in this part represent the arithmetic mean. A detailed description of each theme and subtheme, as well as goal achievement values from both case studies is provided under Tennhardt et al. (2022).

Across the samples, average performance per SAFA subtheme ranged between 11% and 92% of goal achievement. As can be seen from a comparison of boxplots in Figure 10, the performance scores followed similar trends in both case studies for the majority of subthemes. Interquartile ranges overlapped in most subthemes across case studies, with exceptions in eight subthemes including Energy Use, Conflict Resolution, and Stakeholder Dialogue.

Major sustainability issues, i.e. those subthemes scoring significantly below the threshold of 40% of goal achievement, were mostly found in the social and governance dimensions. In each of these two dimensions, seven subthemes scored below 40%. The major issues in the social dimension included the subthemes Support to Vulnerable People, Gender Equality, and Capacity Development. Important indicators that flow into the calculation of these subthemes include social protection of farm workers (52% and 24% in Ecuador and Uganda, respectively), indicating that most farmers and their workers have no financial security in case they are not able to work. Additionally, farmers had limited access to important services such as training (51% and 45%) and advisory services (53% and 71%). While 74% and 67% of farmers in our samples employed hired workers, not all farmers paid male and female employees equally (79% and 94% in Ecuador and Uganda, respectively).

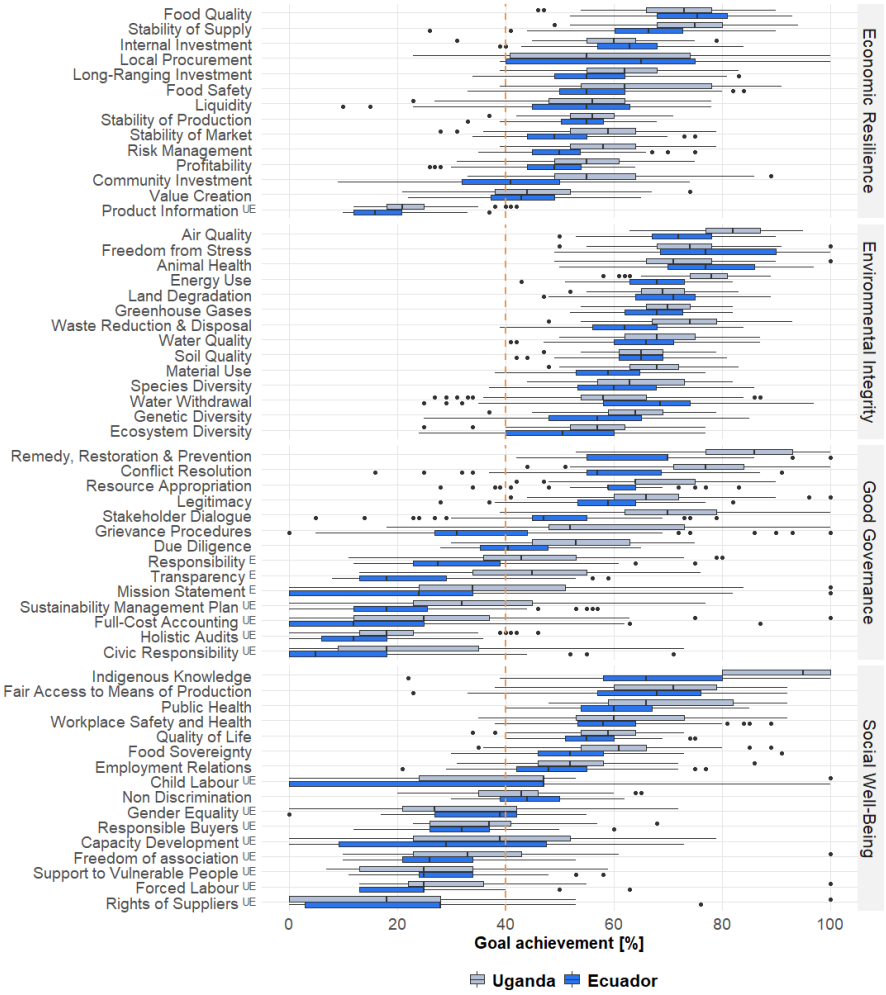

Figure 10: Farmers' goal achievement (between 0 and 100%) in each SAFA subtheme and grouped by sustainability dimension. Identification of major sustainability issues (i.e. mean subtheme values significantly below the threshold of 40% of goal achievement) using a one-sided t-test. Subthemes with means significantly below threshold ($p \leq 0.05$) are indicated by the letter E for the Ecuadorian and U for the Ugandan case study. (Source: Tennhardt et al. (2022))

The subthemes Sustainability Management Plan and Full-Cost Accounting are among the major sustainability issues identified in the governance dimension. Important indicators in these subthemes include keeping agricultural accounts, which most farmers did not (14% in Ecuador and 7% in Uganda). Farmers in both case studies additionally had little knowledge of, and thus showed little commitment to, the principles of sustainability (21% and 54%) and had few plans to improve their farm

accordingly (10% and 37%). Finally, farmers had little knowledge about climate change problems (26% and 34%, respectively).

We did not identify any major sustainability issues in the environmental dimension. Product Information was the only major issue in the economic dimension, indicating a general lack of product information flow along the value chain. Low scores in this subtheme are influenced by the low level of direct sales (6% in Ecuador and 8% in Uganda) and the lack of voluntary social standards for farm produce (0% for both), as both organic certification and the corporate program focus on agri-environmental practices with less focus placed on social criteria.

We tested the robustness of the results on major sustainability by changing the specifications and cut-off points. The same number of subthemes scored significantly below 40% of goal achievement when the p-value was specified at 0.1, 0.05, and 0.01. When changing the cut-off points, 15 subthemes in the Ecuadorian case and 8 subthemes in the Uganda case scored significantly below 35% of goal achievement. 20 subthemes in Ecuador and 15 subthemes in Uganda scored significantly below 45%. These results were not substantial and did not indicate necessary changes in the definition of our cut-off.

2.3.3 Co-benefits and trade-offs

Characterization of high- and low environmental performers

Grouping the sampled farms according to their environmental performance led to the creation of subsets of high environmental performers (HEP) of n=46 (Ecuador) and n=64 (Uganda) as well as low environmental performers (LEP) of n=36 (Ecuador) and n=30 (Uganda). Differences in goal achievements within the five themes of the environmental dimension for both groups and countries were significant with p-values < 0.001 (Table 2). Figure 11 shows the probability with which a farm with a specific goal achievement in each environmental theme is allocated to different subgroups. The best fitting model corresponded to three subgroups in both case studies: LEP represent Subgroup 1 and HEP Subgroup 3.

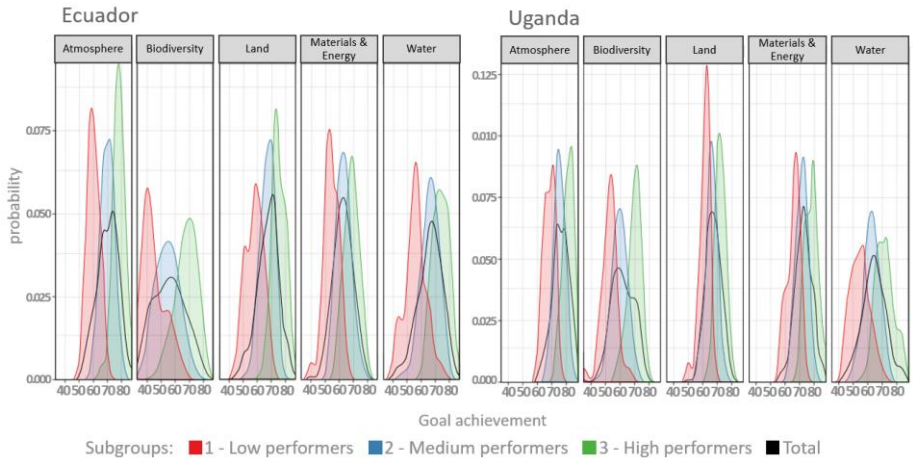

Figure 11: Probability with which farmers with a specific goal achievement in the Environmental Integrity themes belong to subgroups identified through LPA. High environmental performers = Subgroup 3; Low environmental performers = Subgroup 1. (Source: Tennhardt et al. (2022))

Significantly different scores between HEP and LEP were found in 52 and 36 environmental indicators in Ecuador and Uganda, respectively. The most important differences in environmental farm management activities between the subgroups are provided in Table 3. HEP in both countries have, on average, smaller farms with a significantly higher share of cocoa production area and agroforestry systems and apply significantly less pesticides and fertilisers. LEP in Ecuador, however, have significantly higher cocoa yields and higher income from cocoa production.

Table 2: Mean (standard deviation) goal achievements within five Environmental Integrity Themes of the SAFA Guidelines for high and low environmental performers in the Ecuadorian and Ugandan sample. Statistical analysis using a Kruskal-Wallis Test.

	Environmental themes:	Atmosphere	Biodiversity	Land	Materials and Energy	Water
Ecuador	High environmental performers (N=46)	78.00 (3.79)	68.39 (6.71)	75.37 (4.53)	68.52 (4.90)	73.93 (5.50)
	Low environmental performers (N=36)	59.89 (3.99)	44.56 (8.11)	57.86 (6.11)	54.33 (5.19)	55.53 (6.95)
	p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Uganda	High environmental performers (N=64)	81.05 (3.67)	69.98 (4.08)	72.19 (3.39)	77.97 (4.17)	71.53 (6.15)
	Low environmental performers (N=30)	67.93 (3.61)	52.53 (5.66)	61.37 (3.57)	65.47 (4.32)	53.90 (5.86)
	p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Table 3: Mean values (standard deviation) and share of farmers for key farm characteristics among high and low environmental performers in Ecuador and Uganda. Statistical comparison between subgroups using a Kruskal-Wallis Test.

	Ecuador			Uganda		
	High Environmental Performers (N=46)	Low Environmental Performers (N=36)	*p*-value	High Environmental Performers (N=64)	Low Environmental Performers (N=30)	*p*-value
Farm area (ha)	9.06 (8.77)	17.96 (23.03)	0.084	2.06 (1.65)	4.01 (4.34)	0.003
Arable land (share farm area)	0.02 (0.13)	0.04 (0.12)	0.049	0.22 (0.18)	0.39 (0.18)	0.000
Cocoa cultivation (share farm area)	0.70 (0.30)	0.55 (0.32)	0.047	0.64 (0.27)	0.41 (0.21)	0.000
Agroforest (share farm area)	0.57 (0.33)	0.12 (0.22)	0.000	0.67 (0.24)	0.51 (0.20)	0.000
Woodland (share farm area)	0.45 (0.81)	0.69 (1.96)	0.092	0.05 (0.22)	0.09 (0.31)	0.504
Area deforested in past 20 years (share farm area)	0.06 (0.22)	0.29 (0.37)	0.000	0.04 (0.16)	0.13 (0.29)	0.036
Cocoa yields (t/ha)	0.19 (0.21)	0.35 (0.38)	0.004	0.26 (0.28)	0.36 (0.36)	0.272
Income from cocoa sales (USD/year)	1,816 (2,402)	3,172 (2,621)	0.004	495 (714)	833 (1,164)	0.182
Farmers owning livestock (share farmers)	1.0	1.0		0.50	0.70	0.070
Farm products sold (#)	3.17 (1.45)	3.63 (1.65)	0.255	3.48 (1.31)	5.43 (2.30)	0.000
Active substances of pesticides applied (#)	0.72 (0.72)	3.33 (2.04)	0.000	0.23 (0.58)	3.87 (1.76)	0.000
Farmers applying pesticides (share farmers)	0.11	0.36	0.006	0.00	0.43	0.000
Farmers with irrigation system (share farmers)	0.02	0.39	0.000	0.06	0.53	0.000
Farmers applying mineral fertiliser (share farmers)	0.74	1.00	0.000	0.06	0.70	0.000
Farmers applying organic fertiliser (share farmers)	0.15	0.22	0.418	0.50	0.80	0.006
Farmers owning the farm land / with secure tenure rights (share farmers)	0.91	0.92	0.954	0.88	0.87	0.911
Farmers employing hired workers (share farmers)	0.70	0.78	0.408	0.58	0.77	0.078
Participation in training (days)	4.19 (8.12)	2.08 (2.56)	0.637	2.42 (3.00)	1.61 (2.37)	0.386

Social co-benefits and trade-offs of environmentally-friendly farming practices

From 120 indicators that flow into the social dimension in the SMART-Farm Tool, 25 and 28 show significant differences in scores between the HEP and LEP in Ecuador and Uganda, respectively. Four and nine of these (marked with 1 in Figure 12) do not simultaneously influence the environmental dimension and thus did not affect the division of subgroups based on environmental performance. All indicators in the Ecuadorian case study show synergistic trends with social indicators scoring higher among HEP. The Ugandan case study shows six indicators with lower scores among HEP, indicating trade-offs.

A large proportion of indicators for which social co-benefits of environmentally-friendly production practices were identified (13 and 14 indicators for Ecuador and Uganda, respectively) are related to pesticide use. These include indicators that impact the environmental dimension, such as the number of active ingredients used by farmers, the share of farm area not sprayed with synthetic pesticides, and the toxicity of pesticides for nature and humans. These indicators also include some that did not impact the division of farmers based on environmental performance. For example, HEP used less seeds coated with agrochemicals and more often used protective gear, reducing risks for farm workers. HEP in the Ecuadorian case study were also significantly more engaged in community activities for environmental protection, including collective work called "minga" to clean rivers and roads from trash. Finally, burning of farm residues and managing riparian strips, i.e. cultivation and/or pesticide use within three meters of surface waters, which provides benefits for human health through reduced contamination of air and water, was less common among HEP in Ecuador. The Ugandan sample additionally presented six social trade-offs. Compared to LEP, HEP perceived household food security in terms of meals per day and dietary diversity to be lower and created fewer new jobs on their farms.

Figure 12: Ratio of mean indicator values between high (HEP) and low environmental performers (LEP) within the Social Well-Being dimension and with significant differences between these subgroups. Ratios >1 indicate co-benefits with environmental performance; ratios <1 indicate trade-offs. Indicators that influenced the calculation of results in the Environmental Integrity dimension in the SMART-Farm Tool are marked with a superscript one. (Source: Tennhardt et al. (2022))

Economic co-benefits and trade-offs of environmentally-friendly farming practices

The economic dimension in the SMART-Farm Tool is influenced by 187 indicators. Out of these, 24 and 25 scored significantly differently between HEP and LEP in the Ecuadorian and Ugandan case study, respectively. Out of these, six and 17 indicators did not flow into the calculation of the environmental performance (marked with 1 in Figure 13). Many economic indicators with significantly different values between HEP and LEP show synergistic effects. Yet, some trade-offs can be identified, especially in the Ugandan case.

The identified economic co-benefits of environmentally-friendly production practices in both case studies mostly address sustaining the productivity of the farm in the long term. By having more legumes on their arable land and a larger share of agroforestry systems, by implementing measures for soil fertility management, such as humus accumulation, or by promoting beneficial organisms, HEP assure their farm's long-term productivity. These indicators also flow into the environmental dimension and thus influence the division into HEP and LEP. Additionally, HEP in the Ecuadorian sample were more committed to the principles of sustainability and had plans to improve the farms in this regard. HEP in the Ugandan sample additionally had a more secure supply of farm inputs.

However, diverse trade-offs were identified in both case studies, especially with respect to indicators in the subthemes of liquidity, profitability, and internal investments: Ecuadorian HEP were less frequently able to make long-term investments on the farm and the farm infrastructure was consequently in worse shape. These farms also more commonly reported profits to have been declining over the past five years than LEP. In the Ugandan case study, HEP more often experienced decreasing profits, a lack of liquidity, and yield losses. HEP were also more dependent on one major buyer and generally had fewer customers, made fewer long-term investments, and less often kept agricultural accounts. Finally, HEP in the Ugandan sample were less informed about future market or political challenges that could affect their farms than LEP.

Figure 13: Ratio of mean indicator values between high (HEP) and low environmental performers (LEP) within the Economic Resilience dimension and with significant differences between these subgroups. Ratios >1 indicate co-benefits with environmental performance; ratios <1 indicate trade-offs with environmental performance. Indicators that influenced the calculation of results in the Environmental Integrity dimension in the SMART-Farm Tool are marked with a superscript one. (Source: Tennhardt et al. (2022))

2.4Discussion

2.4.1 Cocoa farm sustainability

The primary aim of this study was to identify major sustainability issues in cocoa production by viewing farms through a comprehensive sustainability lens. We found that the farms within our sample of Ecuadorian and Ugandan cocoa farmers scored between poor and well within different sustainability dimensions. We identified similar patterns between both case studies, implying that farmers in different countries largely experience similar challenges and opportunities.

The highest goal achievement in both case studies was in the environmental dimension due to the small holdings and low input systems in which cocoa is mostly grown. These results are in line with other studies applying the same methodology for coffee production in Uganda, Ethiopia, and Brazil (Ssebunya et al., 2019; Winter et al., 2020). The economic dimension scored on average second-highest, with good mean values in subthemes regarding security of input provision and food quality. This is also due to the nature of cocoa systems involving relatively low external inputs that might affect food quality and few inputs facing risk in their supply or availability. Subthemes like profitability or value creation on average scored much lower, mirroring the dire economic situation of many cocoa farmers (Fountain & Huetz-Adams, 2020). This topic has recently gained momentum through the living income debate and the Living Income Community of Practice.

We identified most major sustainability issues in the social and governance dimension of sustainability, highlighting the importance of comprehensive sustainability assessments. This is partly influenced by indicators defined for high-input, market-oriented farms or farms in industrialised countries, so smallholder farmers score lower. We still included these indicators in our manuscript to highlight issues that could be addressed by other actors along the value chains (e.g. buyers, cooperatives, governments) although we do not intend to hold smallholder farmers accountable for additional and partly unrealistic requirements.

Many of the identified issues in the social dimension concerned labour rights, such as low wages of farm workers and the lack of worker organizations, which are known problems in cocoa production (Fountain & Huetz-Adams, 2020). Major social issues additionally included gender and discrimination, which also represent recognized problems in cocoa (Ingram et al., 2016). We detected only a few cases of child labour that impaired school education or included hazardous work, which is often associated with cocoa production, however, more commonly in West Africa (Berlan, 2013; Fountain & Huetz-Adams, 2020).

Identified major issues in the governance dimension, such as transparency and holistic audits, were to be expected. Farmers in both case studies were not formally organized in cooperatives, which often take over governance tasks in contexts of smallholder farmers (Ssebunya et al., 2019). While these governance aims are difficult to reach for individual smallholder farmers, including them in sustainability assessments can guide value chain management in improving value chain sustainability. The higher performance of the Ugandan sample in this dimension might be a result of several observed factors. Farmers in our Ecuadorian sample were very independent with little collaboration with other farmers. In our Ugandan sample, in contrast, farmers were highly engaged at community level and partly holding official positions like chairpersons or community leaders. Thus, SMART-Farm Tool indicators like "Social involvement outside the farm" or "Communication with stakeholder groups" within the governance dimension scored higher among Ugandan farmers than among Ecuadorians.

2.4.2 Co-benefits and trade-offs

Grouping farms based on their environmental performance and consequently comparing high and low performers provided answers to our second aim which was to identify whether environmentally-friendly cocoa farms yield social and economic co-benefits. HEP in our samples were characterized by smaller farm sizes with higher shares of cocoa and agroforestry systems as well as the use of less external inputs, however, also by lower cocoa yields and reported incomes compared to LEP.

We started this study hypothesizing that social co-benefits of environmentally-friendly farms within our data set were low because social sustainability rather depends on the broader socio-political and cultural farm setting. For example, social and cultural settings might determine women's access to land or credit as well as participation in farm work and decision-making (Ingram et al., 2016). We found a major social co-benefit of environmentally-friendly production practices in the reduced risk for farmers and workers due to lower pesticide use, as previously identified by Franzen & Borgerhoff Mulder (2007) and Ramankutty et al. (2019). Safer use of agrochemicals and thus reduced health risk is a general positive social outcome of voluntary sustainability certification (Meemken et al., 2021). However, in line with our hypothesis, we identified few additional co-benefits or trade-offs. Among the identified social trade-offs of environmentally-friendly farms in our Ugandan sample was food security (number of meals per day). LEP in the Ugandan sample had higher shares of arable land, which was mainly used for staple production, such as cassava or sweet potato, and thus might improve food security. Past studies have shown a positive influence of associated crops in cocoa agroforests on household food security (Cerda et al., 2014; Mbow et al., 2014). More generally, however, our findings in Uganda mirror the generally perceived trade-off between ecosystem services conservation and food security (Hanspach et al., 2017).

From an economic point of view, being environmentally friendly held both trade-offs and co-benefits for the farmers in our case studies. Most co-benefits regarded the assurance of farm's long-term productivity like soil fertility management and thus do not reflect the parameters typically considered in economic calculations like yields and profitability. Our hypothesis that environmentally-friendly farms would yield economic co-benefits due to reduced expenses for inputs or income diversification is only partly confirmed. While it was found that HEP in our sample used less external inputs, they also sold a lower number of different farm products despite a higher share of the farm area covered by agroforestry. This contradicts Cerda et al. (2014) and Armengot et al. (2016), who found economic benefits in diversified cocoa agroforests. A diverse product range is especially important for cash crops with highly volatile market prices and has been found to be a major economic benefit of agroforests (Tschora & Cherubini, 2020).

Yields were lower among HEP, which is in line with the results from Middendorp et al. (2018) or Tothmihaly et al. (2019), who reported lower cocoa yields from agroforests. The literature review of Martin et al. (2018) highlights that most studies on ecosystem services provision and human well-being (mainly income) in low- and middle income countries find trade-offs between these two aspects. Past studies in cocoa production systems, however, have shown that the trade-offs between ecosystem services provision from agroforests or shade trees and cocoa yields or farm income are not linear: Co-benefits occur until a certain shade level before yields decline, resulting in a trade-off (e.g. Blaser et al., 2018; Waldron et al., 2012). One reason for this observation might be that intermediate shade balances habitats of different cocoa pests and diseases, as some favour shade while others favour sun (Jagoret et al., 2020). Due to similarities in production systems, research on coffee can provide valuable lessons for cocoa. In Guatemala and Costa Rica, coffee farms with medium shade levels were most productive (Haggar et al., 2021), highlighting the importance of good shade balance. Conversely, coffee farms in Nicaragua had lower productivity with rising carbon stocks and tree diversity (Haggar et al., 2017).

However, much research on environmental-economic co-benefits in smallholder farming systems focussed on the effects of voluntary sustainability certification (like organic) on farm profitability (Haggar et al., 2017; Ramankutty et al., 2019), allowing only limited comparison with our results because HEP in our samples are not remunerated for their environmental performance.

In general, farms in the HEP and LEP subgroup showed substantial structural differences, such as farm size and income (Table 3), which might partly explain the economic disadvantages faced by HEP. This echoes findings from (Beuchelt & Zeller, 2011), who found coffee farmers with organic certification in Nicaragua to have smaller coffee areas, lower per capita coffee incomes, and higher poverty levels than conventional farmers.

2.4.3 Implications for future interventions

Understanding the sustainability performance of a company's supplier base represents the basis for sustainability interventions. The fact that value chain interventions have

mainly addressed agronomic and environmental issues of cocoa production might rather be related to external pressures, reputation risks, and companies' needs for continuous cocoa supply. Our results indicate that they might not address the most severe sustainability issues of the cocoa production system.

To achieve higher co-benefits and reduce trade-offs for farmers, future interventions should be thought through in a comprehensive way. An exemplary aim of reducing pesticide use should provide farmers with knowledge about alternative pest and disease management strategies and assure that farmers have the necessary financial, physical, and social assets to implement these alternatives. Providing financial incentives for high environmental performance or high cocoa quality might create economic co-benefits. The latter is relevant for farmers in Ecuador, for example, who receive the same price for the high quality and traditionally shade-grown fine flavour variety Cacao Nacional as they do for higher yielding modern varieties grown in full-sun systems. As a result, many plots are converted to high yielding and less environmentally-friendly systems because farmers' efforts are not economically valued (Rueda et al., 2018). By engaging in long-term contracts with farmers, companies could demand environmental performance criteria linked to higher prices (Waarts et al., 2019). Voluntary certification schemes provide evidence that price premiums for environmentally-friendly production practices can have positive economic outcomes (Ingram et al., 2018) and price premiums in turn provide farmers with the financial capacities to comply with sustainability requirements (Dietz et al., 2021). This is justified, as environmentally-friendly production practices, such as pruning or phytosanitary measures, often require a higher workload (Armengot et al., 2016; Armengot et al., 2019). Additionally, initial financial incentives for female participants would enable them to engage in environmentally-friendly production practices, such as agroforestry systems, which otherwise might be too costly to implement (Benjamin et al., 2018).

To address broader social and governance issues, companies might need to rethink their approach: while agronomic decisions are taken by individual farmers and thus justify farm-level interventions, social and governance decisions rather depend on the socio-political system in which farmers operate or the farmer group in which they organize. Additional interventions that go beyond the farm level, address systemic

issues (Barrientos, 2011; Ingram et al., 2016) in collaboration with different stakeholders (Barrientos, 2011; Nelson & Phillips, 2018; Thorlakson, 2018; Waarts et al., 2019), and link much stronger to broader policy levers (Mausch et al., 2020) might be required. This includes renegotiating roles and responsibilities of foreign companies with producer country governments, whose involvement has been limited despite being crucial players in any intervention's success (Fountain & Huetz-Adams, 2020; Waarts et al., 2019). This also includes the role of voluntary sustainability certification, which has been criticized in the past for generating power asymmetries in global value chains in favour of downstream actors (Krauss & Barrientos, 2021). Corporate in-house sustainability programs have not yet received the same level of scientific attention and it remains to be seen if these programs will decrease power imbalances between smallholder cocoa farmers and large chocolate manufacturers. While multi-stakeholder and shared learning and responsibility (like the living income community) are already implemented in some geographical regions and for some sustainability topics, such as zero deforestation initiatives in West Africa (Carodenuto, 2019), we did not find such engagement in our case studies.

The results of this study demonstrate the importance of comprehensive sustainability assessments and the evaluation of interlinkages between sustainability dimensions, which should be considered by future research on the sustainability of cocoa production systems in order to capture the true sustainability situation. Finally, the impacts of value chain mechanisms on farm sustainability remain understudied and should be addressed in the future (Lambin et al., 2018; Thorlakson et al., 2018) including long-term co-benefits and trade-offs between outcomes.

2.4.4 Limitations

The SMART-Farm Tool operationalizes the FAO-SAFA Guidelines, which were developed as a comprehensive framework covering all relevant aspects of sustainability. The tool offers a standardized multi-criteria assessment approach for benchmarking farms against the SAFA Guidelines transparently and comparing across different farming systems and regions. However, our results need to be interpreted against the limitations of this approach, namely, the lacking accuracy with respect to some indicators and subthemes (Ssebunya et al., 2019) and the uncertainty

related to the indicator weights (Schader et al., 2019). Aiming at global applicability, the SMART-Farm Tool covers indicators that might not be relevant for all regions and farming systems. An additional compromise lies in the conversion of qualitative and quantitative indicators into percentage values (indicator scores). While conversion is easy for continuous variables (e.g. Share of farm area with mulch), it is more challenging for nominal and ordinal variables, as thresholds need to be introduced (e.g. Number of active substances used: 0 substances = 100%, 1 substance = 75%, 2-3 substances = 50%, 4-5 substances = 25%, >5 substances = 0%) or categorical variables (e.g. Is the farm's liquidity ensured? No = 0%, Partly = 50%, Yes = 100%). Conversion is also difficult for indicators without differentiation between positive performance and non-use (e.g. What proportion of plastic waste is delivered to recycling points or re-used? All plastic waste = 100%, No generation of plastic waste = 100%). These scoring guideline in the SMART-Farm Tool must be taken into account in the interpretation of results and when drawing conclusions. By aggregating indicators with simultaneous positive and/or negative influence in different subthemes calculation, the model already accounts for co-benefits and trade-offs. To create transparency, we differentiated between those indicators that contributed to the calculation of environmental performance and thus are co-benefits and trade-offs inherent to the model, from those indicators that did not by marking the former with a superscript one in the results figures (Figure 12 and Figure 13). These model effects also indicate that scoring a maximum value of 100% across all SAFA (sub)themes is unrealistic. Additionally, the SMART-Farm Tool allows testing for simultaneous occurrence of high indicators and (sub)themes scores. It does not, however, allow for a detailed analysis of causal relationships between identified co-benefits and trade-offs, which would require more in-depth quantitative data and should be considered in future studies on this topic. Moreover, our data only refers to a single reference year and to a sample of farmers from a specific cocoa-chocolate value chain. Co-benefits and trade-offs surely depend on the temporal scale considered (Franzen & Borgerhoff Mulder, 2007) and affect diverse social groups in a different way (Rasmussen et al., 2018), which is not reflected by the current analysis but should be taken up by future research.

2.5Conclusions

Our results on sustainability in two specific cocoa production systems identified major social and governance-related sustainability issues, which compared to the environmental and economic dimension of sustainability receive much less attention by research and are insufficiently addressed in food value chain interventions by private companies. Such interventions rather concentrate on improving agronomic knowledge and environmental impacts with an apparently implicit expectation that further sustainability outcomes will occur indirectly. Results within our samples show that this focus yields some important social and economic co-benefits, especially regarding the direct advantages of reduced pesticide use for human health or internal investments for farms' long-term productivity. Our results, however, also suggest several social and economic trade-offs when farmers implement environmentally-friendly production practices. Improving social and economic sustainability on cocoa farms needs targeted interventions instead of relying on synergistic effects from environmentally-friendly production practices like financial incentives for adopting sustainable practices or for high quality cocoa. Using a comprehensive sustainability assessment methodology allowed us to identify often overlooked sustainability issues in the social and good governance dimensions at farm level and evaluate interrelationships more broadly. This approach enabled more nuanced findings compared to past research on cocoa sustainability, which has largely either addressed environmental impacts or economic outcomes with some studies addressing interrelationships between the two.

In order to provide more sustainable cocoa, companies of the cocoa-chocolate value chain should broaden their sustainability mechanisms thematically to include the underrepresented social and governance sustainability dimensions. As these not only concern the farm level but rather systemic issues and the socio-cultural setting in which farmers operate, different strategies might be needed. Pure value chain interventions might not be able to tackle wider societal challenges (Mausch et al., 2020). As an example, approaches of public-private partnerships or multi-stakeholder initiatives are being tested for particularly salient issues like hazardous child labour or deforestation in West Africa (Carodenuto, 2019; NORC, 2020). However, these

multi-stakeholder initiatives and processes did not always include all stakeholders and thus values and visions in the past (Nelson & Phillips, 2018). Finally, much remains to be understood about how to create more synergistic effects between sustainability dimensions as well as the impacts of sustainability initiatives, which are essential to guide the future development of value chain mechanisms and policies to improve sustainability in cocoa production.

Chapter 3: Value chains for sustainable cocoa farming

This chapter is based on the following manuscript:

L.M. Tennhardt, E.F. Lambin, M. Curran, C. Schader. Implementation of sustainable farming practices by cocoa farmers in Ecuador and Uganda: the influence of value chain factors *(under review)*

Abstract

A key strategy of chocolate manufacturers is the promotion of sustainable farming practices (SFP) among their supplying cocoa producers. A growing body of micro-economic literature has analysed factors influencing the adoption of such practices, yet broadly disregarded value chain factors. Information on how factors *within* single value chains increase the adoption of SFP can help direct chocolate companies' investments and increase return of investments in sustainability. The objective of this study was to understand: a) how important value chain factors are, relative to farmer and farm factors, for cocoa farmers' implementation of SFP and b) through which mechanisms value chain factors influence SFP implementation. We collected data from 394 cocoa farmers in Ecuador and Uganda and analysed the determinants of implementation of 11 SFP across three sustainability dimensions, testing quantitatively whether value chain factors with variation *within* single value chains are significantly associated with SFP implementation. We found that value chain factors are comparable to farmer and farm factors in explaining the implementation of SFP in the environmental, social, and economic dimensions of sustainability. Both capacity building and stable relationships were significantly related with the implementation of certain SFP. Yet these results were weaker than expected, indicating that their potential was not fully exploited within our case study value chains. Through their value chain sustainability initiatives, chocolate companies should disseminate knowledge, address inhibitors to SFP implementation beyond knowledge, and align sustainability goals with all value chain actors.

3.1 Introduction

Global demand for sustainable chocolate is rising and with it, the pressure on chocolate companies to source sustainably produced cocoa. This has motivated several sustainability initiatives in the cocoa sector. Companies are increasingly sourcing certified cocoa or implementing their own in-house sustainability schemes (Fountain & Huetz-Adams, 2020; Perez et al., 2020; Thorlakson, 2018). A key strategy of both certification and corporate schemes is the promotion of sustainable farming practices (SFP) among their upstream producers. We define SFP to cover production practices that contribute to the performance in all three dimensions of sustainability (i.e. environmental, social, and economic).

A growing body of micro-economic literature has looked into factors that influence the adoption of such practices, which is summarised in several recent review studies (e.g. Foguesatto et al., 2020; Meijer et al., 2015; Mozzato et al., 2018; Takahashi et al., 2020). These conclude that the SFP adoption literature has largely focussed on basic and extrinsic characteristics of the farmer and the farm, such as structure and resource endowments. Additionally, value chain factors, such as relationships between actors, are largely disregarded in existing frameworks (Mozzato et al., 2018). In contrast, literature on value chain sustainability indicates that desirable (environmental) outcomes can be influenced by value chain partners (Hansson et al., 2019); through information sharing and economic dependencies (Grimm et al., 2014); and through strong and persistent relationships between actors – referred to as "stickiness" (Reis et al., 2020). There is thus a research gap in evaluating the influence of value chain related factors on farmers' adoption of SFP (Candemir et al., 2021; Mozzato et al., 2018) and on how value chain partners can best increase knowledge and adoption of SFP among small-scale farmers (Liverpool-Tasie et al., 2020). Furthermore, research on adoption of SFP in cocoa has looked into environmental practices (Ali et al., 2018; Aneani et al., 2012; Djokoto et al., 2016), with less attention paid to the social and economic dimensions of sustainability (Amfo & Ali, 2020; Nkamleu & Kielland, 2006). These questions are important in the cocoa sector as the role of voluntary sustainability standards in transforming the food system towards more sustainability is ever more questioned (Meemken et al., 2021) and as influential

downstream value chain actors are increasingly involved and invest in value chain sustainability. Particularly, knowing how factors within single value chains might increase the adoption of sustainable cocoa production practices can help direct investments and improve the cost-effectiveness of investments in sustainable value chains.

The objective of this study was to better understand the relationship between value chain factors and SFP implementation. In this study, we define value chain factors as those that describe information flow towards farmers as well as the organisation between and dependency of farmers and other value chain actors. We posed two main research questions: 1) Relative to farmer- and farm-level factors, how important are value chain factors for cocoa farmers' implementation of sustainable farming practices?; and 2) Through which mechanisms do value chain factors influence SFP implementation? Using our existing data set from two samples of cocoa farmers in Ecuador and Uganda, respectively, we analyse the determinants of implementation of 13 practices across three sustainability dimensions, testing quantitatively whether value chain factors within single value chains are significantly associated with practice implementation. We do this while controlling for farmer and farm factors known to influence practice implementation. By testing the role of value chain factors in two very different cases, we aim to gain an indication of their broader significance. This manuscript first provides an overview of relevant literature and the theoretical framework developed for this study, followed by a description of the case studies and selected analytical approaches. We then present the results and discuss them in light of our research questions and existing literature before providing some concluding remarks.

3.2Conceptual framework

Our conceptual framework combines selected SFP, i.e. outcome variables, with covariates that might explain their implementation on farms. It is informed by underlying theory and literature on the adoption of SFP among farmers. The conceptual framework for this study is based on the technology adoption and the sustainable value chain literature that links downstream actors with upstream

sustainability outcomes. We chose the term practice "implementation" over "adoption", as many SFPs in cocoa production are traditional production practices and partly a legacy of past management instead of new practices that farmers start using on their farms.

3.2.1 Conceptual framework

Based on our existing identical data set from two producer groups, we identified practices from the environmental, social, and economic sustainability dimensions considered important for sustainable cocoa production (Table 4). We are aware that we do not cover all aspects of sustainability, like gender equality, phytosanitary measures, or living incomes. This was largely due to data limitations and maintaining comparability across farms. For example, indicators such as gender equality could only be compared on a sub-sample of farms where both male and female employees were present, and thus was excluded from the analysis. Similarly, we did not identify the practice of "appropriate work for children" as an issue in the Ecuadorian case study, as children on sampled farms were hardly engaged in hazardous work. We recognise potential trade-offs between selected SFP, such as potential negative effects of pesticide-free production on cocoa yields.

Table 4: Overview of selected practices for sustainable cocoa production.

	Analysed practice	Rationale for inclusion	Operationalisation
Environment	Pesticide-free production (1/0)	A wide variety of pesticides are used by farmers for pest and disease management in cocoa. Highly disputed Glyphosate and Paraquat are common herbicides, and Neonicotinoids and Pyrethroid common insecticides. Abstaining from using pesticides reduces the health risk for farmers and consumers, and reduces the environmental impact of cocoa production. (Fountain & Huetz-Adams, 2020)	Takes 1 if farmers produced their cocoa without using any synthetic pesticides.
	Agroforestry (1/0)	Agroforestry systems can reduce the environmental impact of cocoa production through carbon sequestration, biodiversity conservation, soil fertility and moisture conservation, among others. Additionally, agroforestry systems have the potential to reduce deforestation associated with cocoa production. (Fountain & Huetz-Adams, 2020)	Cocoa plots were observed during farm visits. Takes 1 if at least part of the cocoa was produced in an agroforestry system, defined here as the integration of cocoa with other shade trees in a minimum of three strata and with 5 non-cocoa tree species per hectare.
	Shade tree per hectare >12 (1/0)	Shade tree density can have beneficial environmental and agronomic properties. (Blaser et al., 2018; UTZ, 2017)	Farmers were asked about the number of permanent shade trees on their cocoa plots, which was then divided by the size of cocoa plots. Takes 1 if the threshold of 12 shade trees per hectare was met, adopted from UTZ certification requirements.
	Shade tree planting (1/0)	Planting shade trees on cocoa plantations can help reclaim forest environmental functions. (Fountain & Huetz-Adams, 2020)	Farmers were asked if they had planted or nursed self-growing shade trees in their cocoa plots in the past year. Takes 1 if this was the case.
	Organic fertiliser use (1/0)	Nutrient limitation in cocoa fields is a major limiting factor to improve productivity (van Vliet & Giller, 2017).	Takes 1 if farmers applied organic fertilisers.

	Analysed practice	Rationale for inclusion	Operationalisation
Social	Use of personal protective equipment (1/0)	Cocoa farmers are exposed to numerous health and occupational risks, for example during farm activities like spraying of chemicals, cutting, weeding and harvesting. The use of personal protective equipment like gloves, safety glasses, and boots can avoid physical harm during these activities. (Boadi-Kusi et al., 2016; Muilerman, 2013)	Farmers were asked about what they wear during potentially harmful tasks. Takes 1 if the equipment worn was sufficient to provide protection.
	Appropriate work by children (1/0)	More than one million children work on cocoa plantations globally, mainly in West Africa (Fountain & Huetz-Adams, 2020). While the mere involvement of children in farm work is not per se regarded as negative, it becomes an issue when their physical and/or mental development is harmed (ILO, n.d.). Hazardous tasks performed by children in cocoa production include carrying heavy loads or working with pesticides and sharp tools. Our indicator does not consider the length of working hours and time of day when the work is carried out. Additionally, country-specific minimum employee ages were not applied. Instead, we used 16 years as a generic cut-off for this indicator. Thus, it does not fully assess hazardous child labour as qualified by ILO.	Farmers were asked about the tasks performed by their children or hired workers <16 years of age. Takes 1 if these tasks did not pose any risk for children.
	Workers' daily wage (USD/day)	Hiring seasonal workers is common in cocoa production. Workers in rural areas in cocoa producing countries often face precarious working conditions, without contracts, and low wages. (Fountain & Huetz-Adams, 2020; Meemken et al., 2019)	In case farms hire workers, farmers were asked about the lowest daily wage they paid. In Uganda, wages were mostly paid per task instead of per day. Here, the wage for a typical task was divided by the average number of days required for their completion.

	Analysed practice	Rationale for inclusion	Operationalisation
Economic	Farm revenues (USD/year)	Numerous reports suggest that a large share of cocoa farming household live below the poverty line (van Vliet et al., 2021; Waarts et al., 2019) and the call for living incomes for cocoa farmers become louder (Fountain & Huetz-Adams, 2020, 2022). While not able to measure incomes, farm revenues represent an indication of the economic benefits that farmers generate on farm.	Farmers were asked about the quantities of each product sold and the respective average price per unit sold.
	Cocoa yields (tons/ha)	Low yields are often reported from cocoa production systems, with economic implications for farming households. Increasing cocoa yields is regarded as one step towards achieving living incomes for cocoa farming households (van Vliet et al., 2021).	Farmers were asked about the sizes of all cocoa plots as well as the cocoa harvest from each plot in the reference year. Farm yields represent the plot size-weighted average yield per farm. Fresh cocoa bean weight was converted to dry bean weight using the conversion factor 0.38.
	Secure farm succession (1/0)	Youth migration to the cities creates labour shortage, leaving behind an ageing population of cocoa farmers that is unable to afford hiring labour and keep up proper crop management (Abdulai et al., 2020; Mithöfer et al., 2017a). A defined successor of cocoa farms can ensure continuous investment in productive farms.	Farmers above the age of 55 years were asked about a successor. Takes 1 if a clear candidate has been identified.

3.1.1 Theoretical considerations

Our conceptual framework is informed by the expected utility theory (Schoemaker, 1982) and the theory of planned behaviour (Ajzen, 1991). The expected utility theory adopts an economic rationale in which decision-making is based on greatest expected utility. It is considered relevant in the context of economically-constrained farmers who need to manage risk to secure their livelihoods (Meijer et al., 2015). Farmers' participation in sustainability initiatives and the compliance with respective codes of conduct might be a way to access better prices and thus maximise utility. Yet decision-making is not always purely rational and often influenced through social-psychological pathways, which is what the theory of planned behaviour aims to understand. According to this theory, attitude, subjective norms, and perceived behavioural control shape an individual's behavioural intentions, which again is considered the closest determinant of behaviour. Participation in sustainability initiatives and the training sessions offered to farmers within these initiatives, and gaining first-hand experiences with SFP might influence farmers' attitude towards them and ultimately shape farmers' intention to implement them. With these theories as a basis, our conceptual framework builds on the agricultural technology adoption literature and the sustainable supply chain literature that links downstream actors with upstream sustainability outcomes.

Agricultural technology adoption literature: A growing body of micro-economic literature has looked into factors that influence farmers' adoption of sustainable farming practices, mainly regarding agro-environmental practices. The large number of recent review studies is evidence of this trend, each proposing different frameworks based on reviewed studies (Arslan et al., 2020; de Oca Munguia & Llewellyn, 2020; Foguesatto et al., 2020; Liu et al., 2018; Meijer et al., 2015; Mozzato et al., 2018; Piñeiro et al., 2020). Most frameworks distinguish between factors within and factors beyond the farm.

Factors within the farm most commonly include farmers' socio-demographic factors like age and education level. Past studies have shown a mixed influence of farmer factors on practice adoption. In line with the theory of planned behaviour, farmers with higher education levels or higher awareness about environmental threats, for

example, might be more informed about sustainability issues and thus more likely to implement SFP across all sustainability dimensions (Amfo & Ali, 2020; Boadi-Kusi et al., 2016; Nkamleu & Kielland, 2006). Contrarily, female farm managers might be less likely to implement or adopt a new technology as they might face structural inequalities, such as lower access to education or production factors (Djokoto et al., 2016).

Additionally, farm factors are included in most SFP adoption frameworks, including farm structure and management. Past studies found that farms' economic situation positively influences the adoption of environmental, social, and economic practices as a result of greater access to resources and necessary inputs. For example, more resource endowed farmers have shown to be more likely to hire labour and thus involve less children in hazardous tasks (Berlan, 2013; Busquet et al., 2021). Furthermore, a lack of labour can reduce the implementation of labour-intensive environmental practices (Andres et al., 2016) Finally, the cocoa variety has been shown to strongly influence environmental practices, as hybrid varieties, such as the Ecuadorian CCN-51, require higher inputs and tolerate less shade (Rueda et al., 2018).

Factors beyond the farm-level include the biophysical, spatial, socio-economic, and policy environment in which farms operate. Proximity to urban centres and markets might increase farmers' access to information and inputs and thus increase SFP implementation (Foguesatto et al., 2020). Furthermore, social norms and networks can influence SFP adoption (Liu et al., 2018). Finally, the practice characteristics themselves are important influencing factors. For example, cost-intensive practices might obstruct their adoption (de Oca Munguia & Llewellyn, 2020) especially on low-income smallholder farms. Labour-constrained households might be more willing to adopt labour-saving technologies (Arslan et al., 2020).

Sustainable supply chain literature: Commercial partners within value chains can influence practice adoption among farmers (Hansson et al., 2019), for example through incentives or regulatory measures (Piñeiro et al., 2020). Examples include performance-based price premiums and sustainability certification. Cocoa value chains are characterised by a highly diffuse producer base of many small-scale producers and a concentrated downstream actor level, with increasing power (Thorlakson, 2018).

Past research in the value chain literature has focused on compliance of upstream partners with sustainability requirements of downstream companies. Grimm et al. (2014) identified critical factors for achieving supplier compliance, grouping them into factors within and beyond downstream companies. The former includes top management support, which positively influences companies' commitment and available resources for value chain sustainability mechanisms. The latter includes information sharing and commitment between value chain partners. A large body of literature has shown the importance of information sharing through training and extension for practice adoption in cocoa production systems (e.g. Andres et al., 2016; Denkyirah et al., 2016; Okoffo et al., 2016), often provided by downstream value chain actors.

A recent study linked persistent relationships in value chains with sustainability outcomes under the concept of "stickiness" and showed that more persistent soy value chains in Brazil are more effective in creating change in sustainability performance among upstream producers (Reis et al., 2020). Furthermore, upstream actors' economic dependence might increase compliance with downstream companies' sustainability codes of conduct (Grimm et al., 2014). As such, farmers with a higher economic dependency on cocoa for their livelihoods, a greater dependency on one buyer with certain sustainability codes of conduct, and generally fewer cocoa buyers might implement more SFP.

3.1.1 Selected variables

As the literature review displays, a great range of factors have been shown to influence practice implementation or adoption. The selection of groups of factors and specific factors to include in our analysis was restricted by our existing data set. To assess the importance of value chain factors for the adoption and implementation of sustainable cocoa production practices, we controlled for other factors known to influence their implementation. We organised factors influencing SFP into two groups of internal and external factors (Figure 14).

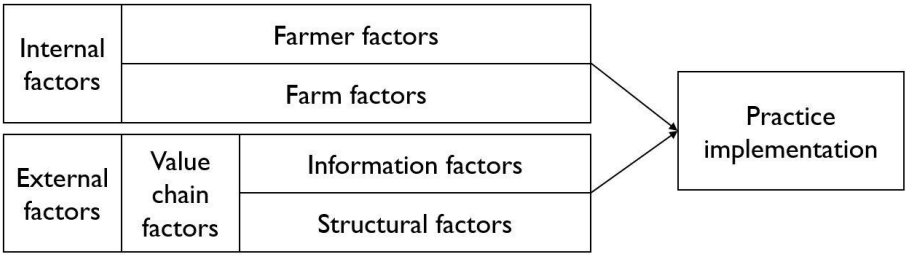

Figure 14: Conceptual framework of factors influencing sustainable practice implementation on cocoa farms. (Source: own graph)

Internal farmer factors: The set of farmer factors controlled for included farmers' age, gender, and formal education years. We additionally incorporated farmers' expressed commitment to sustainability (dummy) and knowledge about climate change (dummy). Given the literature shown above, we hypothesise that farmer factors, specifically farmers' knowledge and conviction, are highly important for the decision to implement SFP in our case studies (Hypothesis 1).

Internal farm factors: Incorporated farm factors comprised multiple indicators for farms' economic endowment, including farm and cocoa plot size (hectares), land ownership (dummy), and livestock units owned (number). Labour availability on farm was covered by the number of family workers. In the Ecuadorian case study, we added the hybrid cocoa variety CCN-51 as a predictor (dummy). Given the mixed picture presented in past studies, we assume that farm factors are less important for SFP implementation (Hypothesis 2).

Value chain factors: We considered both information sharing and organisation as important value chain variables. Within information factors, we included the number of training days farmers participated in (days/year) and farmers' perceived access to extension services (dummy). Additionally, we considered factors that describe the value chain organisation and persistence, adapting the stickiness definition by Reis et al. (2020) to our cross-sectional data. We included farmers' economic dependency on cocoa (share of gross farm revenue from cocoa) and their main customer (share of gross farm revenue from main buyer). Furthermore, we included the number of cocoa buyers per farmer and the years of relationship with the main cocoa buyer. Based on first evidence reviewed above, we hypothesise that downstream value chain actors have several mechanisms available with which they can generate a change in SFP

implementation at farm level, thus value chain factors are important for SFP implementation (Hypothesis 3). These were subdivided into: a) Information factors, covering farmers' access to capacity building through the value chain, which we presume to be a suitable mechanism for downstream value chain actors to increase SFP implementation among their suppliers (Hypothesis 4); and b) Structural factors, including value chain organisation and persistence as well as farmers' dependency on this value chain. Our final hypothesis follows the assumption that long-term and stable relationships along value chains create trust and thus increase SFP implementation (Hypothesis 5).

3.2 Materials and methods

3.2.1 Data analysis

We ran multivariate mixed regression models for each case study, using individual practices as dependent variables and the set of predictors including value chain factors as explanatory variables. Dependent variables were binary and continuous (Table 4) and thus required different types of regression models. In each model, we checked for multicollinearity using variance inflation factors and deleted predictors with values >3. We z-normalised all predictors to facilitate comparison between predictors with differing scales (Bruce et al., 2020).

We approached the estimation of value chain factors' importance for SFP implementation being aware that certain predictors might be endogenous to dependent variables and reverse causality might exist, potentially leading to biased estimates. Thus, we restrained from interpreting any result as impacts and any mention of an effect refers to a change in probability not to a causal effect. Additionally, we do not use data to predict adoption but rather explain current implementation.

We controlled for a potential "village bias", i.e. a potential correlation among close-by farms due to information exchange among neighbours, locally-specific training offers, or local conditions such as topography or road infrastructure. Due to the uneven distribution of farms per village, especially in the Ugandan case, not all mixed models converged when adding the village as a random effect. Therefore, we developed a

standard procedure, which was applied to all models (Figure 15). First, we fit each model with only village as a random effect and without other covariates. If the simple model converged, we added all covariates as fixed effects and kept village as a random effect. If the full model converged, we kept it and interpreted the results. If the full model did not converge after the second step, we introduced the village as a fixed effect instead of as a random effect and checked if the village had a significant effect. If the village showed a significant effect, we kept it and interpreted the results. If the village did not show a significant effect, we removed it as a fixed effect and interpreted the estimates of the model without village. If the simple model did not converge after the first step, we introduced the village as a fixed effect instead of as a random effect and checked if the village had a significant effect. If the village was significant, we kept it and interpreted the results. If the village was not significant, we removed it as a fixed effect and interpreted the estimates of the model without village.

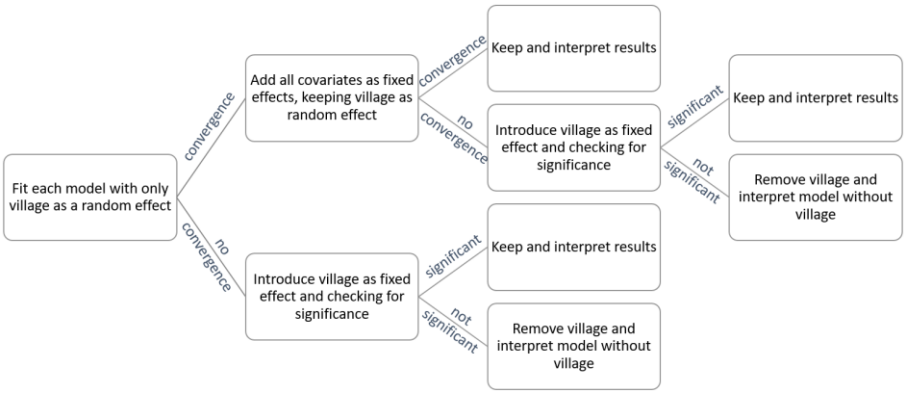

Figure 15: Standard procedure for "village" as fixed effect that was applied to each model. (Source: own graph)

All statistical analyses were performed in R (vers. 4.1.0, R Project for Statistical Computing, RRID:SCR_001905), via RStudio (vers. 2022.02.01+461, RStudio, Q19 RRID:SCR_000432). The analysis was implemented in RStudio's RMarkdown script format, which integrates analysis, reporting, and export functions for highly reproducible research reports (Baumer & Udwin, 2015). Data and code are available here: https://shorturl.at/blwSZ.

Binary dependent variables: Most of the SFP in our database had binary response options, i.e. were applied (= 1) or not applied on a farm (=0). This dichotomous

division is typical in studies that aim at modelling the adoption of agricultural practices (Foguesatto et al., 2020) and allows for a clear differentiation between farms that implemented and farms that did not implement a certain practice. We modelled the effects of predictors on binary SFP using generalized linear mixed models (GLMM) in case the model converged with the village variable introduced as a random effect, and generalized linear model (GLM) otherwise, after confirming the insignificance of the fixed variable "village" (see supporting information). We used glmmTMB() function of the R package glmmTMB for GLMM including village as random effect, glm() function of the R package stats for GLM, and Anova() from the R package car to test for significance of "village" as fixed effect.

Continuous dependent variables: We employed linear mixed regression models (LMM) for continuous dependent variables and log-transformed dependent variables due to skewed data. In those cases where the mixed models did not converged with the village variable as a random effect, we applied Ordinary Least Square (OLS) regression. We used the lmer() function of the R package lme4 for LMM including "village" as random effect and the lm() function of the R package stats for OLS models.

3.3Results

3.3.1 Descriptive results

Table 5 shows the descriptive results of the dependent variables analysed in the environmental, social, and economic dimensions of sustainability as well as the independent farmer, farm, and value chain variables. Most dependent and independent variables show a distribution suitable for further analyses with regression models, with some exceptions: organic fertiliser use in Ecuador and engagement of children in hazardous work was low and further regression analyses were not carried out. Similarly, the use of protective equipment was low and growing cocoa in agroforestry systems was high in Uganda. All farms in the Ecuadorian sample owned some sort of livestock and we excluded this predictor from the regression models for this case study.

Table 5: Mean values (standard deviation) and number (percentages) of farmers for dependent variables and predicting factors. NA = not applicable.

		Ecuador (*n* = 190)	Uganda (*n* = 204)
Environ-mental	Pesticide-free production = Yes	65 (34.2%)	124 (60.8%)
	Agroforestry system = Yes	109 (57.4%)	200 (98.0%)
	Shade trees >12/ha = Yes	132 (70.2%)	166 (81.4%)
	Shade tree planting = Yes	36 (18.9%)	100 (49.0%)
	Organic fertiliser use = Yes	27 (14.2%)	134 (65.7%)
Social	Use protective equipment = Yes	51 (32.1%)	10 (7.9%)
	Worker daily wage (USD/day)	14.08 (3.08)	1.80 (1.07)
	Appropriate work by children = Yes	184 (96.8%)	161 (78.9%)
Economic	Gross farm revenues (USD/year)	5754 (6517)	1641 (2276)
	Cocoa yields (ton/ha)	0.30 (0.34)	0.36 (0.45)
	Secure farm succession = Yes	108 (56.8%)	110 (53.9%)
Farmer factors	Age (years)	51.56 (13.70)	52.81 (12.84)
	Female = Yes	45 (23.7%)	65 (31.9%)
	Formal education (years)	7.74 (4.03)	5.58 (4.59)
	Verbal commitment to sustainability = Yes	69 (36.3%)	157 (77.0%)
	Climate change knowledge = Yes	92 (48.4%)	117 (57.4%)
Farm factors	Farm size (hectares)	12.56 (16.31)	2.82 (2.97)
	Cocoa area (hectares)	5.00 (3.79)	1.30 (1.30)
	Secure land tenure = Yes	172 (90.5%)	178 (87.3%)
	Livestock units (number)	6.96 (14.99)	1.13 (1.73)
	Family workers (number)	2.16 (1.13)	3.81 (2.39)
	Hybrid cocoa variety = Yes	106 (55.8%)	NA
Value chain factors	Access to extension service = Yes	96 (50.5%)	143 (70.1%)
	Training days (days/year)	2.32 (2.90)	2.76 (4.27)
	Dependency cocoa revenue (% farm revenue)	0.58 (0.34)	0.42 (0.31)
	Dependency main customer (% farm revenue)	0.67 (0.27)	0.59 (0.23)
	Cocoa buyers (number)	1.17 (0.47)	1.34 (0.84)
	Relationship with cocoa buyers (years)	8.08 (7.31)	1.1 (4.03)

3.3.2 Relative importance of value chain factors

The results of the different regression models testing the influence of value chain variables on SFP implementation in the environmental, social, and economic dimensions for the Ecuadorian case are presented in Table 6, Table 7, and Table 8, respectively. Results for the Ugandan case study are shown in Table 9, Table 10, and Table 11. Furthermore, the strongest coefficient (*ß*) of significant predictors per factor group and SFP are shown in Figure 16.

Practices within the environmental dimension

Within the Ecuadorian case study, factors from all three groups of predictors showed significant relationships with environmental SFP (Table 6). We found strong predictors among the group of farm factors (Figure 16). Farm size showed a significant and positive relationship with growing cocoa in agroforests (GLMM, *ß* =2.53, $n = 175$, $p < 0.05$), yet larger cocoa plots were significantly and negatively associated with shade tree density (GLMM, *ß* =-1.48, $n = 173$, $p < 0.01$). Growing the hybrid cocoa variety CCN-51 was significantly and negatively related to growing cocoa in agroforestry systems (GLMM, *ß* = -1.12, $n = 175$, $p < 0.01$) and pesticide-free production (GLMM, *ß* = -1.07, $n = 175$, $p < 0.001$). Holding all other variables constant, the odds for farms growing hybrid cocoa to practice pesticide-free cocoa production were 66% lower than for farmers not growing hybrid cocoa. The farmer factor farmers' commitment to sustainability also showed a significant and positive association with pesticide-free production (GLMM, *ß* = 0.81, $n = 175$, $p < 0.01$) and shade tree density (GLMM, *ß* = 0.89, $n = 175$, $p < 0.01$). The strongest value chain factor with a coefficient of -0.99 was farmers' dependency on cocoa revenues, which showed a significant negative relationship with agroforestry systems (GLMM, $n = 173$, $p < 0.05$).

Also in the Ugandan case study, all three groups of predictors showed significant relationships with environmental SFP (Table 9). The number of training days represented the strongest value chain factor, which was significantly and positively associated with pesticide-free production (GLM, *ß* = 0.94, $n = 182$, $p < 0.01$). This indicates that with an increase of 4.3 training days and holding all other variables

constant, the odds of producing pesticide-free cocoa increased by 156%. The farmer factor commitment to sustainability showed a significant and positive relationship with pesticide-free production (GLM, $ß = 0.77$, $n = 182$, $p < 0.001$) and shade tree planting (GLM, $ß = 0.57$, $n = 182$, $p < 0.01$), yet a negative relationship with shade tree density (GLM, $ß = -0.84$, $n = 182$, $p < 0.05$).

Table 6: Multivariate mixed regression models for sustainable farming practice implementation in cocoa production systems in Ecuador – results for practices in the environmental dimension.

Ecuador **Environmental practices** **z-normalised predictors**		**Pesticide-free production (1/0)** *GLMM*[a]		**Agroforestry system (1/0)** *GLMM*[a]		**Shade trees >12/ha (1/0)** *GLMM*[a]		**Shade tree planting (1/0)** *GLMM*[a]	
		ß (SE)	*p*-value	ß (SE)	*p*-value	ß (SE)	*p*-value	ß (SE)	*p*-value
Farmer factors	Farmer age (years)	-0.42 (0.27)	0.113	0.42 (0.27)	0.118	0.38 (0.25)	0.13	-0.32 (0.26)	0.223
	Female = Yes	-0.28 (0.25)	0.248	0.11 (0.26)	0.675	-0.25 (0.23)	0.274	-0.3 (0.25)	0.238
	Formal education (years)	**-0.53 (0.32)**	**0.096**	0.43 (0.28)	0.127	**0.43 (0.25)**	**0.09**	-0.22 (0.28)	0.437
	Verbal commitment to sustainability = Yes	**0.81 (0.26)**	**0.002**	0.04 (0.28)	0.877	**0.89 (0.29)**	**0.002**	0.27 (0.23)	0.241
	Climate change knowledge = Yes	0.02 (0.25)	0.947	**-0.56 (0.27)**	**0.04**	-0.34 (0.24)	0.15	**0.59 (0.25)**	**0.018**
Farm factors	Farm size (hectares)	0.06 (0.45)	0.893	**2.53 (1.13)**	**0.025**	2.75 (1.7)	0.105	-0.01 (0.43)	0.985
	Cocoa area (hectares)	-0.34 (0.33)	0.305	-0.06 (0.38)	0.882	**-1.48 (0.55)**	**0.007**	0.28 (0.29)	0.343
	Land ownership = Yes	-0.24 (0.25)	0.345	0.22 (0.28)	0.415	0.05 (0.25)	0.834	0.14 (0.24)	0.543
	Livestock units (#)	-0.2 (0.41)	0.621	**-2.74 (1.11)**	**0.014**	0.87 (1.35)	0.518	0.54 (0.41)	0.19
	Family workers (#)	0.13 (0.24)	0.604	-0.17 (0.27)	0.533	-0.1 (0.24)	0.682	**0.39 (0.23)**	**0.088**
	Hybrid cocoa variety = Yes	**-1.07 (0.3)**	**0.000**	**-1.12 (0.37)**	**0.002**	-0.4 (0.31)	0.196	-0.34 (0.28)	0.222
Value chain factors	Access to extension = Yes	**-0.47 (0.27)**	**0.086**	-0.07 (0.31)	0.834	**-0.62 (0.3)**	**0.038**	**0.57 (0.29)**	**0.044**
	Training days (#/year)	0.13 (0.28)	0.634	0.71 (0.48)	0.143	0.58 (0.41)	0.161	-0.38 (0.28)	0.181
	Dependency cocoa revenue (% farm rev.)	-0.48 (0.38)	0.212	**-0.99 (0.42)**	**0.018**	**-0.98 (0.41)**	**0.017**	0.27 (0.35)	0.429
	Dependency main customer (% farm rev.)	-0.09 (0.34)	0.804	0.39 (0.41)	0.345	0.33 (0.4)	0.404	-0.3 (0.32)	0.35
	Cocoa buyers (#)	-0.41 (0.31)	0.188	**0.58 (0.27)**	**0.032**	0.1 (0.25)	0.696	0.03 (0.23)	0.881
	Relationship cocoa buyers (years)	**-0.57 (0.27)**	**0.036**	0.04 (0.31)	0.9	**0.51 (0.31)**	**0.095**	-0.09 (0.25)	0.722
Constant		**-1.26 (0.41)**	**0.002**	0.64 (0.64)	0.315	**2.58 (0.67)**	**0.000**	**-1.75 (0.29)**	**0.000**
Observations		175		175		173		175	
Marginal N&S R^2 - GLMM		0.492		0.477		0.789		0.273	
Conditional N&M R^2 - GLMM		0.578		0.708		0.827		0.300	

Notes: Marginal Nakagawa & Schielzeth's R^2 GLMM = proportion of variance by fixed factors alone, Conditional Nakagawa & Schielzeth's R^2 GLMM = proportion of variance by fixed and random factors.

ß = estmated coefficient, SE = standard error.

[a] Generalized linear mixed models (with village as random effect).

Table 7: Multivariate mixed regression models for sustainable farming practice implementation in cocoa production systems in Ecuador – results for practices in the social dimension.

Ecuador		**Use of protective equipment (1/0)**		**Worker daily wage (ln(USD/day))**	
Social practices		*GLMM*[a]		*LMM*[b]	
z-normalised predictors		*ß* (SE)	*p*-value	*ß* (SE)	*p*-value
Farmer factors	Farmer age (years)	0.25 (0.26)	0.349	0.01 (0.02)	0.493
	Female = Yes	0.00 (0.24)	0.994	-0.01 (0.02)	0.749
	Formal education (years)	0.21 (0.26)	0.416	0.02 (0.02)	0.393
	Verbal commitment to sustainability = Yes	0.36 (0.24)	0.14	**0.05 (0.02)**	**0.009**
	Climate change knowledge = Yes	0.09 (0.24)	0.701	**-0.04 (0.02)**	**0.045**
Farm factors	Farm size (hectares)	0.72 (0.57)	0.204	-0.06 (0.04)	0.123
	Cocoa area (hectares)	-0.27 (0.3)	0.364	-0.01 (0.02)	0.539
	Land ownership = Yes	-0.12 (0.28)	0.676	-0.01 (0.02)	0.595
	Livestock units (#)	-0.55 (0.56)	0.325	0.03 (0.03)	0.356
	Family workers (#)	-0.25 (0.26)	0.336	**-0.05 (0.02)**	**0.017**
	Hybrid cocoa variety = Yes	0.4 (0.32)	0.218	**0.06 (0.02)**	**0.006**
Value chain factors	Access to extension = Yes	0.3 (0.3)	0.309	-0.01 (0.02)	0.608
	Training days (#/year)	**0.63 (0.32)**	**0.046**	0.02 (0.02)	0.39
	Dependency cocoa revenue (% farm rev.)	**-0.68 (0.36)**	**0.06**	-0.04 (0.03)	0.118
	Dependency main customer (% farm rev.)	0.19 (0.34)	0.583	**0.04 (0.02)**	**0.078**
	Cocoa buyers (#)	-0.11 (0.28)	0.701	0.02 (0.02)	0.422
	Relationship cocoa buyers (years)	0.2 (0.24)	0.405	0 (0.02)	0.867
Constant		**-1.15 (0.38)**	**0.002**	**2.61 (0.03)**	**0.000**
Observations		146		127	
Marginal N&S R^2 - GLMM		0.258		0.194	
Conditional N&M R^2 - GLMM		0.383		0.283	

Notes: Marginal Nakagawa & Schielzeth's R^2 GLMM = proportion of variance by fixed factors alone, Conditional Nakagawa & Schielzeth's R^2 GLMM = proportion of variance by fixed and random factors.

ß = estmated coefficient, SE = standard error.

[a] Generalized linear mixed model (with village as random effect),

[b] Linear mixed model (with village as random effect).

Table 8: Multivariate mixed regression models for sustainable farming practice implementation in cocoa production systems in Ecuador – results for practices in the economic dimension.

Ecuador		**Gross farm revenue (ln(USD/year))**		**Cocoa yields (ln(ton/ha))**		**Secure farm succession (1/0)**	
Economic practices		*LMM*[b]		*LMM*[b]		*GLMM*[a]	
z-normalised predictors		ß (SE)	*p*-value	ß (SE)	*p*-value	ß (SE)	*p*-value
Farmer factors	Farmer age (years)	-0.06 (0.07)	0.357	-0.06 (0.08)	0.451	0.05 (0.29)	0.855
	Female = Yes	**-0.17 (0.07)**	**0.011**	**-0.16 (0.07)**	**0.028**	-0.19 (0.25)	0.444
	Formal education (years)	0.08 (0.07)	0.305	0.02 (0.08)	0.797	-0.27 (0.28)	0.342
	Verbal commitment to sustainability = Yes	0.1 (0.07)	0.175	0.09 (0.08)	0.254	0.41 (0.3)	0.165
	Climate change knowledge = Yes	0.02 (0.07)	0.764	0.07 (0.07)	0.32	0.19 (0.27)	0.478
Farm factors	Farm size (hectares)	0.15 (0.15)	0.32	0.02 (0.17)	0.903	1.25 (1.52)	0.411
	Cocoa area (hectares)	**0.35 (0.09)**	**0.000**	**-0.27 (0.1)**	**0.005**	-0.27 (0.47)	0.558
	Land ownership = Yes	-0.06 (0.07)	0.371	-0.06 (0.07)	0.404	0.15 (0.28)	0.594
	Livestock units (#)	**0.29 (0.14)**	**0.044**	0.19 (0.16)	0.229	-0.54 (0.94)	0.569
	Family workers (#)	-0.07 (0.07)	0.277	-0.09 (0.07)	0.238	**0.62 (0.32)**	**0.057**
	Hybrid cocoa variety = Yes	0.02 (0.09)	0.843	-0.03 (0.1)	0.754	0.08 (0.31)	0.799
Value chain factors	Access to extension = Yes	-0.05 (0.08)	0.504	-0.07 (0.09)	0.414	-0.15 (0.29)	0.599
	Training days (#/year)	0.09 (0.08)	0.303	0.14 (0.09)	0.133	0.05 (0.35)	0.889
	Dependency cocoa revenue (% farm rev.)	**-0.29 (0.1)**	**0.004**	**0.47 (0.11)**	**0.000**	-0.16 (0.37)	0.67
	Dependency main customer (% farm rev.)	-0.03 (0.09)	0.711	-0.04 (0.1)	0.681	**0.59 (0.35)**	**0.095**
	Cocoa buyers (#)	0.01 (0.07)	0.846	0.04 (0.07)	0.63	0.13 (0.26)	0.607
	Relationship cocoa buyers (years)	0.02 (0.07)	0.756	-0.1 (0.08)	0.218	0.27 (0.33)	0.422
Constant		**8.1 (0.21)**	**0.000**	**-1.77 (0.21)**	**0.000**	**1.71 (0.4)**	**0.000**
Observations		175		173		123	
Marginal N&S R^2 - GLMM		0.387		0.224		0.369	
Conditional N&M R^2 - GLMM		0.589		0.447		0.396	

Notes: Marginal Nakagawa & Schielzeth's R^2 GLMM = proportion of variance by fixed factors alone, Conditional Nakagawa & Schielzeth's R^2 GLMM = proportion of variance by fixed and random factors.

ß = estmated coefficient, SE = standard error.

[a] Generalized linear mixed model (with village as random effect),

[b] Linear mixed model (with village as random effect).

Table 9: Multivariate mixed regression models for sustainable farming practice implementation in cocoa production systems in Uganda – results for practices in the environmental dimension.

Uganda **Environmental practices** **z-normalised predictors**		**Pesticide-free production (1/0)** *GLM*[b]		**Organic fertiliser (1/0)** *GLMM*[a]		**Shade trees >12/ha (1/0)** *GLM*[b]		**Shade tree planting (1/0)** *GLM*[b]	
		ß (SE)	*p*-value	ß (SE)	*p*-value	ß (SE)	*p*-value	ß (SE)	*p*-value
Farmer factors	Farmer age (years)	0.15 (0.19)	0.428	-0.25 (0.19)	0.182	0.24 (0.27)	0.375	**-0.38 (0.19)**	**0.048**
	Female = Yes	0.21 (0.2)	0.294	**0.61 (0.21)**	**0.004**	-0.26 (0.27)	0.331	**-0.32 (0.19)**	**0.098**
	Formal education (years)	-0.1 (0.2)	0.601	**0.62 (0.21)**	**0.003**	0.02 (0.26)	0.95	0.21 (0.19)	0.273
	Verbal commitment to sustainability = Yes	**0.77 (0.19)**	**0.000**	0.24 (0.19)	0.198	**-0.84 (0.35)**	**0.016**	**0.57 (0.2)**	**0.004**
	Climate change knowledge = Yes	-0.06 (0.19)	0.739	-0.11 (0.2)	0.562	**0.68 (0.27)**	**0.014**	-0.11 (0.19)	0.554
Farm factors	Farm size (hectares)	**-0.43 (0.2)**	**0.033**	0.26 (0.42)	0.537	**-0.9 (0.37)**	**0.015**	-0.15 (0.31)	0.64
	Cocoa area (hectares)			-0.13 (0.35)	0.702			0.23 (0.31)	0.461
	Land ownership = Yes	0.02 (0.17)	0.907	0.07 (0.18)	0.678	0.09 (0.25)	0.727	0.19 (0.17)	0.271
	Livestock units (#)	-0.19 (0.18)	0.288	0.22 (0.22)	0.314	**1.09 (0.46)**	**0.018**	0.08 (0.18)	0.635
	Family workers (#)	0.02 (0.19)	0.93	0.09 (0.18)	0.605	-0.27 (0.24)	0.256	**0.37 (0.18)**	**0.04**
Value chain factors	Access to extension = Yes	0.19 (0.19)	0.317	0.24 (0.19)	0.213	0.24 (0.24)	0.326	**0.32 (0.18)**	**0.083**
	Training days (#/year)	**0.94 (0.36)**	**0.009**	0.3 (0.22)	0.175	-0.02 (0.22)	0.925	-0.09 (0.17)	0.593
	Dependency cocoa revenue (% farm rev.)	**-0.51 (0.22)**	**0.02**	0.05 (0.22)	0.812	-0.16 (0.29)	0.579	-0.09 (0.21)	0.654
	Dependency main customer (% farm rev.)	0.27 (0.21)	0.188	-0.19 (0.2)	0.337	0.44 (0.27)	0.108	**-0.34 (0.19)**	**0.069**
	Cocoa buyers (#)	0.16 (0.2)	0.433	0.03 (0.2)	0.893	-0.11 (0.25)	0.644	-0.15 (0.19)	0.433
	Relationship cocoa buyers (years)	-0.09 (0.17)	0.597	-0.07 (0.18)	0.686	0.46 (0.4)	0.249	-0.08 (0.19)	0.657
Constant		**0.59 (0.19)**	**0.002**	**0.74 (0.25)**	**0.003**	**2.38 (0.35)**	**0.000**	-0.24 (0.17)	0.156
Observations		181		181		181		181	
Nagelkerke pseudo R^2		0.298				0.335		0.278	
Marginal N&S R^2 - GLMM				0.217					
Conditional N&M R^2 - GLMM				0.270					

Notes: Marginal Nakagawa & Schielzeth's R^2 GLMM = proportion of variance by fixed factors alone, Conditional Nakagawa & Schielzeth's R^2 GLMM = proportion of variance by fixed and random factors.

ß = estmated coefficient, SE = standard error.

[a] Generalized linear mixed model (with village as random effect),

[b] Generalized linear model.

Table 10: Multivariate mixed regression models for sustainable farming practice implementation in cocoa production systems in Uganda – results for practices in the social dimension.

Uganda		**Appropriate work by children (1/0)**		**Worker daily wage (ln(USD/day))**	
Social practices		*GLM*[a]		*LMM*[b]	
z-normalised predictors		*ß* (SE)	*p*-value	*ß* (SE)	*p*-value
Farmer factors	Farmer age (years)	0.05 (0.24)	0.852	0.08 (0.06)	0.158
	Female = Yes	-0.07 (0.24)	0.77	-0.04 (0.07)	0.563
	Formal education (years)	-0.08 (0.23)	0.744	0.07 (0.07)	0.317
	Verbal commitment to sustainability = Yes	-0.14 (0.24)	0.558	0.02 (0.06)	0.691
	Climate change knowledge = Yes	**-0.49 (0.25)**	**0.049**	-0.03 (0.06)	0.619
Farm factors	Farm size (hectares)	0.76 (0.58)	0.187	-0.01 (0.1)	0.906
	Cocoa area (hectares)	0.04 (0.45)	0.933	0.02 (0.09)	0.803
	Land ownership = Yes	0.25 (0.19)	0.171	-0.03 (0.06)	0.571
	Livestock units (#)	-0.19 (0.21)	0.376	0.01 (0.05)	0.784
	Family workers (#)	**-0.95 (0.23)**	**0.000**	-0.02 (0.06)	0.74
Value chain factors	Access to extension = Yes	-0.14 (0.23)	0.554	-0.03 (0.06)	0.651
	Training days (#/year)	0.4 (0.27)	0.135	**0.11 (0.06)**	**0.069**
	Dependency cocoa revenue (% farm rev.)	0.01 (0.25)	0.96	0.01 (0.07)	0.936
	Dependency main customer (% farm rev.)	**0.41 (0.22)**	**0.069**	0 (0.06)	0.982
	Cocoa buyers (#)	-0.19 (0.22)	0.376	0 (0.06)	0.989
	Relationship cocoa buyers (years)	0.13 (0.26)	0.611	-0.04 (0.05)	0.502
Constant		**1.71 (0.25)**	**0.000**	**0.44 (0.06)**	**0.000**
Observations		181		114	
Nagelkerke pseudo R^2		0.285			
Marginal N&S R^2 - GLMM				0.071	
Conditional N&M R^2 - GLMM				0.085	

Notes: Marginal Nakagawa & Schielzeth's R^2 GLMM = proportion of variance by fixed factors alone, Conditional Nakagawa & Schielzeth's R^2 GLMM = proportion of variance by fixed and random factors.

ß = estmated coefficient, SE = standard error.

[a] Generalized linear model,

[b] Linear mixed model (with village as random effect).

Table 11: Multivariate mixed regression models for sustainable farming practice implementation in cocoa production systems in Uganda – results for practices in the economic dimension.

Uganda **Economic practices** **z-normalised predictors**		**Gross farm revenue (ln(USD/year))** *LMM* [c] ß (SE)	*p*-value	**Cocoa yields (ln(ton/ha))** *OLS* [b] ß (SE)	*p*-value	**Secure farm succession (1/0)** *GLM* [c] ß (SE)	*p*-value
Farmer factors	Farmer age (years)	-0.11 (0.08)	0.152	-0.11 (0.08)	0.14	0.29 (0.51)	0.572
	Female = Yes	**-0.16 (0.08)**	**0.052**	-0.1 (0.08)	0.216	0.12 (0.52)	0.816
	Formal education (years)	0.04 (0.08)	0.669	0.03 (0.08)	0.735	-0.37 (0.46)	0.419
	Verbal commitment to sustainability = Yes	0.00 (0.08)	1	0.11 (0.08)	0.153	0.1 (0.41)	0.804
	Climate change knowledge = Yes	0.07 (0.08)	0.421	-0.11 (0.08)	0.152	0.36 (0.48)	0.453
Farm factors	Farm size (hectares)	**0.47 (0.14)**	**0.001**			0.84 (0.8)	0.288
	Cocoa area (hectares)	0.05 (0.13)	0.724	**-0.17 (0.07)**	**0.026**		
	Land ownership = Yes	0.04 (0.07)	0.557	-0.05 (0.07)	0.482	0.17 (0.42)	0.686
	Livestock units (#)	**0.15 (0.08)**	**0.062**	**0.17 (0.08)**	**0.032**		
	Family workers (#)	0.09 (0.08)	0.241	-0.08 (0.08)	0.309	**4.62 (1.94)**	**0.017**
Value chain factors	Access to extension = Yes	0.05 (0.08)	0.569	0.08 (0.08)	0.292	-0.67 (0.6)	0.266
	Training days (#/year)	0.07 (0.08)	0.399	-0.07 (0.07)	0.379	0.05 (0.66)	0.934
	Dependency cocoa revenue (% farm rev.)	0.1 (0.09)	0.289	**0.74 (0.09)**	**0.000**	-0.44 (0.54)	0.422
	Dependency main customer (% farm rev.)	**-0.19 (0.08)**	**0.022**	**-0.18 (0.08)**	**0.033**	0.14 (0.46)	0.753
	Cocoa buyers (#)	0.1 (0.08)	0.257	0.1 (0.09)	0.241	1.03 (0.71)	0.145
	Relationship cocoa buyers (years)	0.04 (0.08)	0.591	**0.16 (0.08)**	**0.045**	-0.51 (0.32)	0.107
Constant		**6.79 (0.09)**	**0.000**	**-1.63 (0.07)**	**0.000**	**6.2 (2.02)**	**0.002**
Observations		181		168		109	
Adapted R^2				0.334			
Nagelkerke pseudo R^2						0.592	
Marginal N&S R^2 - GLMM		0.341					
Conditional N&M R^2 - GLMM		0.351					

Notes: Marginal Nakagawa & Schielzeth's R^2 GLMM = proportion of variance by fixed factors alone, Conditional Nakagawa & Schielzeth's R^2 GLMM = proportion of variance by fixed and random factors.

ß = estmated coefficient, SE = standard error.

[a] Linear mixed model (with village as random effect),

[b] Ordinary least square model,

[c] Generalized linear model.

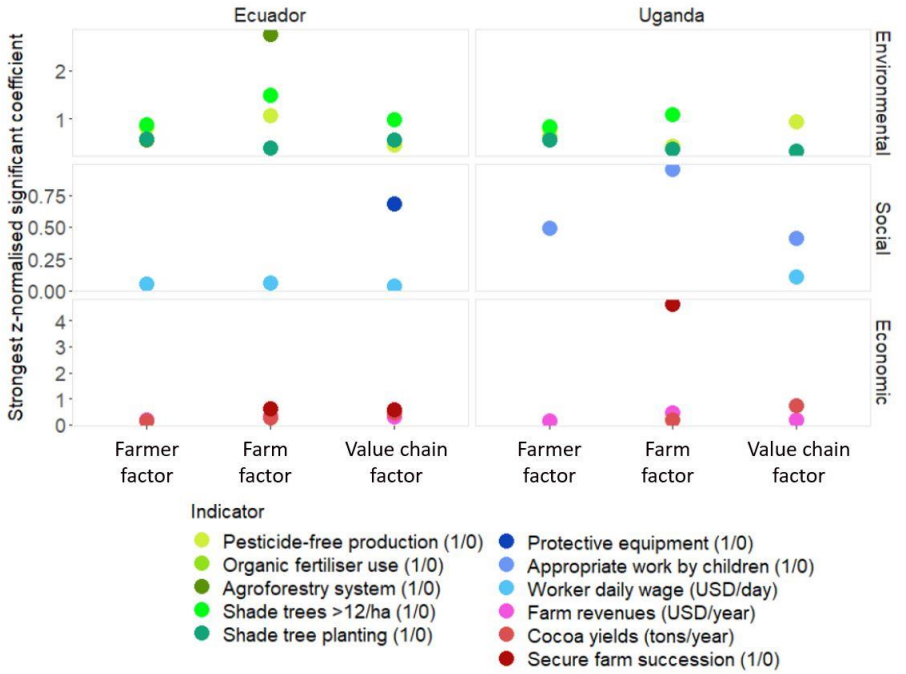

Figure 16: Comparison of strongest z-normalised significant coefficient among farm, farmer, and value chain factors for each sustainable farming practice and country. (Source: own graph)

Practices within the social dimension

Our covariates showed rather weak predicting power for the implementation of social SFP among sampled Ecuadorian farmers (Table 7). Farmers reported that they had received some personal protective equipment, such as rubber boots, through the sustainability program. Training participation was significantly and positively associated with the use of protective equipment (GLMM, $ß = 0.63$, $n = 146$, $p < 0.05$). The average daily wage for a farm worker in this case study was 14 USD. As reported by farmers, wages partly depend on the tasks (e.g. manual weeding receives a lower wage than using an electric grass cutter due to the higher risk involved), the gender of the worker with women often receiving lower daily wages, and farmers' ability to pay. Farmers' commitment to sustainability showed a significant and positive relationship with wages (LMM, $ß = 0.05$, $n = 127$, $p < 0.05$).

Workers on farms in the Ugandan sample received on average 1.8 USD per day. Ugandan farmers mostly pay workers per task, requiring an estimation of the

associated workload. Training days were significantly and positively associated with paid wages (LMM, ß = 0.11, n = 114, $p < 0.1$, Table 10). Furthermore, most farms in this case study included children up to 16 years of age in farming activities. For the vast majority of children, farm work did not impair their school assistance or performance as they engaged during school holidays or the weekend. However, on 21% of sampled farms, children were involved in hazardous work like using sharp tools or spraying pesticides. The number of family workers as farm factor showed the strongest relationship with this outcome variable (GLM, ß = -0.95, n = 181, $p < 0.001$). Farmers' dependency on their main customer, contrarily, showed significant and positive relationships with appropriate work by children (GLM, ß = 0.41, n = 181, $p < 0.1$).

Practices within the economic dimension

All factor groups showed significant relationships with economic SFP within our Ecuadorian sample (Table 8, Figure 16). Female farmers had significantly lower gross farm revenues and cocoa yields (LMM, ß = -0.17 and -0.16, n = 173, $p < 0.05$). While the number of livestock units and cocoa plot size showed a significant and positive relationship with gross farm revenues (LMM, ß = 0.29 and 0.35, n = 175, $p < 0.1$), cocoa plot size showed a significant and negative relationship with yields (LMM, ß = -0.3, n = 175, $p < 0.05$). Finally, farmers' dependency on cocoa revenues showed a significant and negative relationship with gross farm revenues (LMM, ß = -0.29, n = 175, $p < 0.01$), yet a significant and positive relationship with cocoa yields (LMM, ß = 0.47, n = 173, $p < 0.001$). This indicates that, holding all other variables constant, with a 34% increase in the share of farm revenues from cocoa, cocoa yields increase by 60%.

The results of the Ugandan case study mirror several findings from the Ecuadorian data (Table 11). As such, the share of revenues generated by cocoa showed a significant and positive relationship with cocoa yields (LMM, ß = 0.74, n = 164, $p < 0.001$), female farmers generated lower gross farm revenues (LMM, ß = -0.16, n = 164, $p < 0.1$), and farm size and the number of livestock units were significantly and positively related to gross farm revenues (LMM, ß = 0.47 and 0.15, n = 164, $p < 0.1$).

In summary, we found the largest number of significant relationships within our models estimating SFP implementation in the environmental dimension, with lowest explanatory power of our models estimating SFP implementation in the social dimension (Figure 16). The relative importance of value chain factors to explain SFP implementation was similar to the importance of intrinsic farmer and farm factors within all sustainability dimensions.

3.3.3 Value chain mechanisms that influence SFP implementation

We tested the relationship of two value chain factor subgroups, i.e. mechanisms of value chain influence, and SFP implementation at farm level. These were information and organisational factors.

Information factors: Within both samples, few information factors were significantly associated with the implementation of SFP. Among Ecuadorian farmers, training days showed a significant and positive relationship with the use of protective equipment (GLMM, $ß = 0.63$, $n = 173$, $p < 0.05$, Table 7) and access to advisory service was negatively associated with pesticide-free cocoa production (GLMM, $ß = -0.47$, $n = 173$, $p < 0.1$, Table 6). Among Ugandan farmers, training days were significantly and positively associated with pesticide-free production (GLM, $ß = 0.94$, $n = 182$, $p < 0.01$, Table 9). In Ecuador (GLMM, $ß = 0.57$, $n = 173$, $p < 0.05$, Table 6) and Uganda (GLM, $ß = 0.32$, $n = 181$, $p < 0.1$, Table 9), farmers with access to extension were more likely to plant shade trees in their cocoa plots. In conclusion, we found limited evidence for hypothesis 4 that information sharing and capacity building along value chains increases the implementation of a large number of SFP at farm level.

Organisation factors: Organisation factors showed some important significant relationships with SFP implementation. The most significant predictor was farmers' dependency on cocoa revenues, which showed several significant relationships. In the Ecuadorian case, farms with greater dependency on cocoa were less likely to have a shade tree density of above 12 trees per hectare (GLMM, $ß = -0.98$, $n = 173$, $p < 0.05$, Table 6), grow cocoa in agroforestry (GLMM, $ß = -0.99$, $n = 173$, $p < 0.05$), use

personal protective equipment (GLMM, ß = -0.68, n = 146, $p < 0.1$, Table 7), and had lower gross farm revenues (LMM, ß = -0.29, n = 175, $p < 0.01$), yet higher cocoa yields (LMM, ß = 0.47, n = 173, $p < 0.001$). This trend was partly mirrored in the Ugandan case, where dependency on cocoa revenues was significantly and positively associated with cocoa yields (OLS, ß = 0.74, n = 168, $p < 0.001$, Table 11) and showed a significant negative relationship with pesticide-free production (GLM, ß = -0.51, n = 182, $p < 0.05$), while dependency on the main customer was significantly and negatively associated with shade tree planting (GLM, ß = -0.34, n = 181, $p < 0.1$, Table 9). Long-term relationships with cocoa buyers were significantly and negatively associated with pesticide-free production in Ecuador (GLMM, ß = -0.57, n = 175, $p < 0.05$, Table 6) but showed a significant positive relationship with cocoa yields in the Ugandan case (OLS, ß = 0.16, n = 168, $p < 0.05$, Table 11). These results indicate that value chain organisation and stability can influence SFP implementation at farm level providing evidence for hypothesis 5.

3.4Discussion

Our study tested the relative importance of external value chain factors compared to internal farmer and farm factors in explaining SFP implementation on cocoa farms across the environmental, social, and economic dimensions of sustainability. It furthermore examined two specific mechanisms within value chains for their relationships with SFP implementation, namely information provision through and organisation of the value chain. We observed strong differences across practices and sustainability dimensions in terms of which factors influenced SFP implementation. Despite some differences between case studies, we also identified a few reoccurring important factors. This suggests that the factors influencing adoption of SFP are partly context dependent and cannot be generalised across the board. As a result, the supporting evidence for the various hypotheses was more nuanced and contextual. All three groups of factors showed significant relationships with the implementation of SFP across sustainability dimensions, yet were strongest for environmental SFP. We discuss these results in detail in relation to our original hypotheses below.

3.4.1 Relative importance of value chain factors

Intrinsic farmer factors are important for SFP implementation (Hypothesis 1): From the farmer factor group, significantly associated predictors mainly cover farmers' intrinsic motivation and go beyond SFP implementation in the environmental dimension. These results confirm the importance of intrinsic and attitudinal factors for SFP implementation (Dessart et al., 2019; Meijer et al., 2015).

Farm factors show mixed results for SFP implementation (Hypothesis 2): Our models included multiple factors that represent farmers' economic endowment, which have been shown to be positively associated with practices that require financial investments (Arslan et al., 2020). We observed some important relationships in our results, such as farm and cocoa plot size and the number of livestock units, which were positively related to gross farm revenue generation in both case studies. Remarkably, no significant relationship was identified between farm economics and the use of personal protective equipment, as previously found by Boadi-Kusi et al. (2016), Okoffo et al. (2016), and Owombo et al. (2014). This indicates that farmers' economic situation is not solely responsible for SFP implementation. Our results for Uganda furthermore support the notion that the relationship between farms' economic endowment and hazardous child labour is not unidirectional and more complex (Berlan, 2013; Busquet et al., 2021). In our case, larger households with more members involved in farm work were more likely to involve children in hazardous tasks, which is contrary to past findings from Côte d'Ivoire (Nkamleu & Kielland, 2006). Finally, cocoa yields decreased with increasing cocoa plot sizes in both case studies, in line with past findings (Bymolt et al., 2018).

Current demographic changes are affecting cocoa farming systems, as farmers report aging managers and labour shortage (Mithöfer et al., 2017a). This especially affects SFP that are considered labour intensive, such as good cocoa management practices (Armengot et al., 2019) or agroforestry systems (Armengot et al., 2016). Farms with more family workers in our samples were more likely to implement the laborious task of shade tree planting and have a secure farm succession. More generally, however, and in light of recent demographic changes in cocoa growing communities, the

relationship between labour availability and SFP implementation should receive additional attention.

Finally, our results mirror prior research on the role of the hybrid cocoa variety CCN-51, which is becoming more common among Ecuadorian cocoa farmers due to its relative disease resistance and higher productivity (Boza et al., 2014). Farmers with the hybrid cocoa variety CCN-51 were more likely to apply synthetic pesticides and grow cocoa in full-sun systems compared to the fine flavour cocoa variety, in line with past findings (Blare & Useche, 2013; Middendorp et al., 2018; Rueda et al., 2018). Contrasting these past findings, growing hybrid cocoa was not accompanied by economic co-benefits in our case study.

Value chain factors are comparatively important for SFP implementation (Hypothesis 3): Our results highlight the importance of all predictor groups for SFP implementation in the environmental dimension, supporting past research on the importance of value chains for environmental decision-making at farm level (Hansson et al., 2019; Liverpool-Tasie et al., 2020). Our results also highlight a similar importance of value chain factors and intrinsic farm and farmer factors in the social and economic dimensions, which was not known before.

3.4.2 Value chain mechanisms that influence SFP implementation

Information can be a relevant factor for SFP implementation (Hypothesis 4): In general, value chain factors regarding information flow showed few relationships with SFP implementation, and these could be explained based on existing farmer training programmes. In the Ecuadorian case, the sustainability program promoted the use of personal protective equipment and these were handed to farmers during trainings. Past studies also found clear relationships between access to extension service and the use of protective equipment among cocoa farmers in Ghana, Nigeria, and Cameroon (Boadi-Kusi et al., 2016; Okoffo et al., 2016; Owombo et al., 2014). In this value chain, the Swiss chocolate company's in-house sustainability program is the only source of advisory service or training on cocoa production for most of the sampled farmers. Governmental advisory services were scarce and farmers' level of

organisation for joint commercialisation was low, representative for Ecuadorian cocoa farmers (Huetz-Adams et al., 2016). This highlights the important role of corporate capacity building in delivering services to farmers that are underprovided by the state.

In the Ugandan case, farmers who had participated in more training days were more likely to produce pesticide-free cocoa despite our observations that all farmers had access to agro-shops and thus pesticides. This is in line with farmers' conversion to organic certification at the time of data collection as the restriction of synthetic pesticides was an important topic in the export company's trainings to prepare farmers for the upcoming audit. However, since training participation is voluntary, causality could be reversed due to positive selection bias, with farmers who used no or few pesticides more eager to take part in trainings. Voluntary training participation and the delay in payment of price premiums might also explain that almost 40% of sampled farmers were not complying with organic regulation. Low compliance rates have been reported from certified cocoa producers in Ghana, pointing to the need to further invest in capacity building and compliance verification (Ansah et al., 2020; Schader et al., 2021). Regardless, our results suggest that farmer training can be an important aspect for SFP adoption, in line with past studies that identified positive effects of training or cooperative membership on practice implementation (Adebayo et al., 2021; Effendy et al., 2019; Piñeiro et al., 2020).

Our results did not show a relationship between training and advisory service and other SFP, despite Ecuadorian farmers receiving training on topics such as cocoa management practices to increase productivity and growing cocoa in agroforestry systems for product diversification. This indicates implementation constraints beyond knowledge.

The value chain organisation can be an important factor for SFP implementation (Hypothesis 5): The relationships between value chain organisation factors and SFP implementation observed in our samples were weaker than expected and sometimes even negative. In the Ecuadorian case, long-term relationships with intermediaries reduced the likelihood of pesticide-free cocoa production. This could in part be due to the double agency role of intermediaries, as both buyers of cocoa and sellers of inputs. Reports from farmers suggest that long-standing relationships with local intermediaries facilitated the receipt of loans or inputs, which farmers repay with the

next cocoa harvest. For pest or disease management, many Ecuadorian cocoa farmers seek advice from input providers (Blare & Useche, 2014), highlighting their importance for reducing synthetic pesticide use in cocoa. Reis et al. (2020) demonstrated that stable relationships between value chain partners can improve the sustainability performance by comparing *between* value chains. Our results indicate that long-term relationships *within* single value chains can also influence SFP implementation, yet only when all actors involved share the same sustainability goals. In our two cases, downstream chocolate manufacturers aimed to reduce pesticide residues in cocoa and thus their use on farms, while input-supplying intermediaries distributed synthetic pesticides and provided loans for them.

Our results also highlighted significant relationships regarding farmers' economic dependency. In the Ecuadorian case, farms' dependency on cocoa revenues was negatively associated with gross farm revenues. At the time of data collection, cocoa prices in Ecuador were relatively low and some farmers had already or planned to switch to more attractive commodities, such as passion fruit. In Uganda, however, cocoa prices were higher than those for traditional commodities, such as coffee. A higher dependence on cocoa revenues and thus specialisation, however, increased farms' cocoa yields across cases, yet at the expense of shade tree density and planting. These results support the notion that income diversification strategies, especially when cocoa prices are low, are important for smallholder livelihoods and resilience (Aneani et al., 2011; Cerda et al., 2014), despite potentially reducing downstream companies' power to enforce rules for sustainable cocoa production (Grimm et al., 2014). Ecuadorian farmers in our sample who diversify their cocoa buyers too much are sanctioned by no longer receiving in-kind premiums, a threat commonly associated with sustainability initiatives (Grabs & Carodenuto, 2021). Thus, promoting diverse agroforestry systems and income diversification might require a balancing act from downstream companies to ensure living incomes and resilient systems for supplying farmers while not losing too much leverage to generate change in cocoa farming practices.

Farm workers' wages have recently received attention with potential implications for value chains. Farmers in our case studies paid their workers 70% of the national minimum wage (Ecuador) and 18% of the estimated living wage (Uganda) (Global

Living Wage Coalition, 2021; Wage Indicator, 2022). Low wages are generally perceived as a result of commercial value chain practices with uneven value distribution and low prices paid by buyers (Lebaron, 2021), following which farmers are not able to pay adequate wages. Meemken et al. (2019) assessed the effect of Fairtrade certification on cocoa farm workers' annual wages in Côte d'Ivoire and concluded that given current payment modalities, smallholder farmers were not incentivised to pay higher wages without clear rules and their monitoring.

3.4.3 Limitations and future research directions

In this study, we show several significant relationships between value chain factors and SFP, while controlling for numerous confounding factors. This illustrates the importance of value chain factors despite the lack of attention paid to them in the literature thus far. However, some caveats are required in the interpretation of results due to several limitations in our study design. First, the results are largely exploratory and causal inference between value chain factors and sustainability outcomes should be avoided due to potential endogeneity issues. Future studies on the adoption of SFP should therefore consider an experimental approach that controls for endogeneity, potentially with instrumental variables. Second, our farmer sample might not represent a sample of "typical" Ecuadorian and Ugandan cocoa farmers but rather farmers from the "sustainable cocoa" segment and part of specific value chains with sustainability orientation. Thus, our results are generalisable only to a certain extent. Third, we were limited to the data set available and several potentially important groups of factors were thus not included in our analysis, such as the broader economic or climatic situation. The importance of attitudinal and social aspects for practice adoption is increasingly recognised (Arslan et al., 2020; Dessart et al., 2019; Meijer et al., 2015), which we were only partly able to cover. Our study furthermore did not cover the role of (financial) incentives, which can be a strong element in farmers' decision making (Piñeiro et al., 2020). Also the role of additional contextual factors like the broader economic situation or climatic conditions. In the future, different value chain characteristics including incentives could be combined with an in-depth analysis of farmers' social setting and motivation to implement or adopt certain practices to determine their importance.

3.5Conclusions

Chocolate companies are increasingly investing in value chain sustainability initiatives, highly focusing on sustainable practice uptake among upstream producers. Yet little is known about if and how value chain factors influence practice implementation, especially within the social and economic dimension of sustainability. Our results from two cocoa value chains connecting cocoa producers in Ecuador and Uganda with Swiss chocolate brands suggest that value chain factors can have a substantial influence on the implementation of SFP among cocoa producers. While observed relationships were weaker than hypothesised, our results indicate that value chain factors are just as important as farmer and farm factors for SFP across sustainability dimension.

Our results highlight that chocolate brands have various levers within their own value chains to improve the sustainability performance of their supplying farmers and assure the long-term supply of sustainably produced cocoa. However, their potential was underexploited in both case studies. Capacity building is an important mechanism for downstream actors to increase SFP implementation at farm level, especially when training and extension target specific practices. Training and extension service organised by downstream companies should therefore address specific practices beyond agro-environmental practices. In addition, resource transfer might provide farmers with the necessary resources to enact change. In our case studies, this is currently done through in-kind premium distribution and promised price premiums, yet could be extended to address inhibiting factors for practice implementation beyond knowledge. Our results furthermore suggest that stable and long-term relationships between value chain actors can influence SFP implementation on farms, yet require a common definition of sustainability goals. Chocolate manufacturers should clearly define and communicate their sustainability goals along the entire value chain and align all actors in order to avoid contradictory agendas from single parties. In order to fully exploit the potential to generate change, chocolate companies need to continuously invest and establish strong collaborations along their entire value chain.

Chapter 4: Cocoa farming under changing household labour availability

This chapter is based on the following manuscript:

L.M. Tennhardt, E.F. Lambin, G. Lazzarini, K. Martin, C. Schader. The role of household labour for sustainable intensification in smallholder systems: A case study in cocoa farming systems *(Submitted)*

Abstract

Sustainable agricultural intensification aims at increasing yields on existing agricultural land without negative environmental impacts. Managing pests and diseases contributes to increasing yields. Without synthetic pesticides, this management is labour intensive. Smallholder farming systems heavily rely on manual and household labour, which will be affected by future demographic changes. Knowledge on how these changes will affect sustainable intensification is limited. Based on a case study of Ugandan cocoa farms, we tested the impact of increased household labour availability on pest and disease management (PDM) practices and pesticide use. We made use of a unique quasi-experimental design, in which household labour increased during the national Covid-19 lockdowns as children did not attend school and family members returned from cities. Our survey data from 2019 and 2021 showed that household labour availability increased on average by 0.8 (±2.5) household members and 16% of labour days per hectare. Using different regression models complemented by qualitative insights, we found that the uptake of alternative PDM practices significantly reduced pesticide quantities. The implementation of alternative PDM practices was only weakly influenced by household labour availability and increased with farmer training and trust in alternative practices. These results imply that alternative PDM is an important pillar for production with little or without synthetic pesticides and their adoption requires support and incentives, especially on labour or resource-constrained farms.

4.1 Introduction

With sustainability as a guiding principle for global development ambitions (UN, 2015), sustainable agricultural intensification (SI) has become a leading strategy for agricultural development (Pretty, 2018; Rasmussen et al., 2018; Rockström et al., 2017). SI aims at increasing yields without generating adverse environmental impacts or cultivating more land (Pretty, 2018). Pests and diseases represent a major challenge for SI, as they are responsible for up to 30% of yield losses among major food crops (Savary et al., 2019). To control pests and diseases, many farmers resort to synthetic pesticides, of which several have been found to harm human and environmental health (Mahmood et al., 2016; Rani et al., 2021). Pest and disease management (PDM) that involves highly-efficient or no application of synthetic pesticides, paired with alternative management practices can thus be one key pathway towards SI (Pretty, 2018). This is especially important for smallholder production systems in low- and middle-income countries, who produce up to 34% of the global food supply (Ricciardi et al., 2021), yet face many barriers to increasing their yields, such as low nutrient input or lack of investment opportunities (Sheahan & Barrett, 2017).

SI practices in smallholder systems with low mechanisation are often labour-intensive (Dahlin & Rusinamhodzi, 2019; Leonardo et al., 2015). Mozzato et al. (2018) found that higher family labour availability plays a positive role in environmental practice adoption. The relationship between labour availability and practice adoption is especially pronounced when labour availability is low and the practice is labour saving (Arslan et al., 2020; de Oca Munguia & Llewellyn, 2020). The amount of available labour thus clearly influences smallholder farmers' decision to invest in SI (Adolph et al., 2020). However, demographic changes like urbanisation or population increase are observed globally. So far, we have only limited knowledge about how these changes will influence SI (Vanlauwe et al., 2014) because conducting experiments on the effect of changing labour availability is difficult.

One exemplary smallholder crop with low levels of mechanisation and strong reliance on manual labour is cocoa (Voora et al., 2019). Pests and diseases are a major cause for low cocoa yields (Kagorora et al., 2021) and their management represents a major challenge for cocoa producers. This has resulted in agricultural policies and

recommendations in producing countries that promote synthetic pesticides (Aneani et al., 2012). Many cocoa farmers, however, lack knowledge about active ingredients and correct dosage as also personal protective equipment for safe application (Oyekale, 2018). Simultaneously, the demand for organically-produced cocoa has been on the rise (Meier et al., 2020). Additionally, many chocolate manufacturers increasingly source cocoa with voluntary sustainability certification or through their in-house sustainability programs. These aim to eliminate (in case of organic certification) or reduce the use of (highly toxic) synthetic pesticides and promote SI and alternative PDM (APDM). Importing countries are also regulating pesticide residues in agricultural imports, such as the European Union (The European Parliament and the Council of the European Union, 2005).

Many of the APDM practices in cocoa are labour-intensive. Manual weeding requires higher labour investments than spraying herbicides (Bymolt et al., 2018). Labour input for cocoa production that includes pruning, weeding, and phytosanitary measures is greater than for traditional cocoa management (Folefack et al., 2021; Juhrbandt et al., 2010; Scudder et al., 2022). Diverse agroforestry systems that rely on natural cycles for PDM require greater labour investments than full-sun cocoa systems, mainly due to pruning of cocoa and shade trees (Armengot et al., 2016). The amount of available labour can thus determine how smallholder farmers manage their cocoa (Bymolt et al., 2018). Household labour remains an important input for cocoa production as hiring labour is expensive for cocoa farmers (Fountain & Huetz-Adams, 2020; Vigneri et al., 2016). Demographic changes also affect cocoa farmers, who increasingly worry about labour shortage (Dormon et al., 2004; Mithöfer et al., 2017a). Especially elderly farmers might be unable to keep up proper crop management themselves or hire workers (Abdulai et al., 2020; Kongor et al., 2018).

Past literature on practice adoption on cocoa farms have looked into farm labour as one explanatory factor among many and have compared labour availability between farms at a single point in time. Quantitative labour data collection is rare, as household size is often used as a proxy for farm labour or labour inputs are estimated through key informant interviews. Studies in Ghana did not find significant relationship between household size and weeding frequency (Aneani et al., 2012), pesticide use (Denkyirah et al., 2017; Kehinde A. D. & R., 2017; Wongnaa & Babu, 2020), or

pruning and mulching (Wongnaa & Babu, 2020). By contrast, Danso-Abbeam et al. (2014) found that Ghanaian cocoa farms with larger households had lower expenditures for agrochemicals. Scudder et al. (2022) found a positive relationship between labour investment and improved PDM in Indonesia based on "theoretical" farms. Vigneri et al. (2016) found a general correlation between cocoa yields and adult household labour demand in Ghana and Côte d'Ivoire.

Using cocoa as a case study for a labour-intensive smallholder crop, this study aims at testing the relationship between household labour availability and pesticide use among Ugandan farmers. Specifically, it tests whether increased household labour availability, mediated by the implementation of APDM practices, reduces synthetic pesticide use quantities and expenditures. Manipulating household labour availability in an experimental setting is difficult and we thus make use of a unique quasi-experimental design. Following Covid-19 regulation in Uganda, farm labour availability increased due to children not visiting school and family members returning to farming households. We compare data from just before the pandemic and two years into the pandemic. Our research questions are: 1) How is additional household labour allocated on smallholder cocoa farms?; 2) Is the implementation of alternative pest and disease management associated with a reduction in pesticide use?; and 3) Do changes in household labour availability increase the adoption of alternative pest and disease management practices in cocoa? Our underlying hypothesis is that, with increasing household labour availability, the share of farms implementing APDM practices increases and the use of synthetic pesticides consequently reduces. We followed a quantitative approach, complemented with detailed qualitative insights.

The rest of this manuscript first describes the case study setting, including the Ugandan government's response to the Covid-19 pandemic and consequent changes in rural areas, before presenting the methodological approach. The results show how greater labour availability is invested on farms and how this relates to pesticide use and APDM. We then discuss the results first within our specific case study and then in light of broader SI ambitions on smallholder farms, before providing a conclusion.

4.2 Materials and methods

4.2.1 Case study description

Cocoa production in Uganda has been increasing in the past few decades (FAO, 2022b) and is expected to grow further due to the country's increasing climatic suitability for cocoa cultivation (Bunn et al., 2017) and governmental efforts to promote its production (Kagorora et al., 2021). However, cocoa yields remain comparatively low with 0.494 tons/hectare on average, compared to major cocoa producing countries like Ghana with average yields of 0.552 tons/hectare (FAO, 2022b). Pests and diseases are a major contributor to low yields. Ugandan farmers largely apply synthetic pesticides as a primary strategy in pest and disease control (Andersson & Isgren, 2021). Pesticides are easily accessible and effective in managing a broad spectrum of pests, diseases, and weeds. Store-bought organic alternatives are not easily available. Uganda faces problems with the widespread use of unregulated and/or counterfeit pesticides, which has become an issue of increasing public concern (Yiga, 2022).

The Covid-19 pandemic in Uganda was met with strict governmental responses. It imposed two major national lockdowns (24.03.-30.04.2020 and 10.06.-30.07.2021) including the closure of schools, suspension of public transport, ban of inter and intra district movement, and a night curfew. Schools remained closed from March 2020 to January 2022. Additionally, formal and informal income generating activities in urban areas reduced dramatically (Kansiime et al., 2021; Steverding & Margini, 2020), resulting in the return of many urban workers to their home villages hoping to satisfy their basic food needs.

4.2.2 Collected data

To test the relationship between farm labour availability and pesticide use, we collected data for three groups of indicators. Quantitative data on each indicator was complemented with qualitative information collected during the farmer interviews to enrich the interpretation of results. Furthermore, enumerators' observations were

collected regularly. Qualitative insights for the reference year of 2021 were grouped into: i) Farmers' perceived changes during the Covid-19 pandemic (including general impacts at personal and regional levels, farm labour availability, and market developments); and ii) Perceived changes in pest and disease pressure and consequent changes in management from pre-Covid times to the reference year.

Pest and disease management practices: Respondents were asked about the synthetic, organic, and home-made pesticides they applied (commercial name, quantities, expenditures in Ugandan shilling (UGX), and ingredients for home-made concoctions[1]) and the crops on which they applied them at both baseline and endline. To reduce recall bias, respondents were asked about the packaging to corroborate quantities and commercial names. We then collected information about active ingredients and their concentrations for each synthetic pesticide mentioned, and calculated quantities of active ingredients (in grams) for each farm to achieve comparability between input quantities. A clear allocation of input quantities to individual crops was not possible due to the existence of mixed crops (e.g. agroforestry systems in which farmers sprayed both cocoa and banana without clear knowledge about the share of pesticides sprayed on each crop). Thus, quantitative information is only available at farm level. Additionally, respondents were asked whether or not they carried out APDM, specifically pruning of cocoa trees, the application of concoctions, and phytosanitary measures (selectively eliminating diseased pods and plant parts and removing them from the field) in cocoa.

Farm labour availability: At baseline and endline, respondents were asked the number of working weeks and the average number of working hours per week for each farm worker, including household members and hired labour. The total household labour and hired labour hours for the entire farm operation and each reference year were calculated and converted into 6-hour labour days. By collecting data during the same months at baseline and endline, we avoided part of the potential bias due to changes in labour needs throughout the year. A household was defined as the unit of people living, eating, and operating a farm together. We collected quantitative information for the entire farm and did not quantitatively break down

[1] Concoctions refer to farm-made natural inputs for PDM, e.g. fermented mix of urine, ash, and tobacco leaves.

labour investments for specific farm activities, as we estimated the level of uncertainty to be very high. Instead, we opted for a more qualitative approach to explore changes in farm labour availability and farm labour allocation to specific tasks during the endline survey. Farmers were asked to estimate how the total time investment for specific cocoa-growing activities changed since the start of the Covid-19 pandemic in comparison to before the pandemic (response options: increased, similar, decreased, practice not done on the farm).

Control variables: To control for different factors that might influence pesticide use and expenditures on cocoa farms, we collected numerous additional variables for each farm at both baseline and endline. These included farmer factors, comprising farm managers' age, gender, farming experience, household size, training participation, and seven pesticide need statements[2] with a 5-point Likert scale as response option with which we calculated a pesticide need index (mean value). This was used as a proxy for farmers trust in APDM practices. We furthermore collected data on farm characteristics, i.e. farm size and revenues from single crops and products.

4.2.3 Statistical analyses

Comparative analyses

To get an overview of general changes among sampled farmers, we compared main farm characteristics of the entire farmer sample between 2019 and 2021. Then, we grouped farms into those with increased household labour availability and those with similar or lower household labour availability. Finally, we compared the two subgroups regarding the estimated changes in time investment for specific cocoa growing activities before Covid-19 to 2021 as well as other control variables (e.g. farm size, cocoa yields, cocoa revenues). We compared categorical variables using

[2] 1) Using pesticides increases farm profits. 2) If I do not use pesticides, my crop will be lost. 3) Cocoa production without pesticides is impossible. 4) The easiest and best method of pest control is spraying synthetic pesticides. 5) Synthetic pesticides help in fighting pests and diseases. 6) Organic agriculture is not a good alternative to conventional agriculture. 7) Eating foods sprayed with pesticides is harmless for my family.

Chi-squared test and non-parametric continuous variables using Wilcoxon rank sum test, applying paired tests for the comparison of same farms in different years.

Causal identification

We hypothesised that increases in household labour availability reduce the amount of synthetic pesticides applied on farms because labour-intensive APDM would be carried out instead. We tested this hypothesis in a two-step approach. First, we tested the influence of the APDM practices pruning, phytosanitary practices, and concoctions use in cocoa on pesticide quantities and expenditures. Second, we tested the influence of increased household labour availability on the implementation of these practices. We estimated ordinary least square (OLS) regression and generalised linear regressions (GLM) models of our cross-sectional data and fixed effect (FE) models using our panel data. This combination of methods was selected for robustness check and to exploit the strength of each methodology: OLS and GLM allowed us to control for time-invariant factors and coefficients for which data from only one year were available, while they do not allow for causal inferences. FE models, on the contrary, allowed us to control for both unobserved time-invariant farm level variables that might affect the outcome variables as well as time-variant unobserved variables that may affect all farms equally.

Step one

Ordinary least square (OLS) models: We estimated OLS models to test the relationship between changes in pesticide quantities and expenditures and the implementation of APDM practices. All data refer to the entire farm size. To control for other factors that might influence the outcome variables, we added a vector of covariates from the 2019 data with few exceptions from the 2021 data (indicated in Table 17). These included farm-specific covariates (farm size, commercial vegetable production (dummy), average pesticide prices per kg of active ingredient, and remittances (dummy)) and farmer-specific covariates (gender, age, farming experience, years of formal education, household size, training participation since 2020 (dummy), and a pesticide need index).

We estimated an OLS model (Equation 1) in which ΔY_i represents the change in outcome variable by subtracting 2019 from 2021 data at the individual farm-level i.

β_0 represents the intercept for sampled farms and β_1 the population slope coefficient for X_i, a vector of the three dichotomous alternative practices for the i^{th} individual farm. β_2 represents the population slope coefficient for E_i, representing a vector of variables that potentially influence the outcome variable. ε_i represents a random error term. Our main interest lies in the coefficient β_1 as it indicates the relationship between changes in pesticide quantities and expenditures and the implementation of alternative practices.

$$\Delta Y_i = \beta_0 + \beta_1 X_i + \beta_2 E_i + \varepsilon_i \qquad (1)$$

The distribution of the dependent variables was continuous, including negative, zero, and positive values, with a wide distribution. To retain negative and zero values, we applied an inverse hyperbolic sine (IHS) transformation (Bellemare and Wichman, 2020). Our models show a predominantly linear relationship between the residuals and the fitted values, with the exception of three outliers. We thus assume the linearity assumption to be satisfied. We verified the non-existence of multicollinearity and correlation with the error term in our models using variance inflation factors (all values <2). The distribution of residuals across the models show some deviation from normality, indicating potential violations of the OLS assumptions of random sampling and a conditional mean of zero. Furthermore, our models suffer from slight heteroskedasticity.

Linear two-way fixed effect (FE) models: Making use of the two-period balanced panel data, we used a FE model to gain additional insights into how changes within each farming household influenced the outcome variables. We introduced both a farm and a year FE.

We estimated the linear FE model using Equation 2, in which Y_{it} represents the outcome variable for an individual farm i at time t. β_i represents farm-specific intercepts that capture heterogeneities across farms and β_t represents time-specific intercepts that capture heterogeneities over time. β_1 represents the coefficient of the vector of variables of interest X_{it}, i.e. the implementation of APDM practices, and measures the causal effect on Y_{it}. We additionally control for time-varying confounders in vector F_{it} and included training participation since 2020 (dummy), commercial vegetable production (dummy), and remittances (dummy). Z_{it} represents

a vector of time-invariant explanatory variables and ε_{it} a random error term for an individual farm i at time t. After estimating the FE model, the intercept β_{0i} and the time-invariant vector Z_{it} cancel. We clustered the standard errors at farm-level to control for heteroskedasticity and autocorrelation.

$$Y_{it} = \beta_i + \beta_t + \beta_1 X_{it} + \beta_2 F_{it} + \beta_3 Z_{it} + \varepsilon_{it} \quad (2)$$

Step two

Generalised linear models (GLM): We estimated GLM models to test the relationship between the dichotomous outcome variables, i.e. implementation of APDM practices, and changes in household and hired labour availability, subtracting 2019 from 2021 data. Again, quantitative data refer to the entire farm area. Just as in the OLS models, we controlled for additional covariates that might influence practice implementation on farms. In the GLM models, we also included household size and households' dependency ratio, i.e. the share of household members below 15 and above 64 years.

We estimated a logit model, in which the dichotomous outcome variable Y_i with {0,1} indicates whether or not a practice is implemented on an individual farm i, and p indicates the probability of $Y = 1$, $p = P(Y = 1)$. ΔX_i in Equation 3 represents the vector of the predictor variables of interest, i.e. changes in household and hired labour availability between 2019 and 2021 and E_i represents a vector of additional covariates that might influence the outcome variables. The logistic regression estimates β_0, the intercept for sampled farms, as well as β_1 and β_2, representing the respective population slope coefficient for the vectors X and E, via maximum likelihood method:

$$logit(p) = \log(p/(1-p)) = \beta_0 + \Delta\beta_1 X_i + \beta_2 E_i \quad (3)$$

Conditional fixed-effects (FE) logit models: The conditional FE models were estimated to test the influence of household and hired labour availability and the dichotomous outcome variables describing the implementation of APDM practices. Just as in the linear FE models, we introduced both a farm and a year FE to the models and controlled for other time-varying confounders.

We employed logit FE model to examine the likelihood of a farm to implement individual APDM practices Y_{it} with {0,1}, where i and t index farms and years. As

FE models examine change over time, the case of interest is $Y_{i1} + Y_{i2} = 1$, which can either be $w_i = 1$ when $(Y_{i1}, Y_{i2}) = (0,1)$ (practice adoption) or $w_i = 0$ when $(Y_{i1}, Y_{i2}) = (1,0)$ (practice dis-adoption). All farms without change in the outcome variable and thus $Y_{i1} + Y_{i2} \neq 1$ are excluded from the model and do not contribute to the coefficient estimate. Based on Chamberlain (1980), the probability that a farm (dis-)adopts a practice over time and thus $w_i = 1$ is:

$$\Pr(Y_{it} = 1 \mid Y_{i1} + Y_{i2} = 1) = \frac{\Pr(w_i=1)}{\Pr(w_i=0)+\Pr(w_i=1)} = \frac{EXP(\beta\prime(X_{i2}-X_{i1})}{1+EXP(\beta\prime(X_{i2}-X_{i1})} \quad (4)$$

Software used

All comparative analyses and analyses using Equations 1-3 were performed in R (vers. 4.1.0, R Project for Statistical Computing, RRID:SCR_001905), via RStudio (vers. 2022.07.00+548, RStudio, Q19 RRID:SCR_000432). The following R functions and packages were used: From the stats package, the lm() function was used for OLS regression models, the glm() function for the GLM regression models, and the fisher.test() function for Fisher's exact test. From the fixest package, we used the feols() function for the FE models. The analyses using Equation 4 were carried out in Stata (StataSE vers 17) using the xtreg command. The questionnaire, data, and R-code are available here: https://shorturl.at/oCHU4.

4.3Results

4.3.1 Descriptive results

General farm information

General characteristics of the final sample of 194 cocoa farms in Mukono district (Table 12) reveal that farm managers were mainly male (69% in 2019 and 68% in 2021), on average 53 years in 2019, and managed on average 2.9 hectares of land in 2019. Farm and cocoa revenues did not change significantly between the years despite farms selling significantly less products in 2021 compared to 2019 (paired Wilcoxon test, $p = 0.041$). Significantly more farmers reported having off-farm income sources in 2021 compared to 2019 (paired Chi-squared test, $p < 0.001$), despite many households commenting that remittances from relatives in towns and cities as well as

off-farm self-employment opportunities reduced due to national Covid-19 regulations. Despite cocoa yields increasing significantly from 0.36 to 0.64 tons/hectare (paired Wilcoxon test, $p < 0.001$), cocoa revenues remained similar.

Estimated crop shares of the total farm area indicate that cocoa is on average the crop with the largest cover (17% ±12%) followed by coffee (14% ±11%) (Table 13). Input-intensive grain and vegetable production cover 11% (±10%) and 10% (±8%) of the farm area on average.

Covid-19 impacts

Farmers reported mainly negative economic impacts through the Covid-19 pandemic and governmental responses. Prices for agricultural goods destined for national and international markets generally decreased. Among the products for national markets were vegetables, beans, and eggs, which farmers usually sold in towns or had agreements with local schools to buy their produce. Transportation costs increased drastically following national Covid-19 regulation, leaving many farmers unable to pay and resorting to sell their produce in the villages, which again led to oversupply and plummeting prices. Cash crops for international markets included both vegetables and spices for neighbouring countries like Kenya, as well as coffee and cocoa for global markets. Difficulties in border crossings delayed exports and markets for perishable goods ceased. Coffee and cocoa had relatively stable markets and prices. Due to transportation restrictions, there were generally fewer coffee and cocoa traders, paying lower prices and buying cocoa on credit, which they repaid in instalments to the farmers. Export companies for these crops are often well-established, in comparison to other products which are distributed by personal trucks. In consequence, most farmers in our sample reported that cocoa and coffee have been the most important source of income in the past two years.

Among social impacts, a few farmers reported spending more time with their family and resorting to traditional medicine to better prepare for the disease. 24% of farmers reported a case of Covid-19 within their household. Greater numbers of children and youths in the villages without a proper occupation generated social tension in the villages, with many farmers reporting youth stealing crops and livestock as well as teenage pregnancies.

Table 12: Mean values (standard deviation) and n (percentages) of general farmer and farm information for 2019 and 2021. Statistical comparison between years using paired McNemar's Chi-squared test with continuity correction for binary variables and paired Wilcoxon rank sum test with continuity correction for continuous variables.

	2019 (n = 194)	2021 (n = 194)	Difference	p-value
Age of farm manager (years)	52.65 (12.51)	54.06 (13.54)	+1.41	< 0.001
Male farm manager (% farmers)	133 (68.6%)	131 (67.5%)	-2	0.789
Education farm manager (years)	6.98 (3.57)	6.98 (3.57)	0	1.000
Household size (people)	5.73 (2.72)	6.36 (2.91)	+0.63	< 0.001
Livestock ownership (% farmers)	133 (68.6%)	175 (90.2%)	+42	< 0.001
Farm size (ha)	2.85 (3.02)	2.85 (3.02)	0	1.000
Cocoa yields (tons / ha)	0.36 (0.46)	0.64 (0.67)	+0.28	< 0.001
Cocoa revenue (million UGX)	2.40 (3.65)	2.54 (4.25)	+0.14	0.221
Farm revenue (million UGX)	6.10 (8.45)	5.50 (7.04)	-0.6	0.188
Sold farm products (number)	4.37 (2.29)	3.95 (1.63)	-0.42	0.041
Off-farm income (% farmers)	106 (54.6%)	145 (74.7%)	+39	< 0.001

Table 13: Mean percentages (standard deviation) for different crop types of total farm area in 2019 (partial overlap exists for short-cycle crops due to two cropping seasons).

Crop type	Mean (sd) percentage of farm area
Cocoa	17.35% (12.39%)
Coffee	13.67% (11.38%)
Fallow	13.08% (11.02%)
Grasses (elephant grass, grassland, sugar cane)	12.82% (10.72%)
Grains (maize, rice, etc.)	10.69% (9.65%)
Vegetables (tomato, cabbage, pumpkin, etc.)	9.75% (6.83%)
Trees (eucalyptus, umbrella tree, etc.)	8.22% (9.03%)
Bananas (sweet banana, plantain, etc.)	7.79% (6.46%)
Roots/tubers (sweet potato, yam, cassava, etc.)	7.73% (6.43%)
Pulses (ground nut, soy bean, etc.)	5.81% (4.71%)
Spices (vanilla, cinnamon, etc.)	4.61% (5.25%)
Fruits (avocado, jackfruit, orange, etc.)	2.98% (3.63%)

4.3.2 Changes in pest and disease management

The share of sampled farmers applying synthetic pesticides on their farm and in cocoa remained similar for 2019 (63% and 40%, respectively) and 2021 (65% and 42%, respectively) (paired Chi-squared test, $p = 0.80$ and 0.61, respectively; Table 14). This was despite farmer reports that pest and disease pressure in cocoa was lower in 2021 compared to prior years, which farmers attributed to higher rainfall amounts and thus better cocoa growth. Yet, most farmers in Mukono carried out preventative calendar instead of curative pesticide applications. Farmers reported that green stink bugs (*Bathycoelia thalassina*) and mealy bugs (*Planococcus spp.*) are major pests in cocoa. Qualitative information from farmers revealed that they had been avoiding synthetic pesticide application in cocoa as they were undergoing organic certification since 2017 and were promised higher cocoa prices once certified. However, their cocoa was still not bought with price premiums at the time of the second data collection and many farmers resorted back to spraying synthetic pesticides out of fear of losing their harvests. Few farmers applied biopesticides (0.5% in 2019 and 1% in 2021), yet many farmers commented on their willingness to buy them if they were effective and available in their region. Only 7% of farmers reported input shortages due to national Covid-19 restrictions

Table 14: Mean values (standard deviation) and n (percentages) of pest and disease management variables for 2019 and 2021. Statistical comparison between years using paired McNemar's Chi-squared test with continuity correction for binary variables and paired Wilcoxon rank sum test with continuity correction for continuous variables.

	2019 (*n* = 194)	2021 (*n* = 194)	Difference	*p*-value
Pesticide use (% farms)	123 (63.4%)	126 (64.9%)	+3	0.798
Pesticide use in cocoa (% farms)	77 (39.7%)	82 (42.3%)	+5	0.614
Pesticide use (kg of active ingredient / ha)[1]	0.86 (2.37)	1.52 (5.15)	+0.66	0.701
Expenditures synth. pesticides (1000 UGX / ha)	44.61 (92.96)	59.90 (123.28)	+15.29	0.052
Active substances applied (#)[1]	1.63 (1.77)	1.89 (2.04)	+0.26	0.040
Expenditures biopesticides (1000 UGX / ha)	0.08 (1.1)5	0.17 (1.82)	+0.09	0.789
Expenditures homemade concoctions (1000 UGX / ha)	0.62 (3.29)	2.74 (9.57)	+2.12	< 0.001
Concoctions use in cocoa (% farms)	45 (23.2%)	75 (38.7%)	+30	< 0.001
Pruning of cocoa trees (% farms)	60 (30.9%)	162 (83.5%)	+102	< 0.001
Phytosanitary measures in cocoa (% farms)	76 (39.2%)	122 (62.9%)	+46	< 0.001

Notes: [1] Values refer to the entire farm area.

Table 15: Overview of active ingredients used by >5% of sampled farms in 2019 and/or 2021. HPP = highly hazardous pesticide.

Active ingredient	Type	% farms 2019	% farms 2021	Difference	PAN Bad Actor	HHP
Cypermethrin	Insecticide	43%	42%	+1%	No	Yes
Glyphosate	Herbicide	39%	26%	-13%	Yes	No
Profenofos	Insecticide	15%	20%	+5%	Yes	Yes
Chlorpyrifos	Insecticide	10%	4%	-6%	Yes	Yes
2,4-D Amine	Herbicide	8%	6%	-2%	No	No
Lambda-Cyhalothrin	Insecticide	6%	21%	+15%	No	Yes
Mancozeb	Fungicide	6%	11%	+5%	Yes	Yes
Abamectin	Insecticide	5%	7%	+2%	Yes	Yes
Acetamiprid	Insecticide	5%	7%	+2%	No	No
Malathion	Insecticide	3%	6%	+3%	Yes	Yes
Thiamethoxam	Insecticide	4%	21%	+17%	No	Yes

The active ingredients most applied by farmers in 2019 and 2021 were the insecticide cypermethrin (43% and 42%, respectively; Table 15) and the herbicide glyphosate (39% and 26%, respectively). In total, 11 active ingredients were applied by >5% of farmers, six of which are considered "Bad actors" by the Pesticide Action Network (PAN)[3] and eight of which are regarded as highly hazardous pesticides (HHP)[4].

The share of farms implementing APDM practices also increased from 2019 to 2021. Applying concoctions on cocoa increased from 23% to 39% of sampled farmers (paired Chi-squared test, $p < 0.001$; Table 14). Many farmers commented that collecting plants and brewing concoctions is tedious and not suitable for large cocoa plots. The share of farmers pruning cocoa increased from 31% to 84% (paired Chi-squared test, $p < 0.001$) and applying phytosanitary measures from 39% to 63% (paired Chi-squared test, $p < 0.001$).

4.3.3 Changes in labour availability

Our results show a significant increase in the number of household members involved in farm work from an average of 3.9 in 2019 to 4.8 in 2021 (paired Wilcoxon test, $p < 0.001$; Figure 17). Qualitative information from farmers revealed that family members and friends joined them in their rural homestead when the national lockdowns were announced to avoid income and food shortage in urban areas. Despite 24% of farmers reporting cases of Covid-19 infections within their household, only 4 farm managers mentioned consequent longer-term absences from farm work. The median number of 6-hour working days per hectare invested by household members in farm work increased by 16%, from a median of 303 in 2019 to 350 in 2021 (paired Wilcoxon test, $p < 0.001$). Additional household members but also children out of school contributed to this growth. Furthermore, many activities to generate off-farm income were subject to governmental restrictions. At the same time, farms hired significantly less labour (on average 83 6-hour labour days per hectare in 2019 and 14

[3] Pesticide action network (PAN) created "bad actors" to identify the "most toxic" pesticides, which are at least one of the following: Known or probable carcinogens, reproductive or developmental toxicants, neurotoxic cholinesterase inhibitors, known groundwater contaminants, known high acute toxicity (Pesticideinfo, n.d.).

[4] Highly hazardous pesticides "cause disproportionate harm to environment and human health including: severe environmental hazards, high acute and chronic toxicity" (UNEP, n.d.).

in 2021; paired Wilcoxon test, $p < 0.001$) and only 19% of farms hired more labour in 2021 than in 2019. Qualitative information suggest that plenty of willing workers were available in the villages at low daily fees, yet farmers hired less due to economic constraints or lack of need.

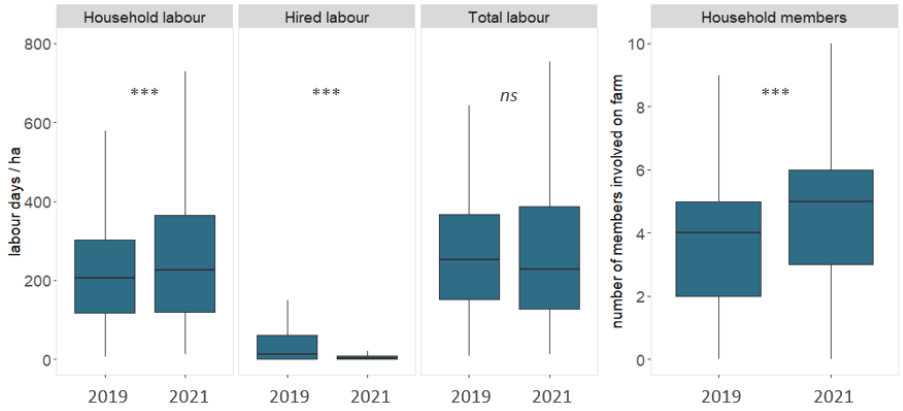

Figure 17: Overview of household, hired, and total labour days as well as household members involved on farm in 2019 and 2021 (shown here without outliers). Statistical comparisons using paired Wilcoxon rank sum test. (Source: own graph)

Our sample included a subgroup of 128 farms (66% of the sample) with more household labour available in 2021 compared to 2019 and a subgroup of 66 farms (34% of the sample) with similar or less household labour availability. These two subgroups were largely similar regarding major characteristics (Table 16). However, farms with increased household labour availability were more often male-managed (Chi-squared test, $p = 0.028$) and had higher cocoa revenues in 2019 and 2021 (Wilcoxon test, $p = 0.034$ and 0.016, respectively). Finally, the share of farmers applying concoctions in cocoa was significantly higher among farmers with increased household labour availability in 2021 (Chi-squared test, $p = 0.008$).

Table 16: Mean values (standard deviation) and n (percentages) for key characteristics of farms with more as well as same/less household labour availability in 2021 compared to 2019. Statistical comparison between groups using McNemar's Chi-squared test with continuity correction for binary variables and Wilcoxon rank sum test with continuity correction for continuous variables.

	Same/less household labour availability (n=66)	Increased household labour availability (n=128)	*p*-value
Change in pesticide quantities (kg active ingredient / ha)	1.11 (4.41)	0.42 (4.13)	0.368
Change in expenditures for synthetic pesticides (1000 UGX / ha)	33.76 (116.93)	5.76 (139.68)	0.303
Farm size (ha)	2.42 (1.95)	3.07 (3.43)	0.191
Male farm manager (%)	52 (78.8%)	81 (63.3%)	0.028
Age farm manager (years)	51.49 (13.47)	53.26 (12.00)	0.341
Training participation since 2020 (%)	35 (53.0%)	70 (54.7%)	0.826
Cocoa yields 2019 (tons / ha)	0.36 (0.56)	0.36 (0.40)	0.269
Cocoa yields 2021 (tons / ha)	0.55 (0.55)	0.68 (0.72)	0.159
Cocoa revenue 2019 (million UGX)	2.39 (4.42)	2.40 (3.21)	0.034
Cocoa revenue 2021 (million UGX)	2.15 (4.00)	2.74 (4.37)	0.016
Pruning cocoa 2019 (%)	19 (28.8%)	41 (32.0%)	0.643
Pruning cocoa 2021 (%)	55 (83.3%)	107 (83.6%)	0.963
Concoctions use in cocoa 2019 (%)	15 (22.7%)	30 (23.4%)	0.912
Concoctions use in cocoa 2021 (%)	17 (25.8%)	58 (45.3%)	0.008
Phytosanitary measures in cocoa 2019 (%)	23 (34.8%)	53 (41.4%)	0.375
Phytosanitary measures in cocoa 2021 (%)	36 (54.5%)	86 (67.2%)	0.084

4.3.4 Changes in farm labour allocation

Farmers reported that most of the additional household labour was allocated to producing food crops to sustain the household's food stocks and cater for the increased amount of household members or even provide food for relatives in cities. According to our respondents, additional household members and children mainly engaged in manual weeding and harvesting, as these are practices that do not require specific skills.

65% of farmers perceived their labour investments in cocoa production in 2021 to be greater than prior to the Covid-19 pandemic (Figure 18). This additional labour was mainly invested in manual weeding, which increased on 62% of farms, and pruning of cocoa and shade trees, which respectively increased on 49% and 30% of farms. Comparing the subsamples with and without increased household labour availability regarding their perceived changes in total labour time investment for specific cocoa growing tasks in 2021 compared to pre-Covid times shows that 69% of the group with increased household labour availability increased their time investment in cocoa production compared to 58% of the group with similar or lower household labour availability (Fisher's exact test, $p < 0.001$) (Figure 18). This difference is also found when comparing specific practices like manual weeding and pruning of cocoa trees, for which respectively 68% and 53% of farms with increased household labour availability incremented their time investment compared to 52% and 42% of farms without increased household labour availability (Fisher's exact test, $p < 0.001$). A significantly larger number of farms with increased household labour availability augmented time investments in spraying synthetic pesticides compared to farms without increased household labour availability (Fisher's exact test, $p = 0.002$). Qualitative information from farmers revealed that fetching the water for mixing synthetic pesticides is labour intensive and if outsourced costs 500 UGX for 20 litres, discouraging farmers with large fields to spray.

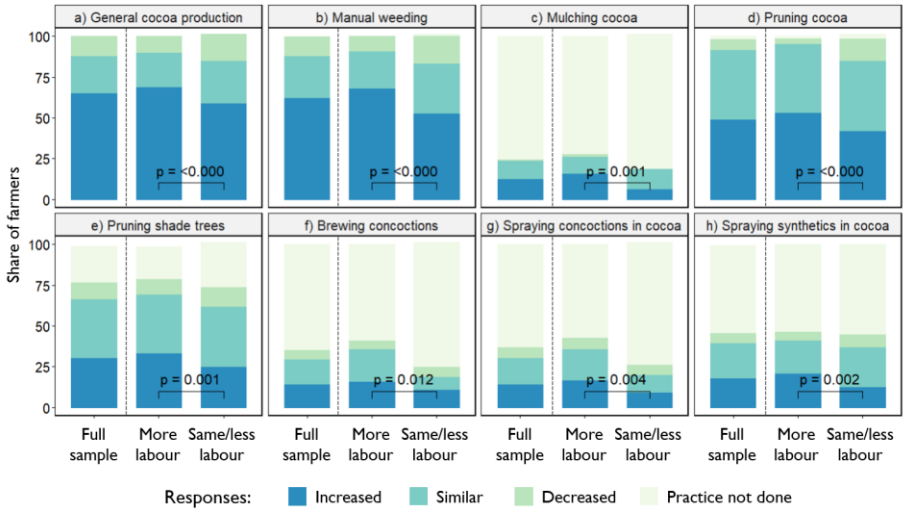

Figure 18: Estimated changes in labour time investment for specific cocoa production tasks in 2021 compared to pre-Covid-19 times for the full farmer sample ("Full sample"), the subsample with more household labour availability ("More labour"), and the subsample with similar or lower household labour availability ("Same/less labour"). Statistical comparison of the response option "Increased" between the two subsamples using a Fisher's exact test. (Source: own graph)

4.3.5 Impact of increased household labour availability on pesticide use and expenditures

The results of the quantitative OLS and FE models testing the influence of APDM practices on pesticide quantities and expenditures are presented in Table 17. The OLS models showed a significant positive relationship between using concoctions in cocoa and changes in pesticide use quantities and expenditures (OLS, respective coef. = 2.85 and 3.09, $p < 0.05$). This indicates that within the entire sample, farms that applied concoctions in cocoa in 2019 increased pesticide quantities and expenditures in 2021 compared to 2019. The FE models, however, showed a significant negative influence of concoctions use and phytosanitary measures in cocoa on pesticide quantities and expenditures. This suggests that with the uptake of these practices within farms over time, pesticide quantities and expenditures decrease. Furthermore, commercial vegetable production significantly and positively influenced pesticide quantities and expenditures.

The results of the quantitative GLM and FE models testing the influence of increased household labour availability on APDM practices are presented in Table 18. The GLM models showed a significant and positive relationship of increased household labour availability and concoctions use in cocoa (GLM, coef. = 0.14, $p < 0.05$). While the FE models did not mirror these results, they showed a significant and positive influence of household members, as a proxy for household labour availability, on cocoa pruning (FE, coef. = 0.604, $p < 0.01$), while an increasing dependency ratio significantly and negatively influenced cocoa pruning (FE, coef. = -0.037, $p < 0.05$). The GLM models furthermore showed a significant and negative relationship of concoctions use and phytosanitary measures in cocoa and farmers' perceived pesticide need (GLM, respective coef. = -1.11 and -0.45, $p < 0.05$). Finally, the FE models showed that training participation since 2020 significantly increased the implementation of pruning, concoctions use, and phytosanitary measures in cocoa within farms over time (FE, respective coef. = 2.25, 1.02, and 0.81, $p < 0.05$). Although the effect is weak, these results suggest that increased household labour availability slightly influenced the implementation of APDM practices within our sample.

Table 17: Results of the ordinary least square (OLS) and linear fixed effect (FE) models testing the relationship between practice implementation and pesticide use and expenditures. FE models include farm and year FE.

	Pesticide quantities (g active ingredient / ha)[1]		**Pesticide expenditures (UGX / ha)[1]**	
	Change 2021-2019	2019 and 2021	Change 2021-2019	2019 and 2021
	OLS	FE	OLS	FE
Pruning cocoa (1/0)[2]	-0.33 (0.96)	-0.82 (0.47)	-1.70 (1.52)	-1.39 (0.71)
Concoctions use (1/0)[2]	**2.85** (0.93)**	**-1.97*** (0.56)**	**3.09* (1.46)**	**-2.92*** (0.86)**
Phytosanitary measures cocoa (1/0)[2]	-0.34 (0.90)	**-1.21** (0.40)**	1.82 (1.36)	**-2.07** (0.65)**
Male farm manager (1/0) [2]	-1.24 (0.95)		-0.04 (1.59)	
Age farm manager (yrs) [2]	0.09 (0.05)		0.08 (0.07)	
Education farm manager (yrs) [2]	0.04 (0.12)		0.02 (0.20)	
Farming experience (yrs) [2]	-0.05 (0.04)		-0.08 (0.06)	
Training since 2020 (1/0)	-0.95 (0.83)	0.09 (0.52)	-0.05 (1.33)	0.39 (0.849)
Commercial vegetable production (1/0)[3]	**7.19*** (1.70)**	**1.80* (0.73)**	**7.91** (2.58)**	**2.24* (1.10)**
Pesticide price (M UGX/kg AI) [3]	-4.97 (2.85)		8.57 (4.71)	
Farm size (ln(ha))	-0.41 (0.56)		-0.85 (0.91)	
Pesticide need index[3]	**2.32*** (0.40)**		**3.92*** (0.63)**	
Remittances (1/0) [3]	-1.79 (1.58)	**-1.50* (0.61)**	-2.53 (2.40)	**-2.29* (1.03)**
Constant	**-8.51*** (2.57)**		**-12.73*** (3.74)**	
Observations	194	388	194	388
R^2	0.27	0.747	0.27	0.723
Adjusted R^2	0.21	0.476	0.22	0.427
Residual Std. Error (df = 179)	5.65		8.8	
R^2 Within		0.173		0.160
R^2 Within Adj.		0.147		0.133
F Statistic (df = 14; 179)	4.68***		4.83***	

Notes: *p<0.05; **p<0.01; ***p<0.001, Robust standard errors in OLS and clustered standard errors in FE.

[1]IHS transformed

[2]2019 data in OLS regressions

[3]2021 data in OLS regressions

Table 18: Results of the generalized linear (GLM) and conditional fixed effect (FE) logistic models testing the relationship between household labour availability and alternative practice implementation. FE models include farm and year FE.

	Pruning cocoa		**Concoctions use in cocoa**		**Phytosanitary measures in cocoa**	
	2021 GLM	2019 and 2021 FE	2021 GLM	2019 and 2021 FE	2021 GLM	2019 and 2021 FE
Household labour (100 h/ha)[1,4]	-0.04 (0.07)	-0.009 (0.008)	**0.14* (0.07)**	0.006 (0.012)	0.10 (0.06)	0.005 (0.010)
Hired labour (100 h/ha)[1,4]	0.01 (0.15)	-0.058 (0.04)	-0.02 (0.12)	-0.020 (0.025)	-0.06 (0.11)	-0.051 (0.035)
Household size (# people)[4]	0.10 (0.16)	**0.604** (0.215)**	-0.02 (0.12)	-0.225 (0.318)	0.19 (0.12)	0.398 (0.235)
Dependency ratio (% household members)[3]	0.01 (0.01)	**-0.037* (0.017)**	0.005 (0.01)	0.005 (0.019)	0.002 (0.01)	0.001 (0.018)
Training since 2020 (1/0)	0.09 (0.44)	**2.251*** (0.516)**	0.64 (0.37)	**1.023* (0.448)**	0.11 (0.34)	**0.814* (0.366)**
Male farm manager (1/0)[2]	-0.29 (0.50)		-0.07 (0.41)		0.02 (0.40)	
Age farm manager (yrs)[2]	-0.03 (0.06)		0.01 (0.02)		-0.001 (0.02)	
Education farm manager (yrs)[2]	0.04 (0.06)		0.003 (0.05)		-0.03 (0.05)	
Farming experience (yrs)[2]	0.03 (0.02)		-0.01 (0.02)		-0.01 (0.02)	
Farm size (ln(ha))	0.30 (0.28)		0.41 (0.26)		0.08 (0.22)	
Importance cocoa (% farm revenues)[4]	0.07 (0.60)	1.737 (0.965)	0.18 (0.58)	0.164 (1.029)	-0.14 (0.56)	-0.107 (0.849)
Pesticide need index[3]	-0.37 (0.22)		**-1.11*** (0.22)**		**-0.45* (0.18)**	
Constant	2.45 (1.38)		1.21 (1.26)		1.99 (1.06)	
Observations	189	234	189	120	189	176
Nagelkerke Pseudo R^2	0.095		0.321		0.112	
Log Likelihood	-80.42	-44.99	-101.02	-36.60	-115.97	-48.97
AIC	186.85		228.04		257.94	

Notes: *p<0.05; **p<0.01; ***p<0.001, Robust standard errors in GLM.

[1]IHS transformed in GLM regressions

[2]2019 data in GLM regressions

[3]2021 data in GLM regressions

[4]2021-2019 data in GLM regressions

4.4Discussion

4.4.1 How is additional household labour allocated?

Increasing household sizes appear to be a two-sided coin for smallholder households. On one hand, they require higher expenditures and infrastructure, which can place a burden on limited farm incomes. On the other hand, they represent seemingly free farm labour, which is highly important in systems with limited mechanisation that heavily depend on manual labour (Dahlin & Rusinamhodzi, 2019). In our sample, increased household labour was first used to cover the basic household needs for food. Once this was covered, additional investments were made in other (cash) crops. However, our data did not show a correlation between household labour investment and farm revenues or cocoa yields, in contrast to Juhrbandt et al. (2010) and Higuchi et al. (2022).

With increasing household labour, farms in our sample hired less labour. Our data are not conclusive on whether these savings were entirely invested in greater expenditures for larger households. Farms typically hire labour when household labour is constrained or they have a high incentive to invest in hired labour for certain practices (Bymolt et al., 2018; Martínez & Martínez Pachón, 2021). Past economic assessments of cocoa production systems showed that up to 37% of expenditures were invested in hired labour (Folefack et al., 2021). This indicates that increasing "free" household labour might free up some economic resources that can be used for other purposes.

4.4.2 Is alternative pest and disease management associated with a reduction in pesticide use?

Our quantitative data confirmed that the implementation of certain APDM practices can reduce pesticide quantities and expenditures on cocoa farms. Cocoa pruning did not show the same results as concoctions and phytosanitary measures. Apparently, farmers perceived concoctions and phytosanitary measures as actual alternatives to synthetic pesticides. Most farmers in our sample applied prophylactic calendar

spraying, which might mask beneficial effects of APDM on pest and disease pressure. Changing practices from prophylactic to curative spraying can be challenging and requires a high level of trust that alternative practices and inputs sufficiently protect farmers' crops. Perceived risks can delay practice adoption, especially among farmers with fewer economic resources (Foster and Rosenzweig, 2010). Changing calendar spraying also depends on seasonal climatic changes and local agro-dealers, who recommend farmers when and what to spray.

Organic certification, which bans the use of synthetic pesticides, might also influence pesticide use in our sample. Most farmers were willing to comply with organic regulation, yet lost their motivation over time and resorted back to spraying synthetic pesticides to secure their yields. This occurred especially after their cocoa was not bought with a price premium, even after five years of conversion to organic. Promising premiums for compliance and not following through represents a major breach of trust and commitment from export companies, as it impacts the income of resource-poor farmers. Trust and commitment are key relationship elements to ensure compliance with sustainability goals (Kumar and Rahman, 2015). Yet even farms that are fully organic certified do not always comply with organic regulation, as shown for Fairtrade-organic certified coffee farms in Uganda that reduced yet not eliminated synthetic pesticide spraying (Vanderhaegen et al., 2018) or organic certified cocoa farmers in Ghana (Schader et al., 2021).

While cocoa revenues represented on average 39% and 45% of farm revenues in our sample in respectively 2019 and 2021, other input-intensive crops were also of economic importance for farmers. Especially commercial vegetable production increased pesticide use in our sample, which is common in small-scale vegetable production (De Costa et al., 2021; Enthoven and Van den Broeck, 2021; Mergia et al., 2021). Organic certification of small farms does not require a whole-farm conversion. A risk for human and environmental health persists if other plots are still treated with synthetic pesticides. Drift can easily transport pesticide residues to cocoa plots (Benzing et al., 2021). If the aim is to reduce pesticide residues in cocoa, the entire farming system might need to be addressed.

4.4.3 Do changes in household labour availability influence pest and disease management?

Our qualitative data showed that perceived time investments in cocoa management and APDM increased significantly more often on those farms with increased household labour availability. Our quantitative results, however, only allow for a very cautious conclusion that increased household labour availability positively influences adoption of APDM in cocoa. The significant positive influence of household members on cocoa pruning and significant negative influence of households' dependency ratio on pruning suggests that pruning requires a strong workforce (Andres et al., 2016).

Nonetheless, APDM increased significantly for the entire sample, illustrating a general willingness of farmers to test or implement different options for PDM. This might have been motivated externally by organic certification and trainings, or intrinsically, as most farmers know about and have experienced the negative effects of synthetic pesticides on human and environmental health. This is in line with Andersson & Isgren (2021). However, farmers fear that not spraying their crops will reduce their yields and ultimately affect their livelihoods. Spraying effective organic pesticides was mentioned as an alternative option by many farmers, however they are rarely sold in local agro-shops. This situation is a major reason for non-compliance with organic regulation among certified cocoa farmers in Ghana (Awudzi et al., 2022). The adoption of PDM practices might also be influenced by farmers' economic concerns and the question whether increased dedication to cocoa production pays off. While Juhrbandt et al. (2010) and Bymolt et al. (2018) found that investing labour in good cocoa management is economically beneficial, Scudder et al. (2022) found that improved cocoa management required more labour input and was economically not viable for farmers at current cocoa prices.

Two years into the Covid-19 pandemic, schools reopened and life in Ugandan towns and cities was almost back to normal. This has motivated many people to return to their urban jobs and thus household labour availability changed again. It remains to be seen whether farmers return to hiring more labour, which labour-intensive practices they will prioritise given a reduced household labour availability, and whether the implementation of APDM will become established.

4.4.4 Labour availability for sustainable intensification of labour-intensive cash crops in smallholder systems

While our results only allow for cautious conclusions that increased household labour availability may promote SI in smallholder systems, past research has generated stronger claims. Access to resources and labour is often mentioned as one or the major barrier for SI in smallholder farming systems in Sub-Saharan Africa (Adolph et al., 2020) (Tittonell and Giller, 2013; Dahlin and Rusinamhodzi, 2019), including cocoa (Abdulai et al., 2020). Limited household labour availability can motivate farmers to use their time better and increase eco-efficiency (Heidenreich et al., 2022). Yet when household labour availability shrinks below what is needed, hired labour needs to fill the gap. Following this logic, the most resource-constrained farmers are less likely to implement practices for SI (van Vliet et al., 2021) (Martin et al., 2018;) and remain stuck in a 'poverty trap' (Tittonell and Giller, 2013). This might be exacerbated by sustainable sourcing practices, as better-off farmers are more likely to participate in sustainability certification of cash crops (Jones & Gibbon, 2011) (Jones and Gibbon, 2011; Dietz, Grabs and Chong, 2021) and sustainability initiatives and programs tend to focus on larger farms for efficiency reasons (Hirons et al., 2018).

Household labour investments in SI are also linked to opportunity costs, as farmers with low opportunity costs are more likely to adopt sustainable practices (Piñeiro et al., 2020; Wollni & Andersson, 2014). Different demographic trends have varied implications for labour opportunity costs (Chiarella et al., 2022). With increasing urbanisation and young people leaving farming, household labour availability will likely diminish and the cost of hired labour rise (Mithöfer et al., 2017) (Bymolt et al., 2018). As a result, farmers' opportunity cost to invest their labour on their own farm increases and the attractiveness of earning off-farm income as labourers may rise. In Uganda, Akoyi & Maertens (2018) calculated a daily revenue of 8249 UGX per person-day among coffee farmers; substantially lower than the average of 10,000 UGX in our sample. In rural regions with high population densities and few opportunities for non-agricultural employment, opportunity costs for household labour are low. Labour is thus best invested in farming activities to increase labour intensity (Chiarella et al., 2022). The loss of non-agricultural job opportunities due to

national Covid-19 regulation in our case study lead to low opportunity costs for household labour.

Future interventions aimed at promoting sustainable farming and intensification need to take labour as an important adoption barrier into account (Abdulai et al., 2020). This could be achieved by reducing labour demand through increasing mechanisation for smallholder farmers. In cocoa, pod breaking machines were developed with the aim of reducing post-harvest labour demand and injuries. Yet their uptake by farmers is low, potentially due to high investment costs. Smallholder farmers require options that are relatively low-risk and provide short-term returns on investment (Vanlauwe et al., 2014). Alternatively, labour investments in sustainable production and intensification practices could be incentivised (Martínez & Martínez Pachón, 2021) though pricing mechanisms like payments for ecosystem services or voluntary sustainability certification schemes to reduce opportunity costs. This might generate social-environmental co-benefits, which is a rare outcome of SI in low-income countries (Rasmussen et al., 2018). Our results confirm that labour availability is not the only barrier to SI. Knowledge about diverse practices (Adolph et al., 2020), trust in and perceived benefits of a practice (de Oca Munguia & Llewellyn, 2020), or membership in farmer organisations (Adolph et al., 2020; Meijer et al., 2015) are other factors influencing the SI of cash crop production in smallholder systems.

4.4.5 Limitations and future research directions

This study also faces some limitations. Our data did not distinguish between additional household labour through adult migrants or children, who provide different labour intensities. The return of migrants is furthermore associated with lower remittances, which might also influence farm management. Regarding data quality, we observed some uncertainties about estimates of farm size, applied input quantities, and expenditures. This was mostly due to the lack of official land titles with exact plot and farm sizes, which is a common situation (Vigneri et al., 2016), and the lack of bookkeeping that would allow the verification of input quantities and expenditures for the entire reference year. Collecting farm labour data is particularly difficult as substantial changes in a "normal" day are common and a recall bias exists, especially when covering an entire year (Arthi et al., 2018; Bymolt et al., 2018). To reduce this

bias, we only considered labour investments for the entire farm and did not quantitatively break them down to specific crops or farming practices. By collecting data identically at baseline and endline, the bias was considered to be constant and thus comparability granted. We furthermore included household size as a proxy for household labour with a lower measurement error. Future research should collect data on input and labour investments more frequently to reduce the recall bias and allow for disaggregation between different crops and tasks on one farm. This would enable a direct cost-benefit estimation for specific cocoa management practices, as in Dahlin & Rusinamhodzi (2019).

Our results provide insights on the influence of household labour availability on the adoption of SI practices in smallholder systems. We analysed a situation of increased labour availability, while other situations are characterised by a decrease of farm labour due to urbanisation and off-farm job opportunities. We cannot necessarily expect that the effects of changes in labour are symmetrical, i.e. that the effects of decreasing labour availability for farms that have already an established set of management practices are necessarily the converse of the effects of increasing labour availability. This deserves further research.

4.5Conclusions

We evaluated empirically the importance of labour availability for a sustainable intensification of labour-intensive cash crops in smallholder farming systems. More specifically, this study represents an original, rigorous analysis of the relationship between changes in household labour availability and pesticide use on smallholder cocoa farms, mediated by the use of alternative pest and disease management practices. We selected a cocoa case study and made use of a unique quasi-experimental setting, in which household labour availability increased due to national Covid-19 restrictions in Uganda. Comparing data for the years 2019, just prior to the Covid-19 outbreak, and 2021 showed that household labour availability increased, while hired labour decreased significantly within a sample of 194 cocoa farms in Mukono district of Central Uganda. Our results showed that increased household labour was first used to satisfy basic food needs, but was also invested in cocoa

production. Farms with increased household labour availability in 2021 compared to 2019 augmented their labour investments in cocoa production and alternative pest and disease management significantly more often than farms without increased labour availability. While our quantitative results only allow for a cautious conclusion that increased household labour availability influenced the adoption of alternative pest and disease management practices, they did confirm the important role of specific practices, namely phytosanitary measures and farm-made concoctions in cocoa, associated with a reduction in synthetic pesticide use on cocoa farms.

These results have implications for the sustainable intensification of labour-intensive cash crops in smallholder systems. The adoption of alternative PDM practices represent an important pillar for the reduction or elimination of synthetic pesticides from these systems. However, their adoption requires support and incentives, especially on labour or resource-constrained farms. While organic certification in theory provides economic incentives to eliminate the use of synthetic pesticides through a price premium, it had not yet been paid to farmers in this study. It remains to be seen if premiums are sufficiently high to motivate farmers to not only reduce pesticide use but also invest their limited household labour in alternative pest and disease management practices.

Chapter 5: Conclusions

This section concludes the work presented in this dissertation. I first outline the general findings (Section 5.1), then reflect on the methodological choices of this work (Section 5.2), outline the main contributions of this dissertation for science and policy (Section 5.3), provide a positionality statement (Section 5.4), and conclude with some overarching limitations and suggestions for future research (Section 5.5).

5.1 Main findings

Assessing farm-level sustainability in a comprehensive way offers the potential to simultaneously shed light on a wide array of indicators across sustainability dimensions. Comparing the farm-level sustainability performance within two diverse cocoa producer communities in Ecuador and Uganda in Chapter 2 revealed lowest sustainability scores in the social and good governance dimensions. Overall, results suggest similar sustainability challenges and opportunities for cocoa farmers in both samples and potentially even beyond. These results also show that the mere sourcing of cocoa through value chains that apply SSP does not assure that chocolate manufacturers are actually purchasing "sustainable" cocoa. While environmentally-friendly cocoa production holds important social co-benefits regarding human health and important economic co-benefits with respect to resource conservation for farms' long-term productivity, Chapter 2 also shows the co-occurrence of lower farm investments and profitability. This implies economic trade-offs of environmentally-friendly production.

Cocoa producers are not just farmers, but wives or husbands, entrepreneurs, community members – simply humans with complex decision-making processes and exposed to multifaceted constraints. Our results in Chapters 3 and 4 reflect the literature in that practice implementation and adoption is highly context-specific and heterogeneous. At the same time, the importance of value chains for food system transformation is increasingly recognised. Our results in Chapter 3 confirm that downstream companies have various levers within their own value chains to improve the sustainability performance of their upstream farmers. These include capacity

building and stable relationships between value chain actors, yet require resource transfer to provide farmers with the necessary resources to enact change as well as a common definition of sustainability goals for each value chain actor to appropriate and apply to their individual realities.

The role of household labour availability for sustainable intensification is gaining importance in light of demographic changes in farming communities with low mechanisation. Chapter 4 explores this role through the specific example of a rapid increase in household labour availability following a national Covid-19 regulation in Uganda and pest and disease management in cocoa. The results show no direct influence of a change in household labour availability on pest and disease management practices. However, they confirm the important role of specific practices, namely phytosanitary measures and farm-made concoctions in cocoa, associated with a reduction in synthetic pesticide use on cocoa farms. These results indicate that alternative pest and disease management is one important tool to reduce pesticide use in cocoa and thus contribute to the sustainable intensification of the sector.

5.2 Methodological reflections

5.2.1 Reliance on primary farm-level data

A substantial time of my dissertation was invested in collecting primary data from cocoa farms in Ecuador and Uganda. All data used for the empirical analyses in Chapters 2 to 4 were primary farm-level data. This allowed an in-depth look into two specific cocoa value chains, linking the farm level with buyers, exporters, and Swiss chocolate manufacturers, the sustainability initiative in place, as well as impacts of the Covid-19 pandemic. I highlight potential limitations to primary data collected through farmer interviews in Section 1.2.4, such as social desirability or recall bias. Despite being aware of these challenges and taking measures to reduce bias, for example by comparing input quantities mentioned by farmers with packaging sizes, they can not be fully eliminated. Within both case studies, the respective export companies collected farm-level data. These, however, did not cover sustainability comprehensively and were not of the rigor required for this study. Retrospectively, a

combination with other data sources might have helped to triangulate some information and increase its validity, such as the use of satellite images to corroborate farmers' statements on land use change.

The discussion on data validity from farmer interviews is especially important for the quantitative link between household labour availability and pest and disease management (Chapter 4). My experience confirms the difficulty of determining the estimated labour input on the basis of a one-time recall, as described by Arthi et al. (2018), especially when it comes to individual farming tasks. In this dissertation, we compared labour inputs between two years and collected data identically (same questions, same months/season), generating a similar and thus acceptable recall bias. Future research projects aiming to collect reliable farm labour data thus need to factor in the greater effort required for more frequent data collection, as for example the bi-weekly data collection implemented by Schader et al. (2021) to evaluate the performance of organic farming in Ghana and Kenya.

5.2.2 Farm-level sustainability assessment methodology

Using a standardised tool with a widely accepted reference framework to evaluate farm-level sustainability in this dissertation allowed me to compare between our cases and with prior research. The comparison between our cases shed light on similarities and differences between cocoa farming systems on two continents, while comparing with different smallholder farming systems or farming systems in the same countries (Ssebunya et al., 2019) allowed to identify more widespread challenges. Despite the values of standardisation, these approaches lack a context-specific adaptation and participatory selection of indicators that reflect the views and priorities of the researched community. Yet, there is an increasing call for inclusive approaches for sustainability and trade-off analyses (Hugé et al., 2013; Kanter et al., 2018). A standardised assessment followed by a participatory interpretation and discussion of the results might have been a valuable combination to bridge these seemingly contradictory expectations.

Covering a very broad range of topics relevant to comprehensively assess farm-level sustainability offered a multidimensional insight into farming households, farm

management, and cultural-social setting. However, I experienced the common trade-off of scope and precision in sustainability assessment methods (Binder et al., 2010; Schader et al., 2014). Specific measures, such as biodiversity impacts or farm profitability, were assessed efficiently and thus rather represent a rough estimation. A detailed assessment of species, genetic, and ecosystem diversity or comparing all farm revenues to costs would have provided more accurate results, yet been much more complex and not feasible within a single farm survey. I see great value in this very broad approach as a first screening step in assessing farm-level sustainability. Based on these results or explicit needs, resources could then be directed towards more in-depth analyses of specific sustainability goals.

The calculation of farms' level of goal achievement using the SMART-Farm Tool includes a trade-off estimation. For example, irrigating with ground water negatively affects the scores for water withdrawal, yet positively for stability of agricultural production. The direction and weight with which specific indicators influence specific sustainability goals in the tool was generated in an expert Delphi process (Schader et al., 2016). Just as the general sustainability assessment, this analysis also holds the trade-off between specificity and scope. Generating in-depth insights into site-specific, causal relationships between indicators or sustainability dimensions requires different approaches. For example, estimating trade-offs between productivity and environmental impacts requires a quantitative approach that was beyond the scope of my work. In this dissertation, I compared social and economic scores between farms with high and low environmental scores and thus assessed co-occurrences. Grouping farms according to their environmental performance, however, did not allow a differentiation between environmentally-friendly cocoa production by choice or by default (structurally different farms of smaller sizes with low input use generated high environmental scores in the SMART-Farm Tool). This differentiation would be important to better understand the trade-offs farmers are willing to make for environmentally-friendly cocoa farming.

5.2.3 Applied econometrics

Econometric models are useful to estimate the relationships between different variables or evaluate the effectiveness of interventions. In Chapter 3 of this

dissertation, I estimated the importance of value chain factors for practice adoption. In Chapter 4, I used a quasi-experimental approach to identify causal relationships between changes in household labour and pesticide use using panel data, making use of a quasi-experimental setting. As described in Sections 1.2.1 and 1.2.4, the design of these models and the quasi-experiment was rather flexibly, following changes to the original aims of this dissertation due to the Covid-19 pandemic, and after already having collected baseline data. While flexibility and creativity can advance research, they also hold potential difficulties. In this case, these included a potential omitted variable bias and a pre-defined sample size. Being able to plan the econometric analyses from the start might have resulted in some changes, such as a sample size selection based on power calculations that would have been better suited to detect changes in the outcome variable.

5.3 Main contributions of this dissertation

5.3.1 Scientific contributions

Scholars from diverse disciplines have assessed factors that influence cocoa farm management (e.g. Dessart et al., 2019; Piñeiro et al., 2020). In addition, much research has been devoted to the impact of cocoa farm management on sustainability (e.g. Blaser et al., 2018; NORC, 2020; Renier et al., 2022). Within this dissertation, I integrated these two themes, examining factors influencing cocoa farm management and the consequent sustainability impacts, and going beyond the state of the art in each theme.

As such, I first contribute to scholarship on the sustainability of cocoa production systems by advancing the comprehensive understanding of current sustainability challenges many (mainly smallholder) systems face, including potential trade-offs between sustainability dimensions. Using a standardised approach allowed for cross-country comparisons. By showing that major sustainability issues lie within the social and good governance dimensions of sustainability, I show that largely focussing on environmental impacts may not fully represent most pressing sustainability issues within these farming systems. Future sustainability assessments in cocoa production

systems should include important indicators from the social and governance dimensions, such as farmers' involvement in the farmer group and community, gender equality, or working conditions for farm workers.

Furthermore, I contribute to the understanding of factors that influence sustainable cocoa farm management, focussing on the under-studied factors of value chains and labour availability. I explored this in-depth in two specific value chains with variability of their relationships with individual farmers. This way, I extend knowledge gained in previous studies about the importance of value chain organisation and governance in bringing about change on farms at a larger level, such as Reis et al. (2020), who looked into supply chain stability, or "stickiness", and deforestation outcomes in Brazil, or Sellare et al. (2020a), who looked into cooperative characteristics and certification impacts in Côte d'Ivoire. I show that individual value chain characteristics can generate change among farmers. The results also show, however, that this potential was underutilised within these two case studies and potentially also beyond. This hints on the difficulty of developing suitable theories of change within SSP and then implementing them in a successful way. For example, while all farmers were offered to participate in trainings within both case studies, not all farmers did. With this detailed exploration of two value chains, I hope to inspire other researchers to combine this in-depth evaluation within single value chains with a wider assessment with greater value chain sample sizes to allow for generalisability.

Finally, this dissertation, to the best of my knowledge, includes a first empirical quantitative assessment of how sustainable cocoa farming, specifically pest and disease management, changes following a fast increase in household labour availability. In this specific case, the role of household labour availability was weaker than hypothesised. By showing that alternative practices play an important role in reducing synthetic pesticide use by cocoa farmers, this dissertation contributed to the discussion on potential pathways to low/no-pesticide production. This is important beyond the cocoa sector in other smallholder cash crop farming systems, especially in countries with high use of highly hazardous and/or unregulated pesticides like Uganda (Yiga, 2022).

5.3.2 Policy relevance

Severe sustainability challenges in cocoa farming systems remain, despite two decades of SSP, even in the "sustainable" cocoa segment. Food system transformation, including the cocoa sector, is necessary to reach the SDG targets (IPCC, 2022; Webb et al., 2020). Findings in this dissertation emphasize that this transformation should address the social and governance dimensions of sustainability due to their major shortcomings. While agronomic decisions are taken by individual farmers and thus justify farm-level interventions that focus on agri-environmental practices, social and governance decisions rather depend on the wider socio-political system in which farmers operate. This highlights how current SSP may not totally align with the results of comprehensive sustainability assessments, but also the potential limits of their influence. Already, multi-stakeholder initiatives exist to address particularly salient sustainability challenges that go beyond farm-level decisions, such as child labour (NORC, 2020). Our results thus support current developments, which address both the farm and wider landscape level, such as jurisdictional approaches (Lambin & Thorlakson, 2018; von Essen & Lambin, 2021). These might be more effective in generated the needed change in the social and governance dimensions, even beyond those farms forming part of SSP and thus extend their reach.

The co-occurrence of high environmental performance and low scores in important economic farm performance hint on the existence of economic trade-offs of environmentally-friendly cocoa farming. Ambitions towards more environmentally-friendly cocoa thus requires compensation, as already suggested by past research (e.g. Vanderhaegen et al., 2018). This is specifically important since farms with highest environmental performance were small farms with low input use and lower revenues. These results confirm observations that households with less resources benefit less from sustainable value chains (van Vliet et al., 2021) and indicate a conflict between SSP in the cocoa sector and the "leave no one behind" notion of the SDGs (Mausch et al., 2020). A concrete example to generate synergistic effects between more environmentally-friendly cocoa farming and economic development beyond the farm level includes private or public support of entrepreneurs to produce ready-made organic inputs. Many farmers in these samples mentioned their limited availability at

local agro-shops and their willingness to pay for them. Off-farm jobs are crucially needed to diversify income sources, especially among farms with small land resources, and enable rural households to generate living incomes (van Vliet et al., 2021).

While knowledge about the impact of voluntary sustainability certification on environmental and socio-economic outcomes is well advanced, very little is known about the effectiveness of different sustainability initiatives in the value chain, such as company programmes. For large private actors at the downstream end of cocoa value chains, this highlights a need for in-situ studies with clear counterfactuals and transparently communicated results. This would foster a wider learning process for the entire sector and contribute to faster, transformative change. While a growing number of companies have internal monitoring and evaluation frameworks in place (Thorlakson, 2018), data collection is diverse in rigor and scope. Standardised protocols for monitoring and evaluation of SSP, such as within the World Cocoa Foundation's CocoaAction initiative or the framework by the Swiss Cocoa Platform, can help decision-making towards more cost-effective SSP.

Despite substantial sustainability challenges in cocoa producer communities and a lack of large-scale improvements, cocoa traders/processors and chocolate manufacturers have been doing economically well. Consequently, public policy in producer and consumer countries has to step up and provide an enabling environment for truly sustainable cocoa farming systems and sourcing practices. Smart mixes of voluntary and binding measures can motivate private companies and thereby contribute to sustainable value chains, even beyond the jurisdiction of consumer countries (Home et al., 2021). For public policy, this requires identifying which (set of) measures can support and strengthen private initiatives in the cocoa sector and other global value chains with similar structures and characteristics.

5.4 Positionality statement

I am a white woman with Central European education and residence, yet brought up in and with strong familiar ties to Latin America. My views of the world are thus influenced by diverse cultural and value systems and this might allow me to

understand better the different realities of people. But this surely does not apply equally across the globe. Ugandan culture was much more "foreign" for me than Ecuadorian culture, potentially also influenced by the existing language barrier between farmers and I in Uganda. The connecting language in Ecuador allowed me to personally collect primary data without losses in translation. Despite spending several months in each producer community, this situation might have influenced my understanding and interpretation of data from both case studies. At the same time, I believe that my personal history and cultural competences have facilitated the data collection in both countries, including the coordination with the local team and partners and organisation of logistics.

Being a white woman and a foreigner in both producer countries did not go unnoticed in the villages or on the farms. Furthermore, the data collection was done by myself and a team in each country, all of whom were outsiders to the specific farming communities. These aspects might have generated initial distrust or false expectations among the interviewees. Distrust, as farmers feared governmental representatives in both countries: Ecuadorian farmers were often afraid of losing their social welfare payments, Ugandan farmers feared registration and taxation. False expectations, as some farmers might have hoped to gain something from participating in this study, simply as a result of my presence and as the research was organised by a Swiss institute. At the start of each interview, we made sure to take sufficient time to clarify our aims, use of data, and that farmers were free to deny their participation, which few farmers did. Contrary to many reports of fatigue by (mainly West African) cocoa farmers to participate in research projects, the vast majority of farmers in our samples were very open to share details about their farms and households, including sensitive topics, often even happy to share their stories.

Despite my background, I can surely not free myself of a certain Eurocentricity in my views, which might be reflected in this dissertation. After all, cocoa production and trade itself is a result of colonial history, in which European countries outsource(d) many sustainability problems to other continents. I adopted a definition of sustainability, for example, which reflects the views of a global institution but is probably still strongly influenced by actors and views from industrialised nations. This definition and consequent method is accepted in academia, but it might not

necessarily reflect farmers' views and priorities. I conducted this research within the framework of a project by the Research Institute of Organic Agriculture (FiBL) and personally recognise important benefits of organic agriculture. But I also see its limits, especially for smallholder cash crop producers in low-income countries. Thus, I do not equate organic farming or certification with sustainable farming from a comprehensive point of view.

Finally, as farmers are amongst the weakest stakeholders in the global cocoa value chain, I have been inclined to generate much more empathy for their struggle and be on their side compared to the larger companies within our case studies. By closely collaborating and interacting with these companies, however, I aimed to get a better understanding of their realities and reduce this bias. Despite being an outsider to the cocoa growing communities and value chains studied in this dissertation (except for my participation as a chocolate consumer), I hope that this work can generate important insights and benefit the sector.

5.5 Limitations and future research directions

As all research, this dissertation faces some limitations. I mention specific limitations and directions for future research in the individual chapters and explored overarching methodological limitations in Section 5.2. Additionally, this dissertation covers only two case studies and both represent cocoa value chains with sustainability initiative. Integrating producer communities in Ecuador and Uganda holds the disadvantage that past research on cocoa has mostly targeted West African countries and caution is required as I discuss our results in light of this literature. At the same time, I contribute to the research gap on cocoa beyond this geographical area. For a globally-representative picture, more research in other producer countries is necessary. The inclusion of more producer countries and case study value chains in this research would have increased the global validity of results and should be subject of future research. By selecting only farmers from the "sustainable" cocoa segment, our results might be biased in the sense that practice adoption may be influenced by farmers' participation in the sustainable sector.

Furthermore, this dissertation also faces the major ethical limitation of not having given back to participating farmers. The project budget allowed discussing project results with participating companies, including Swiss chocolate brands and cocoa traders. It did not, however, include a budget to present aggregated data to participating farmers. This would have been useful to jointly discuss the implications of the results and potential solutions for improvement.

The research project in the framework of which my dissertation took place was planned in a transdisciplinary way. It integrated chocolate manufacturers in the selection of an intervention based on the baseline results, which was then implemented by the companies and evaluated within the project. Implementing inclusive approaches requires accepting that projects develop in a different way than foreseen and the final outcomes may diverge from the planned outcomes. Future research on such complex or 'wicked' problems as sustainability issues in the cocoa sector should explicitly include mechanisms to foster transdisciplinary approaches, as proposed by Lang et al. (2012) and implemented in the context of cocoa by Thompson et al. (2022). This could democratise research on and global cocoa value chains themselves.

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