Sustainability certification, climate risk perception and smallholder coffee production in Rwanda

Dissertation

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Summary

Coffee production is an important source of export revenue for producing countries, especially for small, agriculture-dependent economies like Rwanda. Coffee production is a key driver in the development and improvement of rural livelihoods, serving as a source of cash income for the many coffee-producing households. The coffee value chain in Rwanda changed visibly since the early 2000s. Since then, the number of Coffee Washing Stations increased considerably, as did the share of fully washed coffee production. Rwanda's coffee sector is now a well-established player in the international speciality coffee market.

Despite considerable improvements, productivity remains low, as farmers struggle with pests and diseases, poor soil fertility and insufficient access to fertilisers. These challenges faced by coffee producers call for suitable and sustainable solutions. With coffee farmers also facing the repercussions of progressing climate change, the present dissertation aims to identify ways to support smallholder coffee producers in their efforts to respond to the challenges they face. Therefore, the thesis taps into two important fields of research on coffee producers – climate change adaptation and sustainability certification. First, the thesis evaluates the role of certification in improving farmers' economic and environmental performance. Secondly, it addresses the question of how farmers respond to climate change, and how they can be supported in their efforts. The dissertation consists of two case studies from Rwanda and one chapter reviewing the literature on climate change adaptation. The data for the empirical research was collected from September to December 2019 in three climatic regions in Rwanda.

The first empirical essay analyses the relationship between Rainforest Alliance certification and environmental-economic outcomes. Results show that certification is significantly correlated with good agricultural practices and biodiversity-related practices. Overall, environmentally friendly practices are commonly used in the research area, and they are more prevalent in the regions more suitable for coffee production. Rainforest Alliances' ability to increase adoption of good agricultural practices is thus higher in regions where initial adoption rates are lower. The connection between the certification and good agricultural practices hence appears to be stronger in the region less suitable for coffee production, where previous adoption rates are lower than in the regions more suitable for coffee production.

Results show no significant association between Rainforest Alliance and socio-economic indicators. The economic outcomes considered in this study depend on other external factors, while the use of good agricultural practices is required to become Rainforest Alliance certified. The increased adoption of good agricultural practices is, therefore, to be expected. The study shows that Rainforest Alliance is indeed able to attain changes in prevalent farm practices.

Effects of certification on economic outcomes and biodiversity-related practices are linked, yet synergies and trade-offs differ across climatic regions. Shade tree density and income simultaneously rise under certification in the regions more suitable for coffee production, pointing towards synergies between these outcomes. Nevertheless, in the region least suitable for coffee production, there is some evidence for minor trade-offs between outcome categories. Here, Rainforest Alliance is associated with either an increase in shade tree density or income.

The second empirical essay investigates the link between smallholder coffee farmers' perception of adverse weather events and their adjustments to them. The study shows that coffee farmers in Rwanda differ regarding their risk perceptions, as four groups based on farmers' risk perception were distinguishable. Farmers perceived adverse weather events as low, medium or high risk for their livelihoods, or perceived only specific events as a threat. Results indicate that farmers' risk perception is connected to changes in the timing of the seasons and the expected amount of precipitation. On a regional level, we can see that farmers differ significantly regarding their experiences and perceptions of specific weather events. Farmers in the region least suitable for coffee production have a significantly higher risk perception regarding the timing and length of the dry season and a short and/or late wet season compared to the other two regions. This is also evident when considering farm-level aspects connected to risk perception, where agro-ecology is the most important factor associated with risk perception.

Farmers' adjustment decisions are closely linked to their risk perception. Yet, their adjustment strategies often represent reactive response actions. This is even more so the case in the region least suitable for coffee production. Farmers located in the regions more suitable for coffee production are more likely to choose more sustainable, farm-based adaptation strategies. Farmers located in the region less suitable for coffee production tend to rely more strongly on short-term adjustment strategies, specifically selling assets and spending cash savings.

The Literature Review evaluates climate change adaptation measures already implemented by coffee farmers, factors influencing their adoption and opportunities to support coffee producers' adaptation. Therefore, keyword searches on the platforms *Web of Science* and *ScienceDirect* were conducted. The literature thus identified was then systematically evaluated to identify relevant studies based on pre-defined criteria.

Reviewing the literature on climate change adaptation adopted among smallholder coffee producers, we find that farmers' responses to climate change are diverse. They can be broadly distinguished into three categories, i.e., Farm-based management approaches, Household strategies and Knowledge and investment. Studies on the adoption of adaptation measures mostly include farm-based management approaches. The majority of current adaptation research focuses on incremental adaptation, i.e., measures that can be implemented in existing systems.

With respect to influencing factors on climate change adaptation, the review shows that a diverse set of indicators has been found to significantly affect farmers' decision making. Although socio-economic factors such as farm size and education, social capital and income sources play an important role in farmers' adaptation, exposure to and perceptions of climate change are as important. Education, extension services and the availability of objective climate information were found to be significant influences on climate change adaptation in several studies. To improve farmers' adaptive capacity, campaigns and participatory approaches present important tools for raising farmers' awareness of climate variability.

Studies on climate change adaptation differ considerably in methodology and scope. There is a notable lack of comparability across studies and geographical regions where research has been conducted. Standardizing the conceptual framing and the methodological approaches may allow identifying cross-regional patterns in farmers' decision-making. Furthermore, incorporating the assessment of multiple stressors may increase the success of planned adaptation interventions and development projects. Lastly, combining research on farmers' vulnerability/adaptive capacity with actual adoption rates as well as research on the suitability of specific adaptation strategies can give insight into the effectiveness of specific adaptation strategies to decrease farmers' vulnerability and increase their resilience.

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When you have a great and difficult task [..], if you only work a little at a time, every day a little, suddenly the work will finish itself. Karen Blixen

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Abbreviations

ADPO	Average Difference in Predicted Outcomes
CWS	Coffee Washing Stations
FAO	Food and Agriculture Organization
GoR	Government of Rwanda
hh	Household
HFIAS	Household Food Insecurity and Access Scale
ICO	International Coffee Organization
IPW	Inverse Probability Weights
IPWRA	Inverse Probability Weights Regression Adjustment
IPM	Integrated Pest Management
m.a.s.l.	Meters above sea-level
MLR	Multinomial Logistic Regression
MVP	Multivariate Probit Model
NAEB	National Agricultural and Export Board
RA	Regression Adjustment
RAB	Rwandan Agricultural Board
RwF	Rwandan Franc

1. General Introduction

Coffee is a tropical crop cultivated in over 50 countries along the equator. For many coffee producing countries, mainly low and middle-income countries, export earnings from coffee present an important source of income (ICO, 2014). In volume, global coffee production has increased by more than 60% since the 1990s. At the same time, the value of annual cross-border coffee exports has more than quadrupled (ICO, 2020), as most of the global coffee production is exported, particularly to North America and Europe (Voora et al., 2019). Only one-third of global production is consumed domestically, making coffee one of the most widely traded agricultural commodities worldwide (ICO, 2020).

Coffee is an important driver of rural development, providing income for millions of people worldwide (ICO, 2014). Yet, coffee production faces many challenges: Environmental problems such as the depletion of natural resources, progressing climate change, and increasing incidences of pests and diseases put pressure on coffee producers. The intensification of coffee plantations contributes to further environmental degradation, resulting in a loss of biodiversity and associated ecosystem services (Jezeer and Verweij, 2015). Changing climatic conditions put additional pressure on coffee producers by causing the loss of areas suitable for coffee production and decreasing coffee yield production (Bunn et al., 2015b; Ovalle-Rivera et al., 2015).

Supporting farmers' livelihoods in fragile, biodiverse regions is thus a priority for many agencies and national governments. Economic incentives for farmers are needed to adopt and maintain sustainable farming practices (Haggar et al., 2017). Farmers also need to implement strategies to adapt to the challenges presented by climate change (Baca et al., 2014; Mulinde et al., 2019). Consumers are also increasingly aware of the challenges producers face, leading to and rising demand for sustainably produced coffee, particularly in the European market (CBI Ministry of Foreign Affairs, 2021). In this context, certification schemes such as Fair Trade, Organic or Rainforest Alliance, support roasters, retailers and consumers to identify coffee produced more sustainably compared to the conventional, non-certified alternative.

Given the many challenges faced by coffee producers and the need for suitable and sustainable solutions, the present dissertation aims to identify ways how smallholder coffee producers can be supported in their efforts to respond to these challenges they face. Therefore, the thesis addresses two important fields of research on coffee producers – climate change adaptation and sustainability certification.

1.1 Sustainability Certification

Sustainability certification is a voluntary market-based instrument to promote more sustainable production systems. Standards such as Fairtrade, Organic, and Rainforest Alliance have gained importance over recent years, as they promise to promote environmentally friendly production while improving farmers' livelihoods by way of increasing their market access (Meemken, 2020). Coffee is one of the tropical crops specifically targeted by sustainability certification. The tropics are home to most of the world's biodiversity, and weak institutions in the producing countries may be unable to implement effective environmental regulations. There is also a great need to improve the livelihoods of smallholder farmers producing export crops such as coffee (DeFries et al., 2017).

Certification in the coffee sector emerged in the 1980s, with non-governmental organizations and private sector actors guiding consumers toward coffee which is produced more sustainably. This meant considering environmental issues such as biodiversity conservation, or social issues such as worker health and safety in the production process while trying to provide larger economic gains for producers (Voora et al., 2019). Coffee was thus one of the first products traded on the global market where collective efforts tried to address socio-economic and environmental issues (Giovannucci and Ponte, 2005). Since then, the share of the coffee market certified under voluntary sustainability standards has increased considerably: Between 2008 and 2016 alone, certified coffee production increased by 24 per cent, accounting for at least 34 per cent of overall coffee production (Voora et al., 2019).

The most important certification schemes in the coffee sector are Organic, Fair Trade and Rainforest Alliance certification. They vary concerning the aspects they emphasise – from social conditions to environmental protection – and rely on different strategies to enhance sustainable production practices. Organic certification emphasizes environmental aspects of (coffee) production and aims to promote natural soil activity and prohibits synthetical fertilizer (Giovannucci and Ponte, 2005). Fair Trade focuses particularly on the social and economic dimensions of sustainability. The standard aims to improve farmers' livelihoods through facilitating long-term trading partnerships, paying a minimum price to cover the average costs of sustainable production and improving market access (Fairtrade

International, n.d.). Rainforest Alliance certification includes criteria on environmental issues, such as biodiversity and forest conservation, as well as social and economic outcomes for smallholder farmers, such as employment conditions and wages for farm workers (Rainforest Alliance, 2017).

Investigating the effect of sustainability standards is relevant, as the share of production adhering to those standards is rising. The certification schemes often promise to foster more sustainable production systems, and minimizing the trade-offs between food production and biodiversity conservation (Mitiku et al., 2018). The success of voluntary certification programs relies strongly on their ability to obtain benefits on the ground: Producers will only follow the criteria set by the standards if they perceive that they will be better off than they would otherwise (DeFries et al., 2017). Previous research found that participating in certification schemes reduces farmers' livelihood vulnerability (Bacon, 2005; Donovan and Poole, 2014), positively affects education, infrastructure investment and monetary savings (Bacon et al., 2008) and increase income and reduce poverty (Chiputwa et al., 2015; Mitiku et al., 2017a; Vanderhaegen et al., 2018). Environmentally, certification can improve coffee growers' environmental performance, reduce chemical input use and increase the adoption of environmentally friendly management practices (Blackman and Naranjo, 2012). Coffee certification programs offer the potential to protect biodiversity (Philpott et al., 2007) and present a way to connect environmental and economic goals (Perfecto et al., 2005). It is also connected with increased forest cover (Rueda et al., 2015) and decreased deforestation (Takahashi and Todo, 2013). Yet, the effect of certification on overall sustainability remains unclear as research mainly focuses on either economic or environmental implications (Vanderhaegen et al., 2018).

1.2 Climate Change Adaptation

Climate change and climate variability are among the most widespread challenges affecting agricultural production (Asayehegn et al., 2017). The expected higher temperatures and changes in precipitation patterns due to climate change also alter crop suitability and land use in many regions (Bro, 2020). The effects of climate change are expected to become more severe over time: Seasonal droughts will rise in frequency and length, and floods due to increased and erratic rainfalls will occur more often (IPCC, 2007). These projected effects will substantially affect the agricultural sector (Lasco et al., 2014). To reduce the adverse effects of climate change, farmers take measures to achieve their food, income and livelihood security (Hassan and Nhemachena, 2008).

Rural farm households in low-income countries will be affected by the consequences of climate change disproportionally, as they are highly dependent on natural resources for their income generation (Bro, 2020). Plantation crops such as coffee are particularly vulnerable to climate change due to their long economic life span, non-irrigated cultivation and high upfront cost (Gunathilaka et al., 2018). Climate change may lead to changes in geographic ranges suitable for coffee cultivation, crop productivity and quality (Bunn et al., 2015b; Ovalle-Rivera et al., 2015). Unsustainable farming practices, e.g. shifting from complex agroforestry systems to monoculture or overusing chemical inputs, further compromise the productive potential of the coffee-growing regions (Bro et al., 2020). This has notable implications for farmer livelihoods and management decisions (Ahmed et al., 2021), and climate change adaptation, therefore, takes a centre stage in the agricultural development discourse (Mulinde et al., 2019).

Climate change adaptation describes changes made by farmers in response to observed or expected stimuli. Adaptation aims to mitigate risk from future threats or take advantage of opportunities associated with environmental change (IPCC, 2007). In the coffee sector, there is a growing need to understand the incentives for household and farm-level adaptation to climate change (Bro et al., 2020). Better understanding how farmers adapt to climate change and considering their needs in the adaptation process will support the development of appropriate and targeted climate change adaptation policies (Eshetu et al., 2020). At the same time, climate change adaptation is place- and context-specific, with local communities being a key factor in the process (Huggel et al., 2015). Smallholders' knowledge of adaptation based on their experiences may be useful for developing planned adaptation strategies (Burnham and Ma, 2016). To develop well-targeted adaptation policies, a better understanding of factors shaping farmers' adaptation to climate change is necessary (Below et al., 2012).

1.3 Research Objectives

The thesis aims to identify ways how smallholder coffee producers can be supported in their efforts to respond to these challenges they face. Therefore, the dissertation has two objectives: First, the thesis evaluates the role of certification in improving farmers' economic and environmental performance. Secondly, it addresses the question of how farmers respond to climate change, and how they can be supported in their efforts.

1.3.1 Research objective 1

The first empirical essay evaluates the role of certification in improving farmers' economic and environmental performance. Evidence on environmental and economic outcomes of sustainability certification already exists, but few studies to date investigated them jointly (Haggar et al., 2017; Ibanez and Blackman, 2016; Vanderhaegen et al., 2018). Accordingly, whether certification can improve farm-level environmental and economic outcomes simultaneously remains an open question. Nevertheless, understanding how certification affects economic and environmental benefits simultaneously is as important as recognising opportunities to reconcile them (Jezeer et al., 2017). The study investigates the relationship between Rainforest Alliance certification and socio-economic as well as environmental outcomes in Rwanda, including potential trade-offs between dimensions. This leads to three specific research questions:

a) Is Rainforest Alliance associated with an improved uptake in good agricultural practices and increased economic outcomes for farmers?
b) Are there trade-offs between these outcomes, i.e., how are changes associated with Rainforest Alliance in one dimension affecting changes in the other dimension?
c) Are the effects associated with Rainforest Alliance differing depending on regional climate?

1.3.2 Research objective 2

To reduce the adverse effects of climate change, farmers take measures to achieve their food, income and livelihood security (Hassan and Nhemachena, 2008). Better understanding how farmers adapt to climate change and considering their needs in the adaptation process will support the development of appropriate and targeted climate change adaptation policies (Eshetu et al., 2020). Climate change adaptation is place- and context-specific, with local communities being a key factor in the process (Huggel et al., 2015).

Awareness of climate change is an important factor in adaptation. It nevertheless does not equate with the perception of climate change presenting a risk. Risk perception is nevertheless an important factor in climate change adaptation (Hyland et al., 2016): If farmers do not perceive climate change as a threat, they will not take measures to mitigate its effects (Ndamani and Watanabe, 2017). However, while most studies investigate farmers' perception of changing patterns and their response actions separately, evidence on the connection between risk perception and adjustment is scarce (Asayehegn et al., 2017).

The objective of the second empirical study is thus to discover patterns in farmers' perception of adverse weather events, identify factors influencing the perception and finally analyse how farmers' perception of adverse weather events relates to measures adopted to mitigate the effects of adverse weather events. The essay, therefore, addresses the following questions:

a) Do coffee farmers in Rwanda perceive adverse weather events as a risk for their livelihoods, and if so, are there differences in what farmers perceive as a risk?
b) Do experiences of adverse weather events and household characteristics shape farmers' risk perception?
c) How does farmers' risk perception of adverse weather events associate with farmers' adjustment to the same events?

The question of how farmers respond to climate change and how they can be supported in their efforts is addressed by reviewing the literature on climate change adaptation among coffee producers, and by empirically evaluating famers' perception of and adjustment to adverse weather events. The literature review addresses the following questions:

a) How do smallholder coffee producers adapt to a changing climate or other livelihood stressors?
b) What are the factors influencing the adoption of adaptations and to what extent have such factors been identified?
c) What are current research gaps?

1.4 Study Context

Rwanda is a landlocked East African country covering 26,338 square kilometres. With 12.9 million citizens and an annual population growth rate of 2.6% in 2020, Rwanda is among the most densely populated countries in Africa (World Bank Group, 2021a). It is also known as “Land of A Thousand Hills” due to its steep landscape and altitudes ranging from 900 to 4500 m.a.s.l. (Prasad et al., 2016). Rwanda is highly dependent on agriculture, and around two-thirds of the national territory is cultivated. Besides the large share of agricultural land, Rwanda is characterised by diverse ecosystems which include mountain rainforests, gallery forests, savannah woodland, wetlands and aquatic forests (World Bank Group, 2021a).

During the civil war in the early 1990s and the subsequent 1994 genocide, approximately 800,000 Tutsi and politically moderate Hutu were killed within 100 days. The civil war left many more people displaced, and millions of refugees returning from DR Congo and Tanzania still needed to be resettled in 1999 (Guariso and Verpoorten, 2018). Yet, since the civil war and genocide, Rwanda development has been considerable. Since the early 2000s, Rwanda’s real GDP per capita growth has been considerably higher than the sub-Saharan African average. This was accompanied by improvements in other measures of economic development, *e.g.* rising life expectancy, increasing primary school completion rate, and a fall in rural headcount poverty (Takeuchi, 2019).

The country is divided into the administrative units of Province, District, Sector and Cell. Rwanda consists of four Provinces, the Northern, Southern, Eastern and Western Province, and the City of Kigali. Besides the Province-level, it is divided into 30 districts, 416 sectors, and 2148 cells. The government decentralization process, which started in 2001, led to establishing stronger local governments and districts that are now autonomous administrative entities with financial autonomy. Sectors and cells also developed into administrative units with specific responsibilities. Sectors for example manage public assets or coordinate activities of special government programs. Cells monitor the delivery of services to the population, prioritise activities for poverty reduction and monitor the implementation of these programs (GoR, 2022).

1.4.1 Coffee production in Rwanda

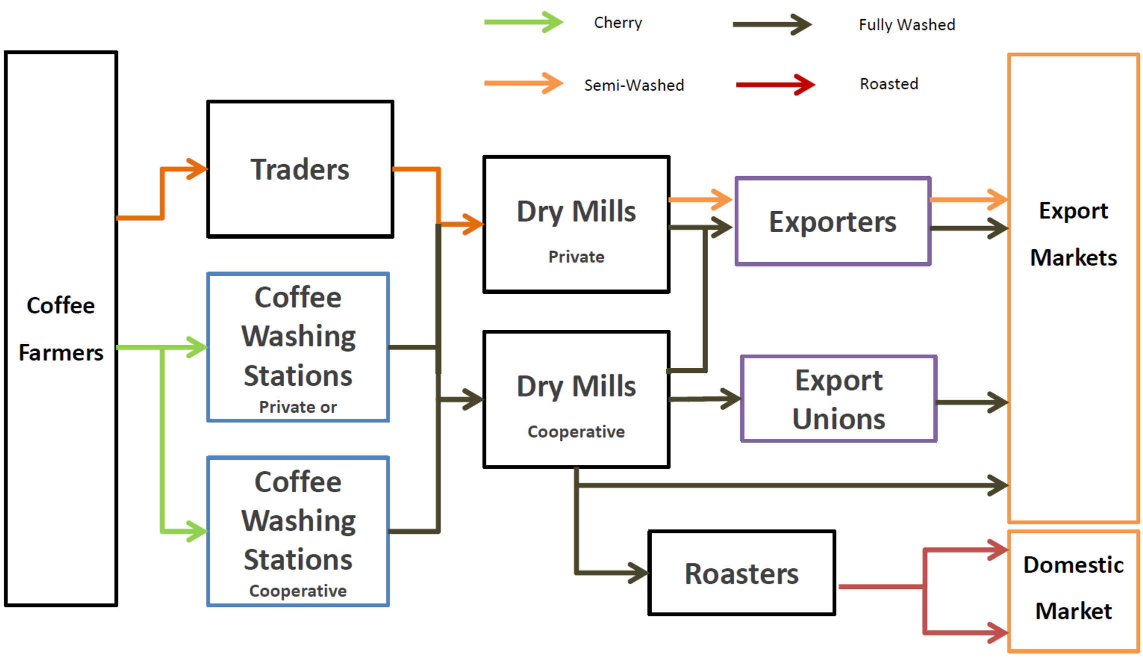
Agricultural activities and the cultivation of cash crops are central to improving living standards and reducing poverty in Rwanda. Coffee represents, besides tea, Rwanda's major export crop and is increasingly recognised as a high-quality product (FAO, 2021). The vast majority of coffee produced in Rwanda is Arabica coffee (Behuria, 2020). Introduced by German missionaries in 1904, the Belgian rulers made cultivation compulsory in 1933 (Guariso and Verpoorten, 2018). When Rwanda became independent in 1962, the post-colonial government prohibited the uprooting of coffee trees. Today, around 400,000 smallholder farm families rely on coffee production, farming about 42,000 ha of coffee plantations (NAEB, 2019). Despite its dependence on coffee for its export revenues, Rwanda remains a ‘price-taker’ on the global market due to its small share of global coffee production (Behuria, 2020).

The volcanic soils, high altitudes and balanced rainfalls create ideal coffee growing conditions so that Rwandan coffee is among the most competitive in the world. Coffee is harvested in Rwanda between March and July. After picking the ripe coffee cherries, they need to be processed into parchment coffee before export. As visualized in Figure 1, coffee farmers in Rwanda sell their coffee either to traders (directly or via middlemen) or sell to so-called Coffee Washing Stations (CWS). The CWS can be privately owned or run by a cooperative. Coffee is then sold to cooperatively or privately owned dry mills, which prepare the green coffee beans for export or local roasting. While the majority of the coffee is sold internationally via export companies or unions, a small proportion of the coffee is roasted locally and consumed domestically (AgriLogic, 2018).

Besides processing coffee, CWS also provide extension and support to farmers within their operational area. Seedlings, fertilizer, and other inputs are often distributed through CWS on receipt of coffee cherries from farmers. However, the governments’ zoning policy from 2016 also limits where and to whom producers can sell coffee cherries (Behuria, 2020). Rwanda's government aims to increase the share of fully-washed coffee, as fully-washed coffee is of higher and more consistent quality than semi-washed coffee (Blouin et al., 2017). The number of CWS has thus been continuously increasing since the early 2000s, as has the percentage of fully washed coffees. In the 2016/17 season, fully-washed coffee accounted for two-thirds of production (AgriLogic, 2018).

CWS also play an integral part in sustainability certification. Since 2014, an increasing share of Rwandan coffee production has been certified under voluntary sustainability standards. Besides Fair Trade and Organic, Rainforest Alliance represents the most prevalent scheme (AgriLogic, 2018), with an estimated certified production of 5590 metric tons of coffee in 2020 (Rainforest Alliance, 2021).

Figure 1.1 Coffee Value Chain in Rwanda



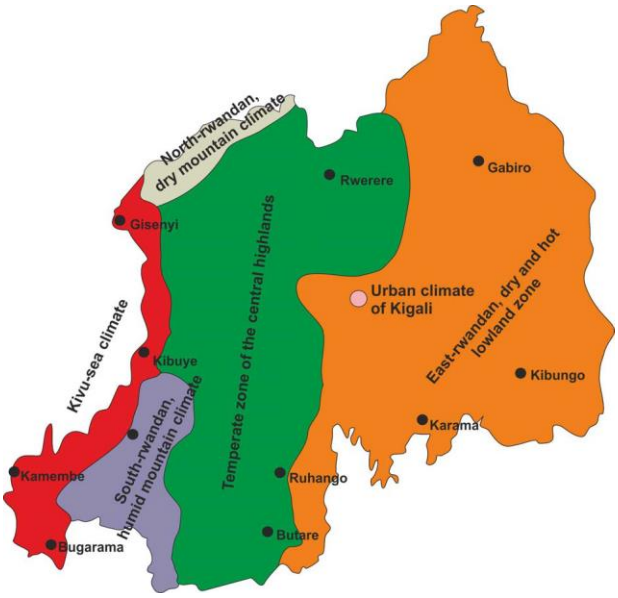
Source: Own representation based on (AgriLogic, 2018).

Despite considerable improvements since the early 1990s, productivity still is among the lowest in East Africa (ICO, 2015). Limiting factors to yield production are pests and diseases, and adoption levels of good agronomic practices such as weeding, pruning, fertilisers, and soil erosion control are low (Ngango and Kim, 2019). Additionally, coffee farmers are faced with poor soil fertility and insufficient access to fertilisers, old and less productive coffee trees, low prices compared to competing for crops (AgriLogic, 2018). Commercial input use among coffee producers is very low, and most labour used in coffee production is manual. At the same time, coffee production represents a primary source of cash income for purchasing household goods and food (Ortega et al., 2019), showing the necessity to identify strategies to further support and improve the coffee sector.

1.4.1 Climate and Climate Change in Rwanda

For a tropical country, the climate in Rwanda is comparatively temperate. Due to its proximity to the equator, temperatures are very stable all year, with an average annual temperature is between 14 and 23°C, and annual precipitation ranges between 850 and 1800 mm. Nevertheless, there is a clear seasonality in precipitation. A dry season, characterised by less than 30 mm of precipitation per month, takes place from June through August. It is followed by a short wet season in October and November, which is characterised by more than 125 mm precipitation per month. A second medium-dry season takes place from December to February with precipitation levels from 80 to 120 mm per month. The second wet season with more than 125 mm precipitation per month takes place from March through May. The variation in precipitation, average temperature and elevation are important factors in crop production patterns throughout the country (Prasad et al., 2016).

Figure 1.2 Climatic Regions and their development in Rwanda



Source: (Henninger, 2013)

Rwanda has four primary climatic regions: eastern plains, central plateau, highlands, and regions around Lake Kivu. Rising gently to the west and characterised by a savannah climate, the "East-Rwandan dry and hot lowland zone" stretches in the east (Figure 1.2). The eastern plains receive an annual rainfall of between 700 mm and 1,100 mm, with mean annual temperature oscillating between 20°C and 22°C (World Bank Group, 2021b). The lowlands in the east connect the "Temperate zone of the central highlands". With the increasing elevation towards the west, rainfall also increases. Yearly temperature swings are less pronounced, and the temperate highlands zone is for that reason Rwanda's most fertile agricultural region (Henninger, 2013). The region enjoys rainfall of between 1,100 mm and 1,300 mm, with an annual mean temperature of between 18°C and 20°C (World Bank Group, 2021b). The third climate zone covers the mountain range of the Congo-Nile watershed ("Crête Congo-Nil") in the south and the volcanic chain of the Virungas in the north, which can be described as Rwanda's "Mountain climate" (Henninger, 2013). These highland regions benefit from an annual rainfall of between 1,300 mm and 1,600 mm and experience annual mean temperatures between 10°C and 18°C (World Bank Group, 2021b). The Lake Kivu Rift Valley presents Rwanda's fourth distinct local climate zones shaped by the land-lake-wind circulation and interacting high evaporation rates. The circulation causes sufficient rainfalls on the western slopes of the Congo-Nile mountain range (Henninger, 2013). Regions around Lake Kivu and Bugarama plains get an annual rainfall of between 1,200 mm and 1,500 mm with annual mean temperatures between 18℃ and 22℃ (World Bank Group, 2021b).

The Rwandan agriculture sector is already subject to a changing climate with rising average annual temperatures observed since the 1950s and shifts in the timing of precipitation increasingly being reported (USAID, 2011). In the southwestern and eastern regions of Rwanda, the mean temperature increased between 1.4°C and 2.6°C from 1971 to 2016. From 1961 to 2016, fluctuations in annual rainfalls became more and more visible. Mean rainfall considerably decreased in January, February, May and June, but increased September to December across the country (World Bank Group, 2021b).

Severe weather events have imposed heavy costs in Rwanda. There are also observable regional differences with droughts in the southern and eastern parts of the country resulting in severe famines and erosion, flooding, and landslides caused by heavy rainfall in northern and western regions (USAID, 2011). Increased runoff and landslides also increase Rwanda's vulnerability to climate change due to its high dependence on rain-fed agriculture. The high level of poverty and a low degree of rural development limits the capacity of farm households to manage the risk arising from climate change (World Bank Group, 2021a).

1.4.1 Data Collection and Sampling

Household-level survey data were collected in four districts of Rwanda between October and December 2019. Districts were purposefully chosen to represent three of Rwandas' climatic zones in which coffee is grown. The first region is Bugesera as part of the "East-Rwandan dry and hot lowland zone", which is, as described in more detail before, characterised by a savannah climate. This region is least suitable for coffee production. Karongi and Rutsiro represent the climate of Lake Kivu Rift Valley, the area most suitable for coffee production. Finally, Huye is located in the "Temperate zone of the central highlands". Regarding its suitability for coffee production, it stands between Bugesera and the Lake Kivu region.

We conducted a multi-stage random sampling. First, we selected CWS processing Rainforest Alliance certified coffee in the three regions from a list of CWS obtained from the Rwandan Agricultural Board. We then matched each certified CWS with a non-certified CWS located in the same district and being similar in terms of processing volume and form of ownership (privately or cooperatively owned). In a second step, complete lists of certified and non-certified farmers were compiled by the selected CWS and with the help of randomly selected lead farmers. We randomly selected around five lead farmers per CWS, who helped us randomly select five to ten farmers for interviews.

Overall, we surveyed 559 coffee producers. We interviewed 286 certified and 273 non-certified farmers. 188 interviews were conducted in Bugesera (87/101 certified/non-certified), 189 in Huye (88/101 certified/non-certified) and 182 in the Lake Kivu Region (84/98 certified/non-certified). As 71 of the certified farmers had a double-certification, they were excluded from the sample for the essay on the effect of Rainforest Alliance certification on environmental and economic outcomes, but included in the study on farmers' perception of adverse weather events.

1.5 Thesis Outline

The remainder of this thesis is organized as follows: Chapter two presents the first empirical essay on the connection between Rainforest Alliance certification and environmental-economic outcomes. In chapter three, the second empirical essay on farmers' perception of and adjustment to adverse weather events is presented. Chapter four contains the literature review on climate change adaptation adopted by coffee producers and the discussion of potential research gaps. The last section summarizes and discusses the main findings of the previous essay. It also highlights limitations of the empirical studies and presents scope for future research.

2. Setting the Standard - Does Rainforest Alliance Certification increase environmental and socio-economic outcomes for small-scale coffee producers in Rwanda?[1]

Abstract

Sustainability certification has become an important tool for promoting sustainable agricultural value chains. Nevertheless, its economic and environmental effects on the producer level remain unclear. We investigate the relationship of Rainforest Alliance certification with socio-economic and environmental outcomes in Rwanda and consider potential trade-offs between dimensions. To reduce potential selection bias in the econometric estimation, we use inverse probability weighted regression adjustment (IPWRA). We find no significant association between certification and socio-economic indicators but a significant correlation between certification and good agricultural practices and biodiversity-related practices. Effects on economic outcomes and biodiversity-related practices are linked; their relationship differs across climatic regions.

[1] This chapter was co-authored by Meike Wollni. Johanna Gather conceptualized the research idea, designed the questionnaire, collected, analysed, interpreted the data, and wrote the manuscript. Meike Wollni commented at different stages of research and helped revising the manuscript.

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2.1 Introduction

Voluntary sustainability standards have become a key approach to promote sustainable agricultural value chains. As a voluntary market-based instrument, sustainability standards aim to improve various environmental, social, and economic dimensions of agricultural production systems (Bray and Neilson, 2017). Certification schemes define a range of criteria that farmers need to comply with and typically promise price premiums and other benefits in exchange (DeFries et al., 2017). Sustainability standards vary concerning the aspects they emphasise – from social conditions to environmental protection – and rely on different strategies to enhance sustainable production practices. Rainforest Alliance certification includes criteria on environmental issues, such as biodiversity and forest conservation, and economic outcomes for smallholder farmers. In this paper, we focus on Rainforest Alliance certification and its implications for economic and environmental outcomes, considering the case of smallholder coffee farmers in Rwanda. The coffee sector is pioneering in the certification of sustainability of tropical food crops (DeFries et al., 2017). Over the past decade, the amount of coffee produced adhering to certification requirements has continued to increase (Panhuysen and Pierrot, 2020).

Previous studies on the impacts of sustainability certification have focused on either economic (Coulibaly et al., 2017; Muradian et al., 2015; Ruben and Fort, 2012; van Rijsbergen et al., 2016) or environmental benefits of certified coffee production (Hardt et al., 2015; Perfecto et al., 2005; Takahashi and Todo, 2013; Tscharntke et al., 2015). Research has shown that participation in certification schemes can reduce coffee farmers' livelihood vulnerability (Bacon, 2005; Donovan and Poole, 2014), increase income and reduce poverty (Mitiku et al., 2017b), and increase food security (Chiputwa and Qaim, 2016). Regarding the environment, studies found that certification reduces chemical input use in coffee production and increases the adoption of environmentally friendly management practices (Blackman and Naranjo, 2012).

Only few studies to date have jointly investigated environmental and economic outcomes of sustainability certification. Accordingly, whether certification can improve farm-level environmental and economic outcomes simultaneously remains an open question. Yet, understanding different coffee management systems' economic and environmental benefits is as important as recognising opportunities to reconcile them (Jezeer et al., 2017). There is first evidence from certified and non-certified coffee farmers exploring interactions between environmental and economic factors. Ibanez and Blackman (2016) find that ecocertified coffee in Colombia is linked to improving environmental outcomes, yet do not identify clear economic benefits. Vanderhaegen et al. (2018) investigate the effect of double-certification among coffee producers in Uganda. They find that it improves either farm incomes or biodiversity yet fails to eradicate the trade-off between economic and environmental outcomes. Haggar et al. (2017) investigate the effect of sustainability certification schemes on coffee producers in Nicaragua. The authors find that the investigated certification schemes positively affect the environmental characteristics of coffee production, provide economic benefits to most farmers, and may contribute to mitigating environmental-economic trade-offs.

We aim to contribute to this scarce evidence by investigating the relationship of sustainability certification with environmental and economic outcomes and the potential trade-offs between these dimensions. We go beyond a narrow focus on yields and agricultural income by including total household income and food security as more general economic welfare outcomes. Our study is implemented among coffee smallholder farmers in three agro-ecological regions of Rwanda. The regions differ in terms of their agro-ecological suitability for coffee production, *i.e.*, the extent to which soil and climatic conditions match the requirements of coffee plants. This is relevant as coffee is highly susceptible to changes in climatic conditions. Increases in temperature and changes in precipitation patterns will affect coffee yields and quality and be particularly severe in regions less suitable for coffee production (Bunn et al., 2015a).

Thus, the objective of this study is threefold. First, we analyse the economic and environmental outcomes associated with Rainforest Alliance certification. Second, we evaluate potential trade-offs between these outcomes. Finally, as the effects of certification are likely to differ depending on regional climate, we investigate whether economic-environmental outcomes and trade-offs associated with certification differ across three agro-ecological regions. The paper proceeds as follows. Section two provides background on the study context and develops a conceptual framework for the study. Section three describes the survey approach and the econometric framework. Descriptive and econometric results are then presented in section four. Section five discusses the results in more detail, and section six concludes.

2.2 Background

2.2.1 Study Context

Coffee represents, besides tea, Rwanda's major export crop and is increasingly recognised as a high-quality product (Food and Agricultural Organisation (FAO), 2021). Around 400,000 smallholder farm families rely on coffee production, farming about 42,000 ha of coffee plantations (NAEB, 2019). Although the sector has experienced growth since the civil war in 1994, productivity still is among the lowest in East Africa (International Coffee Organization (ICO), 2015). Low coffee yields result from different environmental and farm management challenges: Pests and diseases limit crop productivity, and adoption levels of good agronomic practices such as weeding, pruning, fertilisers, and soil erosion control are low (Ngango and Kim, 2019). Coffee farmers face several challenges, including poor soil fertility and insufficient access to fertilisers, old and less productive coffee trees, low prices compared to competing crops, and pests and diseases reducing production by as much as 50% per year at the farm level (AgriLogic, 2018). Commercial input use among coffee producers is very low, and most labour used in coffee production is manual. At the same time, coffee production represents a primary source of cash income for purchasing household goods and food (Ortega et al., 2019).

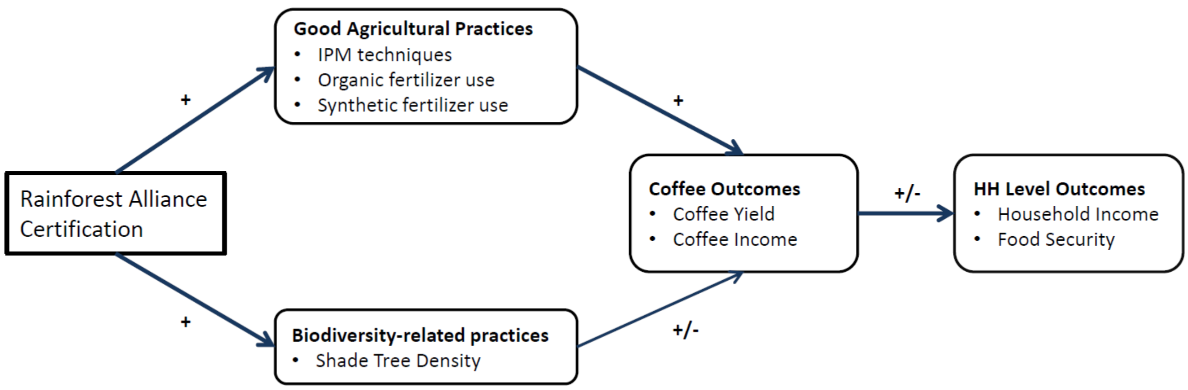
Coffee is harvested in Rwanda between March and July. After picking the ripe coffee cherries, they need to be processed into parchment coffee before export. In Rwanda, coffee is either fully washed in wet mills, so-called Coffee Washing Stations (CWS), where farmers deliver their coffee, or semi-washed at the farm level and then traded via intermediaries (Macchiavello and Morjaria, 2018). Fully-washed coffee is of higher and more consistent quality and is associated with price premia in international markets (Blouin and Macchiavello, 2017). Therefore, Rwanda's government aims to increase the share of fully-washed coffee, and the number of CWS has been continuously increasing since 2002 (AgriLogic, 2018). Besides processing coffee, CWS also provide extension and support to farmers within their operational area. Since 2014, an increasing share of Rwandan coffee production has been certified under voluntary sustainability standards. Besides FairTrade and Organic, Rainforest Alliance represents the most prevalent scheme[2] (AgriLogic, 2018), with an estimated certified production of 5590 metric tons of coffee in 2020 (Rainforest Alliance, 2021). Certified coffee is wet-processed and marketed by certified CWS.

[2] Other schemes in Rwanda include Starbucks' C.A.F.E. Practices, Nespresso's AAA Sustainable Quality Program, and 4C Compliant Coffee (AgriLogic, 2018).

2.2.2 Conceptual Framework

Rainforest Alliances' mission is to conserve biodiversity and at the same time ensure sustainable livelihoods for farmers. The program includes criteria covering environmental and economic farm aspects that support strategies to improve farming practices, management systems, and farmers' knowledge (Rainforest Alliance, 2017). The conceptual framework, depicted in Figure 2.1, visualises the expected relationships between Rainforest Alliance certification, biodiversity-related and good agricultural practices, and coffee-related and household-level welfare outcomes.

Figure 2.1 Hypothesised relationship between Rainforest Alliance certification and outcome variables



Notes: + stands for an expected positive relationship, - for an expected negative relationship between indicators; HH short for household

The certification scheme requires the uptake of good agricultural practices and biodiversity-related measures. An improved uptake in these practices can thus be directly linked to Rainforest Alliance certification, as the adoption of the practices is part of the certification scheme. The standard promotes exchanging synthetic with organic fertilisers and integrates shade trees as part of its continuous improvement system (Rainforest Alliance, 2017). Shade trees are associated with positive effects on the microclimate and contribute to tree species diversity (Souza et al., 2012) and soil fertility (Youkhana and Idol, 2009). Other environmental benefits derived from shaded coffee systems are biodiversity conservation, carbon sequestration, and soil erosion control (Cerdán et al., 2012). Integrated Pest Management (IPM), part of the good agricultural practices promoted by Rainforest Alliance, focuses on reducing pesticide use, e.g., applying biological control measures and precision farming. Previous studies have found that IPM techniques can indeed reduce pesticide use and increase crop yields (Pretty and Pervez Bharucha, 2015) as well as protect soil, water, wildlife and beneficial insects (Rezaei et al., 2019).

The adoption of good agricultural practices, such as IPM techniques and organic fertilisers, is expected to be reflected in higher levels of agricultural productivity and accordingly coffee yields (Pretty and Pervez Bharucha, 2015; Rahn et al., 2018). Higher coffee yields are expected to translate into increased coffee income if the additional revenues exceed additional costs. Nevertheless, trade-offs might exist between biodiversity-related practices and coffee-related outcomes (yield, coffee income). Previous research has shown that shade trees are typically associated with reduced coffee yields (Rahn et al., 2018), which might also lead to decreased coffee income, at least in the short run.

At the same time, coffee and household-related outcomes are likely to be influenced by other aspects linked to certification. For example, the implementation of a farm management plan as required by Rainforest Alliance might affect farmers' overall managerial skills and thus influence outcome variables. We specifically investigate the connection between economic outcomes and the adoption of good agricultural practices, as they are tied to improved environmental effects of coffee production.

Whether farm households can improve their overall wellbeing depends on the extent to which changes in coffee outcomes translate into household-level outcomes. Higher coffee income is expected to lead to higher total household income, which can be used to purchase food (Schleifer and Sun, 2020) and increase household-level food security. Under certain conditions, despite higher cash income from coffee, improvements in household-level outcomes may not be observed. For instance, if labour reallocation occurs in the certification process, reducing off-farm income streams, overall household income may decline (Vellema, Buritica Casanova, Gonzalez, & D'Haese, 2015). Similarly, if additional cash income from coffee is spent on non-food items, household-level food security may not improve (Anderman et al., 2014).

2.3 Material and Methods

2.3.1 Data Collection

Household-level survey data were collected in four districts of Rwanda between October and December 2019. Districts were purposefully chosen to represent three climatic zones that differ regarding their suitability for coffee production. Bugesera is part of the "East-Rwandan dry and hot lowland zone", characterised by a savanna climate and is least suitable for coffee production. Huye is located in the "Temperate zone of the central highlands" and is more suitable for coffee production than Bugesera. Altitude and precipitation are higher than in Bugesera, and temperature swings are less pronounced than those in the eastern lowlands. Karongi and Rutsiro represent the climate of Lake Kivu Rift Valley, the area most suitable for coffee production. The land-lake-wind circulation creates a distinct regional climate system and high evaporation rates prevailing on Lake Kivu.

To construct our sample, we proceeded in two steps. First, we selected Coffee Washing stations (CWS) processing Rainforest Alliance certified coffee in the three regions from a list of CWS obtained from the Rwandan Agricultural Board. We then matched each certified CWS with a non-certified CWS located in the same district and being similar in terms of processing volume and form of ownership (privately or cooperatively owned). In a second step, complete lists of certified and non-certified farmers were compiled by the selected CWS and with the help of randomly selected lead farmers. Based on the lists, we collected a stratified random sample of 202 certified and 286 non-certified farmers. 188 interviews were conducted in Bugesera (87/101 certified/non-certified), 161 in Huye (60/101 certified/non-certified) and 135 in the Lake Kivu Region (55/84 certified/non-certified). A standardised questionnaire was used to obtain information on household demographics, coffee production and marketing, crop production other than coffee, input use on the plot level, and certification.

By sampling farmers via CWS, we limit our sample to those coffee farmers that deliver at least part of their coffee to a CWS and implicitly exclude farmers who process all of their coffee on their farm. As discussed in Chapter 2.2.1, Rainforest Alliance certified coffee produced in Rwanda is wet-processed by certified CWS. We therefore opted to choose both certified and non-certified farmers selling to CWS in order to ensure comparability, e.g., in terms of coffee quality, processing method and access to services that CWS typically provide.

2.3.2 Econometric Framework

To assess the association of Rainforest Alliance Certification with environmental and economic outcomes, we need to compare certified farmers to a suitable counterfactual. Given that certification is a choice variable and typically influenced by a range of observable and unobservable farmer characteristics (Meemken et al., 2021), certified and non-certified farmers are likely to differ systematically. As these characteristics likely correlate with the outcomes of interest, estimates will be biased due to self-selection into certification. To reduce selection bias, we apply inverse probability weighted regression adjustment (IPWRA) (Wooldridge, 2010). The approach consists of two stages, where in the first stage, inverse probability weights (IPW) are derived from the decision to obtain certification. In the second stage, the regression adjustment (RA) method is used to model outcomes.

In the first stage, inverse probability weights are estimated based on the probability of obtaining certification or the propensity score. For this purpose, the propensity score as defined by Rosenbaum and Rubin (1983) is calculated using a range of observable characteristics:

$$\boldsymbol{p}(\boldsymbol{X}) = \mathbf{Pr}(\boldsymbol{T_i} = \mathbf{1}|\boldsymbol{X}) = \boldsymbol{F}\{\boldsymbol{h}(\boldsymbol{X})\} = \boldsymbol{E}(\boldsymbol{T_i}|\boldsymbol{X}) \qquad 1$$

Where X is a multi-dimensional vector of covariates and F{.} a cumulative distribution function. Based on the estimated propensity score $\hat{p}$, inverse probability weights are calculated as $\frac{1}{\hat{p}}$ for treated households, and $\frac{1}{1-\hat{p}}$ for non-treated households. Each observation is thus weighted by the inverse probability of receiving the treatment level it received.

The RA method fits separate linear regression models for certified and non-certified farmers. Covariate-specific outcomes are then predicted for each subject under each certification status. We obtain the average difference between predicted outcomes for certified farmers ($ADPO^C$) under certification and hypothetical non-certification (Hörner and Wollni, 2021). The predicted outcome for certified farmers under hypothetical non-certification takes the specific characteristics of certified farmers into account and can be interpreted as an estimation of the outcome certified farmers would have achieved if they were not certified (given their characteristics). The method thus takes differences in characteristics between certified and non-certified farmers into account, when constructing a hypothetical counterfactual against which certified farmers are compared. Combining the RA method with the inverse probability weights, the IPWRA estimator can be expressed as (Manda et al., 2018):

$$ADPO^{C}{}_{IPWRA} = n_C^{-1} \sum_{i=1}^{n} T_i [r_C(X, \delta_C) - r_n(X, \delta_n)] \qquad 2$$

where n_c is the number of certified farmers and $r_i(X)$ describes the weighted regression models for certified (C) and non-certified (N) coffee farmers with covariates X and estimated parameters δ_C^* and δ_N^*, which are obtained from the weighted regression procedure.

An important underlying assumption of the IPWRA method is the overlap assumption, requiring that, conditional on covariates, each farmer has a positive probability of obtaining certification. This is to ensure that each certified household can be matched with a non-certified household of similar characteristics. If the overlap assumption is violated, estimators are overly sensitive to model specifications. To meet this condition, we set a tolerance level between p = 0.001 and p = 0.999 for the estimated probability of certification. Furthermore, it should be noted that IPWRA seeks to reduce selection bias by conditioning on observed covariates. This implies that estimates are vulnerable to systematic bias in unobserved characteristics. Although controlling for a broad set of observable covariates may help reduce selection bias resulting from unobserved heterogeneity (Imbens and Wooldridge, 2009), our results should be interpreted as associations rather than causal effects.

2.3.3 Empirical Specification

Based on the conceptual framework, we assess the association of Rainforest Alliance certification with environmental and good agricultural practices and economic outcomes, both coffee-related and at the household level. We include binary indicators as to the first set of indicators about whether farmers apply organic fertiliser and integrated pest management. In addition, we measure the number of IPM practices applied. In the context of good agricultural practices, we also use the amount of synthetic fertiliser applied to the coffee plantation as an indicator, as Rainforest Alliance discourages the overuse of synthetic fertilisers. Finally, concerning biodiversity-related practices, we include a binary indicator of whether the farmer integrates shade trees in the coffee plantation and the number of shade trees per hectare.

Regarding the second set of indicators, coffee-related economic outcomes include coffee yields, measured per hectare and year, and coffee income, which equals coffee revenues minus variable costs incurred in coffee production per hectare. We further consider total household income and household-level food security to assess whether potential increases in coffee income translate into better economic outcomes at the household level. Total household income includes income generated from coffee and other crops produced on-farm valued at market price, livestock production, off-farm activities, and private transfers, subtracting the costs incurred by the household.

We use the Household Food Insecurity and Access Scale (HFIAS) to measure food insecurity, comprising nine recall questions covering different food insecurity-related events in the past 30 days. If the respondent experienced a given situation, a follow-up "frequency-of-occurrence" question is asked (rarely, sometimes, or often). Thus, questions can be scored 0-3, so the total HFIAS ranges from 0 to 27. A higher score then indicates a higher degree of food insecurity (Coates et al., 2007). Table 2.1 provides a descriptive overview of the outcome variables and the covariates included in the econometric models.

Table 2.1 Descriptive statistics of variables used in the analysis

	Full Sample		Bugesera		Huye		Lake Kivu	
	Not Cert.	Cert.	Not Cert.	Cert.	Not Cert.	Cert.	Not Cert.	Cert.
Good Agricultural and biodiversity-related Practices								
Use of org. fertilizer	.692 (.462)	.782 (.414)	.574 (.497)	.736 (.444)	.733 (.445)	.75 (.437)	.786 (.413)	.891 (.315)
Synth.fert used kg/ha	265.8 (219.2)	234.6 (204.6)	272.1 (229.4)	204.3 (206.5)	283.7 (222.5)	289.6 (231.9)	236.5 (201.5)	222.8 (155.4)
Use of IPM	.888 (.32)	.951 (.218)	.900 (.300)	1 (0)	.792 (.41)	.917 (.279)	.988 (.11)	.909 (.29)
# of IPM techniques	1.8 (1.1)	2.4 (1.2)	1.7 (.96)	2.4 (.91)	1.8 (1.5)	2.5 (1.6)	1.9 (.86)	2.2 (1.3)
Use of shade trees	.682 (.47)	.792 (.41)	.634 (.48)	.747 (.44)	.753 (.43)	.917 (.279)	.655 (.478)	.73 (.45)
# Shade Trees per ha	134.1 (150.4)	146.9 (143.5)	125.3 (151.9)	138.2 (154.8)	144.6 (147.5)	188.5 (136.6)	131.9 (152.9)	115.2 (122.4)
Coffee-related and Household-level Economic Outcomes								
Yield in kg (cherries)	4778.6 (3773.4)	4638.1 (3523.9)	4756.8 (3772.9)	4732.3 (3540.3)	4670 (3557.5)	4008.1 (3401.4)	4935.2 (4056.3)	5176.5 (3587.7)
Coffee Income In 1000 RwF/ha	374.1 (784.9)	316.4 (710.5)	394.2 (779.2)	324.2 (743.5)	418.6 (700.1)	190.4 (693.7)	296.5 (885. 8)	441.5 (662.5)
Hh Income In 1000 RwF/ha	886.2 (1037.1)	776.0 (940.4)	981.9 (1006.3)	826.3 (995.7)	980.4 (1061.1)	669.9 (913.6)	657.9 (1020.8)	812.3 (884.9)
Food insecurity (HFIAS)	9.4 (7.2)	8.3 (6.8)	9.2 (6.8)	7.95 (6.2)	10.3 (7.4)	8.2 (7.3)	8.6 (7.2)	8.9 (7.3)

Control variables								
HH Size	5.0 (1.8)	5.1 (1.8)	4.6 (1.8)	4.7 (1.5)	5.2 (1.8)	5.2 (1.8)	5.2 (2.1)	5.3 (2.2)
Age of the household head	47.9 (13.1)	51.3 (13.1)	46.1 (12.9)	56.1 (12.4)	48.4 (12.2)	47.2 (12.8)	49.6 (14.0)	48.2 (12.1)
Yrs of formal education	4.3 (2.8)	3.9 (2.9)	3.8 (2.9)	3.4 (2.8)	4.3 (2.7)	4.5 (2.9)	4.9 (2.6)	4.3 (2.9)
HH Type[1]	.33 (.47)	.26 (.44)	.416 (.49)	.22 (.42)	.32 (.47)	.28 (.45)	.24 (.43)	.31 (.47)
Farm Size in ha	.23 (.17)	.26 (.19)	.19 (.153)	.25 (.19)	.24 (.17)	.24 (.16)	.28 (.20)	.27 (.24)
Coffee area in ha	.09 (.07)	.11 (.11]	.07 (.077)	.09 (.09)	.09 (.06)	.13 (.11)	.09 (.08)	.11 (.12)
Exp. in coffee prod. (Yrs)	38.6 (38.8)	43.7 (39.3)	39.4 (34.2)	56.5 (41.8)	32.7 (34.3)	34.4 (28.9)	44.6 (47.5)	33.7 (39.8)
Time to nearest CWS	47.5 (36.3)	46.7 (34.5)	37.6 (29.2)	35.3 (30.7)	58.9 (40.4)	61.6 (29.8)	45.8 [35.3)	48.5 (38.6)
Form of ownership of CWS[2]	.66 (.48)	.56 (.49)	.931 (.255)	.76 (.431)	.58 (.495)	.33 (.475)	.42 (.49)	.509 (.505)

HH=household; CWS=Coffee Washing station; 1) 0=Male Headed, 1=Female headed; 2) 0=Cooperatively owned, 1 = privately owned; Standard Error in Parentheses

2.4 Results

In the following two sections, we present results from the IPWRA estimations. The last section explores potential trade-offs between the use of biodiversity-related practices and economic outcomes. Results tables 2.2 and 2.3 below report the predicted outcomes for certified farmers under hypothetical non-certification, which can be considered the counterfactual. In addition, we report the $ADPO^{C}{}_{IPWRA}$, which indicates the average difference between predicted outcomes for certified farmers under certification and hypothetical non-certification and can be interpreted as the change in the respective outcome associated with Rainforest Alliance certification. We show both p-values and sharpened q-values, the latter being more robust in the context of multiple hypotheses testing (Anderson, 2008).

Regarding the overlap assumption, which is necessary for IPWRA results to be valid, we identify no observation with a probability of certification below the minimum threshold of $\hat{p} = 0.001$ or above the maximum threshold of $\hat{p} = 0.999$. This suggests that we have sufficient overlap in our sample. Furthermore, after applying inverse probability weights, the sample should be balanced between certified and non-certified farmers. Over-identification tests indicate that the null hypothesis of balanced covariates cannot be rejected for any sub-sample. Test statistics for the entire sample are $X^2(10)$ = 7.6745 with p > X^2= 0.6606. For Bugesera, test statistics are $X^2(10)$ = 1.69652 with p > X^2= 0.9982; for Huye $X^2(10)$ = 7.16558with p > X^2= 0.7097; and for Lake Kivu $X^2(10)$ = 5.03991 with p > X^2= 0.8885. Probit model results on the certification decision that are used to derive inverse probability weights are presented in Table A1 in the Appendix.

2.4.1 Management Practices

Overall, Rainforest Alliance certification is associated with a significant increase in the uptake of several environmentally friendly practices, including the use of organic fertilisers, the use and number of IPM techniques, and shade trees (Table 2.2, *Full Sample*). This is despite the fact that good agricultural and environmentally-friendly practices are relatively widely adopted in the research area, e.g., shade-grown coffee is common, with 68% of the non-certified farmers following this practice (descriptive statistics in Table 2.1). Our IPWRA results suggest that certification is associated with a 7-percentage point increase in the likelihood of adopting organic fertiliser, a 6-percentage point increase in the likelihood of applying IPM techniques, and a 12-percentage point increase in the likelihood to maintain shade trees (Table 2.2). Furthermore, certification is associated with an average increase of 0.5 IPM techniques used. However, it should be noted that only the number of IPM techniques and the likelihood to maintain shade trees remain significant when correcting for multiple hypotheses testing. Finally, the amount of synthetic fertiliser applied to coffee is not significantly correlated with certification, neither positively nor negatively.

When regionally disaggregating the results, we find that these general findings are most strongly reflected in Bugesera. The uptake of organic fertiliser, for instance, is significantly associated with certification only in Bugesera. Bugesera is also the region where adoption levels of organic fertiliser among non-certified farmers are lowest (cf. descriptive statistics in Table 1). In this region, which is less suitable for coffee production, certification is associated with a 14-percentage point increase in the likelihood to apply organic fertiliser. Similarly, the results on IPM are even more pronounced in Bugesera than in the full sample. Here, certification is associated with a 20-percentage point increase in the likelihood to adopt IPM and an average increase of 0.92 practices used. Finally, certification is associated with an 11-percentage point increase in the likelihood to maintain shade trees, which is in line with the findings from the full sample. Again, our results are only partly robust to correcting for multiple hypotheses testing, after which only the use of IPM techniques and number of IPM techniques remain significant in Bugesera.

In Huye and the Lake Kivu region, results are mostly qualitatively in line with the general findings, *i.e.*, the $ADPO^C$ have the same signs as in the full sample, but they are not statistically significant. The only significant differences are observed in the context of IPM: In Huye, certified farmers tend to use more practices, whereas in the Lake Kivu region, the likelihood of IPM adoption is lower among certified farmers. However, these two results turn insignificant when taking multiple hypotheses testing into account.

Table 2.2 Association of Rainforest Alliance certification with good agricultural and biodiversity-related practices

	Non-certified PO		$ADPO^C$		p-value	Sharpened q-values
Full Sample; $N^C = 202/ N^{NC} = 286$						
Use of organic fertilizer	0.712	(0.030)	0.07	(0.04)	0.101	0.315
Amount of synt. Fertiliser per ha in kg	260.3	(15.1)	-25.6	(18.6)	0.169	0.433
Use of IPM techniques	0.89	(0.02)	0.06	(0.02)	0.022	0.153
# of IPM techniques	1.9	(0.09)	0.52	(0.12)	0.000	0.001
Use of shade trees	0.67	(0.03)	0.12	(0.04)	0.004	0.03
# Shade Trees per ha	132.6	(9.5)	11.6	(13.6)	0.395	0.653
Bugesera; $N^C = 87/ N^{NC} = 101$						
Use of organic fertilizer	0.599	(0.06)	0.14	(0.07)	0.059	0.256
Amount of synt. Fertiliser per ha in kg	185.6	(26.0)	18.7	(31.7)	0.556	0.812
Use of IPM techniques	0.799	(0.05)	0.20	(0.05)	0.000	0.001
# of IPM techniques	1.5	(0.17)	0.92	(20)	0.000	0.001
Use of shade trees	0.6	(0.05)	0.11	(0.07)	0.089	0.315
# Shade Trees per ha	103.3	(15.0)	34.4	(21.3)	0.107	0.315
Huye; $N^C = 60/ N^{NC} = 101$						
Use of organic fertilizer	0.71	(0.07)	0.03	(0.09)	0.693	0.835
Amount of synt. Fertiliser per ha in kg	301.7	(27.7)	-8.6	(37.8)	0.820	0.877
Use of IPM techniques	0.81	(0.05)	0.10	(0.06)	0.106	0.315
# of IPM techniques	1.8	(0.25)	0.66	(0.32)	0.041	0.197
Use of shade trees	0.82	(0.05)	0.09	(0.06)	0.139	0.386
# Shade Trees per ha	148.9	(22.2)	36.3	(28.5)	0.203	0.433
Lake Kivu; $N^C = 55/ N^{NC} = 84$						
Use of organic fertilizer	0.80	(0.05)	0.09	(0.07)	0.218	0.433
Amount of synt. Fertiliser per ha in kg	217.9	(27.8)	-0.29	(30.8)	0.992	0.938
Use of IPM techniques	0.996	(0.01)	-0.09	(0.04)	0.027	0.166
# of IPM techniques	1.9	(0.12)	0.39	(0.21)	0.067	0.27

Use of shade trees	0.65	(0.06)	0.08	(0.09)	0.337	0.599
# Shade Trees per ha	124.3	(18.0)	-5.6	(24.3)	0.816	0.877

Note: Non-certified PO presents the potential outcome means for certified farms under hypothetical non-certification; $ADPO^{C}$ stands for 'average difference in predicted outcomes' for certified farmers under certification and hypothetical non-certification; Standard Deviation in Parentheses

2.4.2 Economic Outcomes

We do not find any significant association between Rainforest Alliance certification and coffee-related economic outcomes in the full sample, *i.e.*, coffee yield and cash income from coffee. This is despite the fact that certified farmers seem to be more likely to apply organic fertilisers and IPM, as shown in the previous section. The uptake of good agricultural practices associated with certification is highest in Bugesera, so that we would expect the yield effects to be largest in this region. When looking at the regionally disaggregated results, we find that the $ADPO^{C}$, *i.e.*, the yield increase associated with certification, is most prominent in Bugesera but not statistically significant. Furthermore, despite these observed yield increases in Bugesera, this is not reflected in a similar increase in coffee income associated with certification. Increases in coffee income associated with certification are highest in the Lake Kivu region, the region best suited for coffee production, but also here, the $ADPO^{C}$ is not significant. In summary, we do not find significant associations between certification and coffee yields and coffee incomes in any of the three regions.

In the absence of significant changes in coffee-related outcomes, we are also less likely to find significant associations between certification and household-related welfare outcomes. This is confirmed in the full sample and the region-specific samples concerning household income. We find a significant association between certification and reduced food insecurity in the full sample. However, this result is not robust once we correct for multiple hypotheses testing and is also not significant in any of the three regions.

Table 2.3 Association of Rainforest Alliance certification with socio-economic outcomes

	Non-certified PO		ADPOC		p-value	Sharpened q-values
Full Sample; $N^{C} = 202$/ $N^{NC} = 286$						
Coffee Yield In kg per ha	4532.8	(264.3)	127.1	(324.4)	0.695	0.835
Coffee Income In 1000 RwF/ha	332.3	(53.3)	-5.4	(69.7)	0.938	0.938
Household Income	806.5	(70.5)	-20.8	(92.8)	0.822	0.877

In 1000 RwF/ha						
Food insecurity (HFIAS)	9.1	(0.503)	-0.85	(.68)	0.214	0.433
Bugesera; N^{C} = 87/ N^{NC} = 101						
Coffee Yield In kg per ha	3964.2	(621.5)	767.5	(668.5)	0.251	0.455
Coffee Income In 1000 RwF/ha	339.1	(92.7)	2.8	(114.8)	0.981	0.938
Household Income In 1000 RwF/ha	770.9	(121.6)	96.4	(157.2)	0.540	0.81
Food insecurity (HFIAS)	7.2	(0.87)	0.81	(1.1)	0.437	0.695
Huye; N^{C} = 60/ N^{NC} = 101						
Coffee Yield In kg per ha	4454.7	(522.5)	-313.7	(591.2)	0.596	0.835
Coffee Income In 1000 RwF/ha	423.99	(96.8)	-208.4	(126.8)	0.098	0.315
Household Income In 1000 RwF/ha	791.2	(123.8)	-139.5	(152.9)	0.362	0.629
Food insecurity (HFIAS)	9.76	(1.1)	-1.6	(1.4)	0.283	0.51
Lake Kivu; N^{C} = 55/ N^{NC} = 84						
Coffee Yield In kg per ha	4723.9	(486.7)	388.8	(549.4)	0.487	0.749
Coffee Income In 1000 RwF per ha	282.4	(90.5)	142.3	(124.3)	0.252	0.455
Household Income In 1000 RwF per ha	737.5	(149.6)	83.9	(182.0)	0.645	0.835
Food insecurity (HFIAS)	8.9	(0.74)	0.03	(1.2)	0.980	0.938

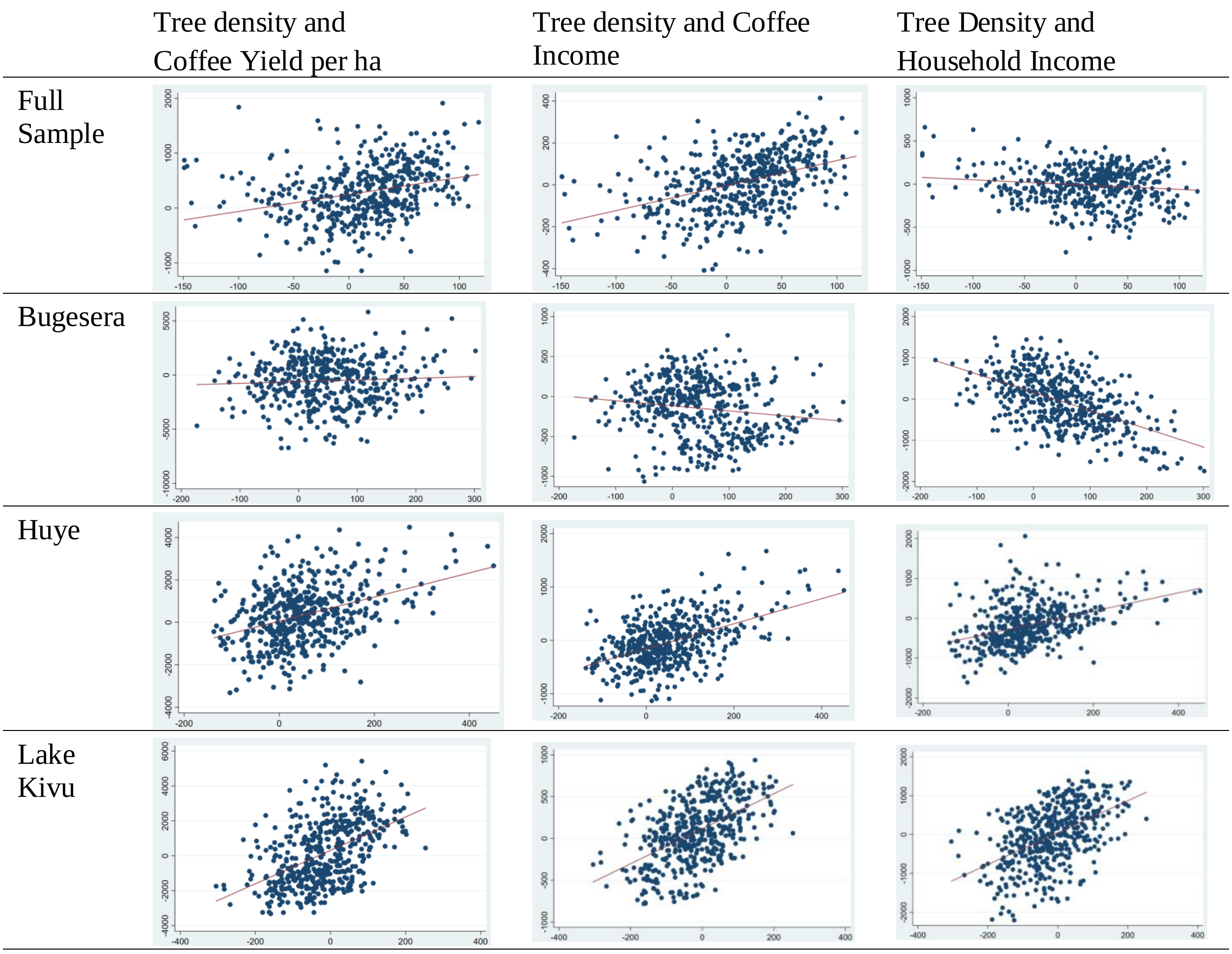
Note: Non-certified PO presents the potential outcome means for certified farms under hypothetical non-certification; ADPOC stands for 'average difference in predicted outcomes' for certified farmers under certification and hypothetical non-certification; Standard Deviation in Parentheses

2.4.3 Environmental-Economic Interactions

To investigate potential trade-offs between environmental and economic outcomes associated with certification, we explore bivariate correlations between the farmer-specific $ADPO^C$ for the number of shade trees per hectare, as an indicator for biodiversity-friendly farm management, and selected economic outcome variables. We chose to focus on the connection between shade trees and economic outcomes, as Rainforest Alliance is significantly associated with an increase in the cultivation of shade trees across the full sample. Furthermore, shade tree management has also been used in previous research to investigate economic-environmental trade-offs of certification (Haggar et al., 2017; Vanderhaegen et al., 2018). Figure 2.2 visualises the relationships between the ADPO of tree density and the ADPO of coffee yield, coffee income, and household income, respectively.

In the full sample, we find slightly positive correlations between environmental and economic benefits associated with certification when considering the relationship between shade tree density and yield effects or coffee income. No strong connection is observable in the full sample between shade tree density and overall household income. Region-specific results are more pronounced, and we can observe some clear differences between the regions. In Huye and the Lake Kivu region, the two regions that are more suitable for coffee production, we observe a positive correlation between environmental and economic benefits associated with certification. In Bugesera, the climatic region least suitable for coffee production, the observed correlations between environmental and economic benefits are negative, indicating the existence of trade-offs. While there is no strong relation between shade tree density and yield changes, increased shade tree density associated with certification is closely related to decreases in coffee income and household income in Bugesera.

Figure 2.2 Correlations between farmer-level ADPO (changes associated with certification)



x-axis: ADPOC for shade tree density; y-axis: ADPOC for coffee yield/coffee income/hh income, respectively.

2.5 Discussion

Although the application of good agricultural practices is already quite common in Rwanda, we find an overall positive association between Rainforest Alliance certification and the uptake of the management practices studied. Yet, the overall increase in the uptake of good agricultural practices does not translate into improved economic indicators among certified farmers. This is in line with findings by Ibanez and Blackman (2016), who find that sustainability certification is associated with an increased uptake of environmentally friendly management practices, i.e. an increased uptake in organic fertiliser, but did not identify any economic benefits. Similarly, Vanderhaegen et al. (2018) found that certification improves either economic outcomes such as productivity or environmental outcomes such as biodiversity, but not both at the same time.

Generally, our results indicate a stronger connection between Rainforest Alliance and changes in environmentally friendly practices in regions less suitable for coffee production, in our case in Bugesera. Although the use of environmentally friendly practices is generally common in our research area, we observe that in the regions more suitable for coffee production these practices are more prevalent among non-certified farmers than in Bugesera. Accordingly, initially lower levels in Bugesera may be the reason why Rainforest Alliance is more strongly associated with an increase in the uptake of practices in this region. As the use of good agricultural practices is required to become Rainforest Alliance certified, the increase in adoption in areas with lower prior adoption rates is not surprising, but rather to be expected. At the same time, this shows that Rainforest Alliance is indeed able to attain changes in prevalent farm practices.

While there is a positive correlation between certification and the use of shade trees, we find no significant connection between certification and the number of shade trees. Overall, the integration of shade trees is widely practiced among coffee farmers in our research area. Increased pressure on land has provided incentives to integrate trees with coffee in Rwanda. Farmers optimise farmland to produce essential goods such as fruits, firewood, and mulch, alongside coffee (Smith Dumont et al., 2019), which is also common among Latin American coffee producers (Méndez et al., 2010). A limitation of our data is that we have no information on the planting date of the trees, and can therefore not trace how many trees were planted after certification. Nonetheless, certification may play an important role not only for providing incentives to plant new trees, but also to maintain existing shade trees, which may otherwise be progressively removed to increase productive efficiency of the coffee plantation. Furthermore, cultivating shade trees is part of Rainforest Alliance's continuous improvement system. As certification is still relatively recent in Rwanda, and farmers have been certified only for a few years, the number of shade trees on certified farms might further increase.

In our study, we do not find significant associations between certification and (socio-) economic outcomes. While the adoption of good agricultural practices is directly within the control of the certification schemes, economic outcomes are only indirectly associated with Rainforest Alliance. Coffee and household income are also directly affected by external factors such as input and market prices or market demand. Overall, an insignificant associations between certification and (socio-) economic outcomes is in line with previous studies on the economic benefits of coffee certification (DeFries et al., 2017). Improvements in economic outcomes can result from the application of good agricultural practices that can lead to yield increases and/or quality improvements. Yield increases and quality improvements are, however, long-term objectives, which may not have materialized in Rwanda yet. Furthermore, previous research has documented a positive association between Rainforest Alliance certification and price premiums (Haggar et al., 2017; Rueda and Lambin, 2013), which can translate into income increases more directly. In Rwanda, the coffee sector is strongly regulated by the National Agricultural and Export Board, NAEB, which sets a floor price for coffee cherries. As a result, certified coffee might not be able to obtain price premiums high enough to translate into substantial income increases for certified farmers (yet). The fact that other studies report similar findings regarding the absence of significant effects of Rainforest Alliance certification on coffee productivity and net income, such as Haggar et al. (2017) for Nicaragua, suggests that further research should specifically focus on economic effects in the long run.

Regarding synergies and trade-offs, we observe different tendencies across regions. In Huye and the Lake Kivu region, shade tree density and income simultaneously rise under certification, pointing towards synergies between these outcomes. In Bugesera, we find some evidence for minor trade-offs between outcome categories, as Rainforest Alliance is associated with either an increase in shade tree density or income. This is similar to Haggar et al. (2017), who find a weak but negative correlation of tree diversity with productivity and net income. In our study, we observe trade-offs in Bugesera, the region that is less suitable for coffee production, suggesting that here increasing production costs associated with the uptake of management practices are not compensated by increases in yields or prices. On the other hand, in the favourable regions of Huye and Lake Kivu the observed synergies between increases in shade tree density and income levels might be related to further improvements in coffee quality and farmers' ability to secure price premiums.

Overall, our results suggest that through the certification of good agricultural practices, Rainforest Alliance certification might be effective in increasing the uptake of environmentally friendly management practices, particularly in regions where initial adoption levels are low. Yet, while in regions that have favourable conditions for coffee production, improvements in production practices seem to go hand in hand with economic benefits, this is less so the case in the region that is less favourable for coffee production. Thus, if certification is promoted in less favourable regions, particular effort needs to be placed on securing economic benefits for farmers, too. This said, our results should be treated with caution since overall the associations between certification and economic outcomes are weak in our sample, which may confound the interpretation of the observed synergies and trade-offs.

2.6 Conclusions

This study investigates the relationship of Rainforest Alliance certification with environmental and socio-economic outcomes of coffee farmers in Rwanda. Using household survey data from three agro-ecological regions, we explore potential trade-offs between these dimensions. Since certified and non-certified farmers are likely to differ systematically, we employed IPWRA to reduce potential selection bias in our analysis. Our results indicate no significant associations between Rainforest Alliance certification and socio-economic outcomes of coffee farming in Rwanda, but a positive association between certification and good agricultural practices. This finding may not be surprising, since the application of good agricultural practices is a requirement of certification, whereas the economic outcomes considered in this study depend on other external factors, including market demand, prices, and climate conditions. We find that the association between certification and adoption of good agricultural practices is particularly strong in the region least favourable for coffee production, indicating that under such circumstances Rainforest Alliance certification could provide leverage in promoting more environmentally friendly coffee production practices. Caution is warranted, however, due to potential trade-offs between environmental and economic benefits. While in the more favourable regions for coffee production, Rainforest Alliance certification tends to be associated with increases in shade tree density and income at the same time, pointing towards synergies, in the less favourable region we find evidence for trade-offs. To overcome some limitations of our data and further substantiate our findings, further research is needed that explicitly takes longer term economic effects of certification into account to provide more comprehensive information on the economic viability of certification for smallholder farmers under different agro-ecological conditions.

2.7 Appendix

Table A 2.1 Probit regression on the certification decision to derive inverse probability weights

	Full Sample	Bugesera	Huye	Lake Kivu
HH Size	.002	.023	.07	.04
Education of hh head	-.02	-.03	.03	-.05
hh type[1]	-.29**	-.899***	.02	.38
Age of the household head	-.004	.028**	-.03**	-.01
Farm Size in ha	-.004	1.3	-1.4	-.74
Coffee area in ha	2.0 ***	-.60	4.5***	2.2
Years of experience in coffee production	.02***	.02	.04***	.01
Time to nearest CWS	.002	.008***	-.001	-.004
Form of ownership of CWS[2]	-.26**	-.898***	-.77***	.22
N	488	188	161	139
LR chi2(9)	39.72	63.38	30.81	10.11
Prob > chi2	0.0000	0.0000	0.0003	0.3415
Log likelihood	-311.13086	-98.101296	-90.912967	-88.244123
Pseudo R2	0.0600	0.2442	0.1449	0.0542

HH=household; CWS=Coffee Washing station; 1) 0=Male Headed, 1=Female headed; 2) 0=Cooperatively owned, 1 = privately owned; Significacet levels: *** p<0.01, ** p<0.05, *p<0.1

3. Perception of and adjustment to adverse weather events among smallholder coffee farmers in Rwanda[3]

Abstract

Changing temperature and precipitation patterns threaten smallholder farmers producing coffee. Adaptation is crucial, and perceiving adverse weather events as a risk is the first step towards it. We therefore investigated the link between smallholder coffee farmers' perception of adverse weather events and their adjustments to them. First, we distinguished four distinct groups of farmers based on their risk perception of adverse weather events. We found that farmers' risk perception is connected to changes in the timing of the seasons and the expected amount of precipitation. Most farmers in the sample adjust to the adverse weather events they experience. We found that farmers' risk perception and adjustment decisions are closely linked.

[3] This chapter was co-authored by Meike Wollni. Johanna Gather, conceptualized the research idea, designed the experiment, collected, analysed, interpreted the data, and wrote the manuscript. Meike Wollni commented at different stages of research and helped revising the manuscript.

The Chapter has been submitted for publication at *Climate and Development.*

3.1 Introduction

The projected effects of global climate change, specifically rising temperatures, rainfall variability, and frequency and severity of extreme weather events, will substantially affect the agricultural sector (Lasco et al., 2014). As farmers' livelihoods are tied to the local agro-ecology, they are most susceptible to sudden events such as droughts and floods (Donatti et al., 2019). Given their dependence on agricultural production, countries in Sub-Saharan Africa, especially their rural population, are highly vulnerable to climate change (Bryan et al., 2013).

To reduce the adverse effects of climate change, farmers can take measures to achieve their food, income and livelihood security (Hassan and Nhemachena, 2008). Yet, farmers are unlikely to have similar preferences about these adjustments (Mugagga, 2017). The risk they associate with a particular event depends on their tolerance of the anticipated harm (Tucker et al., 2010). But perceiving an incident as a risk is the first step towards adjustment: If farmers do not perceive climate change as a threat, they will not take measures to mitigate its effects (Ndamani and Watanabe, 2017). It is, therefore, necessary to understand farmers' perception of risks connected to climate variability and its connection to farmers' subsequent responses.

Research has shown that farmers already observe changes in climatic conditions (Bro, 2020; Chengappa et al., 2017; Mugagga, 2017; Ndamani and Watanabe, 2017), perceive them as a risk (Mulinde et al., 2019) and take measures to adjust (Bryan et al., 2013; Mertz et al., 2009; Mugagga, 2017; Ndamani and Watanabe, 2017). However, while most studies investigate farmers' perception of changing patterns and their response actions separately, evidence on the connection between risk perception and adjustment is scarce (Asayehegn et al., 2017). This study, therefore, investigates the link between farmers' perception of adverse weather events and their management responses.

We focus on coffee production, as changing temperature and precipitation patterns threaten smallholder farmers producing coffee. Climate change related outcomes such as declines in coffee yield, loss of coffee-optimal areas, and increased pests and diseases (Pham et al., 2019) will increase coffee farmers' challenges to meet their basic livelihood needs. Effects are expected to be more severe in regions less suitable for coffee production (Bunn et al., 2015b), leading to a geographic shift in regions suitable for coffee production (Bro, 2020).

Using a data set of coffee farmers in Rwanda, we investigate farmers' perception of adverse weather events and factors influencing their perception. The objective of the study is to discover patterns in farmers’ perception of adverse weather events, identify factors influencing the perception and finally analyse how farmers' perception of adverse weather events relates to measures adopted to mitigate the effects of adverse weather events. We add to the current literature by drawing a link between farmers' perception of adverse weather events and their response actions. Furthermore, we collected data in three regions differing in their agro-ecological conditions, i.e., they differ in soil, landform and climatic characteristics suitable for agricultural production. This allows us to investigate how the perception of and adjustment to weather variability varies with local agro-climatic conditions.

The remainder of the paper proceeds as follows. Section two provides a conceptual framework for the study. Section three describes the data collection process and gives an overview of sample characteristics. Section four introduces the cluster analysis employed and describes the clusters identifying farmers' perceptions of adverse weather events. Sections five and six describe the econometric estimation techniques and present the results on cluster membership and adjustment measures, respectively. Section seven concludes.

3.2 Conceptual Framework

Previous research has documented farmers' awareness of climate change (Deressa et al., 2011) and emphasised that climate risk perceptions are essential for farmers' decision-making (Eakin et al., 2014). Figure 3.1 visualises the links between the experiences of adverse weather events, the risk farmers attach to them, and the measures taken to mitigate the perceived risks. The experience of adverse weather events reflects farmers' exposure to potential risks. In this study, adverse weather events relate to the timing of the wet/dry season[4], the length of the season[5], and the distribution of precipitation throughout the year[6]. Weather and disaster have been identified as the most critical risk factors for farmers in the literature, and socio-economic attributes and farm characteristics are important determinants of risk perception (Ndamani and Watanabe, 2017). Also, farmers' risk perception is

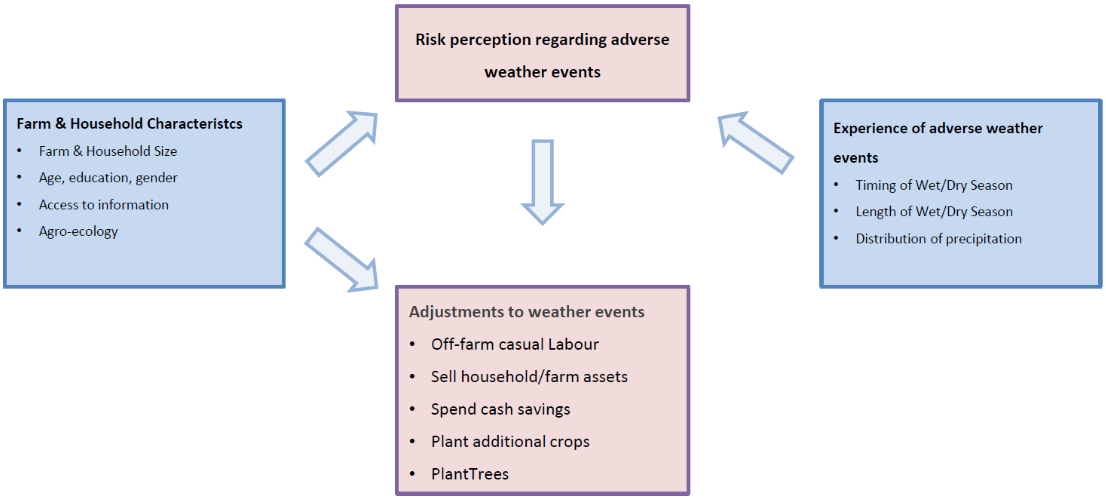
[4] Wet/dry season began earlier/later than expected, respectively

[5] Wet/dry season was longer/shorter than expected, respectively

[6] Wet season/whole year less rainy than expected, respectively; Infrequent heavy rains; Year as a whole too rainy

influenced by their experiences of climate variability and location-specific features (Asrat and Simane, 2018).

Figure 3.1 Conceptual Framework



Adjustments to adverse weather events refer to natural or human systems changes in response to actual or expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities (IPCC, 2007). Common adaptation strategies include shade tree management, farmers changing the crops they cultivate (Asayehegn et al., 2017; Bro et al., 2020; Chengappa et al., 2017; Eshetu et al., 2020; Mulinde et al., 2019; Shinbrot et al., 2019), and off-farm employment (Adane and Bewket, 2021; Eshetu et al., 2020; Hochachka, 2021; Shinbrot et al., 2019). Selling assets and spending cash savings are short-term responses to climate variability, which are, by comparison to the former adjustments, underrepresented in research so far (Bro, 2020; Mulinde et al., 2019). Making adjustments can help farmers achieve their food, income and livelihood security in changing climatic and socio-economic conditions (Kandlikar et al., 2005).

How farm-households respond to adversities is often influenced by the availability of household assets and socio-economic conditions (Mulinde et al., 2019). As presented in Figure 3.1, we expect farmers' choice of adjustment measures, on the one hand, to be associated with farmers' risk perception of adverse weather events. The more farmers perceive themselves to be affected by weather events, i.e., the higher their risk perception concerning adverse weather events, the more likely they will be to choose one or more adjustment measures. On the other hand, we expect farmers' decision making to be associated with different household and farm characteristics. Age, education and farm size have been found to influence farmers' decision-making regarding adaptation measures (Asrat and Simane, 2018). Asayehegn et al. (2017) identified household size, farm income and farmers perceiving changes in climate as drivers of smallholders' adjustment choices. Eshetu et al. (2020) find that location also plays a role in farmers' adjustment decisions. Access to climate change information is another important factor in farmers' adjustment process. Besides access to extension services (Asayehegn et al., 2017; Bro et al., 2019; Eshetu et al., 2020), authors have discussed demand-side factors, such as the production of high-quality coffee or certification, to positively affect farmers' adjustment to adverse weather events (Adane and Bewket, 2021; Borsky and Spata, 2018; Verburg et al., 2019).

3.3 Data Collection and Descriptive Statistics

3.3.1 Data Collection

Household-level survey data were collected in four districts of Rwanda between October and December 2019. Districts were purposefully chosen to represent three climatic zones that differ regarding their suitability for coffee production. Bugesera is part of the "East-Rwandan dry and hot lowland zone", characterised by a savanna climate. This region is least suitable for coffee production. Average annual temperatures lie around 21°C, and annual rainfall is below 1000 mm. Altitude is below 1500 m.a.s.l. Huye is in the "Temperate zone of the central highlands". Elevation mainly ranges between 1500 and 2000 m.a.s.l. and precipitation averages around 1200 mm annually. The average annual temperature is at 19°C. Karongi and Rutsiro represent the climate of Lake Kivu Rift Valley, the area most suitable for coffee production. Yearly average precipitation averages between 1200-1500 mm and elevation range from 1400 to 1800 m.a.s.l.. Annual temperature averages at just below 18.5°C.

We conducted a multi-stage random sampling. First, we randomly selected 18 Coffee Washing Stations (CWS) based on a list obtained from the Rwandan Agricultural Board. In Rwanda, most coffee is fully washed in wet mills, so-called CWS, where farmers deliver their coffee to. Besides processing coffee, the CWS also provide extension and support to farmers within their operational area. We randomly selected around five lead farmers per CWS, who helped us randomly select five to ten farmers for interviews. Overall, we surveyed 559 coffee producers. Since certification with sustainability standards is common in Rwanda and may affect how farmers adjust, we stratified the sample into certified and non-certified farmers. Most certified farmers in our sample obtained Rainforest Alliance certification. We interviewed 286 certified and 273 non-certified farmers. 188 interviews were conducted in Bugesera (87/101 certified/non-certified), 189 in Huye (88/101 certified/non-certified) and 182 in the Lake Kivu Region (84/98 certified/non-certified).

The survey questionnaire collected information on household demographics, coffee production and marketing, crop production other than coffee, input use on the plot level, and certification. Furthermore, it collected information on farmers' experience of potentially adverse events and if farmers perceived the event as potentially threatening their livelihood[7]. Events farmers were asked about covered twelve situations related to a change in timing and length of Rwanda's two main agricultural seasons and change in precipitation throughout the seasons and generally the whole year. If farmers stated they experienced a given event, they were asked about their response actions[8].

3.3.2 Description of sample characteristics

Table 3.1 gives a general overview of the sample characteristics, farmers' experience of adverse weather events, and their adjustments for the complete sample and by agro-ecological region. The descriptives show that while over the entire sample, many weather events have been experienced by approximately half of the sample, the distribution across regions tends to vary. In Bugesera, a late rainy period and a long dry period are much more prevalent than in the other regions. In Huye, farmers more often experienced higher precipitation events. These include an early and long rainy period, more rain than expected over the whole year, and less frequent but heavy rains. Around half of the farmers have experienced adverse weather events in the Lake Kivu region. The differences in the average share of farmers who reported to have experienced the events across regions are statistically significant.

Table 3.1 Descriptive Statistics

	Full Sample	Bugesera	Huye	Lake Kivu	p-values Kr.-Wall.
Household Size	5.1 (1.9)	4.7 (1.7)	5.4 (1.9)	5.3 (2.1)	0.0019
Age of household head	49.5 (12.9)	50.5 (13.3)	49.3 (12.2)	49.1 (13.0)	0.4700

[7] Question: Do you feel this event has/would have strong negative effects on your life? Answer based on 5-Point-Likert-Scale from Strongly Disagree – Strongly Agree

[8] Question: Did you adjust in any particular way to the event? – Options: 1) Not at all, 2) Extra Casual Labour, 3) Financial adjustments (Borrowing money, Spend Cash Savings), 4) Selling Assets, 5) Planted Different Crops, 6) Planted trees

Yrs of formal education of household head	4.6 (3.1)	3.8 (2.96)	4.8 (3.1)	5.3 (3.1)	0.0001
Female-headed household	.31 (.46)	.33 (.47)	.31 (.46)	.29 (.46)	0.8238
Farm Size in ha	.25 (.19)	.22 (.17)	.25 (.17)	.28 (.21)	0.0024
Certification	.479 (.50)	.46 (.499)	.45 (.499)	.53 (.50)	0.3533
Receive weather info on mobile phone	.71 (.46)	.75 (.43)	.72 (.45)	.64 (.48)	0.1364
Distance to nearest extension in km	2.7 (2.3)	1.9 (1.7)	3.1 (2.4)	2.96 (2.5)	0.0001
Farmer experienced event (0/1)					
Early Wet Season	.498 (.500)	.246 (.432)	.696 (.461)	.553 (.499)	0.0001
Late Wet Season	.467 (.499)	.667 (.473)	.288 (.454)	.447 (.499)	0.0001
Early Dry Season	.456 (.499)	.541 (.499)	.369 (.484)	.458 (.499)	0.0176
Late Dry Season	.286 (.452)	.191 (.394)	.353 (.479)	.313 (.465)	0.0203
Short Wet Season	.366 (.482)	.464 (.500)	.25 (.434)	.385 (.488)	0.0016
Less rain during Wet Season	.315 (.465)	.421 (.495)	.201 (.402)	.324 (.469)	0.0013
Long Dry Season	.546 (.498)	.672 (.471)	.467 (.500)	.497 (.501)	0.0012
Yr less rainy	.308 (.462)	.388 (.489)	.163 (.370)	.374 (.485)	0.0002
Long Wet Season	.546 (.498)	.399 (.491)	.701 (.459)	.536 (.500)	0.0001
Short Dry Period	.289 (.454)	.158 (.366)	.369 (.484)	.341 (.475)	0.0008
Yr more rain	.540 (.499)	.393 (.489)	.674 (.470)	.553 (.498)	0.0001
Infrequent heavy rains	.559 (.497)	.437 (.497)	.647 (.479)	.592 (.493)	0.0015
Adjustment to adverse weather events (0/1)					
Sell Assets	.447 (.498)	.432 (.497)	.473 (.501)	.436 (.497)	0.7544
Spend Cash Savings	.401 (.491)	.404 (.492)	.413 (.494)	.385 (.488)	0.8979
Additional Off-Farm Employment	.300 (.459)	.284 (.452)	.326 (.470)	.296 (.455)	0.7165
Planted Additional Crops	.463 (.499)	.372 (.485)	.511 (.501)	.508 (.501)	0.0310

Planted Trees	.333 (.472)	.224 (.418)	.397 (.491)	.379 (.487)	0.0070

Note: For the full sample and the regional samples, means are reported; standard deviation in parentheses

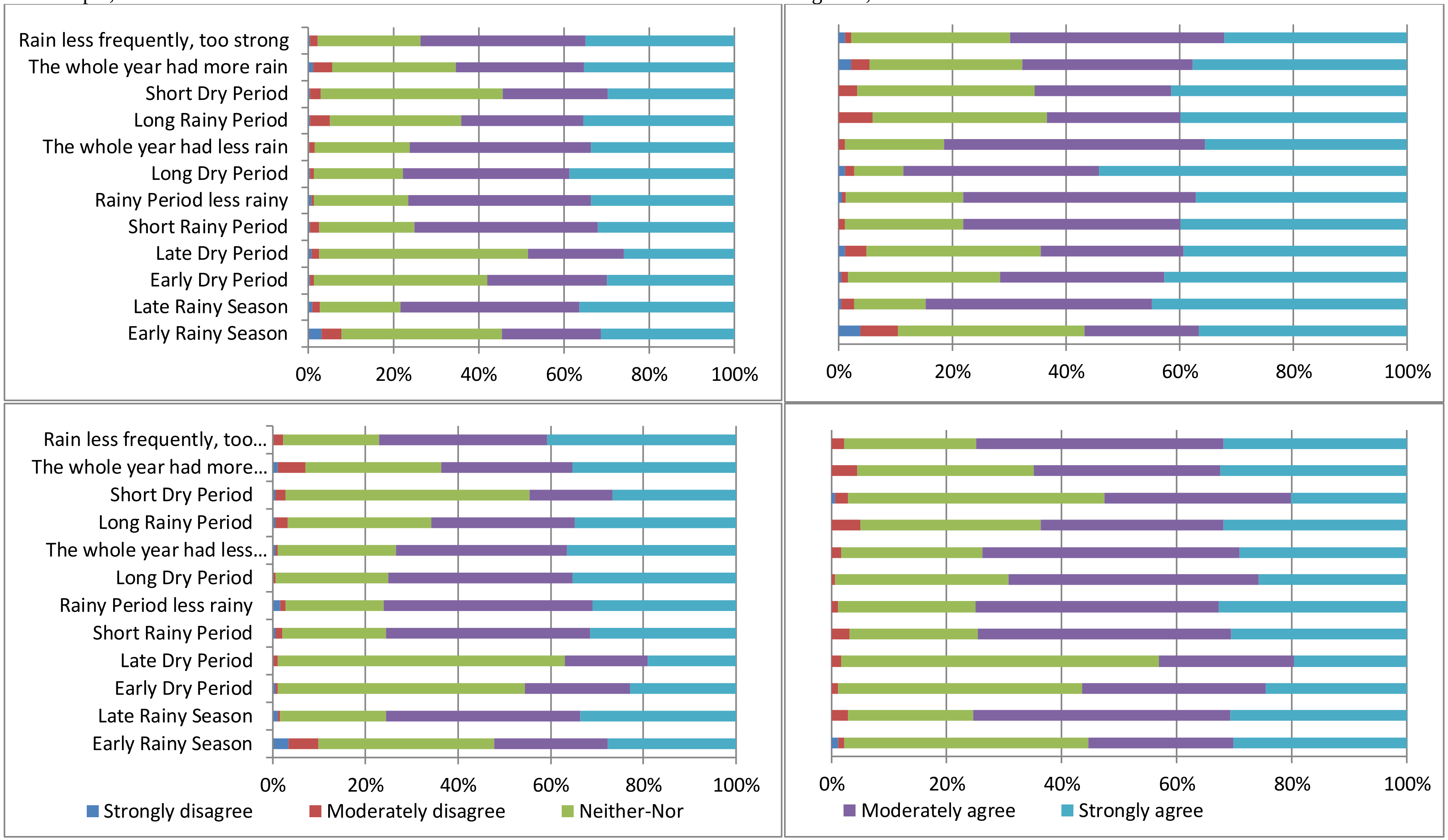
Figure 3.2 shows farmers' perceptions of adverse weather events. Farmers were asked whether they believed that the specific adverse weather event would negatively affect their livelihood if or when the event occurred. While the pattern of what farmers perceive as a risk appears to be similar across regions, we can observe differences in the intensity of risk perception concerning specific events. It is observable that most farmers moderately or strongly agree that a late or short rainy period and a long dry period have adverse effects on their livelihood. Also, farmers perceive that if the wet season and the whole year were less rainy than expected, or if rains were less frequent but intense, this would negatively affect their livelihoods. Too much rain is also perceived as unfavourable by many farmers. Around two-thirds of farmers agree that if the rainy period was longer or the whole year had more rain than expected, this would negatively affect their livelihoods. From visual inspection, farmers in Bugesera overall appear to have a higher risk perception than farmers in the other two regions. Using the Krusker-Wallis test for significance, we find statistically significant regional differences for half of the events in question. In particular, the risk that farmers associate with the timing and length of the dry season (the season is too early/late or too long/short), and their risk perception of a short and/or late wet season differ significantly between the regions. Farmers in Bugesera, the region least suitable for coffee production and characterised by low precipitation and high temperatures (compared to the other two regions), have the highest risk perception concerning these events.

Across all regions, about two-thirds of farmers adjust as a reaction to adverse weather events. Most farmers in the full sample adjust by planting additional crops, selling assets, or spending cash savings. About one-third of farmers adjust by planting trees or seeking additional off-farm employment. While the share of farmers adjusting by spending cash savings, selling assets, or seeking additional off-farm employment is similar across regions, planting additional crops or trees is more common in Huye and the Lake Kivu region than in Bugesera.

Figure 3.2 Farmers perceiving adverse weather events as a threat to their livelihood by Climatic Region

Full Sample; N=559

Bugesera; N=183



Huye; N=184

Lake Kivu; N=179

3.4 Identifying farmers' perception of weather events

3.4.1 Cluster Analysis

To identify patterns in farmers' perceptions of adverse weather events, we use cluster analysis. This allows us to identify groups of farmers who are similar in their risk perceptions. We used the k-means clustering technique to identify groups of farmers with similar risk perceptions. Partitioning methods such as the k-means method require the number of generated clusters to be specified in advance. Randomly chosen 'seed values' act as initial starting values. In an iterative process, observations are then assigned to the group whose mean is closest, creating new group means. This process repeats until no observations change groups. The cluster number was found using Ward's method and applying the Duda-Hart criterion. Prior, the single-linkage method was used to identify and eliminate outliers (Mooi et al., 2018). Thus, thirteen outliers were identified and excluded from the analysis. Clustering was conducted using the remaining 546 observations base farmers' perception of adverse weather events (for more detail, see Chapter 2 Conceptual Framework).

3.4.2 Farmers' perception of adverse weather events

The cluster analysis revealed four groups of farmers with differing risk perceptions associated with adverse weather events. Farmers perceive the risk from various weather events as either low, medium, or high or attach a low risk to specific events and medium risk to others. Figure 3.3 visualises farmers' risk perceptions in each cluster.

Cluster 1 Low Risk Perception

For the most part, farmers in this cluster neither agree nor disagree that the listed weather events would negatively affect their livelihoods. Only concerning a prolonged dry period, one-third of farmers in this cluster moderately or strongly agree that this event would negatively affect their livelihoods. One-fifth of the farmers in this cluster moderately or strongly agree that a change in the timing of the dry period presents a threat to their livelihood. Overall, this group can be considered as having a low level of climate risk perception.

Cluster 2 Selective Risk Perception

Farmers in this group differentiate between events and are mainly concerned with events related to a decrease in precipitation. Farmers in this cluster neither agree nor disagree that a change in the timing of the dry period has negative consequences for their livelihoods. Nevertheless, when the rainy period is later, shorter or less rainy, or the dry period longer than expected, farmers moderately agree that this threatens their livelihood. Also, a considerable share of farmers in this cluster strongly agrees that less frequent but intense rains would negatively affect their livelihoods.

Cluster 3 Medium Risk Perception

This group is characterised by generally moderate risk perception and moderately agreeing to the statements. Farmers in this cluster seem to be more concerned with high precipitation. A large proportion of farmers strongly agree that a long rainy period or a year that, in general, has more rain than expected, would have negative consequences for their livelihoods.

Cluster 4 High Risk Perception

High levels of climate risk perceptions characterise farmers in this cluster. Overall, farmers strongly agree that all of the listed weather events have adverse effects on their livelihoods, indicating a high level of risk perception. Farmers in this cluster do not discriminate between different types of adverse weather events regarding their risk perception.

Figure 3.3 Farmers perceiving adverse weather events as a threat to their livelihood by Risk Cluster

3.5 Econometric estimation strategy

3.5.1 Correlations with risk perception

We estimate a multinomial logistic regression (MLR) to identify factors correlated with risk perception. The risk perception clusters previously identified in the cluster analysis are used as dependent variable. MLR is commonly used for nominal dependent variables with more than two categories. The outcomes are unordered, as their numeric values are interchangeable and have no effect on the estimation or interpretation (Wooldridge, 2010). Let Y denote the risk clusters, taking the values {1, 2, …, J}, and X summarise the factors correlated with risk perception. We are interested in how a change in the explanatory variables X affects the probability of farmers' membership in a risk perception cluster, $P(y = j|x)$.

Corresponding to the four risk perception clusters identified in the cluster analysis, the cluster with the lowest risk perception was initially used as the base category. Setting β_1 to 0, the remaining coefficients then measure the change relative to the group of farmers with low risk perception:

$$P(y = Low\ Risk|x) = \frac{1}{1 + e^{X\beta_2} + e^{X\beta_3} + e^{X\beta_4}}$$

$$P(y = Selective\ Risk|x) = \frac{e^{X\beta_2}}{1 + e^{X\beta_2} + e^{X\beta_3} + e^{X\beta_4}}$$

$$P(y = Medium\ Risk|x) = \frac{e^{X\beta_3}}{1 + e^{X\beta_2} + e^{X\beta_3} + e^{X\beta_4}}$$

$$P(y = High\ Risk|x) = \frac{e^{X\beta_4}}{1 + e^{X\beta_2} + e^{X\beta_3} + e^{X\beta_4}}$$

To investigate determinants of class membership, socio-economic variables and past experience of potentially adverse weather events were included as covariates into the model. The multinomial logit model was run three times, using a different risk perception cluster as the base category each time, to evaluate differences between all clusters, not just concerning the low risk perception cluster.

The MLR assumes independence of irrelevant alternatives (IIA), implying that the probabilities of any category are not influenced by including or excluding an alternative. Hausman diagnostic tests were used to test the IIA assumption.

3.5.2 Correlations with adjustment strategies

To assess factors correlated with adjustment strategies, we estimated a multivariate probit model (MVP), which accounts for farmers potentially choosing multiple adjustments in response to adverse weather events. The approach developed by Chib and Greenberg (1998) enables the joint prediction of responses on an individual-specific basis. Modelling the types of adjustment farmers used, the multivariate probit model may be described as

$$Y_i^* = \beta_i' X_i + \varepsilon_i, i = 1,2, \ldots ,5$$

where Y_i^* represents the propensity of adopting adjustment i, and X_i is a vector consisting of the factors relevant in choosing adjustment i. β_i is a vector of unknown coefficients to be estimated, and ε_i stand for the normally distributed error terms with mean zero and variance one (Chib and Greenberg, 1998; Choo and Mokhtarian, 2008).

To evaluate the connection between farmers' adjustment and risk perception, we use the risk perception clusters identified in the cluster analysis as dummy variables on the right-hand-side of the model. We further include location dummies in the model to account for regional differences, e.g., in agro-ecological conditions. Additionally, we include socio-economic indicators such as farm and household size, age, education and income, and access to information as covariates in the model.

3.6 Econometric results

3.6.1 Correlates of membership in risk perception clusters

Previous experience with adverse weather events and risk perception

Table 3.2 presents the results of a multinomial logit model that analyses the link between farmers' experience of adverse weather events and their risk perception of adverse weather events. Overall, the results indicate that the experience of adverse weather events is strongly associated with farmers' risk perceptions of such weather events. More specifically, irregularities in the timing of the seasons tend to be associated with membership in higher risk perception clusters. The experience of a late wet season significantly increases the likelihood of farmers having a selective or medium risk perception compared to low risk perception. Changes in the timing of the dry period increase the likelihood of medium risk perception compared to low or selective risk perception. Generally, early onset of the wet season seems unproblematic for farmers in our sample, as an early wet season is negatively associated with farmers belonging to the high risk perception clusters.

Our data show that events connected to lower precipitation levels increase risk perception. If the whole year had less precipitation than expected, farmers are significantly more likely to be in the medium or high risk perception clusters compared to the low or selective risk perception clusters. A long wet season and a year with more rain than expected positively affects farmers' likelihood to be in the medium or high risk perception clusters over the selective risk perception cluster. This is not surprising, as farmers with selective risk perception are particularly concerned about events connected to low precipitation. At the same time, these same events decrease farmers' likelihood to be in the high over the medium risk perception cluster. Similarly, infrequent but heavy rains are positively associated with membership in higher risk perception clusters compared to the low risk perception cluster. Yet, they are also negatively associated with farmers' likelihood to be in the high risk perception cluster over the medium risk perception cluster.

Table 3.2 Connection between adverse weather events and risk perception

	Selective Risk Perception	Medium Risk Perception	High Risk Perception
Farmer experienced event (0/1)	Base Category: Low Risk Perception		
Early Wet Season	.11	-.43	-1.1***
Late Wet Season	.65	.51	.43
Early Dry Season	.66	1.2***	.75*
Late Dry Season	.43	1.0**	.47
Short Wet Season	.65	.63	.597
Less rain during Wet Season	-.41	-.15	.54
Long Dry Season	-.11	.56	-.17
Yr less rainy	-1.3*	1.3**	1.0*
Long Wet Season	-.97**	.95**	.17
Short dry period	-.66	-.298	-.51
Yr more rain	-2.1***	-.06	-.67*
Infrequent heavy rains	1.7***	1.96***	1.4***
Early Wet Season	Base Category Selective Risk Perception	-.54	-1.2***
Late Wet Season		-.14	-.22
Early Dry Season		.55	.09
Late Dry Season		.59	.04
Short Wet Season		-.02	-.05
Less rain during Wet Season		.26	.95*
Long Dry Season		.68*	-.06
Yr less rainy		2.7***	2.4***
Long Wet Season		1.9***	1.1***
Short dry period		.37	.16
Yr more rain		2.1***	1.4***
Infrequent heavy rains		.23	-.37
Early Wet Season	Base Category		-.68**

Late Wet Season	Medium Risk Perception	-.08
Early Dry Season		-.46
Late Dry Season		-.56
Short Wet Season		-.03
Less rain during Wet Season		.69*
Long Dry Season		-.74**
Yr less rainy		-.28
Long Wet Season		-.78**
Short dry period		-.21
Yr more rain		-.61*
Infrequent heavy rains		-.60**
MLR Results; N= 546; Log likelihood = -519.82622; Pseudo R2 = 0.2828; LR chi2(36) = 409.89; Prob > chi2 = 0.0000; Significant levels: *** p<0.01, ** p<0.05, *p<0.1		

Household characteristics and risk perceptions

Table 3.3 shows results on the association between household and farm characteristics and risk perceptions. The results show that only few household and farm characteristics affect farmers' risk perception of adverse weather events. Farmers in the Lake Kivu region, which is most suitable for coffee production, as well as farmers in Huye, the region with medium suitability for coffee production, tend to be less likely to belong to the high risk perception cluster. Besides the agro-ecological setting, other farm and household characteristics are mostly not significantly associated with risk perception. Female-headed households appear to be slightly more likely to be in the medium and high risk perception clusters. Yet, the coefficient is only significant when the selective risk perception cluster serves as base category. Higher education is weakly associated with high risk perception, but only in comparison to medium risk perception.

Table 3.3 Connection between household and farm characteristics and risk perception

Base Category: Low Risk Perception	Selective Risk Perception	Medium Risk Perception	High Risk Perception
Lake Kivu	-.98*	-.21	-1.2***
Huye	-.799**	-.27	-.85**
Household Size	.05	.008	-.03
Age of household head	.02*	.0007	.004
Yrs of formal education of household head	-.02	-.06	.04
Female-headed household	-.25	.24	.35
Farm Size in ha	.19	-.20	-.53
Lake Kivu	Base Category: Selective Risk Perception	.77**	-.17
Huye		.53*	-.05
Household Size		-.04	-.08

Age of household head		-.02*	-.02
Yrs of formal education of household head		-.04	.06
Female-headed household		.49*	.60*
Farm Size in ha		-.39	-.73
Lake Kivu			-.94***
Huye			-.58**
Household Size			-.04
Age of household head	Base Category:		.003
Yrs of formal education of household head	Medium Risk Perception		.10**
Female-headed household			.11
Farm Size in ha			-.33

MLR Results; N=546; Log likelihood = -710.462; LR chi2(21) = 37.98; Prob > chi2 = 0.0130; Pseudo R2 = 0.0262

3.6.2 Adjustments

Our results in Table 3.5 show a strong connection between farmers' risk perception of adverse weather events and their adjustment responses. While selective risk perception does not significantly influence farmers' adjustment strategies compared to low risk perception, medium and high risk perception are highly and significantly connected to all adjustment measures.

Farmers in Huye and the Lake Kivu region, the two regions characterised by medium and high suitability for coffee production, are more likely to use on-farm adjustment strategies, *i.e.*, to grow additional crops or plant trees, than farmers in Bugesera, where suitability for coffee production is low. Selling assets and spending savings present only short-term solutions to adjust to adverse weather events; yet, the descriptive statistics showed that a considerable proportion of farmers in our sample adjust in this manner (Table A 3.1 in the Appendix). Although the differences in the rate of adoption between the regions are not statistically significant, in Bugesera, farmers tend to rely more strongly on these short-term adjustment strategies, as indicated by the negative coefficients of Huye and the Lake Kivu region.

Our results further show that farm size significantly affects farmers' decision to sell assets or spend cash savings. On the other hand, farmers with larger farms are less likely to adjust by planting trees. In terms of access to information, farmers receiving weather information on their mobile phones are more likely to spend cash savings and engage in casual off-farm employment but are less likely to adjust by planting additional crops or trees. Households located further away from extension service are significantly more likely to adjust by selling assets, seeking casual employment, and planting trees. Certification has no significant effect on farmers' choice of adjustment strategy.

Table 3.4 Connection between adjustments, risk perception and household characteristics

	Sell Assets	Spend Cash Savings	Add. Off-Farm Employment	Plant Crops	Plant Trees
N	244	219	166	253	182
Selective Risk Percept.	-.12	.27	.44	-.22	-.098
Medium Risk Percept.	1.3***	1.6***	1.6***	1.1***	1.4***
High Risk Percept.	1.3***	1.1***	1.0***	1.1**	1.0***
Lake Kivu	-.19	-.19	-.05	.26*	.26
Huye	-.09	-.05	.008	.31**	.37**
Household Size	.004	.003	.007	-.02	-.05
Age of household head	.003	-.006	-.003	.003	.004
Yrs of formal education of household head	-.01	.01	-.01	-.03	.01
Female-headed household	-.04	.26*	.16	.17	.09
Farm Size in ha	.74**	1.3***	-.41	.18	-1.1***
Certification	.03	.08	.19	.17	.07
Receive weather info on mobile phone	.13	.23*	.24*	-.52***	-.79
Distance to nearest extension service in km	.14***	-.006	.06**	.05*	.07**

MVP results, N = 546; Log likelihood = -1295.0011; Prob > chi2 = 0.0000;Wald chi2(65)= 393.90; Significance levels: *** p<0.01, ** p<0.05, *p<0.1

3.7 Discussion

Farmers' risk perception is significantly associated with their experiences of adverse weather events, specifically changes in expected precipitation and the timing of the seasons. Our results suggest that the timing of the wet season is critical for farmers, which is reasonable since a late start or early end of the wet season make it difficult for farmers to prepare for the planting season (Eshetu et al., 2020). This is especially so as farmers in the study region depend on rain as a source of irrigation since professional watering systems are rare. Our findings are also in line with Chengappa et al. (2017), who found that a delay in the monsoon season and unpredictable timing of seasons influence farmers' perception of climate change in India. In our sample, a deviation from the expected amount of rainfall is also significantly connected to farmers' risk perception. This connects to research by Eshetu et al., (2020), who found that high rainfall variability and drought are threats generally recognised by farmers.

On a regional level, we can see that farmers differ significantly regarding their experiences (Table 3.1) and perceptions (Figure 3.2) of specific weather events. Farmers in Bugesera, the region least suitable for coffee production, have a significantly higher risk perception regarding the timing and length of the dry season and of a short and/or late wet season compared to the other two regions. This is also evident when considering farm-level aspects connected to risk perception, where we find that agro-ecology is the most important factor associated with cluster membership.

Our results show a close connection between risk perception and adjustment. These findings contribute to the research by Asayehegn et al., 2017 and Zuluaga et al., 2015 documenting that farmers' awareness of climate variability, i.e., farmers perceiving changes in temperatures, amount or seasonality of rain, influence their adaptation strategies. Nevertheless, Asayehegn et al. (2017) also show that a significant portion of farmers not perceiving any changes in the climate still adopted adaptation strategies. This contradicts the assumption that farmers only adapt if they perceive changes in the climate. Our results contribute to this evidence by adding the layer of risk perception: We find that farmers do not have equal risk perceptions regarding adverse weather events and those farmers with low risk perception are less likely to adapt. Hence, it is not only farmers' recognition of a changing climate that is relevant for farmers response actions, but also their perception of the risks associated with these adverse weather events.

Besides risk-perception, farm-households responses to climate change often influenced by the availability of household assets and socio-economic conditions (Mulinde et al., 2019). Farm size and distance to nearest extension service both influence adjustments on a statistically significant level. This is in line with Asayehegn et al., 2017, Eshetu et al., 2020 and Mulinde et al., 2019, who find that farm size and access to extension services significantly affect the adoption of adaptation strategies. Location is only significantly related to farm-based adaptation strategies, such as planting additional crops or shade trees. Farmers located in the regions more suitable for coffee production are more likely to choose more sustainable, farm-based adaptation strategies. Farmers located in Bugesera, the region less suitable for coffee production, tend to rely more strongly on short-term adjustment strategies, specifically selling assets and spending cash savings. These are adjustment strategies that could leave farmers possibly more vulnerable than before (Bro, 2020).

3.8 Conclusion

In Rwanda, the consequences of climate change are already visible and affect the rural population. Responding to these changing patterns and the connected risk of adverse weather events is important. As perceiving an event as a risk is the first step towards adjustment, we investigated the link between smallholder coffee farmers' perception of adverse weather events and their adjustments to them. Our study aimed to identify patterns in farmers' perception of adverse weather events as well as factors influencing the perception, and then draw a link between farmers' perception of and adjustment to adverse weather events.

We identified four distinct groups based on farmers' risk perception. Farmers do not discriminate between *what* they perceive as a risk for the main part, yet they differ in their *level* of risk perception. Farmers are characterised by low, medium or high risk perception or perceive only a limited number of adverse events as a risk for their livelihoods.

Many farmers in our sample adjust to adverse weather events; yet their adjustment strategies often represent reactive response actions. This is even more so the case in the region least suitable for coffee production. Farmers in the regions more suitable for coffee production are more likely to choose more sustainable, farm-based adaptation strategies. Farmers in the region less suitable for coffee production tend to rely more strongly on short-term adjustment strategies, which could leave them more vulnerable than before.

In general, research on climate change adaptation adopted among coffee farmers has a strong focus on incremental options such as introducing new crop varieties (Adane and Bewket, 2021; Baca et al., 2014; Mugagga, 2017) or adjusting the planting dates of cultivated crops (Asayehegn et al., 2017; Eshetu et al., 2020; Mulinde et al., 2019). While they are easy to adopt and already widely implemented, they might only suffice to respond to minor changes in the climate. With increasing climate change, agricultural systems need to adapt more substantially, e.g., adding a shade tree layer to coffee or diversifying their production and income strategies (Verburg et al., 2019).

We found that farmers perception of and adjustment to adverse weather events are closely connected. While the connection between perceptions of climate change and adaptation is already established (Asayehegn et al., 2017; Zuluaga et al., 2015), so far, it referred to farmers perceiving changes in temperatures, amount or seasonality of rain. Our results contribute to this evidence by adding the layer of risk perception. This shows that farmers not only need to be aware of a changing climate, but also perceive adverse weather events as a threat.

Location and access to extension are also significantly associated with adjustment. Location (Byrareddy et al., 2021; Eshetu et al., 2020; Mulinde et al., 2019; Zuluaga et al., 2015), the availability of objective climate change information (Asayehegn et al., 2017; Mugagga, 2017; Zuluaga et al., 2015) and access to extension services (Asayehegn et al., 2017; Eshetu et al., 2020; Mulinde et al., 2019) are widely acknowledged drivers in farmers' adaptation decisions. Paired with the evidence on the role of farmers' perceptions of adverse weather events, this indicates that providing weather information at the local level may help farmers to adjust to climate change. Providing extension options is important in educating farmers about options to enhance their resilience and adaptive capacities (IPCC, 2007). To improve farmers' adaptive capacity, campaigns and participatory approaches present important tools for raising farmers' awareness of climate variability (Mulinde et al., 2019). Extension services can support adaptation to climate change through the facilitation and implementation of adaptation programmes or by guiding farmers to implement new farming methods (Antwi-Agyei and Stringer, 2021).

Future research should evaluate extension options to support farmers in the implementation of adjustment strategies. Special attention should be paid to finding sustainable solutions for farmers in regions less suitable for coffee production. A better understanding of both the link between risk perceptions and adjustment responses and the welfare implications of adjustment strategies can help to design appropriate policy interventions to support farmers in their adjustment efforts.

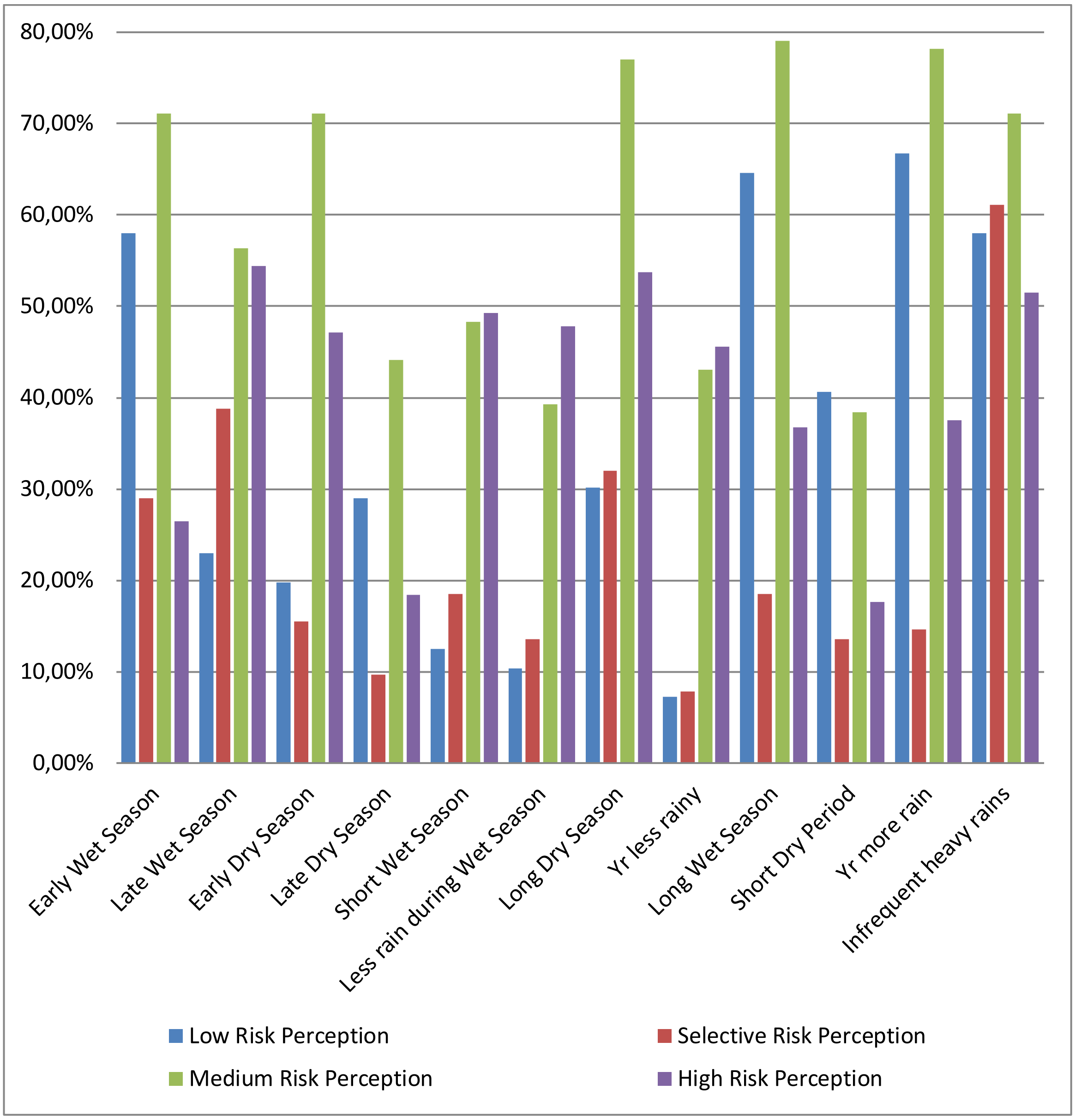
3.9 Appendix

Table A 3.1 Cluster Summary Statistics

	Low Risk Perception	Selective Risk Perception	Medium Risk Perception	High Risk Perception	KWT prob
HH Size	5.2	5.3	5.1	4.9	0.4689
	(1.8)	(1.9)	(1.0)	(1.9)	
Age of the HH head	48.3	51.9	49.3	48.8	0.1915
	(12.1)	(2.8)	(13.5)	(12.7)	
Yrs of formal education	4.98	4.4	4.3	4.9	0.1933
	(3.1)	(3.2)	(3.0)	(3.1)	
HH Type	.27	.22	.336	.35	0.2675
	(.46)	(.42)	(.474)	(.48)	
Farm Size in ha	.26	.279	.244	.23	0.0855
	(.21)	(.18)	(.18)	(.17)	
Coffee area	.11	.104	.09	.09	0.0115
in ha	(.09)	(.075)	(.09)	(.095)	
Household Income	957.9	728.8	1264.3	1165.4	0.0006
	(1139.1)	(970.6)	(1173.8)	(1163.8)	
# crops for food consumption	1.8	2.0	2.1	1.5	0.0001
	(1.1)	(.97)	(1.2)	(.98)	
Certification	.54	.48	.38	.59	0.0085
	(.50)	(.50)	(.487)	(.49)	
Receive weather info on mobile phone	.81	.55	.65	.83	0.0003
	(.39)	(.499)	(.478)	(.376)	
Distance to nearest extension	43.3	43.2	52.9	55.7	0.0733
	(34.3	(34.4)	(41.5)	(44.99)	
Adjustment to adverse weather events (0/1)					
Spend Cash Savings	.125	.175	.607	.449	0.0001
	(.333)	(.382)	(.489)	(.499)	
Additional Off-Farm Employment	.073	.126	.493	.309	0.0001
	(.261)	(.334)	(.501)	(.464)	
Sell Assets	.177	.146	.616	.603	0.0001
	(.384)	(.355)	(.488)	(.491)	
Planted Additional Crops	.229	.175	.635	.581	0.0001
	(.423)	(.382)	(.483)	(.495)	
Planted Trees	.125	.078	.540	.353	0.0001
	(.333)	(.269)	(.499)	(.479)	

Standard Deviation in Parantheses

Figure A 3.1 Experience of adverse weather events by Risk Cluster



4. How Farmers Adapt – Reviewing selected literature on coffee farmers adaptation to climate change

Abstract

Farmers' responses to climate change are diverse and can be broadly distinguished into three categories, i.e., Farm-based management approaches, Household strategies and Knowledge and investment. Studies on the adoption of adaptation measures mostly include farm-based management approaches. Most of the current adaptation research focuses on incremental adaptation, i.e., measures that can be implemented in existing systems. The review shows that a diverse set of indicators has been found to significantly affect farmers' decision making. Education, extension services and the availability of objective climate information were found to be significant influences on climate change adaptation in several studies. Campaigns and participatory approaches may present suitable tools for raising farmers' awareness of climate variability.

4.1 Introduction

The projected effects of global climate change will substantially affect the agricultural sector (Lasco et al., 2014). Plantation crops such as coffee are particularly vulnerable to climate change due to their long economic life span, non-irrigated cultivation and high up-front cost (Gunathilaka et al., 2018). As a consequence, geographic regions suitable for coffee cultivation will change, and crop productivity and crop quality decrease (Bunn et al., 2015b; Ovalle-Rivera et al., 2015). This has notable implications for farmer livelihoods and management decisions (Ahmed et al., 2021). To reduce the adverse effects of climate change, farmers have to take measures to achieve their food, income and livelihood security (Hassan and Nhemachena, 2008). At the same time, climate change adaptation is place- and context-specific, with local communities being a key factor in the adaptation process (Huggel et al., 2015). Cultural, technical and social factors as well as farmers' adaptive capacity are essential in farmers' adaptation process (Quiroga et al., 2015). Better understanding how farmers adapt to climate change and considering influencing factors in the adaptation process will support the development of appropriate and targeted climate change adaptation policies (Eshetu et al., 2020).

To develop planned adaptation strategies, smallholders' knowledge of adaptation based on their experiences can provide useful insight (Burnham and Ma, 2016). Since the early 2000s, there has been a proliferation in the academic literature on adaptation to climate change, examining smallholder farmers' adaptive strategies alongside their vulnerability and adaptive capacity in developing countries. So far, literature reviews on smallholder farmers' adaptation to climate change are broad in scope and do not specifically target empirical literature on plantation crops such as coffee (Below et al., 2010; Burnham and Ma, 2016). Hence, the objective of the present review is to analyse the empirical literature on climate change adaptation among smallholder coffee producers.

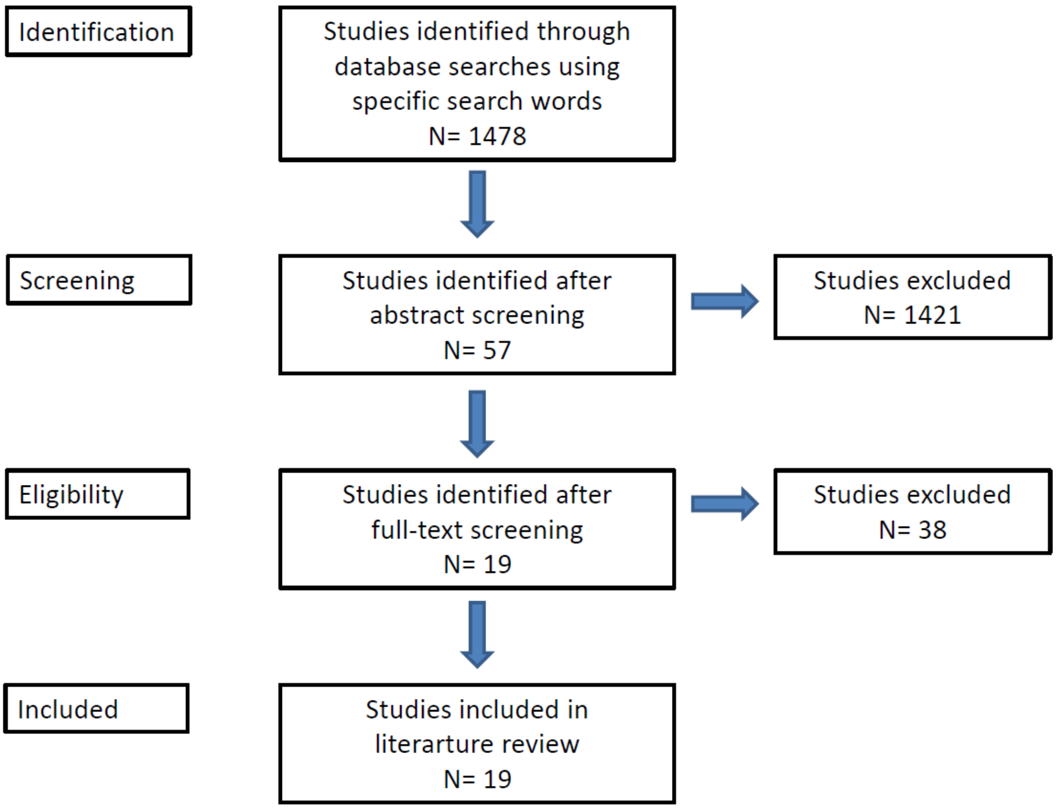
We analyse the literature on climate change adaptation strategies already implemented by coffee producers to synthesize the results to provide useful knowledge for the development of planned adaptations. Our literature review is guided by the following questions: (1) How do smallholder coffee producers adapt to a changing climate or other livelihood stressors? (2) What are the factors influencing the adoption of adaptations and to what extent have such factors been identified? Based on the findings, we discuss opportunities to support farmers' adaptation efforts and identify scope for further research.

The review is structured as follows: In chapter 2, we describe the process of identifying relevant literature for the review. We then present categories of adaptation strategies evaluated in the literature in chapter 3. In chapter 4, we analyse factors significantly influencing farmers' adaptation. In chapter 5, we synthesize the results and discuss ways to support farmers' efforts to respond to climate change.

4.2 Reviewing the literature on climate change adaptation in the coffee sector

In this review, we focus particularly on the behavioural part of adaptation, *i.e.*, the stream of literature on the adoption of adaptation strategies. To ensure that selected studies are relevant, we focus on literature published after 2000. The last time we searched the database was December 2021.

Figure 4.1 Steps undertaken in the screening for relevant literature



The systematic literature search was conducted in three main steps as represented in Figure 4.1. In a first step, an initial search was conducted on *ScienceDirect* and *Web of Knowledge*, searching for the terms *climate (climatic) change*, *climate variability*, *global warming*, *environmental change* paired with *adaptation* and *coffee.* An overview of the exact search terms may be found in Table A 4.1 in the appendix. The search was limited to original empirical research, excluding book chapters, (business) reports and literature reviews. In the second step, abstracts were screened to narrow down the selection further. Lastly, the remaining studies were then read in the full-text version.

To be included in the review, an article had to meet three criteria: First, the findings need to be based on original empirical research, *i.e.*, researchers conducted quantitative or qualitative interviews evaluating farmers' actual or preferred adaptation strategies. Studies evaluating effectiveness of specific adaptation measures, *e.g.*, agroforestry or drought-resistant varieties, regarding their ability to mitigate the (expected) effects of climate change, were thus excluded. Studies discussing possible pathways of adaptation for farmers in connection to a model-based evaluation of climate change and its effects on different regions/different scenarios are also not included. Second, the studies need to target coffee farmers specifically. Studies examining the adoption of adaptation strategies in regions where coffee is one of the multiple crops grown in the study area are excluded. Finally, the article explicitly referred to climate change or variability.

There are nonetheless limiting factors to our literature review. By focusing on these specific criteria, we purposefully exclude studies on farmers' vulnerability/adaptive capacity to climate change, which may provide insight into factors influencing the adaptation process. Furthermore, we might exclude studies that investigate smallholder adaptation to environmental change framing it in terms other than adaptation or climate change. Also, limiting the search for literature to articles indexed on the *Web of Knowledge* or *Web of Science* means potentially missing empirical studies indexed elsewhere.

4.3 Adaptation strategies of coffee producers

Based on the three-step process and the set criteria, we identified nineteen studies evaluating the (potential) rates of adoption of adaptation among farmers. The adaptation measures are studied either in connection with a specific event related to climate change, *e.g.*, droughts, floods, hurricanes or pests and diseases, or to farmers' general perception/awareness of climate change. We classify adaptation practices in three distinct, mutually exclusive categories:

- Farm-level management approaches
- Household diversification strategies
- Knowledge and investment

The majority of studies investigate sustainable, farm-level management approaches such as shade tree management (Adane and Bewket, 2021; Mugagga, 2017; Shinbrot et al., 2019), soil and water conservation practices (Baca et al., 2014; Eakin et al., 2012; Zuluaga et al., 2015), water retention and irrigation (Baca et al., 2014; Bro et al., 2019; Eshetu et al., 2020). Household diversification strategies such as crop or income diversification (Adane and Bewket, 2021; Chengappa et al., 2017; Tucker et al., 2010), though similar to farm management, are not as frequently mentioned. Knowledge and Investment approaches are rarely included.

Table 4.1 Adaptation practices mentioned per category

Category of adaptation	# of different practices mentioned	# of practices mentioned, incl. multiple answers
Farm-level management approaches	16	133
Household Diversification Strategies	6	41
Knowledge and Investment	7	15
Total		189

Studies on climate change adaptation among coffee producers focus disproportionally on Meso-America, namely Costa Rica (Eakin et al., 2014; Harvey et al., 2018, 2017) El Salvador (Baca et al., 2014), Guatemala (Baca et al., 2014; Eakin et al., 2014; Harvey et al., 2018, 2017; Hochachka, 2021), Honduras (Eakin et al., 2014; Harvey et al., 2018, 2017), Mexico (Baca et al., 2014; Eakin et al., 2014, 2012; Shinbrot et al., 2019; Tucker et al., 2010) and Nicaragua (Baca et al., 2014; Bro, 2020; Bro et al., 2019; Quiroga et al., 2015; Zuluaga et al., 2015). Fewer studies were conducted in East Africa, including Ethiopia (Adane and Bewket, 2021; Eshetu et al., 2020), Kenya (Asayehegn et al., 2017) and Uganda (Mugagga, 2017; Mulinde et al., 2019). Coffee production in Asia is rarely considered, with only one study from India (Chengappa et al., 2017) and one from Vietnam (Byrareddy et al., 2021).

4.3.1 Farm-based management approaches

Most climate change adaptations included in adoption studies can be categorized as farm-based management approaches. These practices cover a diverse set of management approaches summarized in Table 4.2. Although adaptation strategies under a specific label, *e.g.*, shade management, are included in multiple studies, their definition may vary across studies, as studies differ considerably concerning the methodology they use. For example, Adane and Bewket (2021) compare adoption rates between certified and non-certified farmers. It nevertheless remains unclear how and why the specific practices were identified as climate change adaptation practices and if farmers implemented the specific measures in response to perceived climatic variability. Asayehegn et al. (2017) on the other hand connect the selected adaptation strategies to farmers' perception of climate change, finding a significant difference in choices adoption between farmers who did and did not perceive any changes. Mulinde et al. (2019) first identify several coffee-based farm-household systems. In a second step, they evaluate the adoption of adaptation strategies depending on coffee-based farm-household systems. Adoption rates, therefore, vary depending on the framing, scope and methodology of the study.

Changing the variety of cultivated crops presents the farm-based adaptation approach most frequently included in adoption studies. Chengappa et al. (2017) observe a shift from Arabica to Robusta production in India of about 10%. Other studies consider farmers conducting changes in plant or crop type/variety without specifically considering coffee (Asayehegn et al., 2017; Eshetu et al., 2020; Mulinde et al., 2019; Shinbrot et al., 2019). Adoption rates overall range from 3.5% (Donatti et al., 2019) to 75% (Shinbrot et al., 2019). Regarding shade tree management, some studies evaluate overall adoption rates of agroforestry (Asayehegn et al., 2017; Chengappa et al., 2017; Eakin and Wehbe, 2009; Harvey et al., 2018, 2017; Shinbrot et al., 2019). Other studies consider farmers increasing their numbers of shade trees (Eshetu et al., 2020) or farmers *willing* to adopt shade-grown coffee production as an adaptation measure (Quiroga et al., 2020). Overall, shade-tree adoption rates vary from below 3% (Quiroga et al., 2020) up to 95% (Harvey et al., 2017).

Also, a range of practices may be summarized under the same label: Conservation practices may refer to soil conservation (Eakin et al., 2012; Harvey et al., 2018; Quiroga et al., 2015; Shinbrot et al., 2019), soil *and* water conservation (Baca et al., 2014; Eshetu et al., 2020), or specific forest conservation practices such as avoiding deforestation, burning pastures (Quiroga et al., 2020) or reforestation (Quiroga et al., 2020; Shinbrot et al., 2019). Water management is included as a general adaptation strategy in multiple studies (Baca et al., 2014; Chengappa et al., 2017; Harvey et al., 2018), but also covers specific practices such as (rain)water harvesting (Adane and Bewket, 2021; Baca et al., 2014; Eshetu et al., 2020), water retention (Bro et al., 2019) and filtration dams (Shinbrot et al., 2019).

Changes in plantation management include practices such as pruning (Bro et al., 2019; Hochachka, 2021; Mugagga, 2017) and renewing the plantation (Quiroga et al., 2020). Adaptations in land management include the cultivation of fragile lands (Mulinde et al., 2019), fallows (Harvey et al., 2017), shifting crops between land types (Asayehegn et al., 2017), and restoring degraded areas (Harvey et al., 2018). Erosion-preventing barriers adopted by farmers may include windbreaks, live fences (Harvey et al., 2017), terraces (Eshetu et al., 2020; Harvey et al., 2017), or grass strips (Eshetu et al., 2020).

Table 4.2 Farm-based management approaches

Farm-based approaches	Number of studies
Change crop variety or coffee cultivar selection	14
Shade tree management	13
Input and Resource Management	9
Conservation practices	9
Irrigation	7
Water management	7
Cover crops & Mulching	7
Adjustments in planting dates	6
Plantation management	6
Changes in Livestock Management	4
Change in agronomic practices	4
Land management	4
Erosion-preventing barriers	4
Disease Control/Pest management	3
Intercropping	1

4.3.2 Household-level diversification strategies

Besides changing their farming practices, coffee producers diversify their income sources to protect themselves against the adversities of climate change. These diversification strategies are taking place both on- and off-farm. In the most radical cases, farmers chose to (temporarily) migrate to find employment (Adane and Bewket, 2021; Asayehegn et al., 2017; Hochachka, 2021; Quiroga et al., 2020; Tucker et al., 2010).

While most on-farm strategies in terms of changing farm practices are still incremental, farmers' income diversification strategies present more transformative adaptations to climate change. Income diversification may mean that farmers are searching for additional work (Bro, 2020), diversifying their direct income in other forms (Shinbrot et al., 2019) or working more hours (Bro, 2020; Zuluaga et al., 2015).

Farmers also peruse different on-farm diversification strategies, mainly changing the crops they cultivate (Adane and Bewket, 2021; Chengappa et al., 2017; Eakin et al., 2014; Quiroga et al., 2020; Tucker et al., 2010), changing the land they allocate to a specific crop, including coffee, (Eakin et al., 2014, 2012; Eshetu et al., 2020; Harvey et al., 2018;

Mulinde et al., 2019; Tucker et al., 2010) or maintaining home gardens (Harvey et al., 2017). Adjustments in household members' food intake were included in only two studies. Households responded by consuming less food, changing the number of meals their expenditure on non-food items (Bro et al., 2020; Mulinde et al., 2019).

Table 4.3 Household-level diversification strategies

Diversification Strategies	Number of studies
Income diversification	11
On-farm Diversification	9
Change land under specific Crops or cultivation	6
(Temporary) migration	5
Adjustments in food intake	2
Crop and livestock production mix	1

4.3.3 Knowledge and Investment

Adaptation responses connecting to Knowledge and Investment are rarely included in adoption studies. External training options, *i.e.*, farmers consulting with extension staff (Hochachka, 2021; Mulinde et al., 2019), receiving labour training (Quiroga et al., 2015), connecting to information sources about natural disasters (Shinbrot et al., 2019) or relying on indigenous knowledge (Mulinde et al., 2019), present the approach most frequently included.

Training options are followed by on-farm investments in machines or productive infrastructure, e.g. depulpers (Quiroga et al., 2020; Shinbrot et al., 2019; Zuluaga et al., 2015). Regarding short-term financial adjustments, farmers were found to sell assets (Mulinde et al., 2019), spending their cash savings in response to climate shocks and/or falling into debts (Bro, 2020). Community investment as an adaptation strategy is only included in the study by (Shinbrot et al., 2019). This includes building roads, waterways, and electricity. The study by (Shinbrot et al., 2019) is also the only one including farmers adapting by storing seeds or livestock or cutting out the middlemen for direct market access.

Table 4.4 Knowledge and Investment

Knowledge and Investment	Number of studies
External training	4
On-farm investments	3
Financial adjustments	2
Community investment	1
Cut out the middlemen	1
Using storage	1

4.4 Influences on Climate Change Adaptation

Out of the nineteen studies evaluating the adoption of adaptation strategies, eleven additionally investigate factors influencing the adaptation decision. When it comes to evaluating factors influencing farmers' adaptation decisions, studies also vary in their approaches. For example, Mulinde et al. (2019) split the sample twice: based on a regional level, and based on the coffee-based farm-household systems identified in a prior step. For each household system, influencing factors are identified for specific adaptations differing from system to system using a Semi-Nonparametric (SNP) univariate binary-choice model. Zuluaga et al. (2015) on the other hand use a binary probit model to investigate general adaptation and a multivariate probit model for the individual adaptation strategies. While most studies which also present the magnitude and direction of the influencing factors' coefficients, Harvey et al. (2017) present only their significance levels.

4.4.1 Socio-economic factors

Farmers' adaptation decision is significantly influenced by a diverse set of socio-economic indicators. Farm Size has been found to influence selected adaptation strategies positively and significantly in multiple studies. Larger farms are more likely to adapt in general (Shinbrot et al., 2019), but also to adopt specific adaptation strategies such as irrigation and/or changing the variety of the cultivated crops (Asayehegn et al., 2017), changing field practices (Bro et al., 2019) or animal feed (Eshetu et al., 2020). Smallholder farmers are less likely than large-holder farmers to use mulch as a drought coping strategy in Vietnam (Byrareddy et al., 2021), and larger farms are less likely to adopt inorganic fertilizer or change their meals per day in central Uganda (Mulinde et al., 2019).

Education levels positively and significantly affect farmers' general decision to adapt (Mugagga, 2017; Zuluaga et al., 2015), but also specific adaptation techniques such as the adoption of conservation practices (Bro et al., 2019; Zuluaga et al., 2015), adjustments in planting dates, expenditures on non-food items and seeking off-farm income (Mulinde et al., 2019), and changes in field practices and input application (Bro et al., 2019). Yet, higher education of the household head also negatively affects households changing their crop varieties, selling assets, applying pesticides and relying on indigenous knowledge in Uganda (Mulinde et al., 2019).

The age of the household head decreases the likelihood of farmers changing the type of cultivated crops (Eshetu et al., 2020), applying herbicides, adapting the planting dates of the cultivated crops and relying on indigenous knowledge (Mulinde et al., 2019). Yet, the age of the household head also significantly affects the number of ecosystem-based adaptation practices adopted (Harvey et al., 2017) as well as household expenditures on non-food items and seeking income sources off-farm (Mulinde et al., 2019).

Household size positively and significantly affects the likelihood of farmers adopting irrigation methods (Asayehegn et al., 2017) and negatively affects the likelihood of adopting changes in field practices (Bro et al., 2019) and input application (Bro et al., 2019; Mulinde et al., 2019). Other socio-economic significantly affecting farmers' adaptation decisions are (Byrareddy et al., 2021; Harvey et al., 2017), farm type (Harvey et al., 2017) and gender of the household head (Mulinde et al., 2019).

Membership in a social group or cooperative has been found to significantly affect farmers' adaptation decisions in multiple studies (Bro et al., 2019; Mulinde et al., 2019; Shinbrot et al., 2019; Zuluaga et al., 2015), but has ambiguous effects: Mulinde et al. (2019) find that membership in a social group decreases farmers' likelihood to use inorganic fertilizer in Central Uganda, but increases the likelihood in Eastern Uganda. Similarly, the authors also find that social group membership decreases farmers' likelihood of consulting extension staff in Central Uganda, but increases the likelihood in Eastern Uganda. Zuluaga et al. (2015) and Shinbrot et al. (2019) find that membership in a producer group increases farmers' likelihood to adapt in general. Zuluaga et al. (2015) also find group membership to increase the likelihood of adopting specific adaptation strategies, i.e., conservation practices and the usage of more chemical inputs. Yet, they find that it decreases the likelihood to work more in the production plots. (Bro et al., 2019) find that cooperative membership increases farmers' likelihood to adopt water conservation practices.

The share of land allocated to coffee production significantly affects the number of ecosystem-based adaptation strategies, but also the number of cultivated shade trees (Harvey et al., 2017). The land allocated to food crop production positively and significantly affects the use of inorganic fertilizer and the number of meals per day consumed by a household in Eastern Uganda, but negatively and significantly affects the same adaptation strategies in Central Uganda. Asayehegn et al., 2017 and Zuluaga et al., 2015 find that farm income and wealth as well as off-farm income significantly affect farmers' choice of adaptation strategies. Zuluaga et al. (2015) find that off-farm work decreases a farms' likelihood to invest, and wealth increases the likelihood to use more inputs, work more hours on the production plots, invest and change the cultivated plots. Asayehegn et al. (2017) find that both farm and off-farm income significantly increase the likelihood of changing the cultivated crop varieties and/or adopting irrigation.

Table 4.5 Socio-economic factors influencing farmers' adaptation decision

Influencing Factor	Variable	Number of studies
Socio-economics	Farm size	5
	Education	4
	Age	3
	Household size	3
	Tenure/Farm ownership	2
	Gender	1
	Farm Type	1
	Experience	1
Social Capital	Group Membership	4
Land Allocation	Coffee & Food Crop Area	2
	Irrigation Method	1
Income Sources	Off-farm income/ work	2
	Farm income/Wealth	2

4.4.2 Access, Exposure, and Information

Access to infrastructure and information as well as exposure to climate change are also important factors in farmers' adaptation process. Market access, such as the distance to the nearest marketplace (Asayehegn et al., 2017), proximity to an all-weather road (Mulinde et al., 2019), time to the closest municipality (Shinbrot et al., 2019) or coffee certification (Adane and Bewket, 2021) are important drivers in farmers' adaptation process. Market access affects general adaptation (Shinbrot et al., 2019), but also the adoption of specific adaptation strategies such as farmers' cultivar selection, adopting shade management, off-farm activities or shifting coffee seedling time (Adane and Bewket, 2021) or irrigation (Asayehegn et al., 2017), the use of inorganic fertilizer and consulting with extension staff (Mulinde et al., 2019). Access to credit increases the probability that farmers respond to climate change in general (Mugagga, 2017; Zuluaga et al., 2015) as well as their likelihood to change the varieties of the cultivated crops (Asayehegn et al., 2017).

Variables connected to farm households' exposure to climate change are also important factors in farmers' adaptation process. Location has been found to significantly affect farmers' adaptation decision in multiple cases (Byrareddy et al., 2021; Eshetu et al., 2020; Mulinde et al., 2019), as has the experience of climate change and extreme weather events (Shinbrot et al., 2019; Tucker et al., 2010). Farmers perceiving climate change affects their decision to diversify their crop-livestock mix (Asayehegn et al., 2017). Zuluaga et al. (2015) show that if farmers perceive changes in temperatures, frequency of rains, rain seasonality and extreme events, they are more likely to adopt in general, but to also choose specific adaptation strategies such as input use, working more hours on the production plots, investing, changing crop varieties, or adopting conservation practices.

Finally, climate information significantly affects smallholder farmers' choice of adaptation options to climate change. Access to climate information has a positive and significant effect on farmers responding to climate change (Mugagga, 2017), specifically on changing planting dates (Eshetu et al., 2020) or crop variety (Asayehegn et al., 2017; Eshetu et al., 2020) and using of conservation practices (Eshetu et al., 2020). Like access to extension services, it also increases the probability to adopt crop-livestock diversification, and irrigation (Asayehegn et al., 2017). Access to formal extension services also significantly influences the probability of adopting conservation practices and changing animal feeding strategies (Eshetu et al., 2020) as well as using inorganic fertilizer and changing the number of meals per day consumed by a household (Mulinde et al., 2019).

Table 4.6 Factors influencing farmers' adaptation decisions connected to access and exposure

Influencing Factor	Variable	Number of studies
Access	Market access	5
	Access to credit	3
	Access to innovative inputs	1
Information	Climate information	3
	Extension services	3
	Radio	1
Exposure	Location/Rainfall Zone/Landscape	4
	Experience of climate change/disaster/ extreme weather events	2
	Perceiving climate change	2

4.5 Discussion

There has been a recent proliferation in the literature on adaptation to climate change. We analysed the literature on climate change adaptation strategies already implemented by coffee producers published after 2000 to identify the main strategies smallholder coffee producers use to adapt to a changing climate as well as the factors influencing the adoption of adaptations. Studies focus disproportionally on Meso-America, specifically Costa Rica, El Salvador, Guatemala, Honduras, Mexico, and Nicaragua. Fewer studies focus on East Africa and only two studies on south-east Asia.

The literature review shows that farmers' responses to climate change are diverse. They can be broadly distinguished into three categories, namely Farm-based management approaches, Household diversification strategies and Knowledge and investment. Most of the adaptation strategies adopted by farmers included in scientific studies fall under the first category, Farm-based management approaches. Very few studies include adaptation strategies connecting to farmers' knowledge and investment structures.

Generally, we see that the majority of current adaptation research focuses on incremental adaptation, *i.e.*, measures that can easily be implemented in existing systems (Verburg et al., 2019). While incremental options such as conservation practices, the introduction of new crop varieties or adjustments in the planting dates of cultivated crops, are easy to adopt and already widely implemented, they might only suffice to respond to minor changes in the climate. With increasing climate change, agricultural systems need to adapt more substantially, *e.g.*, adding a shade tree layer to coffee, diversifying their production and income strategies or structural investments (Verburg et al., 2019). Transformative adaptations addressing the root causes of farmers' vulnerability to climate change by implementing fundamental changes in the production system (Fedele et al., 2020) might be necessary to respond to the long-term effects of climate change.

Farmers' adaptation approaches are driven by socio-economic factors such as farm and household size, social group membership, land allocation or income sources. Exposure to climate change, information and market access were also identified as important factors influencing the adoption of adaptation strategies. The importance of local conditions shows the necessity to tailor adaptation approaches to the specific needs of farmers in a particular region. With extension services presenting both an important source of information on climate change and adaptation strategies (Eshetu et al., 2020) as well as a driving factor in the adaptation process, providing extension options is important in educating farmers about options to enhance their resilience and adaptive capacities (IPCC, 2007). To improve farmers' adaptive capacity, providing timely and accurate weather forecasts, information campaigns and participatory approaches present important tools for raising farmers' awareness of climate variability (Mugagga, 2017; Mulinde et al., 2019). Extension services can support adaptation to climate change through the facilitation and implementation of adaptation programmes or by guiding farmers to implement new farming methods (Antwi-Agyei and Stringer, 2021). Therefore, extension services for modern farming practices should be encouraged should be provided (Eshetu et al., 2020).

Farmer groups and cooperatives can also provide farmers with improved marketing and negotiation power as well as easier access credit (Mugagga, 2017). This could also be provided by sustainability certification through their existing knowledge structures and accessible resources. Sustainability certification schemes are a voluntary market-based instrument promoting more sustainable production systems which gained importance over recent years, as they promise to promote environmentally friendly production while improving farmers' livelihoods (Meemken, 2020). Sustainable and speciality coffee certification has already been connected to increasing the uptake of agronomic practices, *e.g.* shade management (Adane and Bewket, 2021; Takahashi and Todo, 2017), mulching, use of new coffee cultivars and crop diversification (Adane and Bewket, 2021), indicating that certification schemes might provide pathways for supporting farmers' adaptation efforts.

4.6 Opportunities for further research

4.6.1 Standardize conceptual framing and methodological approach

Despite the increasing number of studies on the adoption of adaptation measures, there are still several aspects that can be addressed in the empirical literature. First, there is a notable lack of comparability across studies and geographical regions where research has been conducted. Adaptation strategies such as the adoption of shade tree management, conservation practices or water management have been included in multiple studies. Yet, the overall framing of the research as well as the definition of the specific variables changes from study to study. Framing and methodology vary greatly across studies, so that drawing general conclusions is difficult, if possible at all. Standardizing the conceptual framing and the methodological approaches may allow identifying cross-regional, universal patterns in farmers' decision-making.

4.6.2 Incorporating the assessment of multiple stressors

A second research gap arises from most studies approaching adaptation either from the perspective of farmers' general perception of climate change or their responses to a single specific event (flooding, drought). This point has already been suggested by Burnham and Ma (2016), who argue that changes in a production system are strongly connected to socio-economic, cultural and political forces, and considering climate change adaptation in isolation neglects the influence of structural factors on smallholder vulnerabilities. Asayehegn et al. (2017) found that even farmers who did not perceive any changes in the climate adopted adaptation strategies, contradicting the assumption that farmers only adapt if they perceive changes in the climate. It is, therefore, necessary to also evaluate how the interaction of multiple stressors shapes farmers' adaptation decisions, including other potential risks influencing farmers' adaptation measures within the context of their livelihood decision-making. This may increase the success of planned adaptation interventions and development projects.

4.6.3 Merging streams of literature on climate adaptation

Lastly, combining research on farmers' vulnerability and adaptive capacity with actual adoption rates as well as research on the suitability of specific adaptation strategies can give insight into the effectiveness of specific adaptation strategies to decrease farmers' vulnerability and increase their resilience. For example, agroforestry has been investigated as an adaptation to climate change, and optimal shade levels are identified for specific regions (Lin, 2007). There is also little information on the economic benefits associated with agroforestry in the context of climate change adaptation strategy. Benefits of shaded systems identified to date primarily refer to their ability to improve the micro-climate, coffee quality and water retention (Niether et al., 2020). In the context of climate vulnerability and resilience, it is nevertheless important to also consider farmers' livelihoods, i.e., their income situation, their food security and overall welfare. Adaptation strategies, therefore, need to be investigated not only in terms of existing adoption rates but also regarding their effectiveness depending on specific farm-level preconditions and vulnerabilities.

4.7 Appendix

Table A 4.1 Search Words for Systematic Literature Review

Search words	Science Direct	Web of Science	
"climate change adaptation” coffee	215	146	
"climatic change” adaptation coffee	133	18	
"climate variability adaptation” coffee	163	14	
"global warming" adaptation coffee	241	5	
"environmental change" adaptation coffee	464	18	
"climate-smart" coffee	105	19	
"climate-resilient" coffee	59	8	
	2065	228	2333
After dropping duplicates			1478

5. General Discussion and Conclusion

Coffee production is an important source of export revenue for producing countries, especially for small, agriculture-dependent economies like Rwanda. Coffee production is a key driver in the development and improvement of rural livelihoods, not only in Rwanda, serving as a source of cash income for the many coffee producing households. The coffee value chain in Rwanda changed considerably since the early 2000s, with CWS being established all over the country, increasing the share of fully-washed coffee production. Now, Rwanda's coffee sector is recognised and well-established in the international speciality coffee market. While this transformation has benefited Rwanda at large, coffee producers have benefited the least in the new prosperity (Clay et al., 2016). Despite the considerable improvements, productivity remains low, as farmers struggle with pests and diseases (Ngango and Kim, 2019), poor soil fertility and insufficient access to fertilisers (AgriLogic, 2018).

Also, consequences of climate change are already visible in Rwanda and affect the rural population. Climate change adaptation is therefore important for agricultural developmental discourse. The observable regional differences in the effects of climate change in Rwanda (droughts in the southern and eastern parts, flooding and landslides in northern and western regions) call for solutions considering the needs of the specific regions (USAID, 2011). Coffee production is projected to shift to higher altitudes, particularly threatening geographic regions in lower altitudes already less suitable for coffee production (Ovalle-Rivera et al., 2015). Thus, the present dissertation aimed to investigate the relationship between sustainable certification and environmental and economic indicators as well as evaluate important factors in farmers' adaptation to climate change.

5.1 Main Findings

Rainforest Alliance Certification is significantly correlated with good agricultural and biodiversity-related practices. Environmentally friendly practices are commonly used in the research area, particularly in regions more suitable for coffee production. Rainforest Alliances' leverage to increase adoption of good agricultural practices is thus higher in regions where initial adoption rates are lower. The connection between the certification and good agricultural practices is stronger in the region less suitable for coffee production, where previous adoption rates are lower than in the regions more suitable for coffee production. There is no significant association between Rainforest Alliance and socio-economic indicators. Effects on economic outcomes and biodiversity-related practices are linked, yet their relationship differs across climatic regions. Shade tree density and income simultaneously rise under certification in the regions more suitable for coffee production, pointing towards synergies between these outcomes. Nevertheless, in the region least suitable for coffee production, there is some evidence for minor trade-offs between outcome categories. Here, Rainforest Alliance is associated with either an increase in shade tree density or income.

Coffee farmers in Rwanda differ concerning their perception of adverse weather events: Four distinct groups based on farmers' risk perception were identified. Farmers perceived adverse weather events as low, medium or high risk for their livelihoods, or perceived only specific events as a threat. Results indicate that farmers' risk perception is connected to changes in the timing of the seasons and the expected amount of precipitation. There are also regional differences in farmers' risk perception.

Most farmers in the sample adjust to the adverse weather events, and farmers' adjustment decisions are closely linked to their risk perception. Yet, their adjustment strategies often represent reactive response actions. This is even more so the case in the region already least suitable for coffee production. Farmers located in the regions more suitable for coffee production are more likely to choose more sustainable, farm-based adaptation strategies. Farmers located in the region less suitable for coffee production tend to rely more strongly on short-term adjustment strategies, specifically selling assets and spending cash savings.

Based on reviewing the literature on the adoption of adaptation strategies among coffee producers, three categories of adaptation approaches have been identified: Farm-level Management Approaches, Household Strategies, and Knowledge and Investment. Studies mostly included farm-level adaptation strategies. The majority of current adaptation research focuses on incremental adaptation, i.e., measures that can be implemented in existing systems (Verburg et al., 2019).

Socio-economic factors such as farm size and education, social capital and income sources play an important role in farmers' adaptation, exposure to and perceptions of climate change are as important. Furthermore, education, extension services and the availability of climate information were found to be significant influences on climate change adaptation in several studies. To improve farmers' adaptive capacity, campaigns and participatory approaches present important tools for raising farmers' awareness of climate variability.

5.2 Discussion

Farmers' climate change adaptation is shaped by local socio-economic conditions and needs to be tailored to these conditions. The literature on the adoption of climate change adaptation among coffee farmers has a strong focus on incremental options such as conservation practices, the introduction of new crop varieties or adjustments in the planting dates of cultivated crops. While they are easy to adopt and already widely implemented, they might only suffice to respond to minor changes in the climate. With increasing climate change, agricultural systems need to adapt more substantially, e.g., adding a shade tree layer to coffee or diversifying their production and income strategies (Verburg et al., 2019).

Our study on farmers' perception of and adjustment to adverse weather events shows that coffee farmers in Rwanda differ regarding their risk perceptions of these events and that these perceptions are important factors in motivating adjustment responses. The results also show a close connection between risk perception and adjustment. While many farmers in our sample adjust to adverse weather events, their adjustment strategies often represent reactive response actions. This is even more so the case in the region already least suitable for coffee production. Depending more heavily on short-term adjustment strategies might increase farmers' vulnerability to climate change. Given the importance of education and awareness of climate change in the adaptation process, extension options are a crucial component in educating farmers about options to enhance their resilience and adaptive capacities (IPCC, 2007). As farmers' needs for adaptation still depend considerably on agro-ecological and cultural components, it is necessary to design extension services tailored specifically to the local conditions.

To improve their climate change adaptation, farmers need access to knowledge networks, finance, and appropriate training. As extension services present an important source of information on climate change and adaptation strategies (Eshetu et al., 2020) as well as a driving factor in the adaptation process, providing extension options is important in educating farmers about options to enhance their resilience and adaptive capacities (IPCC, 2007). Extension services can support adaptation to climate change through the facilitation and implementation of adaptation programmes or by guiding farmers to implement new farming methods (Antwi-Agyei and Stringer, 2021).

For guiding the implementation suitable adaptation strategies, knowledge structures, resources, and improved market access may also be provided by sustainability certification. The role of sustainability certification as a support mechanism for climate change adaptation has been discussed and included in several studies (Adane and Bewket, 2021; Borsky and Spata, 2018; Verburg et al., 2019). Sustainable and speciality coffee certification has already been connected to increasing the uptake of agronomic practices discussed in the context of climate change adaptation, *e.g.* shade management (Adane and Bewket, 2021; Takahashi and Todo, 2017), pruning and stumping, mulching, use of new coffee cultivars and crop diversification (Adane and Bewket, 2021).

While the most popular certification schemes do not specifically aim to support climate change adaptation, standards increasingly address specific climate change-related topics. In 2017, Rainforest Alliance integrated climate goals into its basic principles (Rainforest Alliance, 2017). In its certification process, Rainforest Alliance includes sustainable farming practices that are discussed as incremental climate change adaptations in the literature. Fair Trade also developed a so-called climate standard under which projects obtaining benefits for producers and their communities can get certified. Projects need to operate in the field of energy efficiency, renewable energy (for domestic purposes or agricultural production) or reforestation (Fairtrade International, 2015).

Results of the certification essay suggest that through the certification of good agricultural practices, Rainforest Alliance certification might be effective in increasing the uptake of environmentally friendly management practices, particularly in regions where initial adoption levels are low. In regions with favourable conditions for coffee production, improvements in production practices also go hand in hand with economic benefits. Additionally, there is a stronger connection between Rainforest Alliance and environmentally friendly management practices in the region less suitable for coffee production. This indicates that here, Rainforest Alliance might be particularly successful in supporting farmer in adopting sustainable farming practices to respond to climate change. Nevertheless, in this region, there also occurs a trade-off between improved production practices and economic outcomes. Thus, if certification is promoted in less favourable regions, particular effort needs to be placed on securing economic benefits for farmers, too.

Economic outcomes and certification are linked only indirectly, as Rainforest Alliance also does not guarantee a minimum price and price premia paid through the certification solely rely on increased coffee quality. Also, the use of good agricultural practices is required to become Rainforest Alliance certified. The economic outcomes considered in this study depend on other external factors. The increased adoption of good agricultural practices is, therefore, to be expected. It nonetheless shows that Rainforest Alliance is indeed able to attain changes in prevalent farm practices. Synergies and trade-offs differ across regions.

The Rwandan coffee sector is strongly regulated by NAEB, which sets a floor price for coffee. Yet, for a long time, farmers received insufficient compensation for their cherries which was far below the average in the region. A large proportion of coffee growers suffered net losses, as costs of coffee production in Rwanda exceeded the antiquated figures used to determine "fair" cherry prices (Clay et al., 2016). Also, at the time of data collection, certification was still new in Rwanda. Thus, certified coffee might not have been able to obtain price premia high enough to translate into substantial income increases for certified farmers (yet). Furthermore, not all coffee produced in compliance with sustainable certification is also marketed as such. Due to upfront investments necessary to comply with the certification's standards, the lack of differentiation harms the profitability of certified producers (Panhuysen and Pierrot, 2020).

On a broader note, due to the government-driven development of the coffee sector in Rwanda, the produced coffee is of relatively high quality. Nevertheless, quality improvements are stagnating. To obtain premium prices, farm efficiency and quality coffee production need to improve from farm level up. Yet, the many challenges farmers face hamper their motivation to grow coffee as a cash crop. Interventions will need to combine managing technical productivity issues and price incentives (AgriLogic, 2018). CWS can play an important part in this context by offering incentives for farmers to supply the fully-washed channel (Ortega et al., 2019).

5.3 Conclusion and scope for further research

Global coffee production is threatened by environmental problems such as the depletion of natural resources and progressing climate change. Intensifying coffee plantations only results in a loss of biodiversity and associated ecosystem services (Jezeer and Verweij, 2015). Changing climatic conditions put additional pressure on coffee producers by causing the loss of areas suitable for coffee production and decreasing coffee yield production (Bunn et al., 2015b; Ovalle-Rivera et al., 2015). Supporting farmers' livelihoods in fragile, biodiverse regions is a thus priority for many agencies and national governments. Economic incentives for farmers are needed to adopt and maintain sustainable farming practices (Haggar et al., 2017).

In two empirical case studies from Rwanda and a review of the literature on climate change adaptation among coffee producers, the present dissertation aimed to identify ways to support smallholder coffee producers in their efforts to respond to the challenges they face. In the context of increasingly large body of climate change literature, the empirical essay on farmers' perception of adverse weather events provides insight on how farmers perceive different situations for themselves, aspects driving these perceptions and how this perception then relates to adaptation. The study relies on the subjective assessment of adverse weather events. It is also limited on a temporal scale to farmers' experiences of adverse weather events within the last year, not taking prior experiences or awareness of climate change into account. Additionally, the events included only cover incidents connected to precipitation and none connected to unexpected changes in temperature. Finally, the response strategies considered in our research present a limited selection of incremental short-term adjustments, some of which may even increase farmers' vulnerability to climate change.

Future research should therefore evaluate the long-term effects of adjustment strategies on household welfare and farmers' ability to cope with adverse weather events. Besides incremental adaptation strategies, transformative actions need to be evaluated, specifically in the regions which will lose suitability for coffee production. Furthermore, we also did not evaluate farmers' overall climate vulnerability or adaptive capacity. In the context of climate vulnerability and resilience, it is important to also consider farmers' livelihoods, i.e., their income situation, their food security and overall welfare. Adaptation strategies need to be investigated regarding their effectiveness depending on specific farm-level preconditions and vulnerabilities.

Despite the increasing number of studies on the adoption of adaptation measures, there are still several aspects that can be addressed in the empirical literature. First, there is a notable lack of comparability across studies and geographical regions where research has been conducted. The overall framing of the research as well as the definition of the specific variables changes from study to study. Standardizing the conceptual framing and the methodological approaches may allow identifying cross-regional, universal patterns in farmers' decision-making. Furthermore, focussing only on climate change as driver in coffee farmers adaptation process disregards the complexity of their decision-making. The interaction of multiple stressors shaping farmers' decisions also needs to be evaluated. Building on the factors influencing farmers' adaptation measures within the context of their livelihood decision-making when developing planned adaptation projects may increase the success for planned adaptation interventions and development projects.

The essay on the connection between certification and economic and environmental outcomes added to the empirical research on sustainability standards by considering the two dimensions simultaneously. Nevertheless, the study also has a few shortcomings. First, we only evaluate the adoption of good agricultural practices as certified by Rainforest Alliance. Although these practices are acknowledged to improve environmental performance, we cannot draw any conclusions on the environmental benefits of certification. While the studies by Haggar et al. (2017) and Vanderhaegen et al. (2018) already included environmental indicators such as carbon stock and diversity indicators such as the Margalef diversity index, more research is needed on the environmental benefits of certification, particularly in connection with economic benefits. Furthermore, market factors such as input and market prices also affect coffee and household-related outcomes included in the study, confounding the connection between certification and economic outcomes. To overcome the limitations of our data and provide more comprehensive information on the economic viability of certification, further research is needed that explicitly considers longer-term economic effects of certification.

Studies on climate change adaptation differ considerably in methodology and scope, causing a notable lack of comparability across studies and geographical regions where research has been conducted. Standardizing the conceptual framing and the methodological approaches may allow identifying cross-regional, universal patterns in farmers' decision-making. Furthermore, incorporating the assessment of multiple stressors may increase the success of planned adaptation interventions and development projects. Lastly, combining research on farmers' vulnerability/adaptive capacity with actual adoption rates as well as research on the suitability of specific adaptation strategies can give insight into the effectiveness of specific adaptation strategies to decrease farmers' vulnerability and increase their resilience.

6. Literature

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Declaration

1. I hereby declare that this Ph.D. dissertation has not been presented to any other examining body in its present or a similar format.

I also affirm that I have not applied for a Ph.D. at any other higher educational institution.

2. I hereby declare that this dissertation was undertaken independently and without unauthorized assistance.

_____________________________ (Signature)

Göttingen, 22.04.2021