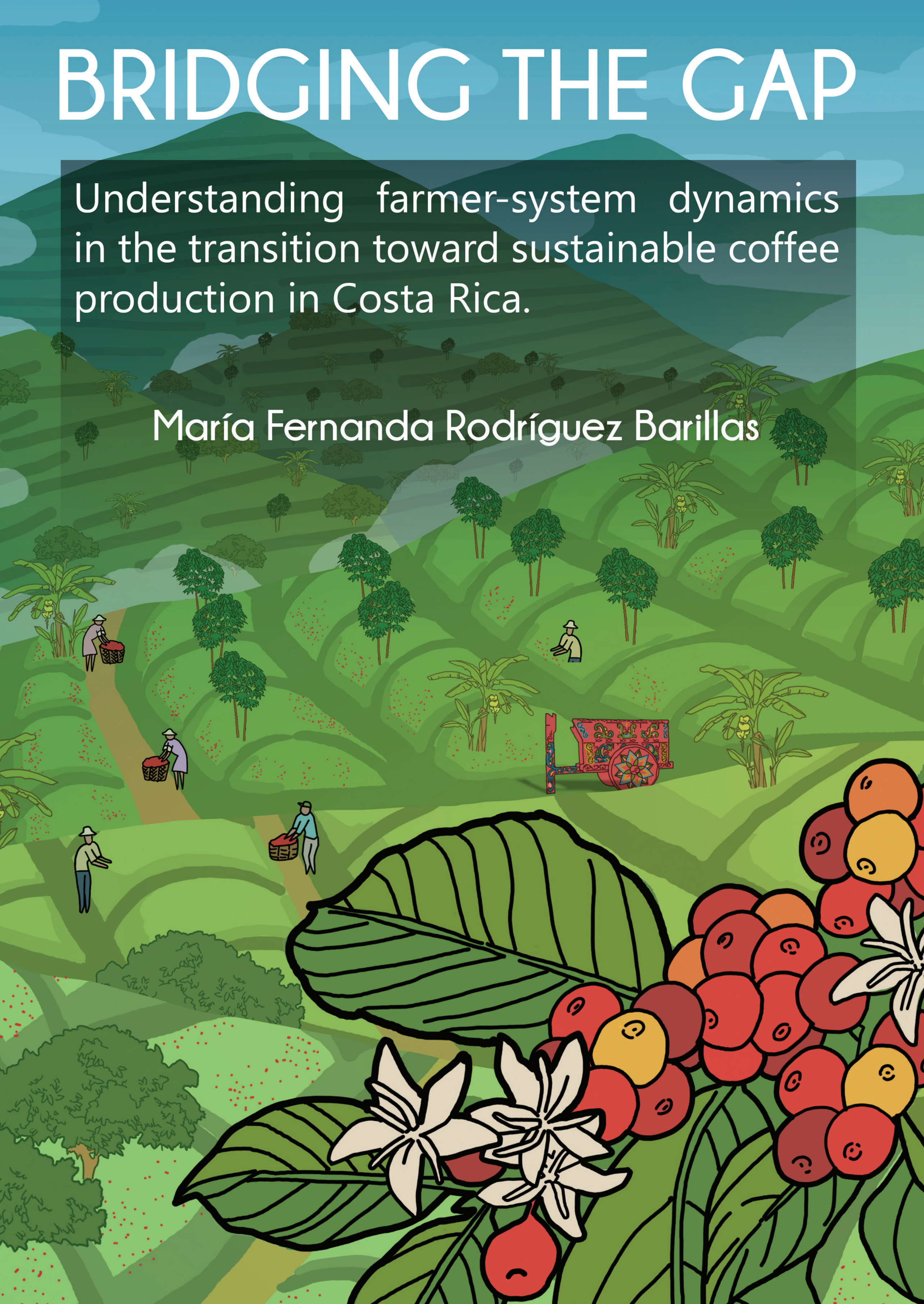
BRIDGING THE GAP

Understanding farmer-system dynamics in the transition toward sustainable coffee production in Costa Rica.

María Fernanda Rodríguez Barillas



Propositions

1. Agrifood regime inertia overshadows transformative policies for driving agrifood system change.
   (this thesis)
2. Climate-smart Agriculture technology adoption models fail to capture the complexities of farmer decision-making.
   (this thesis)
3. The impact of the "recommendations for policymakers" section in academic journals is overestimated.
4. Climate-smart agriculture as scientific field is a typical example of neocolonial science.
5. A culture of "Publish or Perish" threatens the progress of science in tackling societal challenges.
6. Sustainability-related buzzwords are hegemonized by Global North actors.
7. Fixation on PhD milestones is counterproductive for effective learning.

Proposition belonging to the thesis, entitled

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Wageningen, 19 December 2023

Bridging the gap:
Understanding farmer-system dynamics in the transition toward sustainable coffee production in Costa Rica

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Bridging the gap:

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CHAPTER 1

1

General Introduction

"Small and apparently insignificant details can have major impacts on people's behavior. A good rule of thumb is to assume that "everything matters." [...] The insight that "everything matters" can be both paralyzing and empowering. Good architects realize that although they can't build the perfect building, they can make some design choices that will have beneficial effects" (Thaler & Sunstein, 2008, p. 3)

Just as every architect carefully designs a building with a unique design, style, and layout, considering that details may shape its form and function, every choice that a citizen, a company, or a policy officer makes is coupled with the complexity of the context in which they are embedded. Acknowledging that "everything matters" can evoke both a paralyzing uncertainty by the weight of the decisions and can also be empowering, as it highlights the opportunity for positive impact through mindful choices. Whether it is a policy officer designing just policies, companies adopting sustainable practices, or farmers grappling with the complexity of farming, recognizing the significance of every decision can lead to more thoughtful decision-making at any scale. This recognition challenges the idea of purely rational decision making. It highlights the multifaceted nature of human behavior by emphasizing that individual decisions are often influenced by cognitive biases, emotions, and social factors, making them more intricate and context-dependent than classical economics suggests.

1.1 Agriculture and climate change impacts: the need for mitigation and adaptation

The productivist approach to agriculture, with its focus on continuous modernization, strongly emphasizes maximizing production with monocultures, high use of agrochemical inputs, increasing mechanization, and less reliance on labor (Wilson, 2001) and puts pressure on biodiversity, water sources, and soil and air quality. Given the productivist and high external input paradigm, current food systems are large contributors to global warming and were responsible in 2015 for a third – 34% – of overall anthropogenic greenhouse gas (GHG) emissions (Crippa et al., 2021; Vermeulen et al., 2013). The majority of the emissions – 71% – come primarily from agricultural production activities (i.e., N2O and CH4) and indirectly from changes in landcover resulting from agriculture (CO2, mainly composed of carbon losses from deforestation and degradation of organic soils) (Crippa et al., 2021).

Agriculture is a main contributor to global environmental change, and, like agricultural systems, interconnected phenomena such as climate change, biodiversity loss, and resource depletion are also severely impacted by the consequences (Beddington et al., 2012). Recent IPCC (2022) projections signal that, as average temperatures continue to rise, changes in rainfall patterns and greater frequency of extreme events directly impact crop-yield reduction – reducing freshwater availability and contributing to an increase in the vulnerability of the livelihoods of millions of families. The need to transform agricultural systems toward more sustainable production systems – e.g., resilient and low emissions – is therefore becoming increasingly urgent in the face of these complex and interrelated challenges (FAO, 2010, 2019). To promote such transformation, coupled adaptation[1] and mitigation[2] strategies are needed (Amundsen et al., 2010). Numerous interventions can be made to promote resilience in agricultural systems while simultaneously contributing to GHG reduction (Verburg et al., 2019). Demand-side interventions targeted at consumers include healthy and sustainable diets, and waste reduction can enhance agricultural system resilience (Scherer & Verburg, 2017). Supply-side interventions targeted at producers are focused on practices and technologies for increasing soil organic matter and decreasing reliance on inputs by engaging in sustainable intensification, agroecology, organic agriculture, and regenerative agriculture, which can contribute to coping with the uncertainties of climate change while mitigating climate change (Darnhofer, 2015).

To address both adaptation and mitigation challenges in the agricultural system, climate smart agriculture (CSA) has been promoted as an approach to enhance agricultural systems' resilience while improving productivity and contributing to the global effort to mitigate climate change by reducing GHG emissions (McCarthy et al., 2018; Zilberman et al., 2018). CSA represents a shift in traditional agricultural systems by promoting more sustainable agricultural development and addressing the challenges of climate change through a combination of mitigation and adaptation farming practices and technologies (Steward, 2012). This implies scaling up and mainstreaming a CSA system at different administrative scales (individual, farm, value chain, and international agreements), which in turn requires enabling conditions through policy frameworks (e.g., climate change and agri-environmental policies), institutional arrangements, markets, and financial mechanisms. Hence, given its scope, CSA can be considered to form part of sustainability transitions, which comprise a multidimensional process of fundamental changes toward more sustainable modes of production and consumption (Markard et al., 2012)

Research on sustainability transitions emphasizes changes along diverse socio-technical systems (energy, food, health) and dimensions (technological, organizational, institutional, economic, political, cultural) in which new products, services, and organizations emerge (Markard et al., 2012). The sustainability transition literature

1 Adaptation is defined as "the process of adjustment to actual or expected climate and its effects in order to moderate harm or exploit beneficial opportunities" (IPCC, 2022, p. 43).

2 Mitigation is defined as anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2001).

relies on well-established theoretical frameworks to understand socio-technical change. These include the multilevel perspective (Geels, 2002, 2011), technological innovation systems (Hekkert et al., 2007), strategic niche management (Hoogma et al., 2002), and transition management (Kemp et al., 2007; Loorbach, 2007). Such theoretical approaches have been criticized for giving relatively limited attention to the role of individual agency and social and psychological processes (Bögel & Upham, 2018; Schäpke & Rauschmayer, 2014), for their strong focus on the Global North with extensive empirical work in the energy and transportation sectors (Ghosh et al., 2021; Köhler et al., 2019), and for overlooking the agri-food system transition (El Bilali, 2020; Hebinck et al., 2021). A growing number of studies have now started to connect, adapt, and apply such theoretical frameworks to agri-food transition; some have focused on exploring transition dynamics (Ingram, 2018; Vermunt et al., 2020) and systemic barriers to transitions (Schiller et al., 2020) and on characterizing food systems' heterogeneity in view of transitions (Gaitán-Cremaschi et al., 2019).

Similar to transition studies, agricultural innovation system and CSA studies have focused on understanding how different innovations (e.g., technological, social, institutional) are organized and interact (Klerkx et al., 2012). This systems approach sheds light on different governance approaches, institutional networks, and enabling conditions while identifying barriers to, and opportunities for, enhancing innovation (Klerkx et al., 2010; Knickel et al., 2009; Long et al., 2016; Runhaar, 2017). Agricultural innovation system and CSA studies acknowledge the role of the individual as an agent, innovator, and entrepreneur (Long et al., 2019; Senyolo et al., 2018).

Whereas transition studies and agricultural innovation systems perspectives are focused on system change, behavioral theories and agricultural technology adoption literature have examined the determinants influencing behavior and acceptance of more sustainable practices (Doran et al., 2022; Wauters & Mathijs, 2006). By focusing on individual choices, these studies better explain at individual level why certain practices are preferred, or some behaviors and habits prevail. However, it is criticized for assigning the responsibility for driving change primarily to the individual (Kaufman et al., 2021) and advocating a narrow vision that often emphasizes solely technological change (promoting adoption at farm level) without considering the complexities of system dynamics and the diversity of other drivers influencing behavioral change (Leeuwis & Aarts, 2011), such as institutional and social factors.

In the four strands of the literature where this thesis is situated, it is recognized that individual choices are interconnected with a broader context, as individuals are not passive recipients but active participants driving technological change, and their behavior collectively contributes (or not) to a more sustainable system (de Vries et al., 2021; Upham et al., 2019). However, transition and agricultural innovation theories give limited attention to the role of individual agents in promoting change, whereas behavioral theories focus on providing an understanding of individual cognitive and behavioral processes without actively considering the institutional context where the individual is embedded but rather seeing context as an external and passive determinant. Although the embeddedness of individual and system is recognized in transition studies (Edmondson et al., 2019; Markard & Truffer, 2008), agricultural innovation studies (Kuntosch & König, 2018), and behavioral studies (Engler et al., 2019), surprisingly the interconnection between the macro system and the meso level and the micro individual level remains empirically underexplored.

Therefore, this thesis connects four bodies of literature: sustainability transitions, agricultural innovation systems, CSA, and behavior studies. By doing so, it aims to bridge the disconnect between three analytical levels: macro, meso, and micro. At *macro level*, this thesis focuses on the policy context, as political actors, regulatory frameworks, and institutional support can be expected to play a major role in shaping the overall direction, goals, and resource allocation (Geels, 2002). The *meso level* is the connecting device between the policy context that drives changes through strategies, technologies, and practices and the individual on the *micro level*, where individuals shape and respond to interventions, technologies, and practices (Gazheli et al., 2015).

This thesis focuses on how, in the CSA transition, the macro, meso, and micro levels are linked, and, by investigating this, the project intends to fill a knowledge gap in transition, agricultural innovation, and CSA studies. Building on transition and behavioral theories, I argue that the interplay between individual actions, systemic responses, and feedback mechanisms provides valuable insights into how the institutional context (i.e., new policies and regulation) can influence individual behavior and vice versa. The main research question guiding the thesis is: *How are the interactions between CSA policies and individual farmers shaped by systemic and individual-level processes*?

The remainder of this introductory chapter describes the theoretical framework in section 1.2, which describes CSA in more detail, and systemic and individual perspectives that the thesis uses to analyze it; then section 1.3 presents the analytical framework and specific research questions, followed by the research context in section 1.4. and the methodological approach in section 1.5. Finally, section 1.6 presents the thesis outline.

1.2 Theoretical framework

This research combines agricultural innovation system and transition theories with behavioral theories to unravel the dynamics between the CSA policies and farmer practice change shaped to some extent by policy-mix effects and individual decision making. For the macro level analysis, from agricultural innovation systems and transitions research, I use the conceptualization of policy mixes to link policy with technological change (section 1.2.1). Policy mixes are rooted in political science (Howlett, 2014); but their conceptualization for sustainability transitions offers an extended framework that brings a holistic and broader perspective to shed light on the complex interconnections that take place in real-world policy mixes for sustainability transitions (Kern et al., 2019).

The meso level analysis is the connecting between behavior theories and policy mix for sustainability transitions. I use the unified theory of acceptance and use of technology (UTAUT). Specifically, this thesis applies the appraisal of the new technologies' features and social determinants proposed by the UTAUT model to explain individual acceptance of new technologies. Additionally, it combines behavioral drivers with the policy mix appraisal to recognize the context in which the individuals are embedded (section 1.2.2). For the micro level analysis, this thesis uses the protection motivation theory (PMT) as basis and zooms in on individual adoption decisions and unravels the influence of the cognitive processes – threat appraisal and coping appraisal – in farmers decision toward pro-environmental practices (section 1.2.3)

1.2.1 Socio-technical sustainability transition

Transition theories are deemed to help understand the complex processes of transforming existing socio-technical systems toward more sustainable modes of production and consumption (Markard et al., 2012). These socio-technical systems (e.g., energy, water, and agriculture) comprise a set of actors, institutions, and technologies necessary to fulfill societal functions (Farla et al., 2012). At its core, changing socio-technical systems requires not only technological advances but also changes in institutions, values, and behaviors (Geels & Schot, 2010). Socio-technical transitions offer well-established comprehensive approaches for understanding how systems change over time.

Applied to agriculture and food, socio-technical transition involves changing a range of activities in food production and consumption domains but is also multidimensional, as it involves markets, regulations, cultural and social movements, infrastructure, and legitimacy (Geels & Schot, 2010). Agri-food transition research has examined interconnected dynamics, drivers, and barriers that shape the transition from conventional, resource-intensive farm systems to more sustainable, equitable, and environmentally sustainable approaches (Darnhofer, 2015). Agri-food systems transition has been explored via conceptual approaches characterized by heterogeneity (Gaitán-Cremaschi et al., 2019). However, in the application of this perspective, relatively less attention has been paid to the transitions in agri-food systems (El Bilali, 2020; Hebinck et al., 2021), as compared with other systems such as mobility and energy.

What most of the literature on agri-food systems transformation has in common is the reiterated need for policy changes across multiple sectors, beyond just agriculture, to steer the direction and speed of the transition of agri-food systems toward more sustainable paths (Elzen, Barbier, et al., 2012; Klerkx & Begemann, 2020; Köhler et al., 2019), and hence, for the agri-food sector also, attention has been drawn to the importance of coherent policy mixes (see e.g., Hermans et al., 2019; Pigford et al., 2018). The idea of policy mixes is built on the rationale that no single intervention will be enough to push such technological, social, and institutional innovations (Borrás & Edquist, 2013). Research on policy mixes for sustainability transitions has focused on conceptualizing the link between policy and technical change (Rogge, 2018). Instead of examining instruments and their effects in isolation, this broad conceptualization of policy mixes includes strategies and long-term policy goals, policy characteristics (consistency, coherence, credibility, and comprehensiveness), and policy processes (Rogge & Reichardt, 2016). Thus, policy mix research elucidates why and how certain strategies and instruments address some societal issues and not others in which the role of multiple actors and stakeholders is central (Magro & Wilson, 2019). This includes policymakers at various levels (local, regional, national), companies, organizations, and individuals whose roles and interactions are key for effective policy formulation and implementation.

In the study of policy mixes for sustainability transitions, attention has been placed on the study of the policy instrument mix (del Río, 2010; Falcone et al., 2019), the policy strategy (Imbert et al., 2017; Quitzow, 2015), the policy mix characteristics (Kern et al., 2017a; Kivimaa & Sivonen, 2021) as well as the policy process (Edmondson et al., 2019). Most of the research has been situated particularly in the field of energy, with applications to mainly European cases (Del Río, 2014; Edmondson et al., 2020; Flanagan et al., 2011; Gomel & Rogge, 2020a; Kemp et al., 2007; Mavrot et al., 2019; Rogge & Dütschke, 2018), with contributions from China(Chang et al., 2019; L. Li & Taeihagh, 2020) and lately from Latin America (Castrejon-Campos et al., 2020; Garcia Hernández et al., 2021; Kanda et al., 2022; Milhorance et al., 2020).

Policy mixes are contextual, as policy frameworks and regulations are shaped by policy culture (Howlett & Tosun, 2021; Pfotenhauer & Jasanoff, 2017) and the past (Doezema et al., 2019). Determinants such as political will, agenda-setting mechanism (Candel & Biesbroek, 2016) and stakeholders involved are deemed key for promoting socio-technical change. Furthermore, institutional settings (defined as rules, norms, and incentives that shape individuals' and organizations' behavior in innovation, such as funding structures and inclination to collaborate) differ from country to country (Klerkx et al., 2017), and well-functioning institutions and supportive organizations are often significant determinants for promoting change.

1.2.2 Policy appraisal as a starting point for policy feedback

Agricultural innovation system studies and transition studies have recognized the embeddedness and mutual responsiveness of individuals and the broader institutional context (Edmondson et al., 2019; Klerkx et al., 2010), emphasizing that individual choices are shaped by the institutional context (rules, norms, and policies) of which they are part, but also have the ability to influence, following Gidden's (1984) idea on the duality of structure.

From the individual perspective, policy instruments can be used to stimulate behavioral change by influencing economic decisions, by value-based choices, and by providing information (Collier et al., 2010). In practice, policy mixes use levers that fall into more than one of these categories to steer the desired change (e.g., stimulating the use of more sustainable technologies or increasing productivity), as they may complement each other and become synergic. At the same time, the success or failure of such policy mixes depends on individuals' acceptance of them (de Groot & Schuitema, 2012; A. Nilsson et al., 2016). From an innovation systems and transitions approach, policies, policy mixes, changes in socio-technical systems, and changes at individual level are highly interdependent (Edmondson et al., 2019). Thus, policy appraisal influences the success of such policy mixes and in turn individual actions and behaviors toward a new technology and/or practices being promoted (D. J. Pannell & Claassen, 2020; Streletskaya et al., 2020). There are thus feedback mechanisms between the macro and the micro level.

Feedback mechanisms are considered to influence policymaking through diverse groups of actors (Edmodson, 2019). Individual appraisals and acceptance of, or resistance to, policies can play a key role in the policymaking process (e.g., agenda setting, design, implementation, evaluation); specifically, policy formulation can readjust the targets, means, and implementation mechanisms. Moreover, such feedback mechanisms can promote policy learning, which refers to the specific process in which knowledge is used in the concrete development of policy formulation and implementation (Bennett

& Howlett, 1992; Borrás, 2011). According to Edmondson et al. (2019), positive feedback can help policy strategies to achieve stability and become self-reinforcing, and negative feedback results in resistance to new policy strategies and instruments, potentially resulting in a fall in political support.

In line with these two strands (i.e., behavioral and transition), the theoretical basis for assessing meso-level interactions in which the micro and the macro level encounter each other is derived from the literature on behavioral studies, public opinion, and policy acceptance (Coburn et al., 2021; Leiserowitz, 2006; Mills et al., 2018) and is integrated with Reichardt and Rogge's (2016) analytical lens of policy mixes for sustainability transition. Farmers' appraisals are recognized as social constructs of CSA policies and how CSA affects them, influenced by personal experiences, trust in institutions, and the type of policy instrument implemented; and the appraisals can result in a wide variety of decisions among farmers (Rose et al., 2016; Tatsvarei et al., 2018). Thus, understanding farmers' appraisals of CSA policies can enable better positive feedback and counteract negative feedback, to purposively adjust policies and redirect policy programs according to farmers' needs and preferences (Schaafsma et al., 2019) (e.g., targeting farmers who may be less willing to use new technologies).

1.2.3 Individual agency

Behavioral science is a diverse field of inquiry that places human behavior as a central unit of analysis. It encompasses theories and methodologies derived from various disciplines. Integrating insights from various fields, behavioral theories have been widely used to address fundamental issues concerning individual decision-making processes and the cognitive process influencing behavioral change (Kaufman et al., 2021). Several social and psychological theories, including Ajzen's (1991) theory of planned behavior, Davis' (1989) technology acceptance model (TAM), Venkatesh's (2003) UTAUT, Stern et al.'s (1999) value belief norm theory, and Rogers' (1975) PMT, have been used and extended to give a comprehensive explanation of individual decisions in the context of CSA, climate risk adaptation(Ghanian et al., 2020), and the adoption of sustainable agricultural practices (Bopp et al., 2019). Although these models share many similarities, they differ in emphasizing the principal drivers that explain behaviors (Floyd et al., 2000).

This thesis has developed an integrated model of determinants of CSA acceptance and individual engagement in protective behavior, such as adopting CSA. As a basis, we extended two models – Venkatesh's (2003) UTAUT (chapter 3) and Rogers' (1975) PMT (chapter 4) – given their higher explanatory potential in comparison with other models (e.g., TBP, TAM, TRA) (Venkatesh et al., 2003) and the fact that they have also been adapted to agricultural studies to explain farmers' decisions when engaging with new technologies and practices (Faridi et al., 2020a; Liang, 2012).

In connection with critiques on the limitation of behavioral theories (see section 1.1) By extending both models – e.g., by including policy context appraisal – and other determinants, this thesis recognizes the individual's and the context's mutual relation and policy context (policies, regulations, knowledge services) in which the farm operates. It allows me to move beyond individual-related drivers and account for the embeddedness of the individual and the policy environment, as this enables a better depiction of contextual effects on farmers' decision making.

1.2.4 Overview of CSA

CSA was initially presented by the Food and Agriculture Organization (FAO) in 2010 at the Hague Conference on Agriculture Food Security and climate change as an approach that aims to integrate the three dimensions of sustainable development – economic, social, and environmental – by jointly addressing food security and climate change (FAO, 2013). Significantly, the 2010 Roadmap for Action on Agriculture, Food Security, and Climate Change represents the first ministerial-level recognition of the intricate interlinkages between agriculture, food security, and climate change, underscoring the critical necessity for integrated policies to implement CSA effectively (Chandra et al., 2018). Since 2010, the approach has been widely adopted by global research and policy organizations such as CGIAR, FAO, World Bank, and the scientific community (Gardezi et al., 2022a).

In 2012 and 2013, the second and third global Agriculture Food Security and Climate Change conferences in Hanoi and South Africa led to a more detailed conceptualization and foci of the CSA approach. In parallel, global science conferences/workshops were held in 2011, 2013, and 2015 in Wageningen, California, and Montpellier (Zilberman et al., 2018). As an outcome in 2014, the Global Alliance for Climate-Smart Agriculture (GACSA) was officially launched at the United Nations Climate Summit as a multi-stakeholder platform, aiming "to catalyze and help create transformational partnerships to encourage actions that reflect an integrated approach to the three pillars of CSA" (GACSA, 2023).

CSA is an approach that aims to tackle three main objectives: sustainably increasing food security through productivity and incomes, building resilience and adapting to climate change, and reducing GHG emissions compared with a business-as-usual or baseline scenario (Lipper et al., 2015, p. 20). CSA is intended to support and promote efforts across spatial scales, from local to global level (Gardezi et al., 2022a). Thus, CSA is context specific, as it recognizes the need for tailored approaches. The effectiveness of climate-smart solutions may change depending on the institutional setup, financial structures, and political environment (Thornton, Rosenstock, et al., 2018). There are no universally effective CSA strategies; each setting needs a unique strategy to promote climate resilience while maintaining farm productivity.

CSA interventions cover a wide range of areas, such as soil and water management, carbon finance, and incentive systems for low-carbon agriculture (FAO, 2010). Its entry points range from developing technologies and practices to elaborating climate-change models and scenarios, information technologies, insurance schemes, and processes to strengthen the institutional and political enabling environment, particularly focused on rural communities (Gardezi et al., 2022a; Khatri-Chhetri et al., 2019).

1.2.4.1 CSA: the broader policy context and farm-level approaches

A growing body of scientific work has focused on understanding CSA at different scales (e.g., institutional innovation, managerial innovation, and farm-level approaches) (Lipper et al., 2015; McCarthy et al., 2018). The enabling conditions for promoting a CSA system have been studied from systemic approaches. Thornton, Whitbread, et al. (2018) have emphasized the significance of prioritizing research frameworks, whereas others (Totin et al., 2018; Zougmoré et al., 2019) have directed their attention toward institutional settings (e.g., policy initiatives) and Gardezi et al. (2022) have focused on the roles played by international organizations in this context. Studies on the institutional and enabling context have focused on reviewing the potential synergies and trade-offs of CSA interventions (Scherer & Verburg, 2017), actors' interactions, and collective action (Salvini et al., 2016). From these studies, cross-cutting issues on policy development have arisen for promoting a conducive CSA policy environment that calls for coherence between policy domains and coordination between national agricultural policies, strategies, investment plans, and climate-change instruments (Makate, 2019a).

CSA builds on existing experience and knowledge of sustainable agricultural development (Steenwerth et al., 2014). One of the major criticisms of CSA relates to the question of what is defined as CSA technologies or practices (Newell & Taylor, 2018; Taylor, 2018). At farm level, a growing body of scientific literature has addressed this issue and proposed a wide range of technologies and management practices within the CSA "umbrella" approach (Amadu et al., 2020; Kpadonou et al., 2017a; Notenbaert et al., 2017; Smit & Skinner, 2002). Some of these practices range from novel technologies, such as using mobile agro-advisory apps and climate-related information (Beza et al., 2018; Westermann et al., 2018), to longstanding practices, such as agroforestry or soil conservation (Sidibé, 2005; Wauters & Mathijs, 2006). Other include drought-resistant crop varieties, intercropping, efficient use of fertilizers, and improved pest, water, and nutrient management (Ajayi, 2007; Asfaw & Admassie, 2004; Sidibé, 2005). Some technologies focus on plot or farm level, whereas others contribute to broader transformations, e.g., climate-smart landscapes (Chicas et al., 2023; Dunnett et al., 2018; Harvey et al., 2014; Wallbott et al., 2019).

1.3 Analytical framework and specific research questions

This thesis focused on the dynamics between CSA policies and farmer CSA practice change. Building on section 1.2, Figure 1.1 visualizes different levels of CSA transition on which this thesis concentrates. The three levels are i) macro, referring to the policy mix in place for enabling (or not) CSA; 2) meso, the connecting device between the macro and the micro level, referring to the integration of the policy context appraisal and broader institutional determinants; 3) micro, referring to the individual farmer behavior that influences farm-level decision making.

Figure 1.1 Conceptual framework of the thesis

As stated in section 1.1, the main research question guiding the research project is: *How are the interactions between CSA policies and individual farmers shaped by systemic and individual-level processes?*

The specific questions relating to the three levels (macro, meso, micro) are as follows:

> **Research question 1** How has climate and agri-environmental policy evolved to support the emergence and implementation of CSA as a (potentially) transformative policy approach?
>
> **Research question 2** How is farmers' acceptance of CSA technologies influenced by policy context and behavioral drivers?
>
> **Research question 3** To what extent do risk-related psychological determinants drive farmers' adoption of CSA?

The main research question is explored through three empirical studies. As a starting point, this thesis uses the macro-level climate and agri-environmental policy domains to unravel the developments and dynamics of implementing CSA as a (potentially) transformative policy mix (RQ1, Chapter 2). At meso level, the study examines how farmers' appraisal of the policy context and behavioral drivers influences their acceptance of CSA technologies (RQ2, Chapter 3). At micro level, the study focuses on farmers' CSA adoption by identifying the key risk-related drivers influencing the adoption of CSA technologies (RQ3, Chapter 4).

The three empirical studies are situated within Costa Rica's agricultural sector, focused on the coffee sub-sector, the context of which is described in the next section.

1.4 Research context

This section provides a brief overview of the research context.

1.4.1 Key figures on Costa Rica and its agricultural sector

Costa Rica is a Central American country with a population of 5.21 million (INEC & CCP, 2022). Costa Rica stands out in the region for its political and economic stability (OECD, 2017), and, in recent years, it has become established as one of the growing economies in Latin America (Oviedo et al., 2015). Moreover, the country has gained recognition as a frontrunner in innovative environmental initiatives (Fanning et al., 2022) and has invested in its green trademark through its transition from a nation with the highest deforestation rate to a successful reversal of this trend (Fletcher & Breitling, 2012; Wallbott et al., 2019) (Figure 1.2). Despite the progress in economic growth and environmental conservation, social indicators such as poverty (23% of households are poor), inequality in income distribution per capita (Gini coefficient 0.504), and an unemployment rate of 10% (INEC, 2021b) reflect the pressure on the population's welfare.

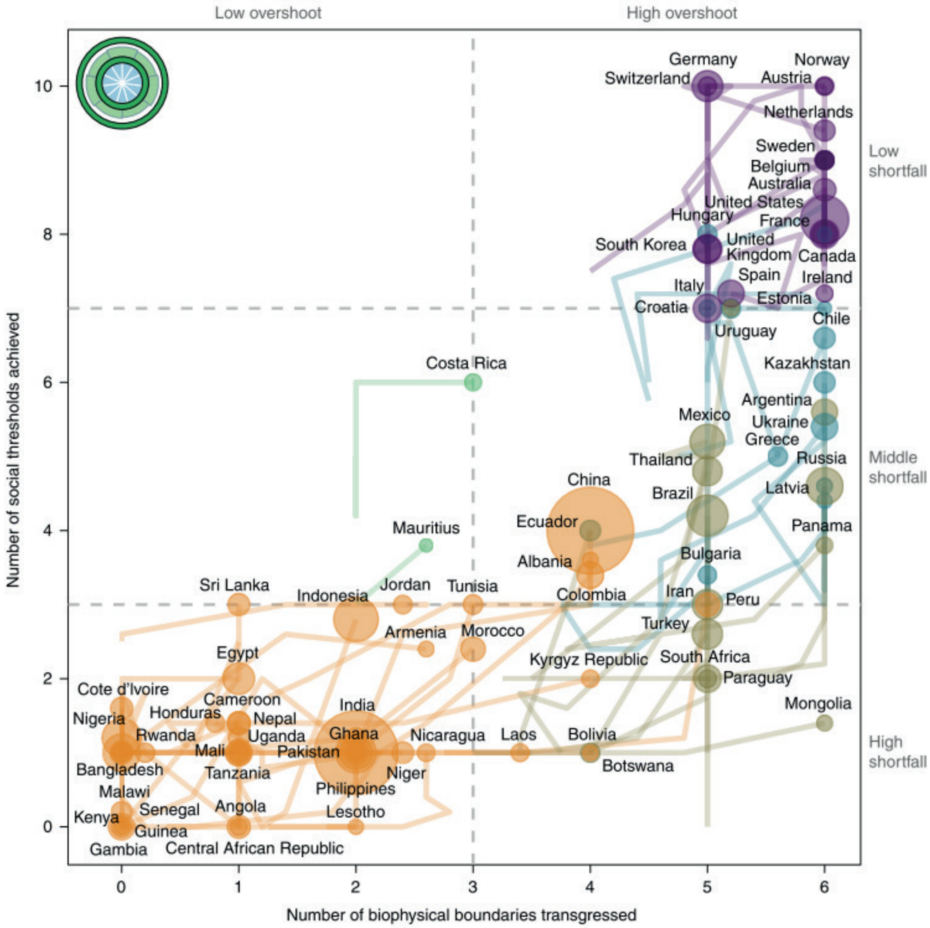

Figure 1.2 The number of social thresholds achieved versus biophysical boundaries transgressed by countries over time, 1992–2015

Note: Circles indicate performance at the end of the analysis period (2011–2015) and are sized according to population. Countries are color coded relative to their performance at the start of the analysis period (1992–1995) clockwise from top right: low shortfall–high overshoot (purple); middle shortfall–high overshoot (blue); high shortfall–high overshoot (brown); high shortfall–low overshoot (orange); middle shortfall–low overshoot (green).

Source: Fanning et al. (2022)

The country's economy has evolved from a rural and agriculture-based economy to a more diversified structure integrated into global value chains (OECD, 2017). Nonetheless, the agricultural sector is the country's second-largest source of employment, employing 11.7% of the economically active population in 2021 (SEPSA, 2022). Primary production accounted for 4.0% of Gross Domestic Product in 2022 (BCCR, 2023) and comprised 41.5% of total exports in 2022 (SEPSA, 2023). Among the most important products in total agricultural exports in 2022 are bananas and pineapples, representing 35.3% of the total share, and coffee (café oro), with a 6.4% share (SEPSA, 2023). Coffee is the largest crop by area farmed, covering 23.6% of the hectares dedicated to agro-industrial production (Figure 1.3). Smallholder farmers dominate coffee production in Costa Rica; in 2021, 85.5% of coffee farmers delivered less than 100 fanegas,[3] contributing 29% to national production(ICAFE, 2022).

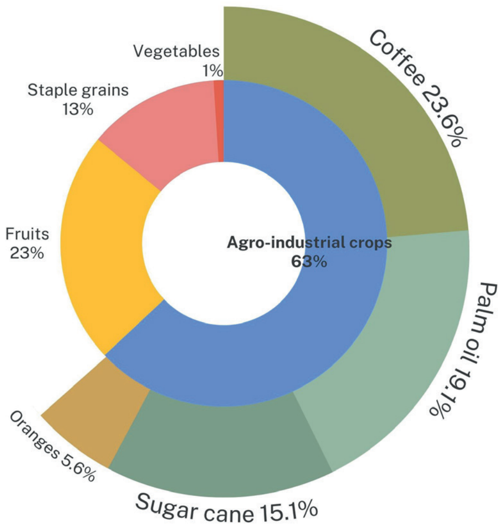

Figure 1.3 Participation by crop in relation to planted area

Despite the importance of the agro-export sector for the country's economy, the current development model is experiencing important socioeconomic and environmental challenges. Conventional production led by transnational corporations threatens biodiversity, water sources, and advances in sustainability (Chacón, 2014). The coffee subsector is no exception. The main problems for coffee production can thus be summarized as 1) low productivity, 2) the need to reduce GHG emissions, and 3) high vulnerability to climate change.

3 Official harvest measure used by ICAFE, representing a unit of volume corresponding to 400 L.

Regarding the first problem, coffee used to be one of the highest value-added crops in the agricultural sector; between 2020 and 2021, productivity fell by 5.97% and has decreased by almost 20% since 2000 (ICAFE, 2022) . Regarding the second, coffee cultivation contributes 9.38% of total N2O emissions (excluding processing, waste, and transport). This points to the high dependency on chemical fertilizers to increase productivity and the need for more sustainable practices. Regarding the third, coffee is highly vulnerable to climate change (Bunn et al., 2015). Diseases such as coffee leaf rust affected 68% of coffee plantations in 2012, and, in 2018, 25.7% of coffee farms were under threat of coffee leaf rust (CICAFE, 2019) – the regions of Perez Zeledón and Coto Brus being the most affected (41.4% of the coffee harvest was under threat) – and generated significant economic losses (Programa Estado Nación, 2020). Moreover, estimates indicate that, under various climatic scenarios, 20% of the coffee production area will be affected by 2050 (Bunn et al., 2015; Ovalle-Rivera et al., 2015).

To cope with climate change and the need to decrease GHG emissions, alternative coffee production systems have emerged. For example, organic coffee represents 0.51% of total production, and voluntary sustainability standards also play an important role. Fairtrade and Rainforest Alliance are the most common voluntary sustainability standards, representing respectively 40.81% and 31.74% of total coffee production (Table 1.1). National efforts, such as the Carbon Neutrality label and the Blue Flag environmental award, encompass the country's efforts to promote more sustainable practices while mitigating climate change. More recently, in 2023, ICAFE, under NAMA Coffee, launched the "low emission coffee from Costa Rica" label as part of the strategy of Café de Costa Rica to promote the adoption of sustainable practices in coffee production and reduce GHG emissions (ICAFE, 2023)

Table 1.1 Voluntary sustainability standard of coffee area harvested and production

	Area harvested [hectares]	Share of the total for the commodity [%]	Production [Metric ton]	Share of the total for the commodity [%]
Fairtrade	20,732	22.13	34,321	40.81
Rainforest	21,831	23.30	26,696	31.74
4C	2,565	2.74	3,964	4.71
Organic	600	0.64	430	0.51

Source: Own elaboration with data from Standard maps (retrieved from https://standardsmap.org/en/trends?products=Coffee&origin=Costa%20Rica)

1.4.2 Costa Rican agricultural policy context

Costa Rica's inclusion of sustainability criteria in its 1990 political agenda led to a revision of the whole development model (Rosendaal et al., 2021). Over the past 30 years, Costa Rican agricultural policies have focused on integrating the sector within international markets and managing responses to external shocks, such as high commodity prices and natural hazards (OECD, 2017). As shown in Figure 1.4, the main policy objectives have evolved from the rational use of natural resources toward fostering agribusiness resilience and climate risk management; however, strategic areas such as competitiveness and increased productivity are constant throughout the policy documents.

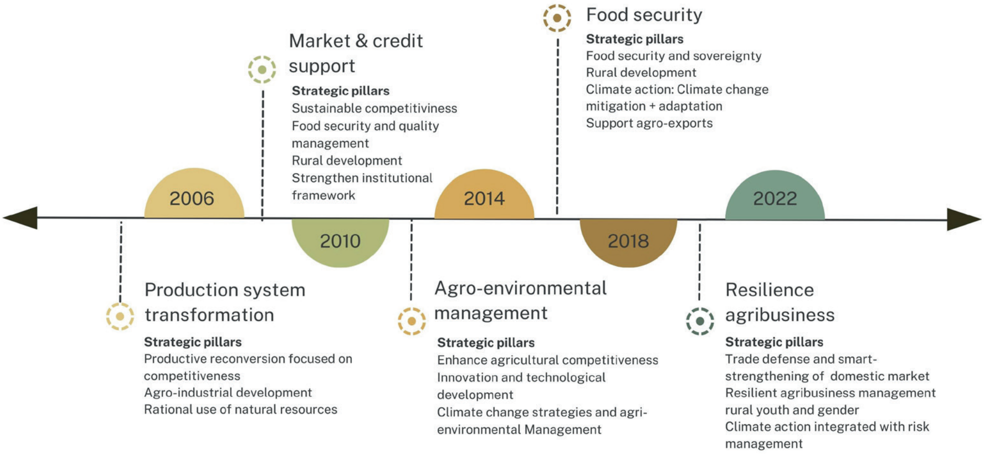

Figure 1.4 Strategic themes of the agricultural sector's sectoral policies 2002–2022

Given the integration within international frameworks (e.g., 1992 Rio Agenda, Agenda 2030, Paris Agreement), policymakers and agri-environmental advocates have managed to include in the political agenda initiatives that promote both more sustainable and competitive agriculture (e.g., conservationist, organic, low carbon) under the realities of climate change. The efforts to transition to a more sustainable and climate-adapted agriculture started with the strong leadership of environmental policies through environmental protection policies that have brought benefits to the economy, and the agricultural sector is no exception (e.g., PES). As a result of environmentally solid regulations, 25.5% of the territory is under some category of environmental protection (MINAE & SINAC, 2022), and lands that were once dedicated to agricultural production are now protected.

Costa Rica's progress to date has stimulated a myriad of inquiries surrounding the foundational policies and institutions, initiatives, programs, investments, and dynamics that have been pivotal in shaping the ongoing transformation in the coffee sector to become climate proof and integrate CSA. Thus, it represents an interesting case study for exploring sustainability transition dynamics "in the making". The next section outlines the methods used to explore these dynamics

1.5 Methodological approach

1.5.1 Research design

The methodological approach for this thesis is a mixed study design with both qualitative and quantitative approaches. This strategy was chosen because qualitative research is more appropriate for investigating variety, diversity, and tensions – explaining the how and the why – whereas quantitative research is better suited to determining the extent of this variation and diversity(Kumar, 2011). Consequently, each chapter employs a distinct methodology for data collection and an approach deemed suitable for its intended purpose.

As indicated briefly already in section 1.3, to unravel the complex dynamics between the macro and micro levels in the CSA transition and where they come together at the meso level, this thesis first looks at the bigger picture of the policy environment and dynamics for CSA in Costa Rica (Chapter 2). Chapter 2's broader perspective allowed me to ascertain the policy developments for CSA, insights into the factors and tensions shaping the transition, and an understanding of the interconnectedness between the macro and the micro level. Chapters 3 and 4 examine the coffee sector by focusing on the individual components and their interaction with the policy context (meso and micro level) to uncover the individual motivations and behaviors that may be overlooked when taking a broader view, but also connecting them to the broader policy and socio-technical systems context.

To ensure internal and external validity in the case of the qualitative chapters, I used multiple data sources to cross-validate the findings, such as interviews, observation, and document analysis. To validate the findings, preliminary reports were shared and presented with the interviewees in meetings or informal spaces (e.g., workshops and training with policymakers) to which I was invited. Regarding the quantitative chapters, the sample size is considered representative, and internal validity and reliability measurement tools were used to reduce measurement errors. The details are presented in Figure 1.5 and in the following sections.

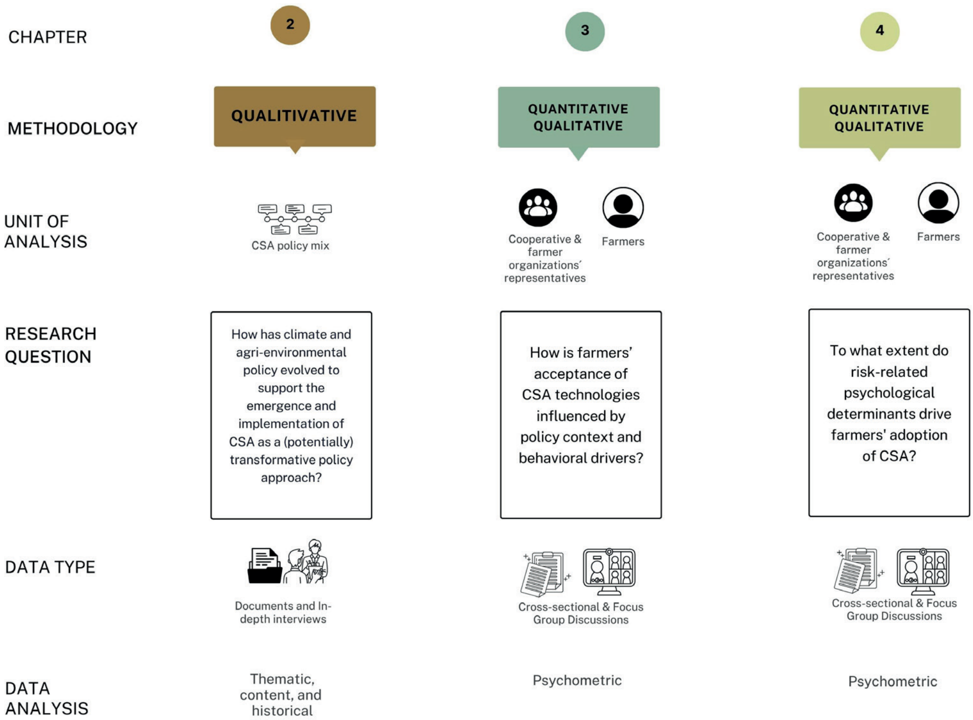

Figure 1.5 Overview of the methodological approach per chapter

1.5.2 Data collection and analysis

The data collection was conducted between December 2020 and November 2021. All the interviews, surveys, and FGD were conducted in Spanish and recorded with the consent of the participants. In this section, I describe the methodological design for each sub-study. Additional information regarding each research sub-question is presented in the individual chapters of this thesis.

Chapter 2: The methods include a combination of secondary data and semi-structured interviews. First, I collected archival data for 2000–2022 and retrieved relevant policy documents (e.g., strategies and plans, laws, decrees), newspapers, and reports with program/initiative information describing what the country and the region were doing to promote CSA. The information from the 214 policy documents was synthesized by constructing an Excel database in which each row represented a different document and each column had an element of the analytical framework (for a more comprehensive description, see Chapter 2). The document analysis was complemented with 21 in-depth online interviews. The interviews were conducted between December 2020 and April 2021 with various actor groups in the policy process (policymakers, researchers, coffee sector technicians and extensionists, and scientific experts on agri-food systems and political science). The interview transcripts and policy documents were coded using a deductive approach, and then a thematic content analysis was performed to derive insights from the data sources that could help build new theory. I developed a coding handbook informed by the theoretical framework, and the codebook was shared with the co-authors. The coding involved several rounds of testing and collaboratively reviewing with peers. This led to the constant revision of the codebook, involving code elimination, merging, and offering more comprehensive explanations of ambiguous codes. The coding and analysis were performed in ATLAS.ti qualitative software. Although certainly not ideal regarding intercoder reliability, I alone coded the interviews and policy documents. Although an intercoder reliability assessment was not conducted, reliability enhancement was achieved through multiple queries and peer debriefing. The data analysis involved multiple queries between the framework elements and the quotations and notes. Triangulation of the interviews and documents was performed to ensure robust results validity, and external validity was achieved by comparison with extant literature (theoretical replication – see Yin, 2018).

Chapters 3 and 4: These chapters focus on the meso and the micro level. Chapter 3 follows a mixed research method approach. Phase one involved two online focus group discussions to explore and obtain detailed information about farmers' perceptions and appraisal of the institutional context (two focus group discussions with in total 11 participants). The second phase involved a large-scale cross-sectional survey among coffee farmers. The survey used in Chapters 3 and 4 aimed to gather information about farmer behaviors, CSA practices, and the policy context. Following the survey development process(Ornstein, 2014), the survey was divided into four sections: 1) general information, 2) socioeconomic and farm characteristics, 3) CSA technologies, 4) climate risk perception, 5) behavioral drivers, and 5) policy mix characteristics and instruments. To test the survey, we ran 13 pretests. The purpose of the pilot was to validate the survey and check the flow of questions and misunderstandings. We applied the interviewees' comments and suggestions to the final version. Together with four enumerators, the author surveyed 530 farmers. I trained the four enumerators, and the first survey was performed under my supervision in case any doubts and questions arose.

The sample size formula for a finite population was used to determine the sample size. Sample representativeness and combined sampling techniques were used to reduce sampling bias. The survey was conducted in two formats from August to December 2021, interrupted by the COVID-19 pandemic travel restrictions and governmental directives. Thus, with the safety of the farmers, their families, and the enumerators as a priority, the surveys were applied via telephone (63.74%) and in person (36.26%)

using electronic devices such as tablets and Qualtrics software to retrieve the data. Farmers were called one week in advance to briefly explain the study; if they agreed, we arranged a date and time for the call. One day before the appointment, they were called to confirm the call. The farmers were randomly sampled based on farmer databases obtained from local partners, mainly ICAFE (where, by Law 2762, the farmers need to be registered), the Ministry of Agriculture, cooperatives, and farmers' organizations. The lists were cross-checked to avoid replicates; farmers were divided according to the region to ensure representation of all Costa Rican coffee-producing regions. Within each region, I assigned a unique number to each farmer and used a random number generator to draw the sample and ensure that everyone had an equal chance of being included. Information from all the Costa Rican coffee-growing regions according to ICAFE was collected: Tarrazú, Occidental, Perez Zeledón, Central, Coto Brus, Orosi-Turrialba, and Zona Norte (Figure 1.5). The data analysis relied on a cluster analysis and a probit model to relate the policy context appraisal and other behavioral determinants to CSA acceptance (Chapter 3) and a multivariate probit model (Chapter 4) to identify the key risk-related drivers influencing several pro-environmental behaviors by adopting various CSA technologies (soil fertility, soil conservation, agroforestry, agro-advisory apps, and alternative coffee farming practices).

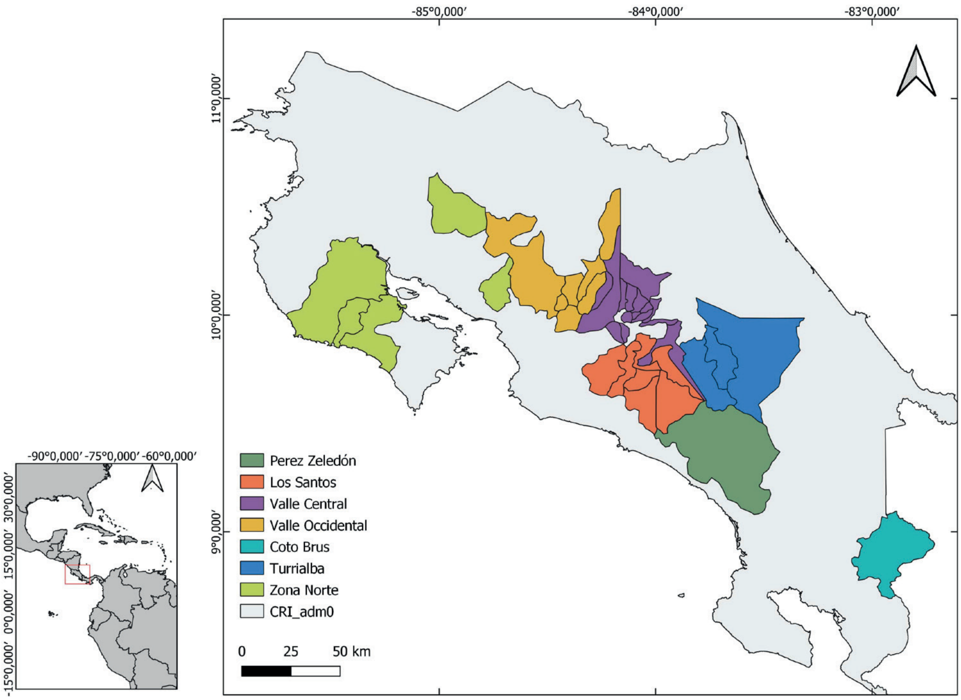

Figure 1.6 Study area

1.6 Reading guide for the thesis

This chapter (Chapter 1) has introduced the concept of the transition to sustainable agriculture in the Costa Rican coffee production sector. The three empirical chapters collectively add to, and broaden, the body of research on behavioral studies, sustainability transitions, and CSA. Commonalities between the three contributions are that no single approach or theory exclusively explains the CSA transition. Conceptually, this thesis bridges the gap between the macro, meso, and micro levels, illustrating the role of context, policy appraisals, and individual cognitive processes in shaping decision making on CSA adoption.

Chapter 2 unravels the developments and dynamics of implementing CSA as a (potentially) transformative policy mix in Costa Rica. The chapter addresses key knowledge gaps on the dynamics of transformative policy development in the agri-food sector in the Global South policy context. Taking a broader-picture approach, the chapter is focused on two building blocks of policy mixes: i) the policy mix elements (strategy and policy instruments) and ii) characteristics focusing on coherence and consistency.

Chapter 3 examines how farmers' appraisal of the policy context and behavioral drivers influence the acceptance of CSA technologies and practices. The chapter assesses how farmers' experiences in the policy context reflect in their appraisal of the policy mix (e.g., perceived consistency, coherence, credibility, and comprehensiveness) and, integrated with farmers' behavioral drivers (e.g., facilitating conditions and technology characteristics), influence the acceptance of CSA technologies and practices.

Chapter 4 aims to identify the key risk-related drivers influencing the interrelated adoption of CSA proposed to mitigate the negative consequences of climate change. The chapter examines farmers' adoption of CSA and explains what drives farmers toward CSA adoption. The chapter conceptualizes a model that integrates the influence of farmers' climate risk and coping appraisal and explores the role of the perceived risks related to the adoption of CSA.

Chapter 5 discusses the overall insights, presents cross-cutting issues from the three empirical chapters, and distills the main methodological, theoretical, and practical implications.

The outline of the thesis is presented in Figure 1.6

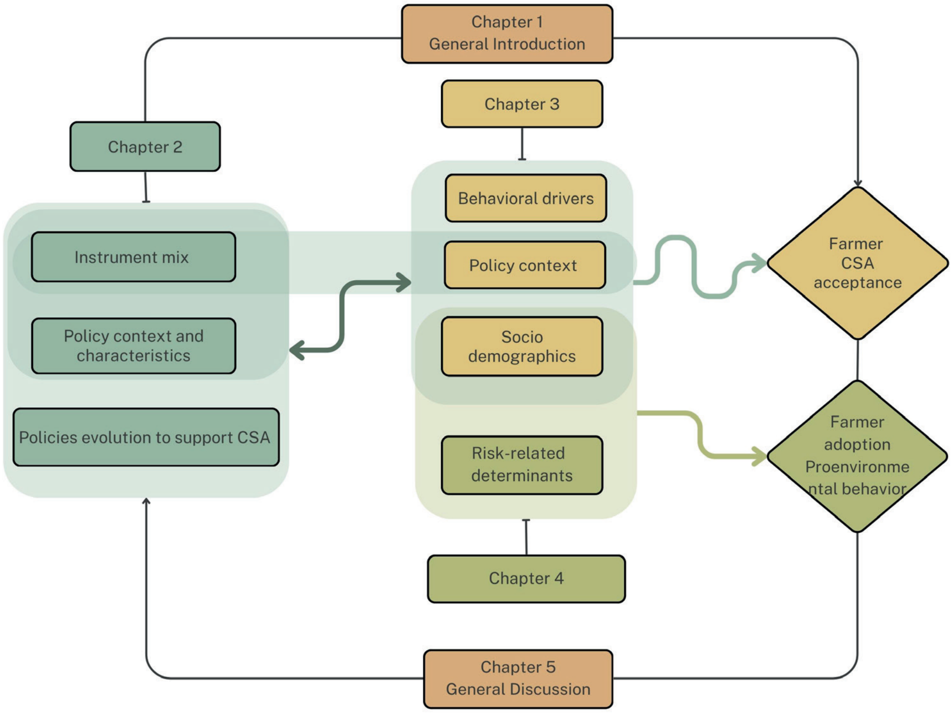

Figure 1.7 Thesis outline

CHAPTER 2

2

Transformative policy mix or policy pandemonium? Insights from the Climate Smart Agriculture policy mix in Costa Rica

Submitted as

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Abstract

This paper focuses empirically on Costa Rica's Climate Smart Agriculture policy mix, which aims to transform agricultural systems to meet the challenges of food security and climate change adaptation and mitigation that globally require a transition to sustainable sociotechnical systems. It addresses key knowledge gaps on the dynamics of transformative policy development in the agrifood sector in the Global South policy context. Results show Costa Rica's policy mix's transformative potential was inhibited by weak implementation capacity and internal and external incoherence between sectors and governance levels, leading to tensions resulting from policy-element interactions such as conflicting goals and interventions with overlapping purposes. The main implication for theory and practice is that successful transformative policy mixes require close scrutiny of both the balance of the mix and how to fundamentally transform the mix. This includes paying more attention to the phasing out of legacy policy instruments and to how countries' particular institutional contexts and policy cultures influence transformative policymaking and implementation.

2.1 Introduction

To address urgent societal challenges such as climate change, food security, and poverty alleviation, many countries worldwide are transforming agricultural production systems (Hebinck et al., 2021; Klerkx & Begemann, 2020; Leclère et al., 2014). Current agricultural production systems threaten biodiversity, soil, and water, as the intensive use of inputs has significant negative effects on the environment and society (FAO et al., 2020). Thus, societal actors and governments are pushing for a change in dominant agriculture production systems, and several alternative farming systems concepts have emerged, such as agroecology and nature-inclusive farming (K. Schiller et al., 2020; Vermunt et al., 2020), organic farming (Shreck et al., 2006), sustainable and ecological intensification (Schut et al., 2016; Tittonell, 2014), and Climate Smart Agriculture (CSA)(Lipper et al., 2014). These alternative farming systems concepts encompass a wide range of technological and non-technological innovations that require considerable changes in local and national governance, legislation, policies, and institutional support (FAO, 2013; Klerkx & Begemann, 2020; Steenwerth et al., 2014).

In the current context, we focus on CSA,[4] which proposes fundamental changes to traditional agricultural production systems by promoting more sustainable agricultural development and addressing the challenges of climate change through a combination of mitigation and adaptation farming practices and technologies[5] (Steward, 2012). Beyond being a combination of technologies and practices, the CSA approach can be considered to contain elements of transformative policy (Barton et al., 2017; Castro et al., 2000; Rosendaal et al., 2021), as not only is it focused on supporting the development and adoption of innovative CSA technologies, but also aims to mainstream sustainable and climate-change-resilient agriculture in national development strategies and plans (Scherer and Verburg, 2017; Steenwerth et al., 2014).[6]

The transformative policy idea was recently introduced by scholars from innovation studies and sustainability transitions, going under different terms and with different emphasis: initially, the literature referred to it as policy mixes for sustainability

4 CSA was proposed by FAO (2010) as an approach to transform agricultural systems to meet food security and climate change challenges.

5 Examples include implementing agroforestry, the use of climate-resistant seed varieties, early warning mobile apps, and soil conservation practices (Chandra et al., 2018; Lipper et al., 2014; Zilberman et al., 2018).

6 Despite its transformative ambition, CSA is not without contestation. It is criticized, first, for its lack of clarity and consensus regarding its definition and measurement, which makes its adoption and use controversial (Neufeldt et al., 2013b; Newell & Taylor, 2018; Taylor, 2018)second, for often being introduced as a top-down approach that, without proper local stakeholder involvement, could result in the imposition of practices not aligned with the local culture (Cavanagh et al., 2017), thereby reinforcing power dynamics and inequalities in agricultural systems.

transitions (Flanagan et al., 2011; Kivimaa & Kern, 2016; Rogge & Reichardt, 2016), more recently, concepts such as mission-oriented innovation policy (Mazzucato, 2018), system-wide transformation (Grillitsch et al., 2019), and transformative change policies (Diercks et al., 2019; Schot & Steinmueller, 2018) have been used. Despite the differences in terms, conceptual basis, and operational characteristics, a review by Haddad et al. (2022) indicated that these policy approaches share multiple characteristics, and all have a transformative goal (see Haddad et al., 2022, for details on similarities and differences in approaches). This paper uses Schot and Steinmueller´s (2018) broad term, transformative policies, reflecting the need to align innovation objectives with tackling social and environmental challenges such as poverty, climate change, and resource degradation.

Enacting transformative policy consists of formulating balanced policy mixes (Rogge et al., 2020; Schot & Steinmueller, 2018), which are complex arrangements with multiple goals and instruments that, in many cases, have developed incrementally over many years (Kern & Howlett, 2009, p. 395). The policy mix includes three building blocks: i) the policy elements containing a policy strategy and an instrument mix, ii) the policy processes, and iii) the policy mix's characteristics (Rogge & Reichardt, 2016, p. 1623). Transformative policy and policy mixes have been examined from various angles. Studies have, for example, addressed a particular policy element such as policy instrument mixes (del Río, 2010; Falcone et al., 2019), the policy strategy (Imbert et al., 2017; Quitzow, 2015), or policy mix characteristics (Kern et al., 2017; Kivimaa and Sivonen, 2021; Rogge and Dütschke, 2018). These studies have focused particularly on the field of energy, with applications to mainly European cases, with some contributions from China (Chang et al., 2019; L. Li & Taeihagh, 2020) and lately from Latin America (Castrejon-Campos et al., 2020; Garcia Hernández et al., 2021; Gomel and Rogge, 2020; Kanda et al., 2022) with case studies from Argentina, Mexico, and Brazil.

What these previous empirical studies have in common is that they highlight the importance of context, dynamism, and temporality in analyses of policy mixes. The dynamism of interactions between new and old policy instruments and goals may lead to synergies, trade-offs, or tensions (Flanagan et al., 2011) which in some cases may reinforce existing systems rather than promote transformation (Diercks et al., 2019). Hence, how the policy goals and the instruments are combined (or not) in a consistent, coherent fashion is germane to the potential of a policy mix to meet targeted outcomes (Huttunen et al., 2014a; Kern & Howlett, 2009), which thus may enable or constrain the desired transformative change.

Despite the emerging literature on transformative policy mixes, more empirical insights are needed on the evolution and dynamics of the implementation of transformative policy in interaction with the evolving and geographically embedded policy context, as work so far has focused on a limited number of sectors and countries. Although, as indicated earlier, empirical research has been undertaken on policy mixes for energy transitions, less attention has been paid to transformative policy mixes in other sectors, with a few exceptions such as bioeconomy and mobility (Grillitsch et al., 2019; Kivimaa and Rogge, 2022; Scordato et al., 2021). However, how transformative policy mixes have come about in an agricultural context has not been widely explored in a Global South context. This links to Hebinck et al.'s (2021) agenda-setting paper on transitions in food systems, which argued that there are knowledge gaps regarding transition studies focused on agriculture and food systems, including the role of transformative policies focused on agriculture (Klerkx & Begemann, 2020). In their agenda for transitions research overall, Köhler et al. (2019) indicated a need for insights on the role of Global South contexts in sustainability transitions. In particular, Ghosh et al., (2021b) argue that the Global South context needs to be understood better in the study of transformative policy mixes, as policy elements play out in contexts where limited public financial support resources, a large influence of informal institutions, and wealth inequality represent significant barriers to enabling sociotechnical change (Chaminade & Padilla-Pérez, 2017). Furthermore, in the Global South, in addition to national governments, transnational actors such as donors, multinational companies, and foreign investors often play a significant role in shaping transitions (U. Hansen et al., 2018).

2

To contribute to filling these knowledge gaps, this article aims to unravel the developments and dynamics of implementing CSA as a (potentially) transformative policy mix in Costa Rica. We focus on two building blocks of policy mixes: i) the policy mix elements (strategy and policy instruments, see section 2.2.) and ii) characteristics focusing on coherence, consistency. As this paper takes a helicopter view of how the mix has evolved over time, it can not explore the underlying policy processes, as this was methodologically outside the scope of this paper. We ask three questions: i) how have the CSA policy mix elements evolved over time?; ii) how do directionality, consistency, and coherence characterize the policy mix over time?; and iii) how does the Costa Rican context influence CSA policy mix dynamics?

The Costa Rica case study offers a setting where agricultural, environmental, and innovation policies are in place, aiming at climate change mitigation, adaptation, biodiversity conservation, and sustainable development (Araya, 2016). Important policy developments in climate action as the pledge to achieve carbon neutrality in 2050, economic incentives for payment for environmental services, and regulatory instruments on sustainable land use (e.g., reforestation and agroforestry)(Castro et al., 2000), in balance with the improvement of social indicators (poverty, inequality), set the enabling conditions for CSA development. The Costa Rican government has enacted an integrated approach in which mitigation measures encourage adaptation and sustainable development objectives that are aligned with the country's landscape-based approach to adaptation (OECD, 2017; Rosendaal et al., 2021). The agricultural–environmental policy domains interrelation provides suitable conditions and necessary elements to analyze the transformative policy setting aimed at supporting the transition toward CSA.

The remainder of the paper is structured as follows. Section 2.2 presents core aspects of the analytical framework; section 2.3 introduces the research methodology; in section 2.4, we present the Costa Rican context as a case study; section 2.5 provides the empirical findings from the operationalization of the CSA transformative policy mix. Section 2.6 presents the discussion followed by the conclusion in section 2.7.

2.2 Analytical framework

To build our analytical approach on transformative policy mixes based on the transformative policy rationale (subsections 2.2.1 and 2.2.4), we use key features to conceptualize and distinguish the elements of transformative policies in the ongoing transition toward CSA. These include a) balanced instrument mixes for both niche support and regime destabilization, b) improving coordination mechanisms, c) addressing directionality. We build on Rogge and Reichardt's (2016) extended concept of the policy mix for sustainability transitions developed to analyze the link between policy and technological change. For our analytical framework (see Figure 2.1), we operationalize relevant parts of two building blocks outlined by Rogge and Reichard (2016): i) the policy elements (instrument mix and policy strategy) and ii) the policy mix's characteristics (consistency and coherence). This is coupled with insights from transitions literature (e.g., Huttunen et al., 2014; Kivimaa and Kern, 2016; Lindberg et al., 2018; Nilsson et al., 2012) and transformative policy literature (e.g., Diercks et al., 2019; Grillitsch et al., 2019; Schot and Steinmueller, 2018; Weber and Rohracher, 2012) to highlight the importance of the policy context, directionality and coordination. This section presents the theoretical lens that guides the analytical framework, by first explaining key features of transformative policy mixes (2.2.1 and 2.2.4), followed by the consistency and coherence of policy mixes (2.2.2), the influence of the historical and institutional context on policy mixes (2.2.3), and policy coordination (2.2.4).

2.2.1 Balanced policy mixes for both niche support and regime destabilization

The policy elements include the policy strategy and instrument mix. Regarding the former, Rogge and Reichardt (2016, p. 1623) define "policy strategy as a combination of policy objectives and the principal plans for achieving them". The strategy is related to directionality, which refers to the direction, orientation, guiding design, and policy intervention implementation toward the desired change (Weber & Rohracher, 2012). In the literature on transformative policies, it is argued that innovation should not be pursued only for the sake of economic growth, but also should address critical societal challenges (Bergek et al., 2023; Diercks, 2019; Grillitsch et al., 2019). Building on eco-innovation, Miedzinski and McDowall (2019) suggested that directionality can be introduced to the policy mix concept by identifying major challenges in policy visions, setting specific policy goals and targets, and translating those goals into criteria guiding policy implementation. Thus, besides identifying the challenges, aligning the policy goals with plans and guidelines may help to steer directionality for the transition process (Rogge & Reichardt, 2016). Policy goals and plans can include long-term targets with quantified levels (e.g., maximum net emissions of 106.53 million tons of carbon dioxide equivalent). Moreover, framework conferences, directives, and national action plans are examples of plans that detail the intended government direction to achieve the objectives (Rogge & Reichardt, 2016). Although strategy documents are a snapshot of a larger strategic phase, they usually identify a group of governmental actors responsible for strategy development and implementation. Directionality is often contested, as there are generally multiple possible transition pathways (Klerkx & Begemann, 2020), hence policy strategies are inherently political and the management of related trade-offs is a critical policy challenge (Imbert et al., 2017; Ladu et al., 2020; Quitzow, 2015).

Concerning the latter component of the policy elements, the instrument mix contains multiple instruments to achieve the stated policy strategy (Li and Taeihagh, 2020). Policy instruments are also known as policy tools and are defined as "techniques of governance which, one way or another, involve the utilization of state resources, or their conscious limitation, in order to achieve policy goals" (Howlett and Rayner, 2007, p. 2). For categorizing, we deviated from Rogge and Reichardt's (2016) proposed typology categorization and followed definitions from Borrás and Edquist (2013), Smits and Kuhlmann (2004), Wieczorek and Hekkert (2012), as these are broader. The instruments can be categorized as follows: i) economic and financial instruments, ii) soft instruments such as standards and codes of conduct, iii) regulatory instruments such as laws, and iv) systemic instruments such as intermediation (see Appendix A1, Table A1).

Policy instruments promoting and supporting experimentation in green niches are key to transformative policy (Schot & Steinmueller, 2018). However, it is increasingly recognized that policies should focus not only on fostering niche creation, but also on destabilizing the current regime configuration (Kivimaa & Kern, 2016; Rosenbloom & Rinscheid, 2020; van Oers et al., 2021). In the agrifood literature, conventional agrifood systems based on industrial agriculture are often denoted as food regimes (McMichael, 2009), and, as Gaitán-Cremaschi et al. (2019) indicated, this concept shows a broad resemblance to the sociotechnical regime concept as used in transition studies (though food regime is perhaps slightly more focused on political economy aspects). Given the above, policy mixes enabling transformative change should include both instruments supporting sustainable niche innovations and instruments aimed at destabilizing the regime.

Instruments targeting niche innovations can potentially address knowledge creation (e.g., innovation platforms), contribute to market formation (e.g., regulations and taxes), and promote entrepreneurial experimentation (e.g., seed capital), among other things (Kivimaa & Kern, 2016). Experimentation means trying out new technologies and associated practices, focusing on learning about the possibilities for overcoming structures that inhibit the diffusion of technologies and practices (Grillitsch et al., 2019). Instruments and deliberate strategies aimed at regime destabilization open windows of opportunity to upscale niche innovations (Rosenbloom and Rinscheid, 2020). Instruments toward such destabilization include policies to pressure regimes, destabilize regime rules, reduce support, and change social networks (e.g., pollution taxes, restricting technologies, laws reforms, removing subsidies, including niche actors in policy offices) (Kivimaa & Kern, 2016). Regarding policy strategies, van Oers et al. (2021) explored the concept of deliberate destabilization as a political strategy (e.g., interests and motivations of policy strategies) and showed the contested nature of the destabilization process and the regime actors' vested interest in continuing business as usual.

2.2.2 Policy mix characteristics: coherence and consistency

To portray the policy mix descriptions, Rogge and Reichardt (2016) identified four characteristics: consistency, coherence, comprehensiveness, and credibility. Although characteristics such as credibility and comprehensiveness are recognized in the literature as describing the reliability of the policy mix and determining the extent to which different rationales for policy intervention are implemented (Bach & Hansen, 2023; Nemet et al., 2017; Rogge & Schleich, 2018; Rosenow et al., 2017), the inclusion of credibility and comprehensiveness was outside the scope of our study because more focused data (e.g., specific indicators of instrument performance and public opinion) would be needed to unravel the reliability of policy commitments. Moreover, including those descriptive features adds extra complexity to analyzing transformative policy mixes, potentially leading to a less parsimonious analysis. Our paper therefore focuses on consistency and coherence to better understand the links and tensions between sectors and governance levels. Moreover, both are key determinants for analyzing policy mix performance, as consistency captures the tensions and synergies between the strategy and the instruments, and coherence captures interactions across and within policy domains (see Table 2.1).

Table 2.1 Policy mix characteristics and conceptualization

Characteristic	Category	Explanation
Coherence	Internal	Alignment and interactions between the policy goals and policy instruments in a single policy domain (e.g., increase the agricultural sector's competitiveness goal in relation to the goal of strengthening domestic market conditions) In each policy domain (agriculture and environment), regional and international guidelines are translated into concrete measures at national and local level
	External	Interactions across multiple policy domains: sectorial goals, policies, and instruments have mutually supporting/counterproductive efforts across the two policy domains (e.g., carbon neutrality goal in relation to agricultural nationally appropriate mitigation actions program)
	Temporal dimension	The interplay between policy domains' goals and instruments over time (e.g., changes in regulations over time, uncertainty, availability of resources)
Consistency	Strategy and Instrument	Overall policy mix consistency is characterized by the ability of the policy strategy and the instrument mix to work together in a unidirectional or mutually supportive fashion
	Instrument: Positive interaction	Strong instrument mix consistency (reinforcing rather than undermining each other in the pursuit of policy objectives) is associated with positive interactions
	Instrument: Neutral interaction	Neutral interactions characterize weak instrument mix consistency, and the impact of the combination is lower than if the instruments are used separately
	Instrument: Negative interaction	A negative interaction captures inconsistency (instruments undermining each other)

Source: Based on Del Río (2014); Huttunen et al. (2014a); OECD (2019); Rogge & Reichardt, (2016)

There is no agreement on the exact meaning of coherence, as it is highly interrelated with policy interaction and integration (Rogge & Reichardt, 2016). To describe tensions and synergies better, we use the definition of coherence provided by Nilsson et al. (2012, p. 396): "an attribute of policy that systematically reduces conflicts and promotes synergies between and within different policy areas to achieve the outcomes associated with jointly agreed policy objectives". Ideally, different sectors' policies and objectives are expected to work synergically to push the desired societal change. However, policies in one sector may trigger conflicts with policy objectives and implemented instruments in another sector (Huttunen et al., 2014a). According to Nilsson et al. (2012), policy coherence may be examined both internally (focusing on a single policy domain) and externally (across multiple policy domains). Policy coherence can also incorporate a vertical dimension (across different spatial governance scales) and a horizontal dimension (between policy domains at the same governance level). We focus on horizontal coherence i) internally, ii) externally, iii) temporally, i.e., the coherence of the agricultural policy domain's goals and instruments and the interplay of the policy goals and instruments between the agricultural and environmental policy domains over time.

Consistency describes strategy–instrument mix interactions and precisely "captures how well the mix elements aligned with each other" (Rogge & Reichardt, 2016, p. 1626). Accordingly, policy mix consistency involves two main interactions: 1) consistency of the instrument and objectives, ii) consistency between instruments. To define the first one, we used Howlett and Rayner's (2013) definition, which relates consistency with the capacity of the policy strategy and the instrument mix to operate in a mutually supportive course. Regarding consistency of the policy instruments, we used del Río's (2014, 2009) description of instrument mix consistency, defined as strong, weak, and inconsistent. Strong instrument mix consistency is associated with positive instrument mix interactions (when adding an instrument magnifies the impact of the combination), neutral interactions characterize weak instrument mix consistency, and negative interactions characterize an inconsistent instrument mix, i.e., when one instrument reduces the effect of another (Cunningham et al., 2013; Del Río, 2014).

2.2.3 Influence of historical and institutional context on policy mixes

Real-world policy contexts encompass diverse policy instruments based on various rationales addressing market, system, and transformational failures (Weber & Rohracher, 2012). Over time, the inclusion of transformative elements within an existing policy mix generates a variety of dynamics in terms of how policy is designed and implemented and how new policies relate to existing policies (Diercks et al., 2019). This connects to both historical and place-related institutional influences that shape public policy formulation and enactment.

Similar to ideas in transition studies that system change can be seen as a change in institutional settings or logics (Elzen, Van Mierlo, et al., 2012; Fuenfschilling & Truffer, 2016; Geels, 2020), policy design studies (Capano, 2019; Howlett & Rayner, 2013; Van Der Heijden, 2011) have drawn on institutional change mechanisms (Béland, 2007; Streeck & Thelen, 2005) to understand the dynamics of the evolution of policy mix elements and goals over time. Given such institutional change analysis, Howlett and Rayner (2013) argued that policy developments are built through incremental or reformulation processes of layering, drifting, conversion, and replacement. Policy layering involves adding elements to the existing arrangements (Capano, 2019) and is the process whereby new goals and instruments are added to old ones without discarding the previous ones. Drifting means replacing an old goal with a new one while keeping the same instruments in place (Howlett & Rayner, 2013). Conversion involves putting in place new instrument mixes while keeping the original objectives constant. Finally, a policy replacement occurs when new policies are consciously created or fundamentally restructured by replacing previous goals and instruments (Rayner & Howlett, 2009, p. 103). In the transformative policy context, Diercks et al. (2019) and Kern et al. (2017) have shown that policy developments recognize that transformative policy paradigms are rarely entirely new but built on legacies and are layered upon previous policy rationales, and Molas-Gallart et al. (2021) found that transformative policy developed through drifting and conversion processes.

Place- and sector-based aspects of transformative policy formulation and enactment should also be considered. Multiple actors and networks play an essential role in promoting transformative change (Grillitsch et al., 2019; Rogge et al., 2020), and how they co-shape and are affected by policies may differ from place to place (e.g., Global North vs. Global South) and sector to sector (e.g., agrifood vs. health), given the structures and power relations that shape political and economic systems and sectors (Coenen et al., 2012; Conti et al., 2021). The development and implementation of innovation policy goals and instruments is shaped by policy cultures (Pfotenhauer and Jasanoff, 2017) and past approaches to innovation policy (Doezema et al., 2019). Furthermore, the institutional settings in innovation systems (defined as rules, norms, incentives that shape individuals' and organizations' behavior in innovation, such as funding structures, inclination to collaborate) differ from country to country (Klerkx et al., 2017). In the context of transitions in the Global South, beyond the influence of national policy and economic contexts, scholars have pointed to the role of intergovernmental organizations, transnational cooperation agencies performing and fulfilling some of the functions of the weaker state apparatus (Sixt et al., 2018). Weaker and less effective government administrations result in unstable regimes and often pose major constraints to niche developments (U. Hansen et al., 2018). Moreover, the relation between the state and the private sector is contested since investments sometimes can be ineffectively shifted, thus reinforcing incumbents' positions (Garcia Hernández et al., 2021)(e.g., powerful companies with strong political links benefit from unsustainable practices and reproduce structures of social exclusion). Hence the role of the public-private in promoting new forms of engagement needed to address social pressures has been recognized by transition scholars (Ramos-Mejía et al., 2018) and transformative policy researchers (Chataway et al., 2017; Ghosh, Kivimaa, et al., 2021; Schot & Steinmueller, 2018).

2.2.4 Policy coordination

In view of the challenges in achieving policy coherence and consistency and the need to navigate complex policy contexts, coordination across actor groups, sectors, and policy domains is crucial for promoting sociotechnical systems change (Weber & Rohracher, 2012). Therefore, transformative policy mixes need to include instruments to improve policy coherence between public policies, but also from the private sector, as well as mechanisms to promote vertical coordination between governance levels (Ghosh, Kivimaa, et al., 2021). Thus, policy coordination is essential to integrate the frequently conflicting economic, social, and environmental objectives, maximize synergies, and minimize trade-offs in the policymaking process. Adding new instruments and goals to an existing one through a layering process may lead to coherent or incoherent policy mixes (Howlett & Rayner, 2013; Kivimaa & Virkamäki, 2014; OECD, 2019). Horizontal and vertical coordination becomes challenging when policies are horizontally interrelated (e.g., health, environment, and agricultural), coordination across ministries and agencies is insufficient, and efficient coordination mechanisms are missing (Carbone, 2008). We included policy coordination tools in our analysis to better understand the efforts enacted over time to achieve policy coherence for promoting CSA, given the complexities of the cross-sectorial policies in place and the relevance of coordination for transformative policy mixes. Thus, coordination and integration are policy mechanisms to avoid policy incoherence (Candel & Biesbroek, 2016; Reichardt et al., 2016).

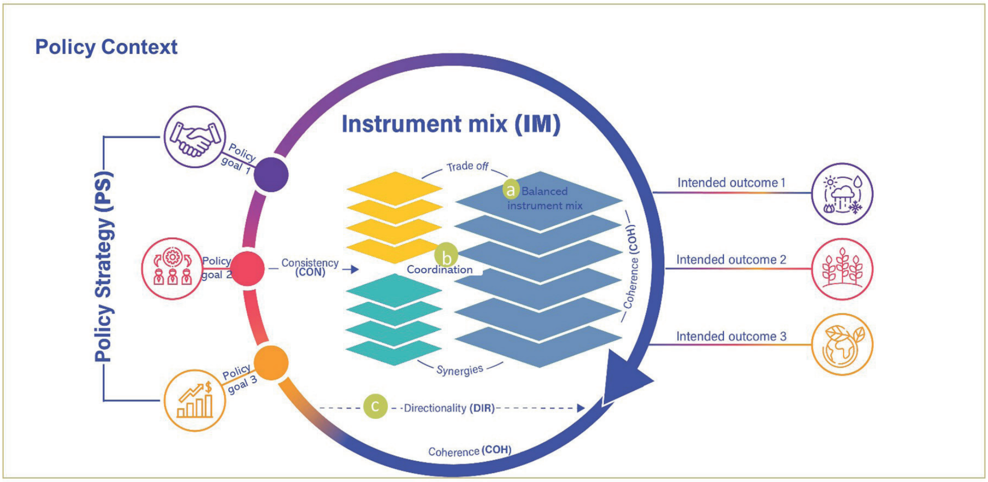

Figure 2.1 Analytical framework of the policy mix and three transformative features: a) instruments targeting niche creation and regime destabilization, b) policy coordination tools, c) addressing directionality

Source: Extended from Rogge and Reichardt (2016, p. 1630) using Schot and Steinmueller (2018) and Weber and Rohracher (2012)

2.3 Methodology

2.3.1 Policy mix: scope, dimensions, and boundaries

We followed a top-down approach to delineate Costa Rica's CSA policy mix to set the mix's boundaries, scope, and dimensions; this implies that a policy mix has an overarching strategy implemented through a set of instruments (Ossenbrink et al., 2019). A 2000–2022 timeframe was chosen because we wanted to explore the enabling policy framework for CSA transition before and after the CSA initiative was promoted globally by the Food and Agriculture Organization (FAO) in 2010 and because the accessibility to historical archives ensured the robustness of the data collected. Regarding the vertical and horizontal dimensions, the CSA policy mix analysis considers multilevel governance: global, Central American, and national, as it operates at different levels and involves several policy domains. Mainly the agricultural sector is responsible for promoting CSA, and its implementation is interrelated with climate action and environmental policies (as it is also about adaptation and mitigation). The main features of the policy strategy include tackling climate change, sustainable development, and increasing on-farm productivity levels (e.g., with green technologies). We included global frameworks and agreements, national strategies, targets, directives, and national development plans in effect in 2022, and the relevant policy instruments are laws, regulations, decrees, R&D support, and voluntary standards.

2.3.2 Data collection

We chose a qualitative research design involving a single case (Yin, 2018) to analyze the potential transformative features of the CSA policy mix. We used two types of information: policy documents and interviews. First, we collected archival data for 2000–2022 and retrieved relevant policy documents (e.g., strategies and plans, laws, decrees), newspapers, and reports with program/initiative information describing what the country and the region were doing to promote CSA. The documents were included if they related to CSA and contained at least two of CSA's three fundamental pillars: adaptation policy, mitigation policy, or productivity/competitiveness-related policies. The inclusion of food security and sustainability keywords was also considered based on the FAO (2013) definition. For this delimitation, we also reviewed CSA-related literature to define inclusion/exclusion criteria for the documents. A total of 214 relevant policy documents were reviewed (see Appendix A2).

The document analysis was complemented with 21 in-depth online interviews. The interviews were conducted between December 2020 and April 2021 with various actor groups (policymakers, academia, technicians, and experts). The participants were chosen based on their role in the formulation/implementation of climate change/agriculture policy (see Appendix A2). Further participants were chosen through a snowball sampling logic, where previous interviewees suggested whom to interview next. The number of interviews was determined by the saturation point of the responses but ensured that different perspectives were represented. The interviews were conducted using a semi-structured interview guide based on the analytical framework. Interviews lasted between 45 and 120 minutes, were conducted in Spanish, transcribed verbatim, and sent to the interviewees for validation and approval. Many respondents availed of the opportunity to provide additional remarks. These interviews were beneficial in validating the timeline and instrument mix, thereby complementing the results from the first steps.

2.3.3 Data analysis

The 214 retrieved documents and strategies were included in an Excel database and classified using the following categories: ID, title, aim, initial date, end date, policy mix building blocks (according to Figure 2.1), type of document (e.g., framework, strategy, policy, plan), description, governance level (e.g., international, national), policy domain, CSA component addressed (adaptation, mitigation, productivity), type of instrument (economic, soft, regulatory, systemic), purpose (niche promotion or regime destabilization), transformative features (directionality, coordination, governance arrangements), and general comments. Using this Excel database, we illustrated the instruments and the strategies by means of a timeline to visualize the historical evolution of the policy mix.

The interviews were also used to describe the characteristics of the policy mix (Table 2.1) and obtain more detail on the transformative features of the mix. Deductive coding of the interviews using Atlas.ti 22 allowed us to conduct a thematic analysis in which we focused not only on the characteristics of the policy mix, but also on the main challenges, agreements, and disagreements between actors. Identifying elements of the policymaking processes in our specific context made an important contribution to explaining the policies' continuity or lack of continuity in mix, styles, tensions, problems, and cultures (Edmondson et al., 2019; Kivimaa & Virkamäki, 2014). This process involved multiple queries between the framework elements and the quotations and notes. Triangulation of the interviews and documents was performed to ensure robust results.

2.4 Costa Rica as a case study: a transition toward Climate Smart Agriculture

Costa Rica has developed from a rural agriculture-based economy to one with a more diversified structure integrated into global value chains (OECD, 2017). Macroeconomic indicators show that primary agriculture accounted for 4.3% of GDP in 2022 and comprised 43.7% of total exports (INEC, 2021a). From 1990 to date, profound changes have been made in the development model to address social shortfalls while promoting green technologies and the management of natural resources (Araya, 2020; Fanning et al., 2022). As a result, 98% of energy produced comes from renewable sources, 25.5% of the territory is under some category of environmental protection, and lands once dedicated to agricultural production are now forests or protected areas (MINAE, 2020).

The agricultural sector has a dual structure, with large disparities between farming systems in terms of productivity, competitiveness, and technological capabilities (SEPSA, 2022). The traditional sector supplies mainly the domestic market (e.g., grains and vegetables), with many technological barriers and low productivity levels (OECD, 2017). The export-driven sector has been oriented to achieve high productivity levels from higher yields through more efficient inputs, improved labor productivity, and innovation (SEPSA, 2022). This model has resulted in economic development and increases in the average income of the overall population; however, some of these agricultural production systems are highly controversial because of the increasing pressures on natural resources and unsustainable production practices (Programa Estado de la Nación, 2019).

According to Harvey et al. (2014), policies favoring conventional agricultural production systems predominate over those promoting climate-smart farming practices. Moreover, farmers targeting local markets and engaged in initiatives such as agroecological, organic,[7] agroforestry, and biodynamic production are not sufficiently protected and supported (Le Coq et al., 2020; Wallbott et al., 2019). More recently, given the pressures of international agreements and the integration of some agrifood systems in the global value chain, the dominant food systems have led initiatives such as low-carbon-emission products – specifically in the case of coffee, sugar cane, bananas – (e.g., 21% of the coffee produced is low in emissions, and 53% of bananas are carbon neutral)(Araya, 2016; GIZ, 2020). This presents a challenge for agricultural production and provides a window of opportunity to advance CSA and alternative production systems (SEPSA, 2011).

7 For example, by 2019, organic agriculture represented 1.9% of the country's planted area (Programa Estado Nación, 2021).

2.5 Development of the transformative policy mix for Climate Smart Agriculture

Our analysis of the CSA policy mix is elaborated in this section. In section 2.5.1, we present an overview of the policy mix elements in terms of policy stages and instruments. In section 2.5.2, we characterize the policy mix in terms of coherence and consistency. In section 2.5.3, we elaborate on the CSA policy context in Costa Rica, and in section 2.5.4 we present tools for policy coordination.

2.5.1 Overview of the policy mix: policy elements

We mapped, counted, and categorized the instruments from 2000 to 2022 to evaluate the mix's overall balance. Laws and law amendments comprised the majority of the instrument mix (25%), followed by decrees (22%), programs and projects (15%), and voluntary standards (5%). According to the typology outlined in the analytical framework (section 2), the instruments were categorized as follows: 36% of them corresponded to systemic instruments, 26% to soft instruments, 27% to regulatory instruments, and 12% to economic instruments (see Figure 2.2).

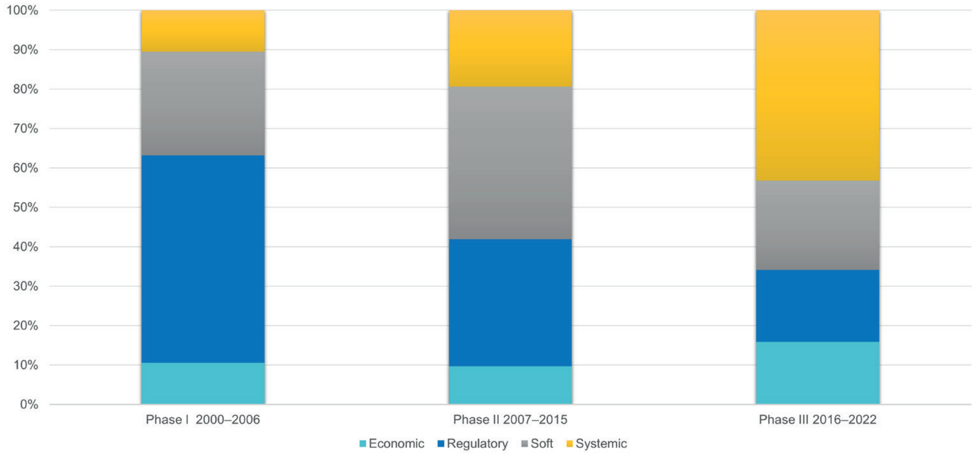

Figure 2.2 Type of instruments grouped by the policy mix strategic phases

The CSA strategy is articulated by a set of policy documents aiming to achieve sustainable development objectives and jointly address food security and climate challenges (Interview 1). The most important strategic document is the National Development Plan (NDP) prepared by the Ministry of National Planning and Economic Policy (MIDEPLAN) in collaboration with the president and his council of government. The NDP establishes strategic objectives and priorities, formulates goals, and allocates resources. Each ministry prepares its sectorial plan (e.g., Policy

Guidelines 2019–2022 for the Agriculture Livestock Fisheries and Rural Sector) to align the national strategy with sectorial plans. In addition, policies emerge strategically, expressing guidelines, objectives, and actions on a topic of public interest (MIDEPLAN, 2016) (see Appendix A3).

From 2000 to 2022, in the national strategy, three phases were marked by changes in, and adjustments to, the long-term objectives. The first phase (2000–2006) was characterized by leadership from the environmental domain and a strong focus on biodiversity conservation and forest restoration (44% of the instruments involved environmental regulations). In the second phase, 2007–2015, the country adjusted the conservation discourse and set the long-term goal of carbon neutrality by 2021. In the third phase (2016–2022), efforts toward carbon neutrality continued but were rebranded as a transition to a just and decarbonized economy by 2050, emphasizing the need for social inclusion and equity.

At national level, the efforts of the agricultural policy domain to integrate instruments promoting more sustainable agriculture and balance conservation with the economic development agenda were pivotal to CSA (Plan Nacional de Descarbonización, 2018).

> CSA is an approach that contributes to the achievement of sustainable development objectives. It integrates the three dimensions: economic, social, and environmental, thus addressing food security and climate challenges jointly. It is based on three main pillars: 1) smartly increasing agricultural productivity and income; 2) adapting and building resilience to climate change; and 3) reducing or eliminating GHG emissions. (SEPSA, 2014, p. 52)

However, CSA has a contested nature at national level. Many respondents indicated that CSA is not deemed a mainstream strategy and that there is no shared vision for climate-smart policies. Thus, it is one of the many possible paths to achieving sustainable agriculture in light of climate change and food security (Interviews 1, 4, 19, 21).

> I hardly talk about climate-smart agriculture, what I interpret in my day-to-day work is that farmers should be more sensitive in the management of resources and demonstrate to them with data that they can be more environmentally responsible while increasing their productive performance....Climate-smart agriculture, regenerative agriculture, carbon neutrality are very politicized concepts, we need to translate what does climate-smart entails according to farmers' reality. (Interview 19)

Building on the three strategic phases that emerged in our analysis (Figure 2.3), we detail the main policy objectives, plans, and instruments implemented to achieve them, and in Figure 2.4 we summarize the CSA policy mix between 2000 and 2022.

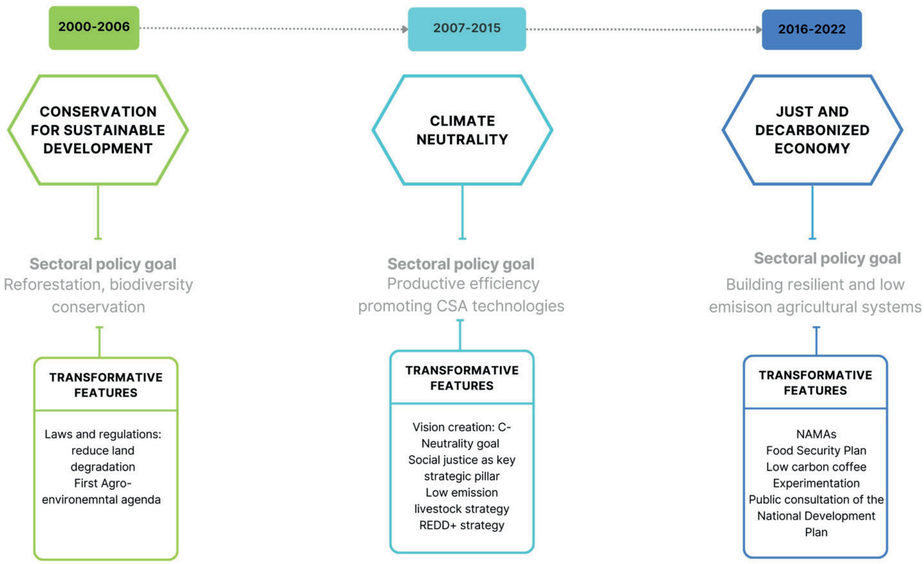

Figure 2.3 Three strategic phases of the CSA policy mix from 2000 to 2022

The interlinkages between national plans, policies, regulations, and the global climate agenda are key in policy development (Interview 4). The international frameworks adopted/aspired to by the country – the 2030 Agenda for Sustainable Development, the Paris Agreement on Climate Change, the Convention on Biological Diversity, and the Convention to Combat Desertification, among others – operate as a referent and as an enabling framework to promote CSA. In addition, at regional level, through the Central American Integration System – formed by eight Central American countries with the objective of optimizing the region's development capacity – cooperation agreements for CSA were formulated and implemented. Examples include the Regional Climate Change Strategy and the CSA guidelines, both of which aim to provide direction and integration across the countries' national polices (FAO & IICA, 2021).

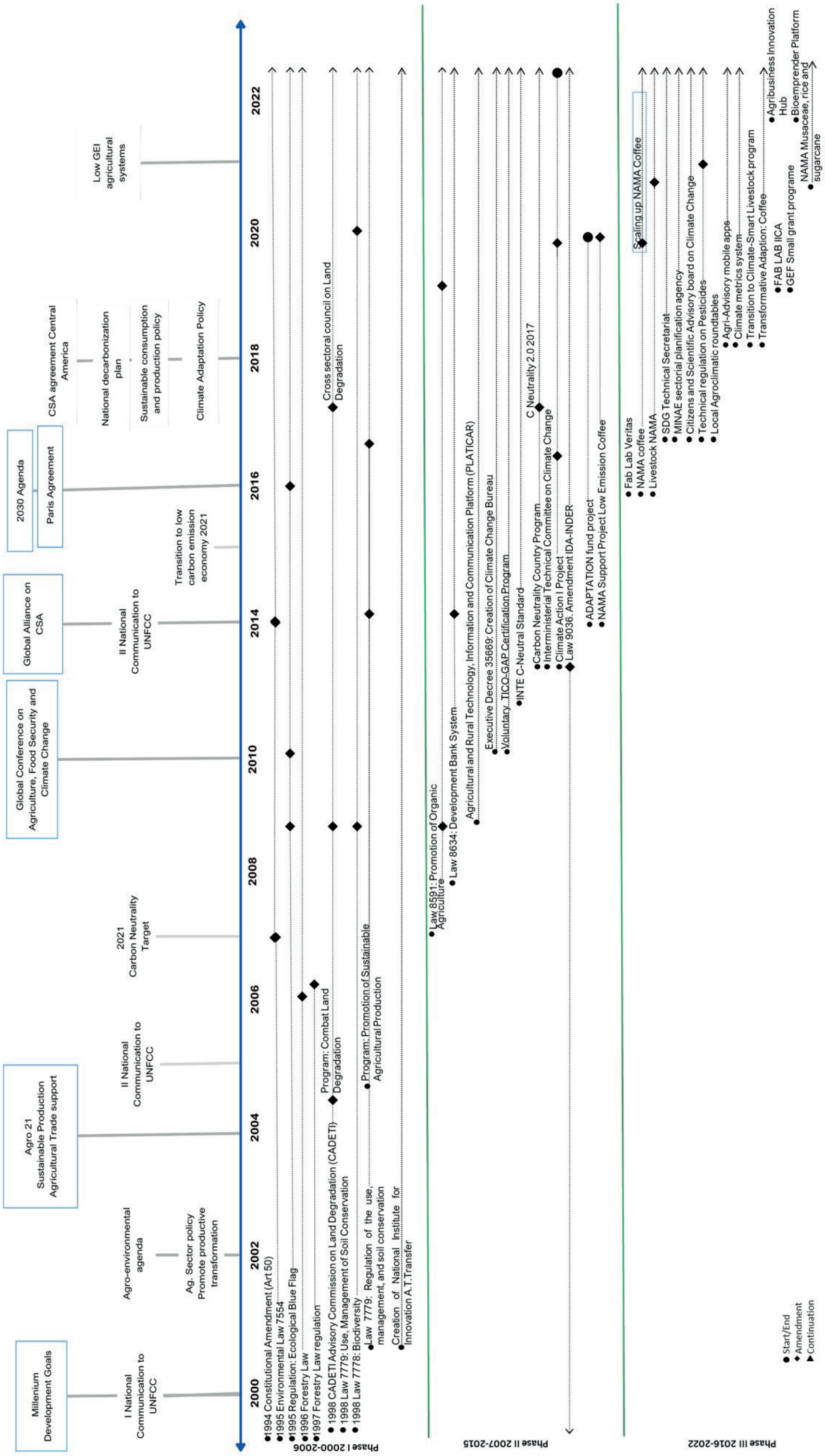

Figure 2.4 Climate-smart policy mix from 2000 to 2020: Mainstream policy goals, plans, and instrument mix

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2.5.1.1 Phase I: 2000–2006 "Matching conservation and agricultural expansion"

Before 2003 – with the implementation of the first agri-environmental agenda – there was no collaboration between the agricultural and environmental domains, but rather conflicts because of their differing and opposite goals (conservation vs. agri-export orientation). The antagonistic objectives of the agricultural and environmental sectors generated confrontation between businesses, farmers, and Ministry of Environment (MINAE). The agricultural sector was perceived as the cause of environmental degradation as a result of the expansion of monocultures, deforestation, erosion, and land degradation (Interviews 15, 16).

> In the past, it was very tense [the relationship between agriculture and the environment] because of this 'Manichean' [cosmic struggle between the good and bad] position that was assumed by one against the other.…the agricultural sector is the 'perpetrator' of the country's deforestation and carbon emissions.… and that has led to unnecessary debate. (Interview 16)

Costa Rica's environmental and conservation policies underwent profound reforms, changing the country's development model, and focused mainly on reversing the impacts of agricultural activities (Interview 3). In the first phase, laws such as the Regulation of Use, Management, and Soil Conservation Law, Forestry Law 7575, and Environmental Law 7554 came into effect. The enabling framework for CSA was based on strong environmental regulation and trade liberalization instruments in the agricultural sector. Some agencies, such as the Institution for Innovation and Technology Transfer (INTA) and the Advisory Commission on Land Degradation, were important in promoting good agricultural practices. The data show that most of the instruments in this phase involved niche support instruments (23 instruments), and two were aimed at regime destabilization (see Appendix A3 for more details).

The 2000–2006 strategy manifested a classical rationale, strategic goals, and plans oriented toward solving market failures, information asymmetries, externalization of cost, and systemic failures, such as the stimulation of physical infrastructure and the prevention of too weak institutions. Most of the policies aimed to increase competitiveness and rural development through productive transformation, strengthening human resources, institutional modernization, and rural development (MAG, 2013). The science, technology, and innovation plans and strategies were not central to the agenda and focused broadly on the overall economic agenda (e.g., creation and development of human capacity, stimulation and growth of production for employment generation, and increasing economic and employment growth).

2.5.1.2 Phase II: 2007–2015 "The radical change in climate action"

By 2009, on the road to the United Nations Climate Change Conference in Copenhagen, Costa Rica announced the goal of becoming carbon neutral by 2021. The carbon neutrality goal (C-Neutrality) shifted the paradigm and direction of the policies, plans, and projects. The redirected efforts changed the country's orientation from being a leading nation in conservation to being a country in transition to carbon neutrality (Paz con la Naturaleza Initiative, 2007). The paradigm shift was perceived as ambitious, uninformed, and unplanned, but it marked the start of a new era for climate action and agricultural policy (Interview 14).

> When Dobles…decided to set the carbon neutrality target, it was a wise political decision because it gave a turn to the way of thinking about climate change and what had to be done in terms of climate change. (Interview 14)

The C-Neutrality long-term goal provided direction and resulted in a sufficiently ambitious and credible goal for environmental and agricultural domains to formulate plans, guidelines, and lines of action (DCC, 2012; Interviews 1, 12).

On the global agenda, the Costa Rican government endorsed two CSA-related events: the 2010 World Conference on Agriculture, Food Security, and Climate Change and the creation of the Global United Nations Alliance for CSA, to which Costa Rica adhered in 2014. As a result, several projects and programs were designed to support CSA systems, such as INTA's research program on low-cost, low-emission, and resilient technologies.

The first set of instruments implemented related to the mitigation of greenhouse gas (GHG) emissions, for example by providing economic incentives for adopting agroforestry in coffee and cacao systems, the Nationally Appropriate Mitigation Actions (NAMA) coffee[8] registration to the United Nations Framework Convention on Climate Change, programs for converting arable land to grassland, and promoting C-Neutrality country voluntary standards. The second set of policy instruments covered actions to promote adaptation to climate change and build farmers' resilience. Several measures were in place, including climate-resistant staple crops and coffee-breeding programs, crop insurance programs, climate-related early warning apps, and climate action discussion roundtables.

8 CR Coffee NAMA "Toward a low emission coffee sector" was recognized as the first agricultural NAMA in the world and started as a pilot project in 2015 funded by cooperation agencies. The project was coordinated and articulated jointly by the Coffee Corporation (ICAFE), MINAE, and the Ministry of Agriculture.

In parallel, the Legislative Assembly approved the organic agriculture Law 8591, stipulating the creation of the National Commission for Organic Activity (created in 2014), allocating 0.1% of fuel taxes to pay for agricultural and environmental services and tax exemptions for organic farmers. The interviewees reported that organic agriculture as a social movement lost strength once it was institutionalized because the core principles were drastically changed between the bill's initial proposal and final publication (Interviews 1, 16, 19). This shows how embedded regime actors are in the legislative apparatus and the policymaking process, hindering the transition toward more sustainable systems.

> The state shall promote organic agricultural activity on equal terms with conventional agriculture and agribusiness.... INTA, without prejudice to programs aimed at other sectors, shall promote and develop research related to organic agricultural production and facilitate technology transfer among producers. (Art 1, 8591 Law, 2009)

Without a formalized transformative intention, transformative elements emerged, including new governance arrangements, multistakeholder consulting groups, protected experimentation spaces, and classic economic instruments with transformative features. First, the new governance arrangements – offices such as the Climate Change Bureau and the technical committee on climate change – were created to add dynamism and "inclusivity" to the climate agenda; second, stakeholders such as civil society, representatives of indigenous communities, and NGO representatives were included in policy formulation and the implementation of national programs (e.g., REDD+, Land Degradation programs); third, some spaces for experimentation were enabled, such as the Alliance for C-Neutrality, where private companies and the public sector met to learn and share experiences on their paths to carbon neutrality; fourth, economic instruments such as the carbon market and Development Bank System included guidelines favoring equitable access to credit for women and the most vulnerable sectors (e.g., smallholder farmers not eligible for credit in the traditional banking system).

2.5.1.3 Phase III: 2016–2022 "Rebranding of the carbon neutrality goal"

Global agreements such as the 2030 Agenda and the Paris Agreement provided the cornerstones of climate and agricultural policy in this phase. Based on the Nationally Determined Contributions (NDC) prepared for COP 21 and the assessment that Costa Rica would not meet the C-Neutrality goal by 2021, the carbon neutrality goal was rebranded as a "Just and decarbonized economy by 2050" through the national decarbonization plan in 2018. The agricultural sector prioritized the strategic objective of "promoting highly efficient agrifood systems that generate low-carbon goods for export and local consumption" (Plan Nacional de Descarbonización, 2018, p. 56).

This phase involved restructuring and rebranding the instrument mix. The 1995 Payments for Environmental Services Program was amended to recognize the environmental services associated with agricultural activity (Ley Forestal, 1996). The Carbon Neutral Country Program was rebranded as Carbon Neutral Country program 2.0 to align it with the country's mitigation objectives. The NDC was updated, and the Decarbonization Plan substituted the Climate Change National Strategy. International cooperation projects were executed, such as experiments with low-emission-coffee technologies and livestock practices. Other NAMAs in the agricultural sector (*Musaceae*, sugar cane, and rice) were created as a result of livestock and coffee NAMAs' learning process, all led by corporations,[9] the public sector, and NGOs.

> On the other hand, a great deal of research is already being done by organized corporations, such as ICAFE, CORBANA, and LAICA, where they promote biological pest control practices, develop resistant varieties, and experiment with bio-inputs. All this is led by the private initiative…most of the practices that work are developed by organized associations or corporations. (Interview 18)

The environmental policy domain led the implementation of more transformative elements (Interview 18), funded by international cooperation. Also, more interventions were explicitly related to CSA (e.g., the germplasm project for CSA in the cocoa system). New spaces for experimentation, i.e., an agricultural fablab with co-creation and social innovation components, were developed. Platforms such as Agro-Innova, Bioentrepreneurship, and Incubators programs were considered instruments with transformative elements because they included multi-actors, multi-sectors, and the tackling of societal challenges.

Regarding niche support instruments, soft and voluntary measures played a key role, as well as private standards led by third parties (RainForest, AAA Nespresso, Global GAP). The services provided by the public sector in terms of advice, technical assistance, demonstration plots, on-farm workshops, and extension services provided by public universities and Ministry of Agriculture and Livestock (MAG) operated

9 Corporations in the local context are autonomous public agencies mandated to support specific agricultural subsectors through research, trade (e.g., maintain an equitable relationship regime between producers and agro-industry) and to represent them in public consultations; for example, ICAFE, the National Rice Corporation (CONARROZ), the National Livestock Corporation (CORFOGA), the National Banana Corporation (CORBANA), and the Sugarcane Industry Association (LAICA).

as awareness-raising spaces and open spaces for experimentation. However, they were developed on a small scale, given extension agents' limited capacity and lack of financial resources.

Policymakers have not embraced the idea of designing tool aiming at destabilizing the regime. The policy discourse was related to achieving eco-efficiency in the farming production system. This suggests that, although transformative goals were proposed within the instruments (e.g., NAMAs, certification schemes), incremental rather than radical changes were promoted in practice.

> The focus was to promote efficient technologies, not to ban old inefficient ones…we also worked a lot with the visualization of the potential benefits, if the new technologies are much cheaper and are much more efficient….at the end of the day, this will result in economic savings for the user. (Interview 5)

2.5.2 Directionality

Costa Rica's long-term vision – influenced primarily by global targets and goals (SDGs, 1.5 C Paris Agreement, UN Global Alliance CSA) – indicates the multilevel integration of global and national goals (Plan Nacional de Descarbonización, 2018). The international framework and the national policies' long-term vision were used as leverage to finance Costa Rica's objectives through international cooperation funds. The first effort (guided by international cooperation funds) to reconcile the agricultural and the environmental domain visions and to build one shared direction was the implementation of the first agri-environmental agenda in the first phase (2000–2006). The agenda was a game-changing coordination mechanism between the agricultural and environmental domains. Furthermore, it sought to resolve a systemic failure related to stimulating interactions that otherwise would have been stymied by inter-sectorial opposing rationales. In the second phase (2007–2015), the strategy positioned ambitious long-term goals with the 2021 C-Neutrality declaration. Moreover, in the third phase (2016–2022), the explicit inclusion of the 2030 agenda in the national strategic planning system and the rebranding of decarbonization of the economy by 2050 acted as key strategic developments for redirecting investments in, and focus on, climate action and social welfare.

Specifically for CSA, the lack of a mainstream strategy meant no clear direction for a transformation toward CSA-based systems (Interviews 9, 13). Two strategies that directly impacted CSA (i.e., the national adaptation policy and the decarbonization plan) were formulated with a transformative vision, i.e., they aimed to phase out the conventional systems through disruptive initiatives rather than conventional regulatory measures, but mainly in principle and have not yet been implemented.

2.5.3 Unraveling the CSA policy mix characteristics

In this section, we unravel the characteristics of the evolving transformative policy mix to shed light on how coherent (2.5.3.1) and consistent (2.5.3.2) the policy mix is. This analytical logic is based on the theoretical framework (Table 2.1) in section 2.2.2; a summary is presented in Table 2.2.

2.5.3.1 Coherence

We used three key aspects to describe the coherence of the policy mix: i) internal, ii) external, and iii) temporal.

The development of the agricultural policy agenda focused on supporting conventional agriculture (export-oriented systems constituting the food regime) while promoting CSA and other alternative systems (which can be considered to a greater or lesser degree as niches). This juxtaposition led to internal contradictions – incoherence – that resulted from a lack of political capacity to challenge the status quo and pursue more radical changes that could potentially destabilize the current regime (Interview 14). From 2000 to 2006, the priority was to increase agricultural productivity and the development of agribusiness and agroindustry, neglecting environmental degradation concerns. In addition, the coherence in the alignment of goals and plans was severely affected by the unexpected changes in the governance of the MAG (five minister abdications in four years). From 2007 to 2015, the CSA-supporting policies were visible mainly at the strategic level (e.g., plans and policies) but were weakened at the operational level (e.g., projects and programs). From 2016 to 2022, CSA had two key intervention areas: adaptation and mitigation; and both interventions showed the public sector's limited implementation capacity. Two stakeholders took the lead in promoting CSA: international agencies – the primary funding source – and national corporations (Interview 21).

Besides the lack of financial resources for translating plans into action (e.g., scaling up NAMAs), we found incoherence associated with the top-down approach to promoting CSA (Interviews 14, 18). The top-down policy implementation led to a debate on extension agents' resistance to change, since the approach does not resonate with the local reality (Interview 3).

> The main concern is that what politicians say is one thing and reality is another. They do not know whether the CSA technologies they are promoting are going to work. For example, farmers are risking a lot to move toward more sustainable practices, and there are no complementary policies such as loans with favorable interest rates or support services for the farmer. (Interview 15)

Regarding the environmental domain, in the 2000s, a coherent alignment of policies and goals related to MINAE's leadership in orchestrating environmental policies (Interview 7). From 2007 to 2015, an essential role of international agreements and global alliances in MINAE's policy formulation was perceived as coherent by interviewees 1, 4, and 6. From 2018 onwards, the climate policy was integrative and holistic, integrating adaptation and mitigation instruments (MINAE, 2020). To translate goals into instruments, like in the agriculture public sector, enforcement depended on international cooperation partners; in some cases, the strategies were restructured or renamed to match the cooperant objectives (Interview 12). For example, some partners' objectives focused mainly on mitigation and others on adaptation, and extra efforts were needed to marry both. The dependence on cooperation projects influenced the continuity of the interventions, with a potential impact on temporal coherence.

In terms of external coherence, the interactions between goals and instruments in both domains changed from "very incoherent to less incoherent" (Interview 3). At national level in early 2000, the sectors had competing purposes, as conservation objectives were not coherent with agricultural expansion goals and trade liberalization policies (Interview 7). To date, efforts have been made to align sectorial targets through implementing agri-environmental agendas, emission-reduction commitments, and instruments such as NAMAs (Interviews 1, 8). Achieving synergies between the Climate Change Bureau's GHG emission reduction goals and MAG's vision of increasing agricultural production agencies was difficult (World Bank et al., 2014). However, considerable progress was made toward incorporating the CSA pillars thanks to enhanced cooperation among catalyst organizations (i.e., corporations, academia, NGOs, and private partners) that acted as intermediaries between the agriculture and environment domains.

Some transformative elements were proposed to improve external coherence, such as new governance arrangements to align objectives, joint plans, and projects that promoted transformational change in the coffee and livestock value chain; however, they were timebound and remained experimental (Interviews 6, 13). Moreover, the respondents noticed three tensions in implementing the emerging transformative features. The first relates to those key actors crucial to destabilizing unsustainable technologies who were not involved in, or invited to, the discussion meetings (e.g., actors from industry, logistics, or input suppliers) (Interview 20). Second, "inclusiveness" was stated only in the policy reports and was not perceived as inclusive by the organizations. "We [associations, cooperatives, corporations] are invited at the wrong time when the policy is formulated only to endorse the policy, and they [policymakers] claim that the private sector is involved" (Interview 15). Thus, stakeholders felt marginalized. Third, including a great diversity of actors made the meetings and workshops extremely diverse spaces with conflicting objectives and actions with the potential risk of losing efficiency (Interview 13).

Regarding the temporal aspect of coherence, three important issues came to light. First, the CSA transition could bring uncertainty to smallholder farmers' phase-out alternatives (Interview 15). The agricultural sector's dependence on foreign direct investments and transnational companies (e.g., Dole, Chiquita, Ecom) could lead to a lack of support for smallholder farmers implementing CSA practices, as regime actors took the lead in adopting CSA practices (e.g., carbon neutral coffee, private certification schemes, free pesticide rice, and NAMAs) in collaboration with government and NGOs.

Second, we observed the short-term nature of most of the CSA projects; their heavy reliance on international cooperation funds generated a gap between adaptation and mitigation initiatives that require long-term planning and implementation; transformative changes do not occur in short periods. Third, policymaking involved high levels of uncertainty in the legislative branch. As a very fragmented legislative assembly was elected in the last two government turnovers, each party could either downplay or support important issues on the agenda accordingly (Interview 8).

2.5.3.2 Consistency

The two interactions described in section 2.2.2 are used to describe the consistency of the policy mix. The first relates to the interactions between instruments, and the second relates to the interactions between the strategy and these instruments.

The data suggest an accumulation of instruments, deriving synergies, tensions and trade-offs. The instruments' consistency can be characterized as weak (Interviews 1, 20, 21). These interactions did not create conflicts or contradictions but did not intentionally encourage synergies (Interview 19). According to interviewees, synergies were not the result of the intentional implementation of instruments. Rather, the synergic dynamics resulted from the rebranding of the existing mechanisms and the alignment with the C-Neutrality goal. For example, the Organic Agriculture Program, Recognition of Environmental Services scheme, TICO-GAP standard and the amendment to the Blue Flag Program, C-Neutral certification, and Coffee NAMA are aimed to promote behavioral change toward the adoption of greener technologies and target different actors in the agricultural system (farmers, processors, retailers). However, the programs were managed by several departments within the public sector with distinct capacities, rules, proceedings, and requirements, generating a challenge to navigate between bureaucracies (e.g., higher transaction costs for the farmers and agribusiness).

From 2007 to 2015, the data show that, although the environmental policies and the agricultural policies had different rationales and their instruments were evoked primarily on mitigation, conservation, and forest protection, they managed to align – when necessary – with the agricultural policy domain so that the instruments did not contradict each other. This indicates that conditions were not optimal for inter-institutional partnerships; thus, the institutional culture encouraged individual work over collaborative efforts between policy domains.

> For example, the instruments could be better linked in the agricultural sector with water management problems and agrochemicals regulations or territorial planning. Evidently, there is a relationship, but the interventions are not formulated with synergic intentionality, and thus benefits can be maximized. (Interview 7)

From 2016 to 2022, instruments with transformative elements interacted with those formulated with other rationales (e.g., Hypatia network, organic markets), and the interaction is perceived as neutral (Interview 7). Moreover, as new instruments did not replace old ones, the projects and experiments sometimes had overlapping purposes (e.g., different public institutions developing apps with the same features). In this phase, we also observed trade-offs between instruments: soft instruments concretizing sustainable production, workshops on low-emission agricultural practices, and in parallel in-kind economic incentives such as fertilizers and pesticides were given to farmers in favor of conventional agriculture (MAG, 2022).

Regarding the consistency between the instruments and the strategy, there were no contradictions between the proposed strategies and the actions taken to achieve them at national level. "We have an ambitious NDC, with clear goals and a decarbonization plan, a national adaptation policy, which is already doing all the processes to have an adaptation plan that comes from the communities upwards, not a top-down national plan" (Interview 18). However, we observed heterogeneous consistency at different governance levels.

Table 2.2 Summary of the policy mix characteristics: Analysis of coherence, consistency.

Coherence is marked (+), incoherence is marked (-), and coherent and incoherent policies are marked (+-). Mutually supportive strategies are marked (+), and counterproductive strategies are marked (-).

Characteristic	Category	Explanation	Tensions
Coherence	Internal	Agriculture policy domain -Agricultural strategic objectives prioritize conventional agriculture -No institutional capacity to scale up NAMAs -High dependence on international cooperation to implement the climate agenda -Dependence on external financing limits the possibility of local and emerging innovations +-There is a robust legal framework for regulating and promoting organic activity, soil conservation, and sustainable practices (which may lead to overregulation of green technologies) -Attempts to change the governance of the public agricultural sector, but actors in the system resist Environment policy domain +Reforms in the institutional framework have allowed it to adapt and formulate strategies according to the country's commitments +Leadership in climate change, forestry regulations, and coherent mechanisms to help meet the country's goal toward C-Neutrality -Strong focus on mitigation, leaving aside adaptation policies +Spillovers of conservation and mitigation strategy into other sectors (agriculture and tourism)	Competing paradigms of agricultural production and climate action Tensions in temporal coherence, given the short-term nature of funding Resistance to change inhibits the effects of transformative features No institutional change to support the transformations The transformative policy entails the inclusion of new actors responsible for strategy development, thereby helping to catalyze cross-domain interactions Instability in government changes inhibits long-term policy development Important niche–regime interactions
	External	-Differences between coherence as stated in the policy documents and practice -In the early stages (1998–2000), the implementation of biodiversity and conservation policies went against the objectives of the agricultural sector (competing objectives) -The country's development model changed from an agri-export dependent model to a service-sector-dependent economy and has changed policy attention +Policies formulated under a vision of transformational change include collaborating with other policy domains +Transversal societal challenges incorporated in both domains: development goals from the Millennium Development Goals to Sustainable Development Goals	
	Temporal	-Strong strategic capacity over time thanks to the leading role of one policy domain -Uncertainty about the phase-out alternatives given the pressure of transnational companies +-Agricultural sector is highly dependent on FDI, and corporations (e.g., Dole, Chiquita) are involved in policy formulation of NAMAs and implement other voluntary sustainability standards (RainForest, Global GAP) and national standards (free of pesticides standard, carbon neutral)	

Table 2.2 Continued

Characteristic	Category	Explanation	Tensions
Consistency	Instrument: Synergies	+Public–private interactions: Loans for renewal of coffee plantations with climate-adapted varieties and incorporated discounts if adaption and GHG reduction technologies were adopted +NAMA project-coffee processors and DBS +-National coffee and financing policy, i.e., two complementary policies, favor sustainable technologies	No culture of reflexive evaluation Limited room for improvement as no mechanisms for policy learning are in place Institutional culture rewards individual work rather than collaborative efforts among ministries No balance between intentional vs. unintentional transformative developments Transformative elements are emerging and promoted by cooperation funds
	Instrument: Neutral interaction	+-The initiatives are in place with overlapping purposes (e.g., National Coffee Institute launches an app, but the cooperatives are also working on their own app) +-There is no integration between the institution's interventions +-Within the same institution, there is no clear direction to operationalize the intervention; for example, the app is launched, but it is not integrated between departments	
	Instrument: Trade-off	-National level: no culture of knowledge sharing and exchange; e.g., climate information -In-kind economic incentives from public institutions in favor of conventional agriculture (e.g., donation of pesticides)	
	Strategy and Instrument	-Contradictions at different governance levels +The policies and instruments promoting CSA are in an early stage of policy implementation (immature stage as a niche) +The carbon neutral program aligned with agricultural policies (RESB in the agricultural sector), agribusiness category to PBE, and modifying organizations category to the carbon-neutral category	

2.5.4 Climate-smart policy mix context

As is clear from the previous sections, there are several influences from the broader policy context. This plays out in different dimensions: spatial (national and international influences), sociotechnical (regime), and temporal (long-term versus short-term action).

In the spatial dimension, the sociopolitical context of Costa Rica's reliance on international cooperation funds and foreign direct investment influenced CSA development (e.g., transnational companies lobbying and powerful relations in the policy agenda). Regarding the former, the lack of financial resources and fragmented governance limited the state's capacity to upscale pilot projects and experiments focused on promoting CSA technologies, leading to solid linkages with/dependencies on international development agencies for policy implementation. International partners provided policy support, financial support, institutional capacity building, and technical assistance, thus, shaping the policy outcomes. As for the latter, interdependency on foreign direct investment (e.g., employment opportunities, economic development) lead to state interventions merely focused on fostering eco-efficiency and demonstrating the effectiveness of adaptation practices and low-emission technologies, since banning and regulating detrimental agricultural practices (e.g., intensive use of agrochemicals, water pollution) is highly contested given the power dynamics between the agroindustry and the state (Interviews 1, 2, 11). In terms of the sociotechnical system, the embeddedness of food-regime actors in policymaking inhibited laws prohibiting unsustainable technologies to discourage unsustainable practices.

Regarding the temporal dimension, although the Costa Rica political system is a stable democracy, CSA developed within an ambivalence between pursuing ambitious long-term targets and policy discontinuity. The former relates to integrating international agreements as a mechanism for proposing direction and setting long-term goals, thereby functioning as an effective tool for legitimizing climate action and proposing ambitious targets such as decarbonization by 2050 (Interview 3). In theory, the guidelines operated as a guiding framework; in practice however, the four-yearly government changes redirected public investment priorities (e.g., allocating smaller budgets to pilot programs, pausing infrastructure developments). Thus, initiatives adopted by a government were discontinued in the following four years, causing instability and weakness in the state apparatus.

Moreover, the policy developments (types and how policies are formulated) led to an excessive accumulation of decrees without fundamentally restructuring or replacing the existing ones. This inertia was caused by new instruments formulated through a fragmented and unreliable legislative apparatus (Interview 8). Decrees were sent for presidential endorsement without proper consultation, with the argument of "being issued in exceptional circumstances, i.e., in the public interest."

> We should take the five laws we have and make them new, proposing a new vision, but people are afraid of the policy outcomes from the Legislative Assembly. For example, if we start the discussion, we might open a black-hole and vested interest might favor environmental deterioration and we might suddenly reverse the progress. (Interview 2)

2.5.5 Policy coordination

Most interviewees appraised CSA policy development as a top-down approach steered mainly by international organizations (e.g., IICA, FAO, and GIZ), MAG, and the Ministry of Environment, with inputs from a plethora of national actors, including universities, research centers, and farmer cooperatives. Policy implementation was highly dependent on international cooperation funds (Interview 3). This led to challenges in implementing CSA, especially in coordination between the international, national, and local level (Interviews 7,16, 19). Coordination tools were visible mainly at the political and the strategic level but were weakened at the operational level. As respondents indicated, there was a gap between the coordination instruments from the environmental and agricultural domains and the coordination perceived by the interviewees (Interviews 1, 7, 12, 18). The main limitation was that, it was considered adequate to merely create coordination mechanisms (e.g., secretariats, steering committees, and councils) by decree. Therefore, providing formal instruments did not involve effective interactions between actors.

Coordination tensions emerged because of the complex governance arrangements in the agricultural public domain. The public agricultural sector and its institutional framework are governed by hundreds of laws and ministerial decrees, making effective governance difficult. Law 8787, on the organization of the public agricultural sector, provides the formal mechanisms to guarantee coordinated action between the regions and the strategic decisions taken at political level (e.g., Regional Sectorial Committee of the agricultural sector) and at local level (e.g., Local Sectorial Committeee of the Agricultural sector). However, communication and coordination between the national and local levels often relied on who was responsible for coordinating, thus changing from region to region (Interviews 7, 13, 20).

2.6 Discussion

In this paper, we aimed to contribute to the debate on transformative policy mixes by showing the developments of transformative policy mixes in practice and by identifying key features of a transformative policy mix that positively or negatively reinforce one another to promote the intended change. We asked three questions: i) how have the CSA policy mix elements evolved?; ii) how do directionality, consistency, and coherence characterize the policy mix over time?; and iii) how does the Costa Rican context influence CSA policy mix dynamics? In the following sections, we first discuss the main findings from the Costa Rican context, then elaborate on broad contributions to the literature on transformative policy mixes, and finally, reflect on limitations and future research.

2.6.1 Costa Rican CSA policy: a transformative policy mix in the making or stifled by inertia?

Our findings highlight a complex policy mix that theoretically has several elements of a transformative policy mix, in which some policy elements were newly introduced, and sometimes existing strategies were repurposed. Although there was strong directionality, with clear targets and long-term strategies – showing an ambitious direction – this was undone through a less coordinated policy formulation and implementation approach. Our study revealed that the Costa Rican CSA policy mix can be described as incoherent (internally and externally) and shows weak consistency, as no synergies between policy instruments were induced purposefully to achieve transformative outcomes. In the last phase (2016–2022), transformative elements were more evident than in the previous two strategic phases (2000–2006 and 2007–2015), but these were inhibited by weak implementation capacity and internal and external incoherence between sectors and governance levels.

In most phases, there was no indication of a conscious evaluation of synergies or tensions resulting from instrument interactions, so, in a sense, Costa Rica's CSA policy is a transformative policy mix in the making but, in practice, it has not come fully to fruition because of fragmentation and a lack of policy coordination and policy legacies (echoing Diercks, 2019, and Grillitsch et al., 2019) but rather leads to inertia. Throughout the evolution of the CSA policy mix, the instrument mix developed through layering (new C-Neutrality goals with new instruments without removing the old ones), drifting (a rebranding of the C-Neutrality goal without replacing the instruments aimed at conservation), and conversion (a rebranding of the goal of decarbonizing the economy and modifying the instruments). There was no evidence of replacement processes (e.g., phasing out instruments and strategies) or careful integration of new instruments.

Regarding the sorts of instruments in terms of niche support and regime destabilization, there appeared to be more niche support strategies (e.g., voluntary carbon-neutral standard, incubator programs with low-emission and adaptation indicators, FabLabs, and agroclimatic scientific roundtables) than regime destabilization efforts (e.g., agrochemical use decree). One reason for this could be that many participants and influencers in policy arenas were food-regime actors, such as transnational agribusiness, policymakers, cooperatives, and national corporations. Moreover, regime actors were strongly embedded, as pointed out in the case of the agrifood sector and Global South transitions (Conti et al., 2021; U. Hansen & Nygaard, 2013; Ingram, 2018; McMichael, 2009; Nygaard & Bolwig, 2017). Nonetheless, a more consistent driver of change came from corporations and cooperatives, integrated into global value chains, that opted to support sustainability transformations (e.g., carbon neutral coffee, certification schemes, free pesticide rice standard, and NAMAs) in collaboration with the government and NGOs – echoing earlier observations of Grabs and Carodenuto (2021), van Oers et al. (2021), and Vilas-Boas et al. (2022). Beyond showing the roles of incumbent food-regime actors in this transition (see also Turnheim and Sovacool, 2019) these findings also demonstrate that the policy arena for (potentially) transformative policies is not only national, and in our case, confined to Costa Rica. This supports Wieczorek's (2018) suggestion that more attention should be paid to these transnational links.

Our findings also show how the Costa Rican context influenced policy developments. Although directionality-shaping-oriented exercises (such as vision creation) provided a sense of purpose and long-term planning, the guiding effect was counteracted by discontinuity caused by radical political changes. This undermined the effectiveness of CSA initiatives and weakened the state's ability to address climate change in a consistent and sustained manner, exercising effective roles as promoter, moderator, initiator, and guarantor of change (as defined by Borrás and Edler, 2020). It is therefore essential for a country to have institutional mechanisms that ensure continuity and coherence in agricultural and climate policies across different administrations. Other features of the Costa Rican sociopolitical context that negatively impacted policy coherence and consistency relate mainly to policy legacies, fragmented legislative apparatus, lack of resources for policy implementation, distrust amongst ministry employees, and extension agents' resistance to change.

2.6.2 Contributions to the transformative policy mix literature

Our analysis makes three broad contributions to the literature on transformative policy mixes. First, our analysis of policy development revealed that emerging instruments with transformative intentions interacted with existing instruments focused on classic rationales. We argue that including instruments with a transformative intention, but without removing or restructuring current policies, led to a great deal of layering, drifting, and conversion of instruments and goals, creating in an extreme case what could be called policy pandemonium. In this sense, our findings align with those of Diercks et al. (2019) and Molas-Gallart et al. (2021); but we add to this earlier work on transformative policy the finding that good intentions toward transformative policies may paradoxically thwart transformative elements. This is because layering, drifting, and conversion in the evolving policy mix may in some cases lead to a neutralization phenomenon, in which the complexity of the policy instrument mix resulting from policy legacies counteracts the transformative instruments. Such policy pandemonium thus stifles efforts to create a consistent and comprehensive but also balanced transformative policy mix. This echoes the need not only for policy learning and reflexive evaluation (Ghosh et al., 2021a; Kern et al., 2017), but also for such learning and reflexivity to lead to a certain degree of policy *unlearning* or *undoing*, phasing out legacy policies that lead to neutralization. A broader question is, however, whether such processes can be fully plannable and to what extent the complex interdependence between instruments can be easily addressed, as they play out across so many levels.

Second, our analysis confirms the usefulness of employing the lens of policy mix characteristics to engage in policy mix diagnosis, signaling synergies and tensions and creating clarity on when layering, drifting, and conversion become counterproductive. Policy mixes can create synergies between instruments, thereby logically contributing positively to transformative change (e.g., the C-Neutrality public and private platform in our case). At the same time, they often contain tensions between instruments in terms of instruments creating confusion (e.g., excessive layering) or not reinforcing one another. Here, we add to previous work on policy mixes (Bodas Freitas, 2020; Greco et al., 2020; Mavrot et al., 2019; Rogge & Reichardt, 2016) by arguing that tensions are not just negative or act only as inhibitors. Our analysis shows that tensions can also have positive effects and become catalyzers. One observed tension and inhibitor is vagueness in the translation of ambitious directionality, i.e., good intentions not resulting in clear action (see section 5.1.2), echoing findings by Scordato et al. (2021) that transformative rationales are often translated vaguely from the strategy to the instrument mix, i.e., weak overall consistency. Our analysis also shows that vagueness may have a paralyzing effect, resulting in less substantial changes in the policy mix. There is also the risk of neutralization effects in the case of a policy pandemonium situation as described in the previous paragraph. A catalyzing effect can be achieved by including a diversity of actors in the policymaking process, where an open space for contestation is observed, mediated by several intermediaries (in our case, NGOs, financing institutions, research clusters, and international cooperants). They facilitate interaction between actors in the agricultural and environmental domains and propose actions that materialize in concrete CSA implementation. This indicates that intermediaries, whose importance has been shown in the practical facilitation of transitions (Kivimaa et al., 2019), also play a prominent role in transformative policymaking (echoing Ghosh et al., 2021a). Hence, we argue that successfully integrating transformative features in an existing instrument mix requires evaluation of catalyzers' and inhibitors' degree or intensity between scales and governance levels in the policy mix. Beyond scientific analysis, this could be part of continuous policy (un)learning (Borrás, 2011).

Third, like in many other Global South countries, the findings on the temporal and the spatial context and diversity of actors – fulfilling some functions that the state does not perform – have relevance for debates on transformative policies. As our analysis indicates, beyond being public-sector driven, they are also private and third-sector driven (see also Klerkx and Begemann, 2020). However, the role of the private and the third sector also brings tensions, such as i) short-term orientation of projects and programs, ii) mismatch of intervention priorities (projects oriented toward low-emission technologies while ignoring countries' adaptation priorities), iii) the top-down approach limits the possibility of experimentation, iv) some technological solutions promoted do not necessarily work in the local context or then need to be adapted. The contested nature of CSA, being promoted as a top-down approach and a generic concept, makes the operationalization and measurement of CSA policies challenging; we argue that more context-specific interventions are needed to promote the intertwined purpose of CSA policies. Globalized transformative policies (as concepts such as CSA are implemented worldwide) thus require attention to be paid to spatial dimensions, cultural and institutional context specificity, and perhaps also links to decolonization debates (Ghosh, Ramos-Mejía, et al., 2021; Pfotenhauer & Jasanoff, 2017).

2.6.3 Limitations and future research

A limitation of our study is that it was a single case study where the policy mix characteristics were analyzed without including an evaluation of the policy mix in terms of efficiency, effectiveness, and feasibility. Also, accounting for scale interactions of a transformative policy mix at national and international level can easily become overwhelming. We acknowledge that our study could not identify the intensity of the spatial influence in the transformative policy mix. Therefore, developing strategies for cross-scale analysis would need considerable attention and could benefit the strand of spatial analysis of sustainability transitions (Binz et al., 2020; Coenen et al., 2012; T. Hansen & Coenen, 2015).

The lack of conscious evaluation of instrument interactions suggests a need for a more systematic approach to policy development and implementation. Whether and how policymakers can find a way to balance efficiently the emerging transformative features with existing and established policy rationales remains an open question. Our study evidenced the need for more careful integration of new instruments with potential transformative features and further evaluation of those interactions (e.g., the degree or intensity of catalyzers or inhibitors). Future research could investigate whether those developments are likely to unfold similarly in a Global South and a Global North context, for which work on political cultures (e.g., Pfotenhauer and Jasanoff, 2017) could be helpful. Identifying challenges, tensions, and context-specific situations could benefit the stronger incorporation of policy process theories using institutional analysis (Edmondson et al., 2019; Gomel & Rogge, 2020a) to uncover the dynamics of the emerging transformative policy.

2.7 Conclusion

This paper has addressed a gap in the literature by analyzing transformative policy mixes in the context of agriculture and the Global South. Using a transformative policy mix analytical framework helped unravel the tensions, dynamism, and evolution of Costa Rican CSA policies, which were found to be both internally and externally incoherent and inconsistent. Because of the embeddedness of food-regime actors, the unbalanced transformative policy instrument mix focused mainly on supporting niches rather than destabilizing the regime. Regarding the transformative elements (directionality, balanced policy mixes, and coordination), our findings showed that, although providing direction, ambitious goals, and setting long-term targets gave a sense of purpose, the vagueness in translating goals into concrete actions undermined the intended change. Some newly introduced policy elements contributed to a transformative policy mix, but layering, drifting, and conversion of existing policies might paradoxically thwart these transformative elements and, in an extreme case, could lead to policy pandemonium. Such a situation can cause a neutralization phenomenon that renders transformative policy instruments ineffective. The main implication for theory and practice is that, if transformative policy mixes are desired, better scrutiny is needed both on the balance of the mix and on how to fundamentally transform the mix. This includes more attention on the phasing out of legacy policy instruments, going beyond policy learning and instigating policy unlearning or undoing, and on how particular countries' institutional contexts and policy cultures influence transformative policymaking and implementation.

CHAPTER 3

3

What determines the acceptance of Climate Smart Technologies? The influence of farmers' behavioral drivers in connection with the policy environment

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Abstract

Context: Climate-smart agriculture (CSA) aims to address climate change, climate variability, and food security while sustaining productivity. The literature on acceptance and adoption of CSA technologies recognizes the importance of the policy environment in shaping farmers' decisions, particularly the policy mix, including economic, regulatory, and information instruments to stimulate CSA acceptance. Behavioral models have been used to better explain CSA acceptance, however, only a few studies integrate farmers' behavioral drivers and their policy mix appraisal, which in combination, are important determinants for the successful acceptance of CSA.

Objective: This paper proposes a model that integrates behavioral drivers and policy mix appraisal influencing the acceptance of CSA technologies. We aim to examine how farmers' behavioral drivers and their appraisal of the policy environment influence the acceptance of CSA technologies and practices.

Methods: We studied the Costa Rican coffee sector and conducted 523 surveys with coffee farmers and two focus groups with experts, extension agents, and cooperatives. An ordered probit model was used to identify factors explaining CSA acceptance.

Results and conclusions: The results indicate that besides the influence of behavioral drivers, policy consistency and comprehensiveness and the type of instrument targeting farmers' behaviors play an important role in explaining CSA acceptance. Our results suggest that a positive appraisal of policy consistency and comprehensiveness are important for increasing farmers' acceptance of CSA and sustainable practices, which nuances earlier thinking on "policy packages" by showing that the farmer's appraisal of the overall policy mix is, to some extent shape their decisions to engage with CSA.

Significance: Our study shows the importance of considering system context effects (policy environment) on farmers' decision-making. Since the integration of behavioral drivers and the appraisal of the policy mix characteristics is relatively underexplored for CSA, our empirical results may help to unravel farmers' decision-making processes. Thus, it can be used for rethinking and adjusting policy interventions toward more balanced and comprehensive policy mixes, as it enables feedback from policy implementation and can further induce policy learning.

3.1 Introduction

It has become increasingly questioned whether traditional farming systems can sustainably ensure food security due to the challenges imposed by climate change (IPCC, 2022). To integrate coping with climate change and climate variability into farming practice, simultaneously meeting the need to adapt and reduce greenhouse gases (GHG), many countries have launched policies and strategies to promote the adoption of Climate Smart Agriculture (CSA) (Campbell et al., 2014; Thornton, Rosenstock, et al., 2018). The CSA umbrella approach provides an opportunity to transform current farming systems by adopting a set of practices and technologies such as agroforestry, organic, agroecology, sustainable intensification, and water and soil conservation that might bring climate resilience while reducing the negative impacts on the environment (Chandra et al., 2018; Mwongera et al., 2017; Sain et al., 2017). The transformation from traditional farming systems towards a CSA-based farming system requires changes ranging from adjusted farming practices and adoption of new technologies at the farm level to changes at the broader system level (Shang et al., 2021; Westermann et al., 2018). These changes can be induced via the value chain through which corporate sustainability policies are enacted but also via the public policy environment (Faling & Biesbroek, 2019; T. D. G. Hermans et al., 2021).

At the farm level, CSA acceptance, defined here as the process that reflects to what extent farmers are willing to use new technology (Venkatesh et al., 2003) leading to adoption (adoption is, however, not assessed in this study), has been widely explored, and the focus has mostly been exploring on-farm variables, socio-economics and farm plot features (Autio et al., 2021; Notenbaert et al., 2017; Sun et al., 2018; Thornton, Whitbread, et al., 2018; Zizinga et al., 2022). More recently, studies on CSA have pointed out the importance of incorporating psychological drivers in explaining CSA acceptance (Abadi et al., 2020; Hochman et al., 2017). Nonetheless, little attention has been paid to studying how farmers' attitudes toward CSA and their behaviors regarding CSA explain their willingness to accept CSA technologies (Kangogo et al., 2021; Khoza et al., 2019).

In the policy environment, enabling policies to promote CSA includes supportive governance and providing incentives and resources for incentivizing farmers' sustainable behavior (Dessart et al., 2019; Makate, 2019b). It has been argued that supporting CSA calls for a combination of policy interventions, i.e., a so-called *CSA policy mix*[10] to stimulate farmer behavioral change, as it requires a full array of instruments working

10 Based on the definition of policy mixes provided by Kern and Howlett (2009, p. 395), the policy mix includes complex arrangements of multiple goals and instruments (e.g., regulations, economic incentives, information, or voluntary and systemic) developed incrementally over the years. In this paper we refer to policy mixes as the combination of instruments and strategies in place toward achieving CSA based farming system.

together to facilitate CSA acceptance (Scherer & Verburg, 2017; Scherr et al., 2012). A CSA policy mix combines economic, regulatory, and information instruments. These may be mandatory and voluntary or public and private, such as technical assistance, laws, standards, voluntary schemes, and payment for alternative environmental services (Vaast et al., 2016), a combination that makes implementing the CSA policy mix challenging. While the literature on CSA recognizes the importance of the policy mix in shaping farmers' decisions and facilitating behavioral change (Gardezi et al., 2022; Hermans et al., 2021), it often sticks to evaluating one single policy instrument and generally does not go deeply into how the overall evaluation of the policy mix shapes farmers' decisions (Scherer and Verburg, 2017; Thornton et al., 2018a). To our knowledge, farmers' policy appraisals have been mostly addressed on one single policy instrument (e.g., land rental policy)(Ariti et al., 2018; Tatsvarei et al., 2018) or qualitative (Honig et al., 2015) without recognizing that in practice, policy mixes are in place to influence farmers behavioral change toward more sustainable farming systems (Makate, 2019b).

This article aims to bridge the gap between individual behavioral and system-oriented studies on CSA acceptance by recognizing the mutual relation of the individual and the policy environment (policies, regulations, knowledge services) in which the farm operates (Engler et al., 2019; Shang et al., 2021). We deem this focus important since policies and farmer behavior do not have static and one-way relationships (i.e., policy results in an outcome). The two interact and reshape each other, opening a space for constant feedback (Engler et al., 2019; Kernecker et al., 2021; Kuntosch & König, 2018). The policy mix aims to influence farm management (Kuehne et al., 2017; D. J. Pannell & Claassen, 2020) and determines to some extent, the "rules of the game" by which farmers operate in terms of knowledge services, regulations, and incentives (Makate, 2019). Farmers' appraisal of the policy mix elements, e.g., trust/distrust or positive/negative perceptions of the instruments and policy strategies, influences the acceptance of such regulations, and incentives, which in turn influences the acceptance of new technologies[11] (Kuntosch & König, 2018). The study examines how more traditional behavioral drivers (e.g., social norms, facilitating conditions) and sociodemographic determinants (e.g., age, education, gender) and farmers' CSA policy mix appraisal explain farmers' acceptance of CSA technologies.

A deeper understanding of farmers' decisions is critical for designing and implementing environmental and agricultural policies (Pannell & Zilberman, 2020). We argue that including farmers' appraisal of the policy, mix may help design effective policy mixes (e.g., policy strategies and complementary instruments) to redress trade-offs and harness synergies amongst CSA's multiple objectives. Since the literature on CSA

11 Technologies are seen here both as novel practices and novel artefacts (e.g. machinery, inputs, apps)

mainly focuses on explaining acceptance by using on-farm variables and only recently has incorporated behavioral variables, cross-fertilizing behavioral science with other conceptual lenses (in this case using policy mixes for sustainability transitions literature, see section 3.3.2) is likely to have more significant explanatory potential. It allows us to move beyond individual-related drivers and account for the embeddedness of the individual and the policy environment as it enables a better depiction of contextual effects on farmers' decision-making (Streletskaya et al., 2020).

We use the Costa Rican coffee sector as our setting since, despite the efforts of the state and private stakeholders in scaling up CSA technologies, in 2014, the World Bank determined that a small percentage of coffee producers were implementing these practices. Moreover, the coffee sector is facing significant challenges from climate change as reducing yields and quality, increasing pest and disease outbreaks, and changing the suitability of areas for coffee growing (Baca et al., 2014; Bouroncle et al., 2017; Bunn et al., 2015). To tackle such challenges, policy instruments have been formulated to provide the conditions to transform coffee production towards a low-carbon and climate-adapted system. The policy mix includes public and private instruments such as Nationally Appropriate Mitigation Actions (NAMA), Payment for Environmental Services in the Agricultural Sector (RES), sustainability standards[12], a blue flag certification program, and tax exemption for organic producers aimed at motivating farmers' behavioral change. However, it is currently unclear under which conditions these policy elements work out and if they are associated with a higher or lower acceptance of CSA technologies. While our study concerns Costa Rica, our insights provide theoretical and policy implications relevant to other regions and countries interested in promoting sustainable agricultural technologies to effectively manage private land natural resources.

The paper is organized as follows. In Section 3.2 we present the theoretical framework and review behavioral drivers and the policy mix appraisals. Section 3.3 presents the data collection methods and explains the case study and the measures. In section 3.4 we present the results. Section 3.5 presents the discussion and conclusion of the paper.

3.2 Farmers' behavioral drivers and the policy environment

Unpacking behavioral variables driving farmers' decision-making related to sustainable practices is key to improving the effectiveness of agricultural and environmental policies (Autio et al., 2021) by addressing and spotting barriers that potentially

12 Also known as eco-labelling or eco-certification defined in this paper as voluntary rules that supply chain actors may follow to demonstrate their commitment to environmental protection and/or social welfare (Meemken et al., 2021).

influence the acceptance or rejection of the technology (Gazheli et al., 2015). Several theories and models have been developed to explain better individual behaviors in accepting new technologies (Schaak & Mußhoff, 2018).

Scholars have used, adapted, and extended well-established models from the field of psychology to explain farmers' decisions toward more sustainable practices. For example, Jorgensen & Martin, (2015) used the Theory of Reasoned Action (TRA) to understand farmers' intentions to use irrigation systems; the Theory of Planned Behavior (TPB) was applied to explain conservation behavior (Lalani et al., 2016) as well as CSA (Faisal et al., 2020). The Technology Acceptance Model (TAM) was adapted by Khoza et al., (2021), to the context of CSA. The Unified Theory of Acceptance and Use of Technology (UTAUT) incorporates several elements of the aforementioned models and has been used to determine the main factors affecting the acceptance of new technologies (Beza et al., 2018; Faridi et al., 2020b; Schaak & Mußhoff, 2018).

UTAUT is commonly used to predict and explain individual behaviors toward accepting new technologies. UTAUT has shown a higher explanatory potential in comparison with other models (e.g., TBP, TAM, TRA) (Venkatesh et al., 2003) and has also been adapted to agricultural studies to explain farmers' decisions engaging with new technologies and practices, as precision agriculture (Liang, 2012), smart farming (Ronaghi & Forouharfar, 2020), soil, and water management, conservation technologies (Faridi et al., 2020b), and mobile SMS technology acceptance (Beza et al., 2018). Given its comprehensiveness and predictive power, we used the UTAUT model from (Venkatesh et al., 2003) as a basis.

To better understand farmers' decisions toward accepting CSA technologies, we extended the UTAUT model with three behavioral constructs: perceived climate risk, perceived cost, and policy mix appraisal. The additional constructs were added since they help understand the underlying behavioral factors influencing farmers' acceptance of CSA (Faridi et al., 2020b; T. Zhou et al., 2010). Extending the model offers broader insights into farmers' behaviors since i) climate change perceptions are shown to influence behavioral change (i.e., farmers with higher beliefs in climate and perceived risk have higher support of adaptation and mitigation practices) (Arbuckle et al., 2015); ii) high implementation cost is the most limiting barrier for acceptance and further adoption of CSA (Fusco et al., 2020; Long et al., 2016; McCarthy et al., 2018) , including farmers perceived cost accounts a greater understanding of farmers barriers which are important for a higher acceptance of CSA; iii) relating policy mix appraisal with technology acceptance recognizes that technology development and farmer's motivation are not sufficient to stimulate the acceptance which acknowledges the complexity of farmers decision making (Zougmoré et al., 2019).

The theoretical definition of each of the components used in the model is displayed in Figure 3.1, and in subsection 3.2.1 we explain the behavioral drivers, and in subsection 3.2.2, the drivers emanating from the policy environment.

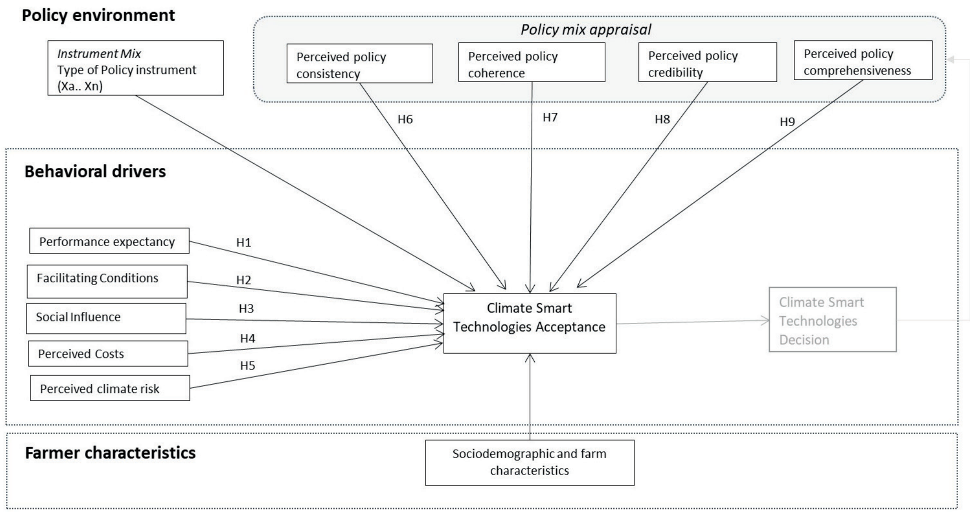

Figure 3.1 Theoretical model[13]

3.2.1 Behavioral drivers on technology acceptance

In our model, we postulate the following behavioral constructs to determine CSA acceptance: i) performance expectancy, iii) social influence, iv) facilitating conditions v) perceived climate risk, and vi) perceived cost.

Performance expectancy (PE) is the degree to which an individual believes that using a system will help to attain better job performance (Venkatesh et al., 2003, p. 447). According to Venkatesh et al. (2003) PE is the stronger predictor of acceptance and remains significant at all measurement points. Beza et al. (2018) and Rose et al. (2016) findings showed that performance expectancy positively, significantly, and without moderators affects the intention to use new technologies. In the literature of CSA, technologies such as weather forecast apps or the use of improved/tolerant varieties are expected to help the farmer increase his/her productivity but also increase his/her

13 The link between Climate Smart Technologies Acceptance and the decision(use) is grey colored. We recognized a direct link between acceptance and the final decision on using CSA; however, studying the relation between acceptance and use is out of the scope of this paper.

resilience which is recognized as one the attractive elements for farmers (Amadu et al., 2020). Thus, the positive expectation about the technologies affects their intention positively (Giua et al., 2022). On this basis following hypothesis is tested:

Hypothesis 1 (H1). Performance expectancy is positively related to farmers' acceptance of CSA technologies.

Facilitating conditions (FC) "defined as the degree to which an individual believes that an organizational and technical infrastructure exists to support the use of the system" (Venkatesh et al., 2003, p. 453). Using CSA technologies require financial resources, but some are classified as knowledge-intensive technologies requiring organizational support (Kangogo et al., 2021). Our research hypothesizes that farmers with access to a good set of facilitating conditions, such as support from experts (e.g., extension agents) and the necessary resources to implement CSA, will have a greater acceptance of CSA technologies and practices. Venkatesh et al., (2003) have hypothesized that FC is non-significant due to the effect being captured by effort expectancy and PE (also supported by Liang, 2012). However, others have shown that organizational support increases the possibility of using the new technology (Ronaghi & Forouharfar, 2020) .

Hypothesis 2 (H2). Facilitating Conditions is positively related to farmers' acceptance of CSA technologies.

Social influence (SI) is defined as the degree to which an individual perceives that important others believe he/she should use the new system (Venkatesh et al., 2003, p. 451). The underlying assumption is that individuals tend to refer to their social network, especially friends and family, about new technologies and can be influenced by the perceived social pressure of significant others. Ronaghi & Forouharfar, (2020) have found a statistically significant and positive impact of SI on farmers' willingness to use smart farming technologies. In our research context, we hypothesize

Hypothesis 3 (H3). Social influence is positively related to the acceptance of CSA technologies.

Perceived cost (PC) refers to the user's perception of the financial costs of adopting a new technology (Shafinah et al., 2013). Faridi et al. (2020) showed significant evidence that relates negatively to the perceived cost and paddy farmers' willingness to adopt water and soil conservation measures. In this study, the perceived cost is defined as all the material (e.g., financial, time-related) and social costs that the coffee farmer believes will be incurred by adopting CSA practices.

Hypothesis 4 (H4). Perceived cost is negatively related to farmers' acceptance of CSA technologies.

Perceived climate risk (PCR) research has shown that perceived risk is one of the major and important determinants of the acceptance of new technologies (Poortvliet et al., 2018). Faridi et al., (2020) found that the higher the perceived risk associated with adopting water and soil conservation measures, the greater the willingness to adopt conservation measures. Furthermore, it has been studied that risk and benefit perceptions are crucial in the successful development of technical innovations (Poortvliet et al., 2018). We followed van der Linden (2015) in their proposed climate risk perception variables. van der Linden, (2015) confirmed that knowledge about the i)causes, ii) impacts and iii) responses to climate change are all positively and significantly related to holistic risk perceptions of climate change. Similarly, Arbuckle et al. (2015) found a positive relation between climate change beliefs and the use of adaptation practices.

Hypothesis 5 (H5). Perceived climate risk is positively related the farmers' acceptance of CSA technologies.

Climate Smart Technologies Acceptance refers to "the possibility that a person may engage in certain behaviors in the future under certain conditions and do something" (Venkatesh et al., 2003, p. 456), and it is often related to the use of the technology. In this study, we referred to acceptance as the willingness of the coffee farmer to use or keep using climate-smart technologies in the future.

3.2.2 Policy environment: Appraisal of the policy mix

It is increasingly recognized that behavioral change is not likely to happen with one policy intervention but with a policy mix (OECD, 2019; Rogge, 2018) , and this has also been noted for CSA (Scherer & Verburg, 2017). The rationale of the policy mix incentivizing CSA encompasses public policy instruments set by the government and private-led instruments[14] (e.g., sustainability standards) (Makate, 2019b). We followed Bemelmans-Videc et al., (1998) instruments typology to illustrate the CSA instrument mix: i) economic instruments are tools providing beneficiaries support in cash or kind (e.g., compensations for environmental services, agricultural inputs); ii) information instruments attempt to influence people through communication, reasoned argument and persuasion (e.g., advisory services, research on new crop

14 Private-led instruments as sustainability standards, are also recognized in the literature as market-based policy instruments due to their reliance on price signals and other economic incentives to modify behavior (Lambin et al., 2014, p. 130).

varieties); iii) regulatory instruments are rules and directives obligatory in nature (e.g., regulation on the use of pesticides).

Appraisal of policies influences farmers' actions and behaviors toward a new technology (Pannell & Claassen, 2020). Farmers' appraisals are recognized as social constructs influenced by personal experiences, trust in institutions, and the type of instrument implemented, and they can result in a wide variety of decisions among them (Tatsvarei et al., 2018). Thus, understanding farmers' appraisals can enable better feedback to adjust purposively policies and redirect policy programs according to farmers' needs and preferences (Schaafsma et al., 2019) (e.g., targeting farmers that may be less willing to use new CSA technologies).

The role of the policy mix in technological change has been explored empirically, mainly through qualitative studies and has pointed out the importance of policy mix characteristics such as consistency, coherence, credibility, and comprehensiveness for technology adoption (Magro & Wilson, 2019). We adapted the conceptualization of the policy mix characteristics developed by Rogge & Schleich (2018) to better understand the link between policy mix characteristics and farmers' acceptance of CSA technologies.

The literature suggests that a higher degree of *consistency* (CON) makes policy mixes more effective (Howlett & Rayner, 2013). Consistency is defined as "how well the elements of the policy mix are aligned with each other, thereby contributing to the achievement of policy objectives" (Rogge & Reichardt, 2016, p. 1626). Hence consistency is a descriptor of the policy mix expressed in terms of the strategy and the instruments' synergies or contradictions (e.g., instruments aligned with the strategy). For example, the joint implementation of economic payments for environmental services and carbon-neutral standards makes mitigation practices more appealing for the farmers, thereby motivating the adoption of mitigation-related CSA technologies (World Bank et al., 2014). We related the perceived policy consistency with CSA acceptance, and we distinguish two levels: first, in terms of how farmers perceive the alignment and support of the instrument mix to foster the acceptance of CSA technologies, and second capturing farmers' appraisal of the alignment between the instrument mix and the strategy in terms of if the instruments work together or undermine each other. These lead us to hypothesize a positive link between consistency and CSA technology acceptance.

Hypothesis 6 (H6). The perceived consistency of policy mixes is positively related to farmers' acceptance of CSA technologies.

The second characteristic is related to the *coherence (COH)* of policy processes and is defined as "synergistic and systematic policymaking and implementation processes" (Rogge & Reichardt, 2016, p. 1626). It captures whether the government constantly adjusts the policy mixes to address emerging obstacles (Rogge & Schleich, 2018) and brings in a complementary mix of economic, regulatory, and information policy instruments. Qualitative studies have shown that coherence is key to improving the efficiency of the policy mix (Kivimaa & Virkamäki, 2013) by enabling the conditions for the achievement of the policy goals (e.g., higher adoption of CSA practices and technologies)(Muscat et al., 2021). In our case, we explore coherence in terms of farmers' perceptions of the policy mix adjustments and whether the policymakers spot and recognize the problems related with CSA technologies and practices on time. Suggesting that if obstacles are spotted, changes and adjustments in the policy implementation can be promoted (Kanda et al., 2022). Accordingly, such changes can eliminate barriers to acceptance of, on the contrary, create barriers to further development. Based on the positive link between coherence and policy effectiveness, we formulated the following hypothesis:

> **Hypothesis 7** (H7). The perceived coherence of policy mixes is positively related to farmers' acceptance of CSA technologies.

Policy mix *credibility* is "the extent to which the policy mix is believable and reliable" (Rogge & Reichardt, 2016, p. 1627). Credibility in policy and policy acceptance has been associated with trust in the government at different levels (Maestre-Andrés et al., 2019). The credibility of the mix is also about the government's reputation and abilities to purposively design, implement and support the envisioned strategy (Rogge & Dütschke, 2018). For example, Bruno et al. (2022) used government trust and policy reliability to establish an indirect link with behavioral intentions, and Rogge and Reichardt (2016) found that a credible policy mix facilitates adoption decisions. In alignment with the approach of Rogge and Dütschke (2018) we describe credibility as farmers´ perceived support for CSA from different policy design and implementation actors. We mainly divided the perceived credibility into two levels: the national level (e.g., Costa Rican Government) and subnational level (e.g., extension agencies, cooperatives, and private firms). The division was based on the roles of these stake holders in the promotion of CSA, where the government primarily plays a role in the design of public policies and the other actors such as field level agents, extension agencies, cooperatives, and private firms are key for policy implementation at the field level. These insights lead us to postulate a positive link between the policy mix credibility and CSA acceptance.

Hypothesis 8 (H8). The perceived credibility of the policy mix, as represented by the national government and field-level agents from extension agencies, cooperatives, and private firms, is positively related to farmers' acceptance of CSA technologies.

As for *comprehensiveness (COM)*, "the comprehensiveness of the policy mix captures how extensive and exhaustive the elements (instruments and strategies) are" (Rogge & Reichardt, 2016, p. 1627). Thus a comprehensive instrument mix includes measures addressing different types of failures (Rogge & Dütschke, 2018) (e.g., reinforcement of laws and regulations, providing incentives towards low-emission technologies, and facilitating spaces for learning). Thus a comprehensive policy mix includes the main instruments but also complementary or flanking policies supporting the desired change (Rogge, 2018). Rosenow et al. (2017) emphasize the need to orchestrate comprehensive policy mixes for incentivizing and steering climate mitigation targets. Our research postulates a positive link between comprehensiveness and CSA technology acceptance.

Hypothesis 9 (H9). The perceived comprehensiveness of the policy mix is positively related to the acceptance of CSA technologies.

Besides looking at elements of the policy mix overall (consistency, coherence, credibility, comprehensiveness), we consider the different types of instruments prioritized by the government (e.g., subsidized credit interest rates, insurance subsidies, direct payments for environmental services, agricultural extension (e.g., services provision) and promoted by private organizations (e.g., sustainability standards). Some authors show that the type of instrument has positive or negative effects on promoting greener or more sustainable behavior (Mills et al., 2018). The provided empirical evidence suggests that farmers are more likely to change towards mitigation and adaptation practices when the policy mix is characterized by a balanced instrument mix (Scherer & Verburg, 2017). For example, it is unlikely that farmers engage with supply-side measures (e.g., agroforestry, organic agriculture) without economic incentives, tax relief, appropriate regulations, or some market incentives (e.g., sustainability standards)(Scherer & Verburg, 2017). Based on this review, we included different types of instruments aimed at encouraging farmers' acceptance of CSA technologies.

3.3 Methodology

3.3.1 Case study: the Costa Rican Coffee sector

Coffee in Costa Rica is a leading agricultural commodity (INEC, 2021a). It represents 25.4% (93 697 hectares) of the area planted in permanent crops (INEC, 2021a), and of the total production, 85.7% of coffee is destined for export (ICAFE, 2022). In 2021, it represented 3.1% of the agricultural and 0.15% of the national GDP. Smallholder farmers dominate coffee production in Costa Rica; in 2021, 85.5% of coffee farmers delivered less than 100 fanegas[15], contributing 29% to national production (ICAFE, 2022).

Since 1961, the structure of the coffee sector has been regulated by Law N.2762 (Ley 2762 Ley Sobre El Régime de Relaciones Entre Productores, Beneficiadores y Exportadores de Café, 2020). Three pillars of the Law include regulations to standardize the quality of "Costa Rican Coffee", including the proportion of harvested green and ripe coffee. The Law includes regulations on the percentages that each actor in the value chain can obtain (for each dollar FOB, 79.3% goes to the producer, 16.9% to the mill, 1.9% to the exporter, and 1.5% to National Coffee Institute (ICAFE). It also institutionalizes ICAFE's role as "Costa Rican coffee" promotor.

Regarding environmental sustainability, the agricultural sector is responsible for 20.5% of total absolute GHG emissions (IMN & MINAE, 2021). Moreover, coffee cultivation contributes 9.38% of total N_2O emissions (excluding processing, waste, and transport). This points to the high use of chemical fertilizers (only 1.9% of farms use organic fertilizers) and the need for more sustainable practices. The predominant type of production is conventional coffee systems (73% of the coffee produced), and only 0.3% of coffee is under an organic farming system (INEC, 2021a). However, the niche markets, such as agroecological, organic, agroforestry, biodynamic, and CSA, are not sufficiently protected and supported (Harvey et al., 2018). As for economic sustainability, the productivity level decrease is becoming more evident. Between 2020 and 2021, productivity fell by 5.97% and has decreased by almost 20% since 2000 (ICAFE, 2022). Furthermore, the confluence of the volatility of global coffee prices and increasing production costs with the COVID pandemic due to the pressure on labor markets affecting coffee harvest also disrupt field visits and extension services (Panhuysen & Pierrot, 2020).

15 Official harvest measure used by ICAFE and represents a unit of volume corresponding to 400 L.

In addition to lower productivity and challenges in terms of emissions, coffee is a highly vulnerable crop to climate change (Bunn et al., 2015). This underlines the need for encouraging adaptation practices since diseases such as coffee leaf rust affected 68% of coffee plantations in 2012, generating significant economic losses (Programa Estado Nación, 2020). This has led to profound shocks to coffee farms and landscapes across Latin America, transforming how and where coffee is grown (Harvey et al., 2021).

The main problems for coffee production can thus be summarized as low productivity, the need to reduce GHG emissions, and high vulnerability to climate change. In response to these problems, government policies designed and implemented a policy mix incorporating national strategies with global objectives, such as the declaration of Decarbonization of the Economy by 2050. Programs encompassing different types of instruments such as Low carbon coffee-NAMA, carbon neutrality, blue flag certification, trusts for renovating coffee plantations, and research on new breeds have been formulated to encourage the reduction of GHG, increase productivity, and adapt to climate change (three fundamental pillars of CSA) (See Figure 3.2). In addition to the incentives and instruments of the public sector, global sustainability standards led by the private sector guide farmers in addressing more environmental-friendly practices (Verburg et al., 2019).

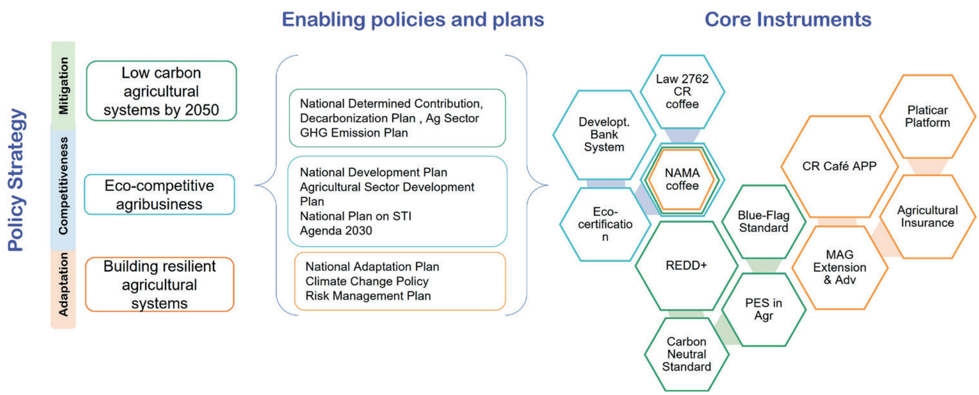

Figure 3.2 Overview of the CSA policy environment

3.3.2 Methods

3.3.2.1 Data collection

In order to answer our research question, the study involved two phases, both informed by the conceptual framework. First, a survey was designed; the survey consisted of the drivers discussed in section 3.2. Second, two focus groups were conducted to validate and gain contextual information about the instrument mix in practice and some possible barriers and benefits of CSA technologies "on the ground". The focus groups with farmers, farmers' organization representatives (e.g., cooperatives, associations), practitioners, and experts were conducted in June 2021. We recorded and transcribed the focus group discussions to understand coffee production under the impact of climate change, farmers' climate perception, their attitude towards accepting CSA farming practices, and policy enablers and barriers.

With the focus group input, we reviewed the survey's first version. Following the survey development process (Ornstein, 2014), the final survey was divided into four sections: 1) general information, 2) socioeconomic and farm characteristics, 3) climate risk perception, 4) behavioral characteristics (SI, PE, FC, CSA), and 5) policy mix characteristics and instruments (See Appendix D for further detail). To test the survey, we ran 13 pretests. The purpose of the pilot was to validate the survey and check the flow of questions and misunderstandings. We applied the interviewees' comments and suggestions to the final version.

The survey took 30 to 50 minutes to complete. Participants were informed of the research purpose, and informed consent was recorded. The survey was conducted from August to December 2021 in two formats via telephone (63.74%) and in person (36.26%) using electronic devices such as tablets and Qualtrics software to retrieve the data. The lead author and four enumerators surveyed 530 farmers (Figure 3.3). After missing or inconsistent data, seven surveys were discarded, and 523 answers from the final survey were used for final analysis. This exceeds the minimum required sample size of 467 surveys (See Appendix B1 for a detailed sample size calculation). Therefore we considered this to be representative. The farmers were randomly sampled based on the databases obtained from local partners, mainly the ICAFE (whereby Law 2762, the farmers need to be registered), the Ministry of Agriculture, cooperatives, and farmers' organizations. The survey was conducted in Spanish.

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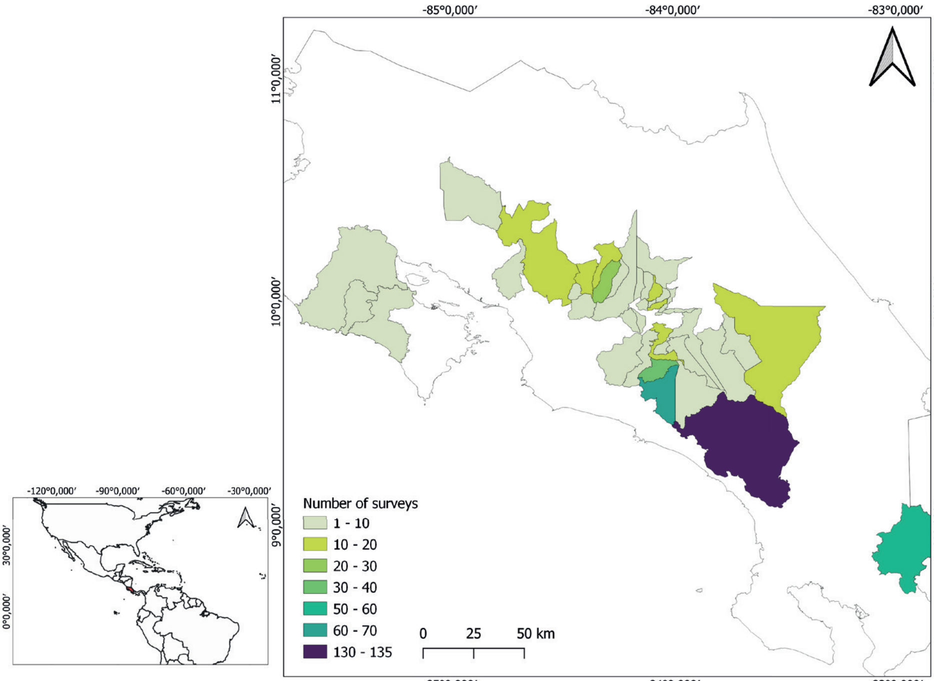

Figure 3.3 Study area and the number of farmers per canton

3.3.2.2 Data analysis

The data obtained from the survey were analyzed using R studio version 4.1.2. First, we performed a Confirmatory Factor Analysis (CFA) to validate the measurement model: dependent and independent variables. After validating the measurement model, the second step was performing the psychometric model estimation.

Measurement model: dependent and independent variables

The items/statements we used had been validated in previous studies, translated to Spanish, and adapted to the local context by conducting two focus groups. The questionnaire contained closed questions and were measured on 5 points Likert scale in which participants were asked to indicate their level of agreement with different statements (1= "completely disagree", 3 =”neither disagree nor agree, 5 = "completely agree"). We conducted a CFA to assess the variables' internal consistency with Cronbach alpha, omega, and Average Variance Extracted and the reliability of the variable construct (Hair et al., 2010). The main constructs[16] were measured as follows (detailed information on each construct and the items can be found in Appendix B3).

Independent variables

Performance expectancy (PE) was measured with 4 items scale following Venkatesh et al. (2003). Others have also shown its applicability in the agricultural sector (Faridi et al., 2020b; Giua et al., 2022; T. Zhou et al., 2010) and found PE influential in farmers' behavioral intentions. An example of one item is "Using CS technologies makes it easier for me to do farming activities in the coffee plantation".

Facilitating condition (FC) was measured following Venkatesh (2003) and Li et al. (2021)with 4 items. One of the items used to measure FC is "Experts are available in the area to address the problems and deficiencies of Climate Smart Technologies".

Social influence (SI) was measured using 3 items following Venkatesh, (2003), Faisal et al. (2020) and Faridi et al. (2020). An example of the item is "People who are important to me think that I should use the CSA technologies".

Perceived cost (PC) was measured using 2 statements based on previous research (Faridi et al., 2020; Schaafsma et al., 2019). Both items were related to the costs of resources needed to commit to CSA technologies. An example of the item is, "I work very hard every day and do not have the extra physical strength to commit to CS Technologies".

Perceived climate risk (PCR), given the dual role of agriculture (adaptation practices needed while also addressing GHG reduction through mitigation actions), is a pressing need to understand how farmers' beliefs and concerns about climate change influence their adaptation and mitigation behavior (Arbuckle et al., 2015). Perceived climate risk was measured using 7 items following van der Linden (2015). An example of an item is "I am concerned about the potential impacts of climate change on my farm operation".

Perceived policy consistency, since there are no extensive studies on the consistency of the mix, the items from Rogge and Schleich (2018) were adapted to the research context. The perceived consistency was measured with three items. The first two are related to the support and reinforcement of the existing instruments. An example is "Funding programs (grants and donations) for investment in equipment/machinery and improvement of practices reinforce each other to support the acceptance of Climate

16 In an earlier version of this study in the measurement model we included the construct Effort Expectancy (EE) defined as "the degree of ease associated with the use of the system" (Venkatesh 2003, pp 450). EE was measured with 4 items, however due to scale reliability problems, specifically AVE and Discriminant validity we dropped EE from the final analysis.

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Smart technologies". The second item captured the instrument mix contradictions "Concerning the policy environment, there are… contradictions in the programs and projects promoted by the government to promote CSA and more sustainable agriculture".

Perceived policy coherence was measured in 3 items following Rogge and Schleich (2018). The items were related to if the policy makers spot/ recognize on time the problems that arise in relation to the acceptance of CSA technologies. "Policy makers are well informed about developments in CSA" as an example of the items used.

Perceived policy credibility was measured by 4 types of items following Rogge and Dütschke (2018): perceived support from the national government, then perceived support of field-level agents of cooperatives, government extension agencies, and private firms (e.g., input suppliers and buyers). Since research has demonstrated cooperatives' important role in supporting the adoption of greener technologies (Snider et al., 2017), we measured perceived support of cooperatives with two items; an example of the item is "Cooperatives encourage me to adopt CST on my farm". Second, regarding the regional extension agency support, we used a dummy variable where we coded as 1 if the category was at least as high as the median value and zeroed otherwise. The item was "In terms of CSA promotion, there is strong support from the extension agency in your region (e.g, ICAFE or the Ministry of Agriculture)". Third, we measured the perceived support of private companies and input suppliers since, in some regions, there is more presence of private advisory services and agro-input suppliers, and the coding was the same as the previous items.

We used Rogge and Schleich's (2018) item to construct the explanatory variable reflecting the perceived comprehensiveness of the instrument mix. For example, "Important flanking policies are missing to promote the diffusion of CSA". We use a dummy variable coded 1 if the response category was at least as high as the median value and zero otherwise.

Dependent variable: CSA technology acceptance

CSA acceptance was measured in four items, using a Likert scale from 1 to 5, similar to other studies (Beza et al., 2018; Faridi et al., 2020b; Ronaghi & Forouharfar, 2020; Venkatesh et al., 2003) and adapted the items to CSA technologies. The survey asked respondents to agree or disagree with four statements related to acceptance. An example of the item is "I would use or will continue using the CS technologies in the future". Before the question, we asked the surveyed if they had heard about CSA before, and if not, we read a brief explanation. After that, the interviewed provided some examples of CSA practices.

We categorized the four items to identify the intensity of acceptance of CSA technologies. We perform a cluster analysis accordingly. Following the methodological steps of other studies (Aguilar-Gallegos et al., 2015; Hyland et al., 2018). We choose the non-hierarchical K-means cluster algorithm using the four CSA acceptance items as the grouping variable. The K-means is a commonly used partitioning-based clustering technique that tries to find a user-specified number of clusters (k), represented by their centroids, by minimizing the square error function (Napoleon et al., 2011). To determine the number of clusters (k), we used: Total Within the Sum of Squares (WSS) (Fraley & Raftery, 2002).

Psychometric model

Since our dependent variable range from “low CSA Acceptance” to “high CSA Acceptance”, we chose a ranking model like Ordered Probit Regression to identify the factors explaining CSA acceptance. The ordered probit model is appropriate because the dependent variable is discrete, nominal, and ordered (Liao, 2003). This model belongs to the class of discrete choice probability models widely used in analyzing attitudes, behaviors, and choices and the likelihood of their occurrence (Greene & Hensher, 2009). A similar methodological rationale in the literature on sustainable production practices and new technologies can be found in Ascough et al. (2002) and Islam et al. (2017).

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The dependent variable was based on categorizing farmers’ rankings of CSA technology acceptance as low, moderate, or high. Although the categories are inherently ordered (low, moderate, or high), the distances between adjacent categories are unknown. The ordered probit model indicates the likelihood of a farmer’s acceptance of a high, moderate, or low CSA technologies. Following Greene and Hensher (2009) the impact of certain explanatory variables on a farmer’s propensity to accept technologies (higher/lower acceptance) is estimated as follows

$$y^*_i = \beta' x_i + \varepsilon_i, \ i = 1, \dots n$$

where y^*_i is an unobservable variable, and x_i is a vector of independent variables and β is a vector of parameters to be estimated, and ε_i= a random error term with mean 0 and variance 1.The selection rule is given by

$$y_i^* = \begin{cases} 0, \text{if } \ yi * \leq \mu 0, \\ 1, \text{if } \ \mu 0 \ \leq \ yi * \leq \mu 1, \\ 2, \text{if } \ \mu 1 \ \leq \ yi * \leq \mu 2 \\ \dots \\ J, \text{if } \ \mu J - 1 \ \leq \ yi * \leq \mu J \end{cases}$$

where $\mu 0, < \mu 1 < \mu 2 < \ldots < \mu J\text{-}1$ are the parameters to be estimated, and are called "cut off points" for each level. Assuming~εN(0, 1)(normalize the variance of the perturbation term ε to 1), the likelihood function for estimation of the model parameters is based on the implied probabilities,

$$Prob = [y_i = j|x_i] = \left[F\left(\mu_j - \beta' x_i\right) - F(\mu_{j-1} - \beta' x_i)\right] \geq 0, j = 0,1, \ldots . J.$$

This way, the sample likelihood function is obtained to further obtain the Maximum Likelihood Estimation, i.e., the ordered probit model. To predict the effects of changes in determinants on dependent categories, marginal effects are derived from probability estimates. This study computed these estimates at the overall means for the data set (Greene, 1990).

The empirical models can be defined as follows:

$$y_{ia}^* = \beta a Behavioral + \delta a\ Farmer's\ characteriscts\ + \varepsilon_i, i = 1,2,3..n$$

$$y_{ib}^* = \beta b Behavioral + \ \delta b\ Farmer's\ characteriscts + \theta b\ Instrument\ mix \\ + \varepsilon_i, i = 1,2,3..n$$

$$y_{ic}^* = \beta c Behavioral + \delta c\ Farmer's\ characteriscts + \theta c\ Instrument\ mix \\ + \alpha c\ Policy\ mix\ characteristics + \varepsilon_i, i = 1,2,3..n$$

The dependent variable y^*_i is 1= Low CSA acceptance; 2= Moderate CSA acceptance 3= High CSA acceptance. To test our hypothesis and account for other factors related to farmers' acceptance of CSA, we include three groups of explanatory variables capturing i) behavioral predictors, ii) farm characteristics ii) instrument mix iii) policy mix appraisal (see Table 3.1 for an overview of the descriptive statistics of the dependent and independent variables and Appendix B2 for further detail).

Table 3.1 Descriptive statistics of the dependent and independent variables

Variable	Type	Description	Mean	SD
Dependent				
CSTA	O	1= Low	7.80%	
		2= Moderate	28.40%	
		3= High	63.50%	
Independent				
Behavioral predictors				
PE	C	Performance expectancy	4.380	0.671
FC	C	Facilitating Conditions	3.647	0.757
SI	C	Social influence	3.647	0.981
PC	C	Perceived Cost	2.554	1.247
PR	C	Perceived climate risk	4.571	0.611
Farmer characteristics				
Age	C	Age of the farmer in years (Years)	52.579	14.077
EDU	D	Farmers formal education: 1= primary diploma; 0= otherwise	0.587	0.493
Farm_Loc	D	Farm location: 1 =if the farm is located in Perez Zeledón; 0 =otherwise	0.258	0.438
Sex	D	Sex of the farmer: 1=male; 0 = female	0.832	0.374
Instrument Mix				
TechAssist	D	Farmer received public technical assistance: 1= Yes; 0= No	0.092	0.289
NAMA	D	Farmer was a beneficiary of NAMA program: 1= Yes; 0= No	0.130	0.337
OrganiAgr	D	Farmer was a beneficiary of Organic Agriculture program: 1= Yes; 0= No	0.272	0.445
Ext_Field Day	D	Farmer participated in field days: 1=Yes; 0= No	0.514	0.500
DifLoanRate	D	Farmer received a differentiate credit rate for farm operations: 1= Yes; 0= No	0.428	0.495
Ag Insurance	D	Farmer have used a crop insurance: 1 = Yes; 0= No	0.042	0.201
SustStndard	D	Certified farm: Yes=1 ; 0=No	0.400	0.490
PES	D	Farmer was a beneficiary of PES: 1= Yes; 0= No	0.126	0.332
Policy mix characteristics				
Consistency	C	Average of PM consistency	4.236	0.047
CON_Contra	D	1 = if contractions are spotted; 0= otherwise	0.612	0.021
Coherence	C	Average of PM coherence	1.707	0.036
CRE_GovSupport	D	1 = if is perceived a government support in favor of CSA; 0 = otherwise	0.426	0.022
CRE_Coop	C	Average of PM perceive support on cooperatives	3.420	1.200
CRE_PrivSup	D	1 = if is perceived the private companies support CSA; 0= otherwise	0.633	0.482
CRE_ExAg	D	1 = if is perceived the extension agencies support CSA; 0 otherwise	0.528	0.500
COM	D	1 = if the PM is perceived as comprehensive; 0= otherwise.	0.744	0.437

Notes: O = ordinal; C = Continuos; D = Dummy; SD: refers to standard deviation; PM: Policy Mix

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3.4 Results

This section presents the results in the same order as our methodological steps for data analysis. First in subsection 3.4.1 we evaluated the measurement model scales reliability through a confirmatory factor analysis. In subsection 3.4.2, we present the model estimation results; in subsection 3.4.3 we present the full model marginal effects.

3.4.1 Measurement model

We performed a CFA to evaluate the scales' reliability and validity, including all proposed items (Appendix B3). Indicators such as Cronbach's alpha, construct reliability, convergent validity, and discriminant validity were used. First, Cronbach's alpha values of most of the variables were above 0.7 (except for FC = 0.685). To ensure indicator reliability, we rejected items with factor loadings less than 0.5, which led to removing 4 items (PC3, SI3,SI4, CON3). Each variable's composite reliability (CR) is above 0.7 (except for FC= 0.689), indicating that the constructs are reliable. Average Variance Extracted (AVE) values are greater than 0.4, suggesting that our scale has an acceptable convergent validity. Most of the constructs meet the discriminant validity criterion to assess whether the square root of AVE exceeds the inter-construct correlations (Table 3.2). The goodness of fit criteria was evaluated, and the results are reported in Table 3.3. Overall, the model shows a good fit and the validity of the measurement model is confirmed.

Table 3.2 Correlation matrix of the measurement model: reliability and convergent validity indicators

	alpha	AVE	CRI	CSTA	PE	FC	SI	PC	PR	CON	COHe	CREDCo
CSTA	0.878	0.671	0.884	0.819								
PE	0.803	0.514	0.809	0.527	0.717							
FC	0.685	0.354	0.689	0.372	0.276	0.595						
SI	0.775	0.569	0.795	0.194	0.337	0.214	0.754					
PC	0.764	0.619	0.764	-0.261	-0.152	-0.195	-0.089	0.787				
PR	0.888	0.545	0.888	0.207	0.313	0.030	0.229	-0.069	0.738			
CON	0.762	0.622	0.766	0.363	0.415	0.151	0.306	-0.087	0.341	0.789		
COHe	0.772	0.545	0.784	-0.085	0.117	0.125	0.159	0.032	-0.037	0.205	0.738	
CREDCo	0.741	0.600	0.748	0.234	0.305	0.501	0.317	-0.172	0.060	0.352	0.242	0.774

Note: AVE=Average Variance Extracted, CRI = Composite Reliability Index, in bold the Square root of AVE, CSTA=Climate Smart Technology Acceptance, PE= Performance Expectancy, FC= Facilitating Conditions, SI= Social Influence, PC= Perceived Cost, PR= Perceived Climate Risk, CON= Consistency, COH=Coherence, CRE_Coop = Credibility cooperatives.

Table 3.3 Summary of Fit indices of the model

Model fit indices	Recommended	Model results
Normed Chi-Square	<3	2.45
Comparative Fit Index (CFI)	>0.95	0.96
Tucker-Lewis Index (TLI)	Near 1	0.95
Standardized Root Mean	<0.7	0.04
Root Mean SQ Error	<0.5	0.04

3.4.2 Model estimation results

3.4.2.1 Dependent variable: Climate-Smart Technologies Acceptance (CSTA)

A k-mean cluster was made to group the producers according to the intensity of CSA technologies acceptance. The results showed that a reasonable number of clusters were three (Appendix B4). Once the k-means cluster was made, each person was assigned a cluster number (Table 3.4, Figure 3.4) . Table 3.4 shows that the three cluster profiles were identified as low, moderate, and high CSTA. Cluster 3 accounts 64% of the farmers, with the highest CSTA average mean. On the contrary, cluster 1-Low CSTA acceptance- groups 6% of the farmers and has the lowest marks in all the grouping variables (e.g., CSTA 1, 2, 3, and 4).

Table 3.4 Cluster profile according to the grouping variables for CSTA

	Cluster 1 n=41		Cluster 2 n=149		Cluster 3 n=333	
	Low CSTA		Moderate CSTA		High CSTA	
	mean	SD	mean	SD	mean	SD
CSTA_Average	2.66	0.48	3.94	0.26	4.90	0.17
CSTA 1_I would use or will continue using the CSA technologies in the future.	2.34	0.82	3.97	0.57	4.90	0.31
CSTA2_I plan to use or will continue using the CSA technologies more frequently in the future.	2.41	0.77	3.91	0.48	4.91	0.30
CSTA3_I would promote the CS technologies to the other farmers.	2.71	1.08	3.83	0.74	4.89	0.33
CSTA4_I would change my practices to cope and adapt to climate change.	3.17	1.00	4.03	0.64	4.89	0.33

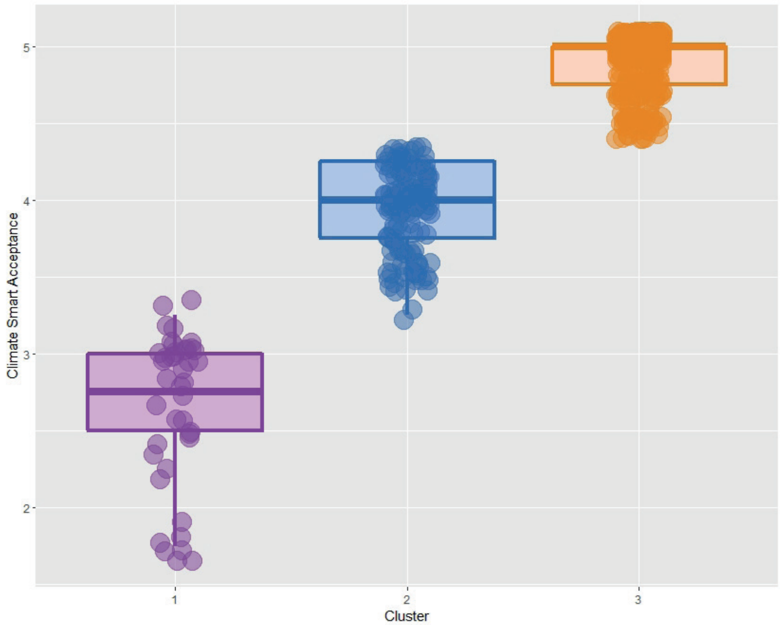

Figure 3.4a Cluster profiling according to the Climate Smart Technology Acceptance

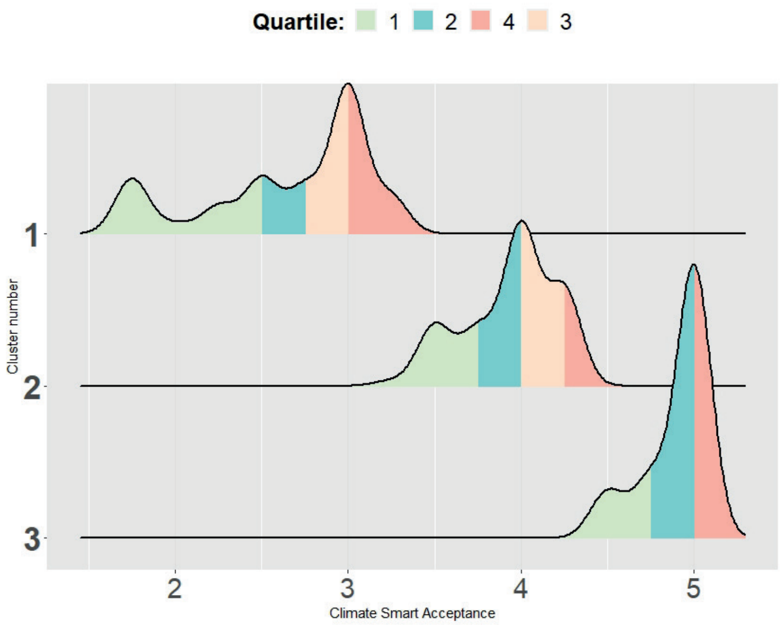

Figure 3.4b Cluster profiling according to the Climate Smart Technology Acceptance

3.4.2.2 Ordered probit regression model

The ordered probit model estimation results are reported in Table 9. We tested three models: a) a model with behavioral predictors; b) a model with behavioral and instrument mix indicators; c) the full model that included behavioral, instrument mix and policy mix appraisal. First, we used the behavioral variables to test whether a simplified version of our final model predicts CSA practices' acceptance. Thus, we included farmer and farm characteristics since they have shown explanatory power in technology acceptance models (Giua et al., 2022) and traditionally in adoptions studies (e.g., Benitez-Altuna et al., 2021; Prokopy et al., 2008). Second, we estimated the instrument mix model, which includes different policy instruments as explanatory variables, thus abstracting from any policy mix appraisal. Finally, the full model was performed to determine whether variables related to behavioral drivers and policy mix appraisal influence CSA acceptance (Hypotheses 1-9). Overall, the three models showed a good fit, with McFadden's R2 greater than 0.2, with higher scores for the full extended model (Table 9).

Behavioral predictors model

In Table 3.5 (Model a) we can observe that overall the signs and significances look consistent with the literature on technology acceptance (Khoza et al., 2021; Mohr & Kühl, 2021; Schaak & Mußhoff, 2018). Positive signs for facilitating conditions, performance expectancy and perceived climate risk implied that an increase in one point of the constructs is related to a higher CSA acceptance. As in many other studies, the expectation about the CSA technologies (PE) is one of the most important driver to predict acceptance. Perceived cost showed a negative sign, meaning that higher perceived cost is related to a lower CSA acceptance. Regarding social influence, we did not have enough evidence to relate social influence with CSA acceptance. This implies that farmers' acceptance of CSA technologies and practices are not mainly influenced by the community, family members, and other farmers.

Farmers' characteristics, such as age and gender were not significant, indicating that we can not relate gender or age with CSA acceptance. Schooling, primary school showed negative sign, meaning that having a primary education diploma decreases the change of accepting CSA. The region where the farm is located (Perez Zeledón) was negatively related to the CSTA.

Instrument mix model

From our results, we showed that farmers were targeted with a mix of information instruments (e.g., extension services, NAMA program), economic (e.g., Payment of Environmental Services, economic differentiated loan rates), as well as private-led instruments such as sustainability standards (e.g., Rainforest Alliance, FairTrade, AAA, Nespresso). As part of the instrument mix, we included various public policy programs, projects, and private initiatives targeting farmers toward accepting and using CSA. These include supporting an array of practices and technologies focused on mitigating GHG while others advocating for adaptation-based technologies (see also section 3.2.2 and Figure 3.2).

Figure 3.5 shows that farmers' participation rate in most of the programs and projects is under 70%. For example, in the case of the extension services provided by the Ministry of Agriculture and other public entities, 24.4% of the farmers in Cluster 1 were beneficiaries of extension services, 50.3% of farmers from Cluster 2, and 55.3% of farmers from Cluster 3 participated in extension activities. Overall, Cluster 3 -high CSTA- is the cluster with the highest participation rates in the three types of instruments. The programs with less involvement were agricultural insurance, blue flag national certification and NAMA program, and PES scheme; most started as a response to the national carbon neutrality strategy in 2012 and focused on reducing GHG and encouraging more sustainable practices.

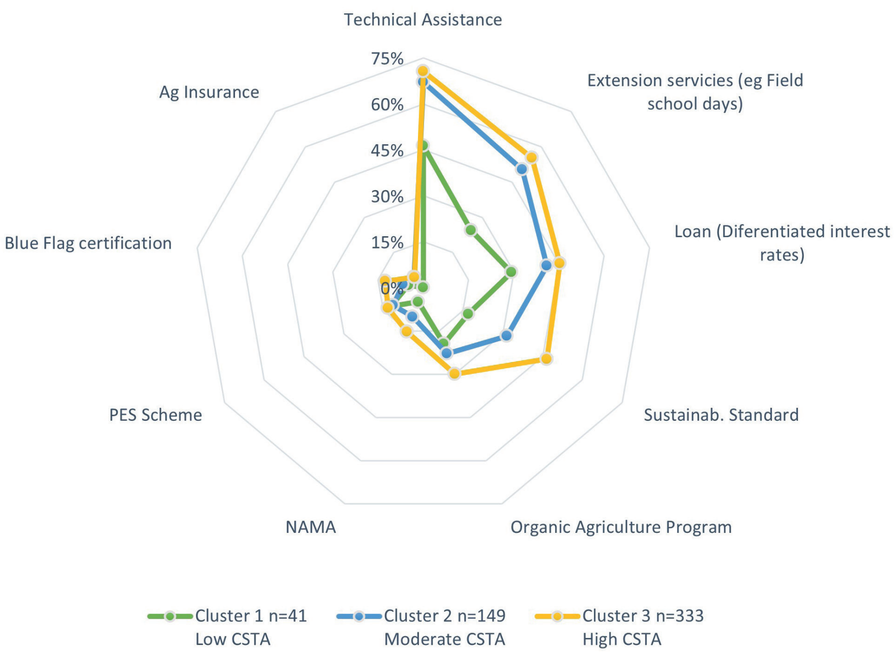

Figure 3.5 Instrument mix participation rates

Note: PES= Payment of Environmental Services, Ag Insurance = Agricultural insurance.

Table 3.5 (model b) instrument mix) showed that most instruments did not explain the intensity of CSA acceptance, with an exception for the positive and negative signs for two instruments: the use of private-led instruments as sustainability standards (positive relation) and economic incentives as participating in PES schemes (negative relation). Thus, participating in other policy programs (e.g., blue flag national standard, agricultural insurance, and differentiated loan interest rates) does not directly link farmers' acceptance of CSA. We did not have sufficient statistical evidence to show the importance of information instruments for accepting CSA.

Full model

Table 3.5 (model c) showed that the instrument mix model improved the fit indicators (AIC and MacFadenR) when we incorporated the policy mix characteristics: coherence, consistency, comprehensiveness, and credibility. Accordingly, 12 of 19 variables were significant at 5% and 1%. The hypothesis H1,H2, H4, H5, H6, and H9 were validated based on the statistical findings. Since the model fit indicators showed significantly better outcomes than models a and b, the findings supported our main argument that pointed out the importance of both behavioral drivers and the policy environment (policy mix in our case) to explain the acceptance of new technologies.

Besides the significance of the behavioral predictors (PE, FC, PCR, PC) and the sociodemographic (schooling and location) the signs of the estimated coefficients for the policy mix characteristics suggest a positive relationship between consistency, comprehensiveness, and being certified -e.g., Organic, Rainforest, Fair trade and CSA acceptance. The negative signs for the credibility in the field, i.e, support of private companies, coherence, and being a beneficiary of PES program, evidenced an inverse relationship between the variables and the CSA acceptance.

Table 3.5 Ordered probit regressions: Models a, b, and c

	Model a)			Model b)			Model c)		
	Behavioral predictors			Instrument Mix			Full: Behavioral + Instrument + Policy Mix appraisal		
	Estimate		Std. error	Estimate		Std. error	Estimate		Std. error
PE	0.765	***	0.095	0.798	***	0.100	0.758	***	0.105
FC	0.340	***	0.065	0.315	***	0.068	0.370	***	0.073
SN	0.061		0.058	0.058		0.060	0.041		0.063
PC	-0.150	**	0.048	-0.184	***	0.050	-0.182	***	0.050
PR	0.215	*	0.092	0.299	**	0.096	0.246	*	0.101
Age	0.003		0.004	0.004		0.004	0.005		0.004
EDU_P	-0.246	*	0.125	-0.480	*	0.190	-0.518	**	0.195
Loc_PZ	-0.261	.	0.135	-0.399	**	0.139	-0.457	**	0.139
MALE	-0.075		0.157	-0.077		0.161	-0.049		0.166
TechAssist				0.057		0.138			
NAMA				-0.026		0.214			
OrganiAgr				0.123		0.202			
Ext_Field Day				0.144		0.192			
DifLoanRate				-0.008		0.146			
Ag Insurance				-0.150		0.129			
SustStandard				0.636	***	0.129	0.705	***	0.137
PES				-0.407	*	0.317	-0.436	*	0.189
Consistency							0.189	**	0.058
CON_Contra							0.144		0.127
Coherence							-0.161	*	0.082
CRE_GovSupport							-0.051		0.143
CRE_Coop							-0.040		0.061
CRE_PrivSup							-0.279	*	0.141
CRE_ExAg							0.237	.	0.134
Comprehensiviness							0.307	*	0.143
Threshold (1->2)	3.422	***	0.645	4.053	***	0.682	4.288	***	0.710
Threshold (2->3)	4.807	***	0.659	5.521	***	0.700	5.839	***	0.730
Log-Likelihood:	-355.090			-337.973			-322.285		
Prob > chi2	0.000	***		0.000	***		0.000	***	
McFadden's	0.196			0.235			0.271		
AIC:	732.18			713.946			686.569		

Signif. codes: ***p < 0.001; **p <0.01;* p < 0.05;. p < 0.1

PE= Performance Expectancy, FC= Facilitating Conditions, SI= Social Influence, , PC= Perceived Cost, PR= Perceived Climate Risk, EDU_P= Primary Education , TechAssist= Public Technical Assistence, NAMA= National Appropriate Mitigation Action program, PES= Payment of Environmental Services, CON_Contra: Contradictions between objectives and instruments

3.4.2.3 Full model marginal effects

Since the parameters estimated by the model are not directly interpretable, average marginal effects were reported to explain the percentage impact on the dependent variable when covariates increased by one unit, holding all other variables constant (Table 3.6). These marginal effects are calculated for each outcome of the full model by considering the continuous variables' mean and the dummy variables' median value. When all the values are in their mean value, the policy mix is perceived as comprehensive, farmers participate in PES, and they implement a sustainability standard, the predicted probability of being in the Low acceptance category is 8.2%, moderate category 28% and highest category 64%.

Behavioral predictors

Marginal effects show that the probability of observing high CSTA increases by 27% with an increase of one point in the performance expectancy (supporting H1). This shows that perceiving the technologies as helpful and valuable may lead to a higher acceptance of CSTA. An increase of one point in the facilitating conditions increases the probability of being in the high CSTA category by 13%, and it decreases the probability of observing moderate CSTA by 10.98%, which means that the greater the access to resources (financial and knowledge) to implement CSA the higher probabilities of observing high acceptance (supporting H2). Regarding the perceived cost, our finding supports hypothesis 4, showing that an increase in one point of PC decreases the probability of observing high CSTA by 7%. Regarding the perceived climate risk, we validated our hypothesis 5 and the main argument for including the perceived climate risk in the behavioral predictors model, which means that an increase in one point of perceived climate risk increases the probability of observing high CSTA by 9%. Thus, the higher the farmer´s concern about the potential impacts of climate change on their farms and communities and their beliefs and perceptions about extreme weather events, the higher the probability of accepting CSA technologies. We did not find empirical support in favor of hypothesis 3, which relates social influence with CSA acceptance.

Socio-demographics, such as age and gender, did not show significance. Holding a primary (elementary) diploma increases the probability of being in a moderate CSA category by 19% and 3% of being in the lowest category. Also, if the farm is located in Perez Zeledón, the farmers have a higher chance of being in the Low-Moderate categories.

Instrument mix and policy mix appraisal

Regarding the policy mix appraisal, we found a positive relationship between the instrument mix consistency and higher CSTA. An increase in one point in consistency increases the probability of being in the highest category by 7%. That means that the higher perception of alignment between the instruments (training programs, grants, donations, and economic incentives) , the higher the probability of falling in the high acceptance category (supporting H6). The relevance of instrument mix consistency for predicting CSA indicates the importance of aligning the instruments with the goals. Regarding the consistency between the instruments and the strategy, we did not find sufficient statistical evidence to relate CSA acceptance to consistency between instruments and strategy; it is worth mentioning that 61.2% of farmers consider that there are contradictions between government programs for supporting and national objectives.

We have hypothesized a positive relation between coherence and farmers' CSA acceptance. However, our findings showed the contrary effects, an inverse relation between coherence and high CSA acceptance leading us to reject hypothesis 7. This means that an increase in one point of perceived coherence decreases the probability of observing high CSTA by 6%. The descriptive statistics for policy coherence showed a very low mean of 1.71 (0.82 SD) measured on a 5 points Likert scale, which points out farmers' appraisals on whether policymakers are informed about last developments of CSA, or if there are adjustments of the policies in favor of CSA and if policymakers remove obstacles related to the use of CSA.

Regarding policy credibility, we referred to credibility as the support of different field-level agents at different levels i) national level ii) regional extension agencies iii) cooperatives iv) private firms. The first level was related to national government support, and we did not have enough statistical evidence to relate it to CSA acceptance. The second level of credibility referred to the perceived support from regional extension agencies (showing a positive sign), meaning that appraising positively the support of the extension agencies increases the probability of being in the highest acceptance category. However, our findings provide weak support for the hypothesis (significant at 10%), most likely due to lower degrees of freedom. Third, regarding the role of cooperatives and private firms, we included it in our model since there are some regions where private organizations have greater involvement in the coffee value chain than governmental or national policies. However, we did not find empirical support to relate the credibility of the support of cooperatives and CSA. However, the credibility of the support of private firms, such as input suppliers and buyers, decreases the probability of being in the higher category by 10% and increases the probability of being in the moderate category by 9%, which means that farmers that appraise positively the support of private companies are more likely to moderately accept CSA technologies.

Appraising a comprehensive mix (e.g., no central and flanking policies missing) increases the probability of being in the highest CSA category by 11%. These provide strong support for hypothesis 9. Even though the policy is perceived as comprehensive, in practice, more efforts are needed to increase the use of the flanking policies (see Figure 3.5) given the effect it may have on CSA acceptance.

In addition, we included two types of instruments in our full model (based on the results of model b): participating in a PES scheme and having a sustainability standard. The analysis of the marginal effects showed that being a beneficiary of the PES program increases the probability of being in a moderate CSTA by 13.7% and decreases the probability of having a high acceptance by 16%. We argue that the PES program mainly focuses on providing incentives for forest conservation and other environmental services, which may compete to some extent with the adoption and use of CSA technologies.

Moreover, our findings also showed that participating in private sustainable coffee certification schemes is a key determinant of high CSA acceptance. This relates to the fact that the coffee as a commodity is linked to the global value chain and is highly connected to a model of external input agriculture (e.g., use of chemical inputs and fertilizers), and adopting sustainability standards includes a transformation of changes in traditional practices to environmentally sustainable practices and technologies that might be to some extent related with CSA technologies and practices.

Table 3.6 The full model estimated Marginal effects on farmers' acceptance of CSA

	Low CST Acceptance			Moderate CST Acceptance			High CST Acceptance		
	prob=		0.08	prob =		0.279	prob=		0.639
	Marginal Effect		Std Error	Marginal Effect		Std Error	Marginal Effect		Std Error
PE	-0.040	***	0.010	-0.232	***	0.035	0.273	***	0.038
FC	-0.020	***	0.005	-0.113	***	0.023	0.133	***	0.026
SN	-0.002		0.003	-0.012		0.019	0.015		0.023
PC	0.010	**	0.003	0.056	***	0.016	-0.066	***	0.018
PR	-0.013	*	0.006	-0.075	*	0.031	0.088	*	0.036
Age	0.000		0.000	-0.001		0.001	0.002		0.002
EDU	0.028	*	0.012	0.159	**	0.061	-0.186	**	0.070
Loc_PZ	0.024	**	0.009	0.140	**	0.043	-0.164	***	0.050
MALE	0.003		0.009	0.015		0.051	-0.018		0.060
SustStandard	-0.038	***	0.010	-0.216	***	0.044	0.254	***	0.049
PES	0.023	*	0.011	0.133	*	0.059	-0.157	*	0.068
Consistency	-0.010	**	0.004	-0.058	**	0.018	0.068	**	0.021
CON_Contra	-0.008		0.007	-0.044		0.039	0.052		0.046
Coherence	0.009	.	0.005	0.049	.	0.025	-0.058	*	0.029
CRE_ GovSupport	0.003		0.008	0.016		0.044	-0.018		0.051
CRE_Coop	0.002		0.003	0.012		0.019	-0.014		0.022
CRE_PrivSup	0.015	.	0.008	0.085	*	0.043	-0.100	*	0.051
CRE_ExAg	-0.013	.	0.008	-0.073	.	0.041	0.085	.	0.048
COM	-0.016	*	0.008	-0.094	*	0.044	0.110	*	0.052

Signif. codes: ***p < 0.001; **p <0.01;* p < 0.05;. p < 0.1

PE= Performance Expectancy, FC= Facilitating Conditions, SI= Social Influence, , PC= Perceived Cost, PR= Perceived Climate Risk, EDU_P= Primary Education , TechAssist= Public Technical Assistence, NAMA= National Appropriate Mitigation Action program, PES= Payment of Environmental Services, CON_Contra: Contradictions between objectives and instruments

3.5 Discussion and Conclusion

This paper has assessed how farmers' behavioral drivers and their appraisal of the CSA policy mix (consistency, coherence, credibility, and comprehensiveness) influence the acceptance of CSA technologies and practices. We have examined several models to test the effects of the behavioral predictors, instrument mix, and policy mix characteristics on CSA acceptance. The results from the full model demonstrated that the intensity of CSA acceptance (low, moderate, and high) is not just a result of farmers' behavioral predictors (e.g., as perceived usefulness and potential benefits of the technologies) and socioeconomic drivers but is also importantly shapes by the appraisal of the policy environment.

Acknowledging how the policy environment shapes the acceptance of CSA widens the scope of behavioral models. It suggests the need to shift the question of merely focusing on behavioral drivers for technology acceptance towards how to integrate farmers' policies appraisal that might lead to changing the current behavior towards more CSA practices and technologies (echoing suggestions by Carter et al., 2018; Chandra et al., 2018; Scherr et al., 2012). The current study goes beyond this earlier work by deepening how farmers' decisions on whether accept or not CSA are shaped by their appraisal of the policy mix and that those decisions are influenced and, in turn, influence the broader policy environment. We will now discuss our findings in five subsections; in subsection 3.5.1, we unpack the role of behavioral predictors on CSA acceptance. In subsection 3.5.2 we connect the composition of the instrument mix with acceptance; in subsection 3.5.3 we unravel the "black box" of the policy environment; in subsection 3.5.4 we elaborate on policy recommendations and implications, and finally, in subsection 3.5.5, some limitations and further questions are presented.

3.5.1 Unpacking farmer's behavioral predictors for CSA acceptance

By using behavioral drivers in the CSA acceptance model, we expanded the UTAUT model. We added three additional constructs (i.e., perceived climate risk, cost, and policy mix appraisal) to the model core drivers (i.e. performance expectancy, facilitating conditions, and social influence). From the results, we showed that performance expectancy is the strongest predictor of CSA acceptance, which is similar to found in the case of mobile apps for agricultural advice (Molina-Maturano et al., 2021), smart farming technologies (Giua et al., 2022) and water conservation practices (Faridi et al., 2020b). What differs between these cases and CSA technologies is that the acceptance is not about a single technology; instead, CSA encompasses a wide range of technologies pursuing climate change adaptation and/or mitigation while increasing farm productivity. Therefore, we argue that sharing and communicating the perceived usefulness of combined CSA technologies, the potential synergies, and the perceived benefits that CSA might bring to the farm are key elements for mobilizing acceptance. Besides the perceived performance of the technologies, our results stress the role of the facilitating conditions, meaning that perceiving support in terms of the availability of field-level experts (e.g., extension) and the necessary resources to implement CSA increases the probability of observing high CSA.

Social influence was not significant to predict acceptance, which is consistent with some previous studies (e.g., Beza et al., 2018; Molina-Maturano et al., 2021) but contrary to others that emphasize the roles of networks and support of the social environment (Giua et al., 2022). We suggest that even though farmers tend to rely on social networks to inform themselves about new technologies, family and other farmers' opinions were not influencing the final decision, meaning that farmers will not accept a CSA technology in response to social pressure. Consistent with Venkatesh et al. (2003), the social influence constructs were not significant in voluntary contexts such as the acceptance of CSA technologies and practices.

The additional behavioral predictors, such as the perceived climate risk and perceived cost, played a key role in explaining CSA acceptance. Our results showed that climate risk perception was significantly and positively related to CSA acceptance, previously found by Arbuckle et al. (2015) and Aryal et al. (2018). Our findings relate to climate change beliefs with adaptation and mitigation practices acceptance, meaning that being aware of the existence of climate change hazards may increase the acceptance of CSA, which is particularly important given the threats of rising temperatures, droughts, and extreme rainfall in the coffee system (Bunn et al., 2015). Furthermore, related to the perceived cost, we showed that the higher perceived cost is related to lower CSA acceptance (echoing Faridi et al., 2020 and Beza et al., 2018). We suggest that the lower the cost of using the technology, the higher the acceptance. Thus, acknowledging that some of the CSA technologies are considered costly in terms of labor use or financial investments (Kangogo et al., 2021), therefore context-specific interventions are needed to overcome these barriers. Furthermore, this confirms qualitative findings on CSA, pointing out that economic constraints are the most critical barriers to adoption (Long et al., 2016). Beyond confirming, we add to the technology acceptance literature by incorporating two additional significant components (cost and climate perceptions) explaining the acceptance of a combination of new technologies such as weather forecast apps, water and soil conservation practices, agroforestry, crop diversification, and drought-resistant varieties.

3.5.2 Behavioral drivers and the composition of the instrument mix

Instrument mixes have different sorts of instruments, i.e., information instruments such as extension services provision, economic instruments such as tax exemptions, and private-led instruments such as sustainability standards. By unpacking instrument mix composition and relating the instruments with CSA acceptance, we showed the importance of both private-led and economic incentives for CSA acceptance but that other instruments seem appraised as important far less. This contradicts earlier work (i.e., Aryal et al., 2018) since our findings showed that being a beneficiary of the training programs, extension services, or having a blue flag national standard did not predict the probability of observing CSA acceptance. Thus, a theoretical and policy implication is that it is essential to consider the instrument mix's composition in terms of presence and its coherence and consistency. We show that a combination of policies in place with low participation rates makes that what seems a comprehensive policy mix that is underutilized in practice. This may be explained in our case by the fact that there is not an interlinked diffusion of the programs amongst the farmers and given the government´s capacity of enforcement, there is no coherent implementation of the mix as a whole but isolated program implementation (see also section 3.5.3).

We found that being beneficiaries of the PES program (focused on providing farmers economic incentives for reforestation or agroforestry) determines the probability of acceptance of CSA, ranging from low to moderate. As also found by previous scholars Arslan et al. (2015), Bopp et al., (2019) and McCarthy et al. (2018), we showed that PES is related to CSA acceptance but was not the most influential driver for acceptance, emphasizing on the importance of behavioral predictors for CSA. Regarding private-led instruments, we found that having a sustainability standard strongly predicts CSA acceptance. This result is in line with other authors who point out that certification increases the adoption of environmentally friendly management practices (e.g., Blackman and Naranjo, 2012) and earlier work in coffee systems which points to the role of certifications for implementing adaptation practices (Verburg et al., 2019). We add to this earlier work showing that more effective drivers for change come from these private-led instruments than from public policies pointing out the embeddedness of coffee farming into the global value chains and the potential synergies between public and private policy instruments.

Our findings contradict other research (i.e. Mills et al., 2018) that strongly relates the importance of information instruments for engaging with environmental practices. We argue that farmers' participation is low in most of the programs, from the policy mix composition, we note an imbalance in the use of the instruments suggesting a preference for instruments such as extension services, differentiated credit rates, sustainability standards, and national organic agriculture program participation. Our results are similar to studies on environmental policy acceptance, indicating a greater acceptance of information instruments than regulatory instruments (Maestre-Andrés et al., 2019). Other instruments included in the mix, such as public standards and eco-labels to reduce GHGs as carbon-neutral standard or ecological blue flag scheme, have the lowest participation rates. We suggest that this may be related to the lack of positioning and the limited connection with the public/local standards (e,g, blue flag recognition) versus private-led sustainability standards (Fairtrade, Rainforest) with established niches markets, thus reinforcing the need to connect supply and demand measures for CSA (Scherer & Verburg, 2017).

3.5.3 Unpacking the "black box" of CSA policy environment: the key role of coherence

This study provides empirical evidence on connecting behavioral drivers towards CSA acceptance to how farmers appraise the policy environment, e.g., the policy mix. Our evidence supports the outcomes of the review paper of Scherer and Verburg (2017) suggesting that a balanced policy mix is key for a broader uptake of CSA. However, these authors did not provide a deeper insight into what such a balanced policy mix looks like, and to some extent, this thus remains a “black box”. Here, our study helps to unravel this black box by showing that the farmer’s appraisal of the overall policy environment to some extent, shapes their decisions to engage with CSA. Our findings add to the existing literature by indicating that farmers are willing to accept CSA if there is a favorable appraisal of the policy mix in terms of policy consistency and comprehensiveness.

The relevance of instrument mix consistency for predicting CSA echoes the findings of Rogge & Schleich (2018), which point out the importance of the alignment of the instruments for reaching the policy goals. Integrating farmers’ appraisal in terms of their perceived consistency, comprehensiveness, coherence, and credibility represents a more robust and inclusive model for understanding the acceptance of climate-smart practices. Even though we did not have enough evidence to relate credibility with acceptance, we showed that the appraisal of a consistent and comprehensive policy mix leads to higher probabilities of observing high CSA.

Surprisingly, our study evidenced an inverse relation between coherence and high CSA acceptance, indicating that most farmers with a high acceptance of CSA score relatively low on their perceived policy mix coherence. Farmers’ coherence appraisal suggests low confidence in governments’ actions to promote CSA. Even though qualitative studies call for coherent policy mixes in CSA (Carter et al., 2018) and other transitions (Kanda et al., 2022; Kivimaa & Sivonen, 2021) and such coherence may be the case in theory, some authors have shown that the policy mixes rarely are coherent (Huttunen et al., 2014b; M. Nilsson et al., 2012; Thow et al., 2018), and we also see this in our case of Costa Rican CSA policies in coffee.

The appraisal of policy coherence in our context may capture the politics of policymaking in Costa Rica and reflect farmers’ contentment or dissatisfaction with the national government regarding regulations, lack of infrastructure, and providing basic and essential services. We suggest going beyond assessing the presence of a balanced CSA policy mix, including coherence in work on CSA policy mixes gives us a better awareness of how some indicators may work for a particular policy context and culture while others may not have the desired explanatory power.

Assessing farmers’ appraisal of the CSA policy mix recognizes the embeddedness of the individual in the policy environment (echoing Engler et al., 2019). Since the appraisal of the policy mix is relatively underexplored for CSA, it comes from a different strand of literature–transition studies. Our empirical results may help bridge the gap between individual behavioral and system-oriented studies on CSA acceptance. Firstly, it may help reconfigure the policy context and policy mix by taking into account farmer appraisal and feedback on policies. Secondly, this type of analysis might be a way of inducing policy learning which can help formulation and implementation of more adequate policies (Borrás, 2011). As regards the latter aspect, we will offer some recommendations in the next section.

3.5.4 Policy implications and recommendations

The findings lead to the following recommendations for policymakers and practitioners. First, given the strong relationship with acceptance of CSA technologies and practices, we suggest that policy interventions aimed at CSA should consider behavioral predictors such as perceived effort, facilitating conditions, and perceived climate risk in policy design. For example, policy instruments may widely support and communicate CSA technologies' potential benefits and usefulness but also facilitate the conditions regarding knowledge, training, and organizational support. Moreover, our findings support that climate change awareness is a key driver for acceptance; thus, extension programs and information campaigns might help to increase farmers' self-awareness of climate change and thus have a greater chance of using adaptation and mitigation practices.

Second, we have shown that farmers' appraisal matter for accepting CSA technologies; thus, the role of comprehensive and consistent policy mixes becomes more relevant. We suggest policymakers and practitioners working on policy implementation and design should consider farmers' appraisals of the whole policy mix. Positive or negative evaluations of the CSA policy mix may inform policymakers and, as a response, motivate them to purposively adjust the policy mix according to the farmer's appraisal (e.g., carefully proposing new instruments to build balanced instrument mixes, creating a better image of public policies). Thus, policymakers thinking about effectively transforming agricultural production to a CSA-based system might include an approach that involves holistic thinking of the policy mix regarding the overall consistency and comprehensiveness of policy mixes, as well as coordination and integration with private-led instruments. This suggests that integrating the beneficiaries' and non-beneficiaries appraisal into policy design may open opportunities to enable synergies between private-led and public policy instruments.

3.5.5 Limitations and further questions

There are some limitations in this study that could be addressed in future research. We argue that even though our study was situated in Costa Rica, the nature of CSA, which includes adaptation and mitigation technologies and practices, the findings can be extended to other contexts. Future research on how farmers accept new technology, particularly in the agricultural sector, may benefit from using this study's findings and conceptual lens. However, it corresponds to a cross-sectional study of coffee in Costa Rica; although it is a representative study of all coffee-growing regions, it is limited to the fact that the data were captured within the constraints of a certain temporal and spatial frame.

Second, incorporating policy environment variables in conjunction with behavioral variables has several methodological challenges; we did not capture the dynamic interplay or interactions over time between the farmer's behavioral drivers and the policy mix, which was beyond this study's scope. Future research could incorporate the analysis of this dynamism between the farmers and the policy environment, following Engler et al. (2019), which may lead to interesting findings on the interactions and relationships between the both. Third, it was beyond the scope of this study to analyze the adoption of CSA practices; we investigated the intensity of acceptance of CSA technologies and practices. However, future research may deep into the link between the adoption and acceptance of CSA.

Although the policy appraisal variables had not been tested in the context of the global south and in the context of agriculture, they showed great potential for predicting acceptability; however, future work could focus on detailing the measurement items and relating one single policy mix characteristic (e.g., coherence or credibility). In our case, we did not have enough evidence to relate credibility to acceptance; however, the results showed a negative appraisal of government support which might be an interesting focus for further research since one of the critical attributes of low policy acceptance is distrust in the government or dissatisfaction with governmental information about the policy.

CHAPTER 4

Unraveling farmers' interrelated Climate-Smart Agriculture adoption decisions under perceived climate change risks

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Abstract

Climate change poses a risk to agricultural activity. Understanding farmers' behaviors is increasingly important for managing climate change risk and improving adaptive capacity. This study aims to identify the key risk-related drivers influencing several pro-environmental behaviors by adopting various Climate-Smart Agriculture (CSA) technologies to reduce climate change risk. We investigate the interrelated nature of the adoption of CSA technologies related to soil fertility, soil conservation, agroforestry, agro-advisory apps, and alternative coffee farming practices. To explore the role of the perceived risks related to CSA technology adoption, we constructed an extended model that combines protection motivation theory, perceived farmers' adoption risks and social and demographic determinants. We collected empirical data from 519 coffee farmers in Costa Rica and analyzed the data through a multivariate probit technique. The analysis reveals how the influence of perceived climate risks severity, perceived vulnerability, response efficacy, self-efficacy, and perceived cost changes according to the CSA technology. As for the perceived adoption risks, we show that the adoption likelihood of CSA technologies aimed at reducing GHG emissions decreases with increasing perceived adoption risk. Other determinants, such as the number of coffee buyers and the farmers' membership in an organization, steer the adoption of soil fertility practices, agroforestry, and agro-advisory mobile apps. Main theoretical implications include the integration of the CSA adoption risk-related perceptions to the protection motivation theory, since it reflects on farmers' fear of potential losses or additional costs associated with implementing these practices. The finding gives a nuanced explanation of farmers' decisions under pressing climate change threats. Practical implications for increasing CSA adoption are that CSA promotion programs must consider that farmers see CSA technologies as interrelated in their adoption decisions, meaning that more fruitful synergies could be promoted by acknowledging the bundled adoption of multiple CSA technologies. Thus, promoting a mix of CSA technologies and practices is essential for achieving resilience while increasing productivity.

4.1 Introduction

Climate change affects agriculture and rural livelihoods. Extreme temperatures, severe droughts, and irregular rain threaten farming activities and farmers' welfare (IPCC, 2022). Agriculture is impacted by climate change but also contributes to it, as they are mutually related and self-reinforcing (Lipper et al., 2015). The impacts of conventional agriculture have led to resource degradation, water and soil scarcity, and biodiversity losses, and it is well-known how increasing temperatures, altered rainfall patterns, and extreme weather events significantly affect agricultural productivity (FAO, 2019). Given such dual relations, farmers' responses might incorporate practices aiming to reduce agricultural activity's impact while adopting coping strategies to face climate change risks (Campbell et al., 2014). Climate-Smart Agriculture (CSA) has been proposed as an "overarching" approach to marrying adaptation and mitigation strategies with food production (FAO, 2018, 2010).

CSA encompasses a wide variety of technologies[17] (e.g., soil conservation, agroforestry, or soil fertility) integrated within an agricultural system across multiple scales (Teklu et al., 2023), which aim to improve resource efficiency, increase farmer resilience and reduce greenhouse gas (GHG) emissions (Djido et al., 2021; Lianget al.,2021). The benefits include optimizing inputs, increasing CO2 sequestration, and minimizing agricultural systems' vulnerability while strengthening smallholders' resilience to current and future climate risks (Akter et al., 2023; Teklewold et al., 2013) Thus, CSA has the potential to deliver synergetic outcomes; however achieving these synergies requires careful integration of multiple reinforcing technologies (Barrett et al., 2020; Ratnadass et al., 2021).

Although efforts have been made to increase CSA adoption, some technologies are not widely adopted (Hochman et al., 2017; Kangogo et al., 2021; WorldBank et al., 2014). Engaging with CSA often is limited by the cost (e.g., use of new breeds), time investment (e.g., water management practices), lack of skills (e.g., use of apps and new machinery), and CSA adoption generally requires considerable capacity development (Amundsen et al., 2010; Long et al., 2016; Neufeldt et al., 2013a). Moreover, potentially adverse effects have been identified that constitute potential adoption risks, including labor burden, unsuitable conditions for certain practices, or lower farm yields (Cavanagh et al., 2017). For example, practices such as minimum tillage or replacement of pesticides might maintain crop yield but increase labor costs for weeding and pest control (Jaleta et al., 2013). In schemes such as agroforestry, trade-

17 CSA technologies encompass a range of tools (e.g., machinery, artifacts) and practices (e.g., agronomic and environmental management practices) aimed at reducing GHG, reducing farmers' vulnerability to climate change while also increasing farm productivity (Lipper et al., 2015).

offs between the shade trees and low coffee productivity has been pointed out since it relies upon the right choice of trees, tree density, and fertilizer application (Haggar et al., 2021; Mercer, 2004). Such trade-off effects on productivity and investments in technology adoption can be considered risky by farmers (Joffre et al., 2018).

Perceived risks thus play a key role in the adoption of CSA, and this role is twofold: 1) it concerns the risk appraisal of climate change (Li et al., 2021; Niles et al., 2013; van der Linden, 2015) and 2) it concerns the risk appraisal of adoption (Joffre et al., 2018). Although the behavioral drivers relating to individual choices under risk have received considerable attention in environmental psychology (Bockarjova and Steg, 2014; Poortvliet et al., 2018; Steg and Vlek, 2009) and also in climate change assessment (Grothmann and Patt, 2005;Li et al., 2021; Mase et al., 2017) the connection with risk appraisal of adopting protective mechanisms have, so far, not been explored (Cummings et al., 2020). As for the protective behaviors, scholars have mainly focused on studying the adoption of single protective mechanisms without recognizing that in practice, the farmer faces multiple decisions, and in order to minimize cost and maximize synergies, individuals might choose to adopt complementary technologies (Leeuwis and Aarts, 2021). Recognizing such interrelations among the decisions in adoption models might lead to a more fruitful understanding of the adoption process (Aryal et al., 2018; Leeuwis & Aarts, 2021; Teklewold et al., 2013). Although some researchers have begun to acknowledge the interconnectedness of technologies (Tekluet al.,2023) the risk-related drivers influencing interrelated adoption decisions under climate risks are yet not widely explored. As far as we know, there are no studies in the agricultural context that combine 1) climate change risks appraisal, 2) the perceived efficacy of the recommended alternatives to face the risks, with 3) the individual appraisal of perceived risks related to the adoption of these technologies (e.g., perceived yield losses caused by implementing pest control practices). In this paper, we put forward the notion that this combined analysis is key to unraveling farmers' decisions under pressing climate risks.

Specifically, this study aims to identify the key risk-related drivers influencing the interrelated adoption of CSA technologies proposed to mitigate the negative consequences of climate change. We investigate the interrelated adoption of technologies related to soil fertility, soil conservation, agroforestry, agro-advisory apps, and alternative practices such as organic farming practices and the use of compost. The CSA technologies were chosen based on their appropriateness to the local context. The model considers the influence of farmers' threat appraisal (perceived severity of climate risk and their perceived vulnerability), coping appraisal (protective mechanisms perceived efficacy, self-efficacy, and perceived cost) and explores the role of the perceived risks related to CSA adoption on farmers' engagement in multiple CSA technologies.

We use a behavioral approach in this paper since behavioral studies on adoption address important cognitive processes to better explain farmers' protective decisions from climate threats (Beedell and Rehman, 1999; Gholamrezai et al., 2021; Klöckner, 2013). Several psychological theories have been used and extended to comprehensively explain adoption decisions (Bockarjova and Steg, 2014; Ghanian et al., 2020). While these models share many similarities, they differ in their choice of emphasizing the principal drivers used to explain behaviors (Floyd et al., 2000). In this study focusing on risk, we deem the protection motivation theory (PMT) by Rogers (1975) the most suitable framework[18] since it emphasizes two cognitive processes: coping and threat appraisal. Thus, the PMT's effectiveness has been demonstrated in predicting protective behaviors under climate risk; however, it fails to acknowledge the possibility that such protective behaviors might be perceived to carry potential risks, and the individual appraisal of the risks might affect the decisions on whether to adopt or not the protective mechanism. Hence, we extend the PMT by also incorporating the perceived risk related to engaging with the protective behavior (see further section 2).

Our research was conducted within the Costa Rican coffee sector, which is a relevant research context for two reasons. First, coffee growers are highly vulnerable to climate change (Verburg et al., 2019) due to the projected increase in the temperature and changes in main region's suitability (Ovalle-Rivera et al., 2015). Second, low coffee prices and disease outbreaks threaten the sector's sustainability, jeopardizing smallholder farmers' livelihoods (Bunn et al., 2015). This demonstrates the urgency to understand better the complexity of farmers' decisions toward implementing adaptation and mitigation actions, which may help boost smallholders' resilience (Avelino et al., 2015). We argue that behavioral components such as CSA's perceived benefits and risks might be key in farmers' decisions and their capacity to tackle climate threats.

The organization of the remaining sections of this paper is as follows. Section 4.2 describes the theoretical background and outlines the research hypothesis; Section 4.3

18 PMT has shown to be a valuable framework for understanding the underlying cognitive processes that influence individuals' decisions to adopt protective behaviors in different contexts and domains (e.g., facing different types of threats). PMT has been applied to a variety of protective behaviors in different domains (for a systematic review, see eg Kothe et al., 2019) . For example, soil conservation management behaviors (Huenchuleo et al., 2012), determinants of conservation and mitigation practices under drought (Keshavarz & Karami, 2016), adoption of sustainable agricultural practices (Bopp et al., 2019), engagement in pro-environmental behavior to reduce pollution (Wang et al., 2019), and farmers responses to mitigate effects of floods (Tabe-Ojong et al., 2020). More broad application of the PMT includes water conservation (Yazdanpanah et al., 2014) or farmers adapting to extreme weather events (Ghanian et al., 2020). Thus, there is a wide body of literature that supports the applicability of the PMT for analyzing CSA adoption.

presents the methods, including an overview of the study area, sampling, survey, and model estimation; Section 4.4 describes the data, followed by the empirical model; Section 4.5 presents the discussion of the main findings; Finally, Section 4.6 provides the study's concluding remarks.

4.2 Theoretical background

In this section, we present the theoretical approach that combines the PMT (subsection 4.2.1), the potential perceived risks of the protective behavior (subsection 4.2.2), and the influence of farmers' social and demographic characteristics (subsection 4.2.3). Finally, we propose an integrated approach that will serve as a basis to construct the extended model to guide our analysis of the drivers influencing farmers' interrelated CSA adoption (subsection 4.2.4).

4.2.1 Protection Motivation Theory

Guided by the principle that the engagement in protective behaviors (in this case adopting CSA) is explained by how individuals process information related to potential threats and the perceived value of the possible solutions to reduce their risk (Floyd et al., 2000; Rogers, 1983). The PMT postulates that two fundamental processes – threat appraisal and coping appraisal – underlie the decision toward protective behavior (Rogers, 1975). The threat appraisal encompasses the perceived severity and vulnerability perceptions (Kothe et al., 2019). Perceived severity reflects the perceived magnitude of an existing risk — i.e., how serious the risk is— and perceived vulnerability covers the extent to which an individual is susceptible to the existing threat (Bockarjova and Steg, 2014). According to Clarke et al. (2021) the higher perceived threat severity and susceptibility resemble a higher engagement in the protective behavior. For example, when farmers are aware of climate risks (drought, floods, soil erosion), they are more likely to care about mitigating the risks, which might result in a higher implementation of pro-environmental practices (Zhou et al., 2020). However, PMT stipulates that protective behavior will only arise if the individual also experiences a coping appraisal.

Coping appraisal includes three components: self-efficacy, response efficacy, and response cost (Floyd et al., 2000). Self-efficacy is the individual's perception of their ability to perform the protective behavior (Bockarjova and Steg, 2014). Response efficacy relates to the belief that the protective behavior will effectively prevent the threat (Rogers, 1983). The higher the self-efficacy and the response efficacy, the higher the engagement in protective behavior (Botzen et al., 2019; Tabe-Ojong et al., 2020). For example, suppose adopting soil conservation practices is considered a possible solution to climate change threats. In that case, self-efficacy refers to farmers' ability to implement drought mitigation strategies, and response efficacy is the perceived effectiveness of the practices (Keshavarz and Karami, 2016). Response cost refers to the perception of the cost associated with the protective behavior and reflects not only an economic burden but also time and emotional effort, thus is expected to relate inversely with the protection motivation (Badsar et al., 2022; Bubeck et al., 2018; Floyd et al., 2000). It has been demonstrated that farmers' decisions to uptake conservation practices and use bio-fertilizers are heavily restricted by time and financial costs (Long et al., 2016).

4.2.2 Perceived risks of protective behavior

As we described in the previous subsection, the PMT is useful for understanding individual protective behaviors, and scholars have shown the predictive power when individuals face different threats (e.g., in realms of health, environment, and climate) (Zhou et al., 2020). However, the PMT does not consider how individuals respond to risks that arise due to attempts to mitigate the perceived threat (primary risk) (Cummings et al., 2020). The higher the perceived primary risk (e.g., drought or soil erosion), the more likely an individual is to implement a self-protective behavior (Bopp et al., 2019; Grothmann and Patt, 2005). However, the attempts to manage the primary risk (e.g. climate risk management strategies) often create untended consequences, trade-offs, inconvenience, or potential adverse outcomes from adopting the protective measures (Newell and Taylor, 2018); this is referred to as a *secondary risk* (in this case, the risks associated with adopting CSA technologies). In the context of technology adoption, some authors acknowledge the contested nature and potential unintended consequences and trade-offs in income, yields, and labor use of the promoted "solutions" to face climate change (e.g., CSA technologies) (Hellin and Fisher, 2019; Taylor, 2018). For example, practices such as integrated pest management require more labor and often lead to a labor burden on women, or soil conservation practices might affect farm productivity via yield reduction (Cavanagh et al., 2017).

Acknowledging the role of secondary risks in decision-making suggests that individuals weigh both the perceived threat and secondary risks when deciding whether to engage in protective behaviors (Cummings et al., 2020). The secondary risk appraisal "reflects individuals' perceptions of the severity and likelihood of experiencing harm as anticipated consequences of their actions" (Cummings et al., 2020, p. 208). Accordingly, if the individual, for instance perceives a high risk associated with using certain bio pest control such as potential harm to beneficial soil microorganisms, yield reduction, or harm to human health, they might be less likely to implement such protective mechanisms. Thus, individuals are expected to reduce their intents and protective behaviors from the primary risk -such as climate change- if they regard the suggested preventive activity as risky (Cummings et al., 2020).

4.2.3 Farmers' social and demographic characteristics

Besides the role of the behavioral drivers in explaining farmers' preferences, technology adoption studies focus on the individual social and demographic characteristics as enablers or barriers to the adoption (Feder et al., 1985; Feder and Umali, 1993). CSA adoption studies have emphasized the role of age, education, gender, and other structural drivers such as farm location, labor, access to credit, and group membership in explaining farmers' decisions (Khoza et al., 2019; Makate et al., 2019; Teklu et al., 2023). The evidence shows that age has a negative effect on the adoption of crop diversification and nutrient management practices (Aryal et al., 2020). Structural drivers such as farm location and labor use are usually positively related to adoption (Prokopy et al., 2019). As for farm location, less distant farms may be keener to uptake new technologies (Teklewold et al., 2013), and some geographical and agroecological conditions may favor the adoption of specific practices while others may not (Lipper et al., 2015; Zilberman et al., 2018). Labor positively affects adoption since having more labor available to implement new technologies might facilitate implementation and promote learning (Jara-Rojas et al., 2012).

Other drivers, such as group membership in farmers' organizations, have shown a positive relationship with adopting certified seeds, soil testing and crop rotation (Kangogo et al., 2021), and soil and water conservation (Makate, 2019). Accordingly, in the coffee sector, farmers who belong to cooperatives have higher chances of adopting water conservation practices than non-cooperative members (Bro et al., 2019). Others have positively associate being a cooperative membership with better/differentiated market prices (Wollni and Zeller, 2007). As for market access, the number of buyers has been related to a higher probability of adoption (Teklewold et al., 2013), suggesting a positive relationship between the number of buyers and CSA adoption. Lack of financial resources is one of the main barriers to adopting new technologies (Long et al., 2017); thus, having access to credit and sufficient financial resources is often positively related to adopting crop diversification practices (Gebrehiwot & Van Der Veen, 2013; Makate et al., 2019) or the adoption conservation practices (Prokopy et al., 2019).

While farmers' social and demographic characteristics are not the primary focal point of this paper, we acknowledge their significance, as highlighted in the existing literature on technology adoption. These characteristics offer valuable insights for attaining a comprehensive understanding of CSA adoption, albeit not at this study's core.

4.2.4 Extended model

Following from the sections above, we integrate the PMT from Rogers (1983) and the cognitive component of secondary threat appraisal proposed by Cummings et al. (2020), and farmers social and demographic characteristics of the farmer for explaining farmers' adoption decisions (Feder & Umali, 1993; D. J. Pannell & Claassen, 2020) (Figure 4.1). Based on subsections 4.2.1 and 4.2.2 we hypothesized the following:

- H1a. Perceived severity has a significant positive effect on CSA adoption
- H1b. Perceived vulnerability has a significant positive effect on CSA adoption
- H2a. Response efficacy has a significant positive effect on CSA adoption
- H2b. Self-efficacy has a significant positive effect on CSA adoption
- H3. Response cost has a significant negative effect on CSA adoption
- H4. Secondary risk appraisal has a significant negative effect on CSA adoption

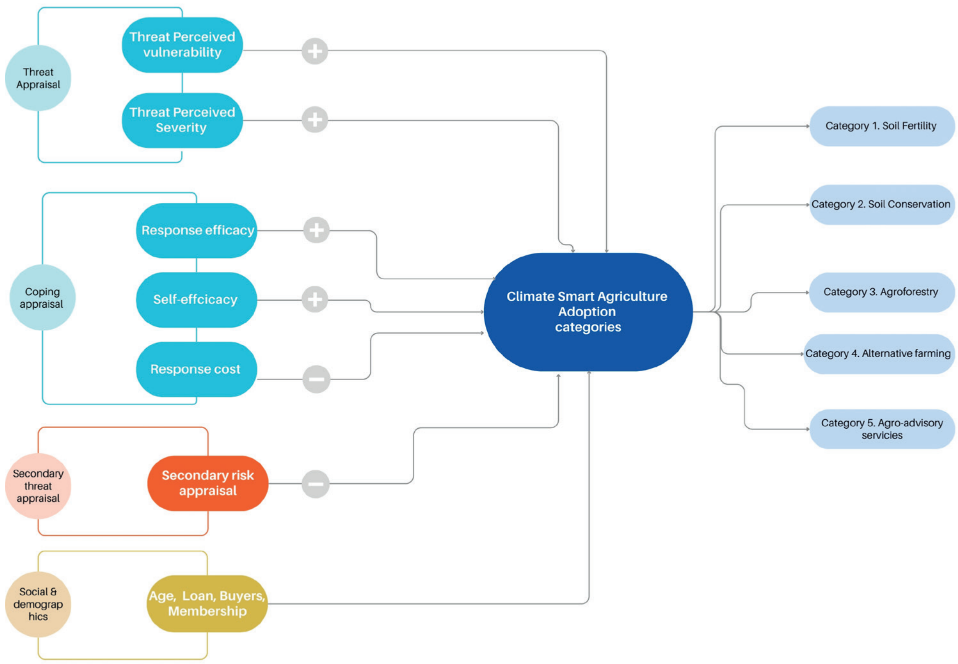

Figure 4.1 Conceptual model of the extended protection motivation theory

4.3 Methods

4.3.1 Study area

The study is focused within the coffee sector in Costa Rica given its vulnerability to climate change (Ordaz et al., 2010). The projected rise in temperatures and shifts in precipitation patterns are expected to have detrimental impacts on coffee production, flowering, and fruiting (Avelino et al., 2015), including a reduction of crop suitability by about 20% by 2050 (Ovalle-Rivera et al., 2015). These climate variations are also anticipated to exacerbate the prevalence of coffee pests and diseases (e.g., leaf rust and coffee berry borer) (Harvey et al., 2017). According to the Ministry of Agriculture (MAG) and National Coffee Institute (ICAFE), in 2018, 25.7% of the coffee farms were under threat of coffee leaf rust (CICAFE, 2019) being the regions of Perez Zeledón and Coto Brus the most affected ones (41.4% of the coffee harvest was under threat). Severe outbreaks of coffee leaf rust resulted in heavy yield and quality losses (Avelino et al., 2006). Consequently has had direct impacts on smallholder farmers — most of them growing on average 2.2 hectares—(ICAFE, 2022) since they are heavily dependent on coffee as their primary source of income (Läderach et al., 2017).

This situation calls for prioritizing strategies for enhancing farmers' resilience to climate change, and as a response, the MAG, ICAFE, research centers, and universities have been financing breeding pilot projects to develop and test rust and drought-resistant varieties (Kahsay et al., 2023). These efforts are coupled with technical assistance to promote better management practices, including shade cultivation and ecological control (Harvey et al., 2021; Lyngbaek et al., 2001). In addition to adaptation strategies, Costa Rica is committed to carbon neutrality and has redirected efforts to reduce GHG (Wallbott et al., 2019). Considering that coffee is a highly nitrogen-intensive crop and is responsible for 9.38% of the country's national N_2O emissions (IMN and MINAE, 2021), technologies aiming at GHG reduction are central (e.g., soil test sampling, integrated pest management, implementing soil conservation practices, and agroforestry) (Pomareda, 2020). Despite the efforts and the urgency, the adoption of both mitigation and adaptation agricultural technologies remains scattered across the sector (World Bank et al., 2014).

4.3.2 Sampling and survey

We implemented a two-step approach to develop the survey. Initially, we organized two focus group discussions involving 11 participants: technicians, researchers, extension agents, farmers, and farmers' representatives. Engaging these diverse stakeholders gathered valuable insights and perspectives about the type of CSA technologies in place, their perceptions about their effectiveness and suitability at the local level.

Drawing insights from the focus groups and theoretical background, we structured the survey instrument to cover general information, socio-demographics, CSA technologies, and behavioral items. A pilot test involving 13 farmers helped refine the survey, resulting in the final questionnaire. The survey was conducted in Spanish from August to December 2021, using electronic devices and Qualtrics software for data retrieval. On average, participants took 40 minutes to complete the survey.

In order to ensure a representative sample, our sample selection process considered the population of 29918 coffee farmers in 2019 (ICAFE, 2019). The ICAFE has categorized the country's coffee-growing regions based on altitude, soil characteristics, and the coffee flavor profiles produced in each area (Figure 4.2).

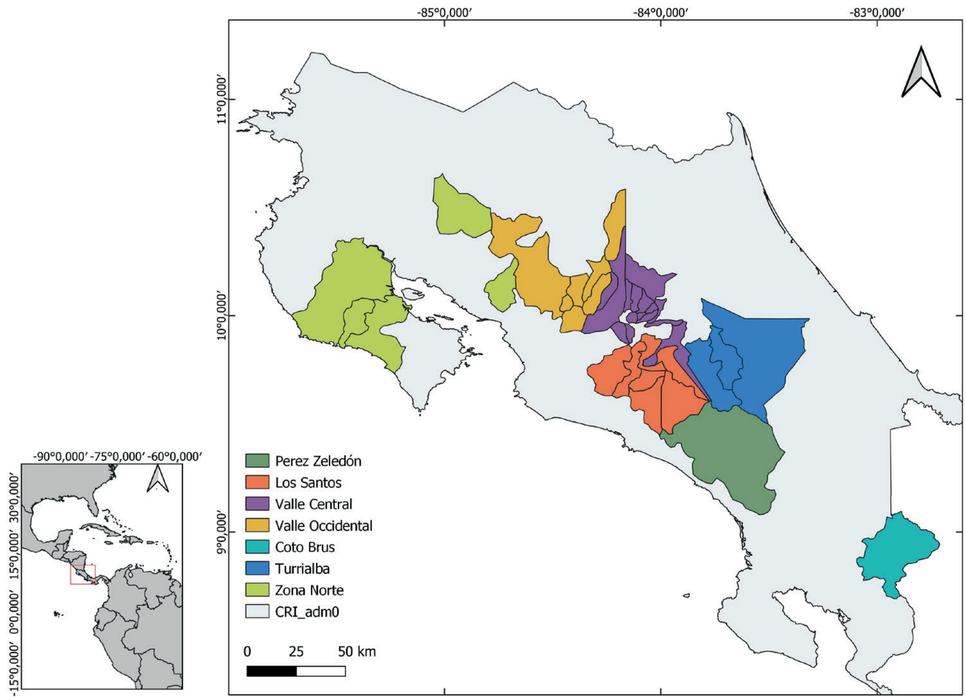

Figure 4.2 Map of the study area divided by coffee regions

We used the sample size formula for a finite population; we aimed for representative sampling with a 4.5% sampling error and a 95% confidence level. The calculated minimum sample size contained 467 farmers; we surveyed 530 farmers (See Appendix C1). However, 11 surveys were discarded due to incomplete information and inconsistent data. As a result, we analyzed 519 surveys using Stata16.0.

4

4.3.3 Variables measurement

4.3.3.1 Independent variables

We conducted a principal component analysis (PCA) including 28 items (see Appendix C2). The results of the PCA showed that seven components should be retained. The identified components were then used as independent variables. We utilized the Kaiser varimax rotation and retained components with eigenvalues greater than one (Kaiser, 1958). We calculated Cronbach's alpha to assess each component's internal consistency. The Cronbach's alpha values ranged from 0.61 to 0.86, indicating adequate reliability (Hair et al., 2010). The Kaiser-Meyer-Olkin (KMO) is considered adequate (KMO = 0.819), and the Bartlett sphericity test ($p<0.000$) indicates correlation between items (see Appendix C3 for more detail). All the items were measured on a five-point Likert scale.

Regarding the threat appraisal, we measured *perceived severity* by averaging respondents' agreement with five statements about the threat of yield losses due to climate change, affections on bean quality, and increased plant diseases. We measured *perceived vulnerability* with five statements about farmers' likelihood of experiencing negative consequences from climate change.

As for the coping appraisal constructs, since the strength of the CSA approach relies on the wide variety of technologies targeting different objectives (productivity, adaptation, mitigation), response efficacy was divided in two subgroups. The first group —*response efficacy type a*— comprises four items measuring the extent to which the CSA technologies (e.g., soil fertility practices, the use of pest/climate resistant breeds, and the usefulness of weather forecasting information and agro-advisory mobile apps) help farmers reduce cost and increase productivity or the quality of the harvested coffee. The second group —*response efficacy type b*— includes three items measuring the extent to which soil and water conservation and shade trees are valuable to the coffee plot and help to increase farm resilience. Similarly, the respondents were asked to rate their confidence in performing CSA technologies to measure self-efficacy. The first group —*self-efficacy type a*— included items related to farm management, such as soil fertility and efficient use of inputs delivering high-quality coffee beans. Moreover, the second group —*self-efficacy type b*— is defined by three items related to using agriculture-related apps and climate information systems. As for the response cost, we use one item related to the time and financial investment of implementing CSA technologies.

We measure the secondary risk appraisal with four items indicating the perception that CSA has, or could have, negative consequences on the farm and reflecting farmers' fear of potential losses (e.g. yield, labor, quality) associated with implementing these practices (See Appendix C3 for a detailed description).

4.3.3.2 Pro-environmental behavior: CSA adoption

Broadly, we define pro-environmental behavior as the adoption of CSA technologies. Since, at the farm level, CSA is context-dependent to ensure its appropriateness, we conducted two focus group discussions to list and prioritize the CSA technologies collectively. We considered 14 technologies ranging from novel technologies, such as using mobile agro-advisory apps and climate-related information (Beza et al., 2018; Emileva et al.,2023), to longstanding practices, such as agroforestry or soil conservation (Akter et al., 2023; Wauters and Mathijs, 2006). In order to be able to use all of the 14 technologies, we group them into five broad categories, using as basis existing categorizations on CSA (e.g., Kpadonou et al., 2017, Amadu et al., 2020; Smit & Skinner, 2002). The five broad categories include soil fertility, soil conservation, agroforestry, agro-advisory mobile apps, and alternative farming practices (Table 4.1).

Table 4.1 Description of the CSA technologies

CSA category	Types of technology	Description	Benefits (+) and trade-offs (-)	Reference
Soil fertility	Soil analysis Soil amendments Use of fertilizers according to soil type	Practices aimed an efficient fertilizer usage for long-term soil productivity.	+Enhance soil health +Increase soil organic matter +Optimize nutrient availability +Reduce the overall GHG -Knowledge-intensive practices	Chandran and Joseph, 2009; Faridi et al., 2020; Lyngbaek et al., 2001; Walling et al., 2011
Soil conservation	Soil conservation practices Windbreaks barriers Plant vegetative measures	Implementing practices to reduce soil erosion and optimize nutrient management.	+Carbon sequestration +Resiliency to extreme rainfall events -May increase labor costs	(Bunn et al., 2015; Jara-Rojas et al., 2013; Valkama et al., 2020; Verburg et al., 2019)
Agroforestry	Use of non-conventional shade threes Agroforestry Rainwater harvesting techniques	Practices that combine annual and perennial crops with coffee plants and where necessary coupled with rainwater harvesting techniques	+Water uptake +Buffer daily temperatures +Income diversification +Carbon sequestration + Less energy and input intensive - Reduced flowering intensity and cherry load in intensive monocultures. -may increase coffee leaf rust disease incidence.	Avelino et al., 2006; Chain-Guadarrama et al., 2019; Harvey et al., 2018; Mercer, 2004; Rapidel et al., 2012
Agro-advisory apps	Early warning apps Harvest forecast app	Includes climate-related information apps to check the weather forecast, early warning apps (live alerts on coffee leaf rust spraying recommendations), and harvesting forecast apps coupled with management practices recommendations to reduce the impact of threatening events	+ Preparedness and response to unpredictable weather patterns and extreme weather events +Plan agricultural activities based on climate and extension advice -Knowledge-intensive and limited to internet connectivity	Aggarwal et al., 2018; Beza et al., 2018; Westermann et al., 2015; WorldBank et al., 2014
Alternative farming	Crop diversification Organic fertilizer Organic farming practices (no pesticides use)	Using organic inputs for pest control (e.g., biopest control), use of bio/organic fertilizer, and crop diversification (ginger, turmeric, cassava)	+Increases in the organic matter +Water infiltration and retention +Removing CO_2 +Beneficial interactions between various crops +Reducing the prevalence of weeds, pests and diseases +Income diversification -Higher labor investments	Bhattacharyya et al., 2022; Lyngbaek et al., 2001; Teklewold et al., 2019

Since our primary goal is to study the multiple pro-environmental behavior in form of the adoption of CSA technologies, we categorize farmers from each category as an adopter or non-adopter. To define the adoption variable, in the case of soil fertility was coded as one if the number of technologies adopted were at least as high as the median value and zeroed otherwise. Thus, soil fertility is presented as a binary variable. We follow the same method to calculate the adoption/non-adoption of the other categories (See Appendix C4).

4.3.4 Models estimation

We use a Multivariate Probit (MVP) model to evaluate the drivers explaining the likelihood of adopting several CSA categories (subsection 4.3.4.1). Since studies in climate adaptation and mitigation have shown significant differences between the drivers explaining adaptation and mitigation strategies (Etumnu et al., 2023; Grothmann & Patt, 2005; Markanday & Galarraga, 2021), we performed a supplementary analysis to get a more comprehensive understanding of farmers' motivations or barriers to explaining adaptation and mitigation behaviors (adoption of mitigation/adaptation-led CSA technologies). We used a bivariate probit model since the literature has shown interrelation between the adoption of adaptation and mitigation practices (Niles et al., 2016) (subsection 4.3.4.2).

4.3.4.1 Multivariate Probit

Farmers' adoption decisions can be explained using univariate or multivariate models. Univariate approaches do not recognize that farmers' choices on whether to adopt or not technology or practice are interrelated (Kassie et al., 2013). We use an MVP econometric model based on the assumption that farmers may choose to adopt one or more technologies given their needs and conditions (Aryal et al., 2018). We follow similar methodological approaches used to study multiple technology adoption (e.g,Kangogo et al., 2021; Teklewold et al., 2013; Teklu et al., 2023). Following Greene (2003) and Greene & Hensher (2009), our econometric model accounts for the potential correlation of unobserved error terms of the binary-dependent CSA technologies.

The MVP model is determined by a set of binary dependent variables (Y_{ig}), such that:

$$Y_{ig}^{*} = X_{ig}\beta_g + \varepsilon_{ig}, \qquad g = Soil\,fertility, \ldots agroforestry\; i = 1,2,\ldots n \tag{1}$$

and

$$Y_{ig} = \begin{cases} 1 \; if \; Y_{ig}^{*} > 0 \\ 0 \; otherwise \end{cases} \quad g \; = \; Soil\,fertility\,practices \ldots agroforestry\; i = 1,2,\ldots n \tag{2}$$

Assuming an i[th] farmer (i= 1,2,….n) deciding on whether to adopt or not g[th] CSA technologies such as 1= soil fertility, 2= soil conservation, 3= agroforestry, 4= alternative farming, 5= agro-advisory mobile apps. If Uo represents the benefits of non-adoption and Uk the benefits of adopting gth technology/practice. The farmer decides to adopt the gth technology if $Y^*_{ig} = Uk - Uo > 0$. In this case, the net benefit the CSA technologies adoption is a latent variable (Y^*_{ig}), determined by the observed farmer threat appraisal, coping appraisal, perceived adoption risks and socio-demographics drivers (X_{ig}) and unobservable drivers capture by the error term ε_{ig}. The vector of the variables to be estimated is represented by β_g.

In the MVP, since it is feasible the adoption of multiple technologies, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean, a unit of variance, and a symmetric covariance matrix (Ω)

$$\Omega = \begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} & \rho_{15} \\ \rho_{21} & 1 & \rho_{23} & \rho_{24} & \rho_{25} \\ \rho_{31} & \rho_{32} & 1 & \rho_{34} & \rho_{35} \\ \rho_{41} & \rho_{42} & \rho_{43} & 1 & \rho_{45} \\ \rho_{51} & \rho_{52} & \rho_{53} & \rho_{54} & 1 \end{bmatrix}$$

Where ρ is the pairwise correlation coefficient of the model's error terms of any two adoption equations. The sign a significance of ρ provides evidence of the nature of the relationship between equations. A positive sign denotes a complementary relationship, while a negative indicates substitute technologies (Teklewold et al., 2013). If the error terms correlation shown in the off-diagonal elements of the variance-covariance matrix becomes non-zero, Equation 2 becomes an MVP model.

4.3.4.2 Bivariate probit

According to Greene & Hensher (2009) the bivariate probit model (BVP) considers two dichotomous decisions simultaneously instead of multiple simultaneous decisions as the MVP. The BVP is an extension of the probit model and has been has been used to explain joint technologies adoption (see, e.g., Jara-Rojas et al., 2013). The specification of the BVP can be expressed as:

$$y^*_{ai} = \beta_a{'}x_a + \varepsilon_{ai}, \quad [y_{ai} = 1 \; if \; y^*_{ai} > 0, 0 \; otherwise] \tag{4}$$

$$y^*_{mi} = \beta_m{'}x_m + \varepsilon_{mi}, \; [y_{mi} = 1 \; if \; y^*_{mi} > 0, 0 \; otherwise] \tag{5}$$

Where $y*_{ai}$ = Adoption/non-adoption of adaptation-led technologies[19]; $y*_{mi}$ = Adoption/non-adoption of mitigation-led technologies; i=1,2, ...n; x'= vector of independent variables; β_a, β_m = parameters; $\varepsilon_{ai}, \varepsilon_{mi}$ = error terms. The error terms are assumed to be distributed bivariate normal and it uses the maximum likelihood estimation to estimate the parameters:

$$\binom{\varepsilon_a}{\varepsilon_m} \sim N\left[\binom{0}{0}, \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix}\right]$$

Where $\binom{\varepsilon_a}{\varepsilon_m}$ = 0, Var(ε_a)= Var(ε_m) =1, Cov (ε_a, ε_m) = ρ. The significance of ρ suggests that the two models are interrelated and that the two equations can be jointly estimated to yield unbiased estimates. Since the model coefficients are not directly interpretable we computed the marginal effects following Greene (1996).

4.4 Results

We organize the results of this section into three subsections: 4.4.1 we present the descriptive statistics; 4.4.2, we describe the CSA adoption rates and the drivers explaining the adoption of multiple CSA categories; and 4.4.3, where we provide a supplementary analysis of the joint adoption of mitigation-led and adaptation-led technologies.

4.4.1 Descriptive statistics: dependent and explanatory variables

The descriptive statistics of the dependent and independent variables are shown in Table 4.2

19 Besides the general categorization (subsection 4.3.3.2) we investigated if 14 CSA technologies and practices were mainly oriented to fulfill adaptation or mitigation objectives. Since adaption and mitigation technologies are context-based, some CSA technologies jointly contribute to both targets: adaptation and mitigation. We built our categorization based on the focus group discussions. The participants were asked to categorize the primary purpose of CSA technology/practice. Based on their categorization we classified the 14 technologies and practices accordingly (see Figure 4.3 section 4.4.3). To determine the adoption of adaptation-led technologies if the farmers adopt at least four out of eight technologies. Similarly for mitigation-led category a farmers are considered adopters is they use at least three of six technologies.

Table 4.2 Summary statistics of dependent and independent variables

Variable	Description	Mean	Std. Dev.
Dependent variables			
Soil fertility	1 if the farmer adopts at least three technologies, 0 otherwise	.601	.490
Soil conservation	1 if the farmer adopts at least two technologies, 0 otherwise	.609	.488
Agroforestry	1 if the farmer adopts at least two technologies, 0 otherwise	.528	.499
Agro-advisory mobile apps	1 if the farmer adopts one technology, 0 otherwise	.379	.486
Organic/Alternative	1 if the farmer adopts one technology, 0 otherwise	.408	.492
Adaptation-led CSA	1 if the farmer adopts at least four technologies, 0 otherwise	.374	.484
Mitigation-led CSA	1 if the farmer adopts at least three technologies, 0 otherwise	.480	.500
Explanatory variables			
Perceived Severity	Average of 4 items: farmer perception on how harmful the consequences of climate change are	4.255	.734
Perceived Vulnerability	Average of 5 items: farmers' likelihood of experiencing negative consequences from climate change.	3.984	.969
Perceived response efficacy [a]	Average of 4 items measuring the efficacy of type a CSA technologies	4.130	.770
Perceived response efficacy [b]	Average of 4 items measuring the efficacy of type b CSA technologies	4.719	.454
Perceived Self-efficacy [a]	Average of 4 items measuring farmer's ability to enact the type a CSA technologies	4.181	.726
Perceived Self-efficacy [b]	Average of 4 items measuring farmer ability to enact the type b CSA technologies	2.654	1.132
Perceived costs	Average of 2 items measuring effort investments of CSA technologies	2.553	1.249
Secondary risk appraisal	Average of 4 items measuring farmer evaluation of the magnitude of harm associated with engaging with CSA	1.914	.864
Buyers	Number of mills/business the farmers sells coffee to	1.206	.471
Group Membership	1 if the farmer is a member of a cooperative or a farmers' organization, 0 otherwise	.761	.427
Labor	1 if the farmer hires labor for farming activities, 0 otherwise	.362	.481
Loan	1 if the farmer has a loan to finance coffee farming, 0 otherwise	.526	.499
Region: Central Valley	1 if the farm is located in the Central Valley region, 0 otherwise	.169	.376
Age	Farmers age in years	52.601	13.984

4.4.2 Drivers explaining interrelated CSA adoption

In this subsection, we tested the drivers explaining the adoption of interrelated CSA technologies (Table 4.3). Section 4.4.2.1 presents the findings related to climate risk appraisal (Hypothesis 1a and 1b) and coping appraisal (Hypothesis 2a, 2b, and 3). In section 4.4.2.2. we tested hypothesis 4 related to the secondary risk appraisal. Section 4.4.2.3 presents farmers' social and demographic characteristics. Finally in Table 4.4 we present a summary of key findings.

The results from the pairwise correlation coefficients across the residuals of the MVP model are statistically significant (See Appendix C5) . From ten correlation coefficients, eight resulted in significant and positive correlated —complementary technologies— showing that the probability of adopting a technology/practice is conditioned on whether or not a technology/practice in the subset has been adopted. The X^2 test ($X^2(10) = 43.1398$ Prob > $X^2 = 0.0000$) supports the estimation using the MVP approach. The pairwise correlation reveals that soil fertility positively correlates with soil conservation, agroforestry, alternative farming, and agro-advisory apps. Soil conservation practices have a synergetic or complementary effect on agroforestry and alternative practices. We did not find evidence to suggest a correlation between the use of apps and soil conservation and alternative farming. We did not see a negative correlation between CSA technologies.

4

The MVP regression results are reported in Table 4.3 to identify the key drivers of adopting interrelated CSA technologies. Our estimates show that the model fits the data well (Wall X^2 (70) = 298.90 Prob > X^2 = 0.0000). The results evidenced that the model accounts for the unobserved correlation across farmers' decisions to adopt multiple CSA technologies.

4.4.2.1 Climate change risk and coping appraisal

The results showed mixed effects between perceived severity and CSA adoption. Perceived severity is positively associated with adopting soil fertility practices and agroforestry. The probability of adopting such practices- soil fertility and agroforestry- is higher for farmers with a higher perception of climate change risks than those with low climate risk severity (supporting H1a). However, perceived severity is unrelated to adopting soil conservation or alternative farming practices (not supporting H1a). As for perceived vulnerability (M =3.98 SD=0.85), our results showed a negative relationship between the perceived vulnerability and the adoption of soil conservation practices, agroforestry, and alternative practices, meaning that a higher perception of being affected/harmed by climate risks the less likely for the farmer to adopt the soil conservation, agroforestry, and alternative practices (contrary to our H1b).

As for the coping appraisal, we find that farmers perceived response efficacy (type a) is positively related to adopting agroforestry and agro-advisory apps (Supporting H2a). However is not related to the adoption of soil conservation, soil fertility, and alternative practices. In the case of response efficacy type b (the extent to which soil conservation practices and shade trees are useful to prepare against climate change), the higher the response efficacy, the more likely to use agro-advisory mobile apps. Adopting alternative practices, agroforestry, soil conservation, and fertility practices is not predicted by response efficacy type b. Type a self-efficacy — mainly associated with farmers' perceived ability to manage farm resources efficiently, including inputs, labor, herbicides, and fertilizers—is positively related to adopting soil fertility and conservation. In the case of type b self-efficacy, related to farmers' ability to implement technologies to protect themselves from climate change, as well as the use of high-tech in the coffee plots, our findings show a positive relation, the higher the farmers' type b self-efficacy, the more likely to adopt soil conservation, soil fertility, and agro-advisory apps. Both results support hypothesis H2b

The perceived cost is inverse to the adoption of technologies related to the agroforestry categories, pointing out that farmers are less likely to adopt those technologies when they expect high monetary and time constraints (Supporting H3). Cost does not predict the adoption of alternative practices and the use of apps. We found a direct relation between perceived cost and the adoption of soil fertility practices (the higher the cost, the more likely the adoption of the practice), signaling a dependency between soil fertility practices and farm productivity.

4.4.2.2 Perceived risks of protective behavior

The evidence shows that farmers perceived the secondary risk as low (M= 1.92 SD =0.86). The perception that CSA has or could have negative consequences on the farm or that CSA can lead to reduced yield/production of harvested coffee is not perceived as a high threat. Although evaluating the magnitude of harm associated with engaging with CSA technologies is perceived as a low threat — i.e., low perception of the secondary risk— our findings show that it is negatively associated with adopting soil fertility practices. Thus, in the case of soil fertility practices, the higher the perceived secondary risk, the less likelihood to adopt (supporting hypothesis 4). The perceived risk of CSA fails to predict the adoption of soil conservation practices, and we do not find enough evidence to relate it to agroforestry and alternative practices (significant at 10%).

4.4.2.3 Farmers' social and demographic characteristics

We find that age is negatively related to adopting alternative practices, meaning that the more age, the less likely to adopt alternative practices. Farmers from Central Valley are less likely to adopt soil fertility practices, which can relate to the soil type, usually known as the most fertile area in Costa Rica because of the volcanic soil type (Payán et al., 2009). The number of coffee mills where coffee farmers sell their produce plays an important role in adopting soil fertility and agroforestry. The more buyers, the more likely to adopt both types of practices. Regarding farmers' membership in organizations as cooperatives, we find associated farmers more likely to adopt soil fertility, alternative farming practices, and agro-advisory apps. Moreover, the other variables, such as hired labor and access to credit, failed to predict the adoption of the different CSA categories.

Table 4.3 Multivariate probit model estimates for CSA technologies

	Soil Fert	Soil Cons	Agrofor	Alternat	Apps
P. Severity	0.28***	0.03	0.29***	0.08	0.12
	(0.101)	(0.096)	(0.100)	(0.091)	(0.094)
P.Vulnerability	-0.03	-0.22***	-0.17**	-0.15**	0.05
	(0.074)	(0.077)	(0.073)	(0.071)	(0.074)
Response efficacy[a]	0.06	0.09	0.18**	0.08	0.17*
	(0.091)	(0.091)	(0.089)	(0.089)	(0.093)
Response efficacy[b]	0.17	0.21	0.04	0.04	0.34**
	(0.152)	(0.146)	(0.139)	(0.137)	(0.157)
Self-efficacy[a]	0.19**	0.20**	0.08	0.10	-0.05
	(0.096)	(0.091)	(0.089)	(0.091)	(0.095)
Self-efficacy[b]	0.18***	0.19***	0.09	-0.03	0.23***
	(0.061)	(0.060)	(0.061)	(0.058)	(0.061)
Perceived Cost	0.17***	-0.08*	-0.15***	-0.03	-0.03
	(0.051)	(0.048)	(0.048)	(0.048)	(0.050)
Secondary risk	-0.17**	-0.08	-0.13*	-0.13*	0.14**
	(0.075)	(0.069)	(0.072)	(0.071)	(0.073)
Buyers	0.44***	0.21	0.35***	-0.13	0.04
	(0.137)	(0.138)	(0.131)	(0.125)	(0.128)
Group_Mem	0.34**	-0.02	-0.01	0.24*	0.36**
	(0.146)	(0.147)	(0.144)	(0.141)	(0.146)
Labor	0.09	-0.04	0.12	-0.19	0.19
	(0.128)	(0.130)	(0.127)	(0.126)	(0.130)
Loan	-0.04	0.11	-0.07	0.17	0.10
	(0.128)	(0.125)	(0.124)	(0.124)	(0.127)
REG_Central Valley	-0.36**	0.07	0.15	0.22	-0.15
	(0.179)	(0.179)	(0.176)	(0.175)	(0.180)
Age	-0.00	-0.00	0.01	-0.01**	-0.00
	(0.005)	(0.004)	(0.004)	(0.004)	(0.005)
Constant	-3.77***	-1.33	-2.13***	-0.05	-4.24***
	(0.823)	(0.825)	(0.795)	(0.797)	(0.869)

Table 4.3 Continued

	Soil Fert	Soil Cons	Agrofor	Alternat	Apps
LogLik	-1584.7987				
Wald $X^2(70)$	298.78				
Prob > X^2	0.0000				
AIC	3340.065				

Notes: Robust standard errors in parentheses ; *** p<0.01, ** p<0.05, * p<0.1; Soil Fert = Soil fertility, Soil Cons =Soil conservation, Agrofor = Agroforestry, Alternat = Alternative farming, Apps = agro-advisory mobile apps

4.4.3 Drivers explaining the adoption of adaptation and mitigation-led CSA technologies

Since CSA is about promoting mitigation and adaptation technologies (Figure 4.3), as a supplementary analysis, we provide a detailed explanation of the differences in drivers explaining the joint adoption. Accordingly, 47% of the farmers adopt mitigation led, 37% adopt adaptation led, and 23% of the farmer both.

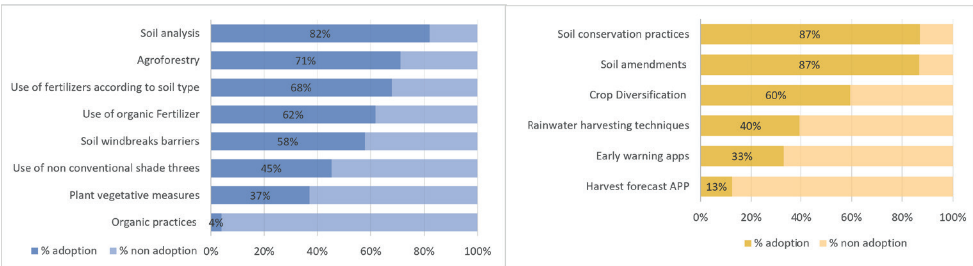

Figure 4.3 Percentage of the adopter and non-adopters of adaptation-led (blue colored) and mitigation-led technologies (yellow colored).

The bivariate probit estimates predicting the adoption of mitigation or adaptation-led CSA are shown in Table 4.4. As expected, the positive sign of mitigation and adaptation correlation errors means that the practices are complementary (Wald test of rho=0: $X^2(1) = 11.9953$, Prob > $X^2 = 0.0005$). Regarding the overall evaluation of the model, 6 of 12 variables were significant at 5% in the mitigation equation and 4 of 12 in the adaptation model.

The perceived severity is positively related to adopting adaptation technologies (supporting H1a), and we do not have the evidence to relate it with mitigation lead technologies. Farmers´ perceived vulnerability is negatively related to adopting mitigation and adaptation-led technologies (does not support H1b). The higher the perceived vulnerability, the less likely they are to adopt mitigation and adaptation technologies. Regarding the coping appraisal, the higher the values of response efficacy, the higher the probability of adoption mitigation and adaptation technologies

(Supporting H2a). Moreover, self-efficacy shows a positive relation with mitigation-led technologies (supporting H2b) and not a significant relation with adaptation. Constraints such as perceived cost determine the probability of adopting adaptation in inverse relation, meaning that the higher the perceived cost, the lower the probability of adopting adaptation technologies and practices (supporting H3). The secondary risks are negatively related to adopting mitigation strategies (Supporting H4). The number of buyers is positively related to adopting mitigation technologies.

Table 4.4 Bivariate probit model of mitigation and adaptation-led technologies

	Mitigation		**Adaptation**	
	coeficients	rob std error	coeficients	rob std error
P Severity	0.14	0.092	0.26***	0.094
P Vulnerability	-0.12*	0.071	-0.19***	0.072
Self-efficacy	0.24***	0.055	0.08	0.055
Response efficacy	0.23***	0.084	0.26***	0.091
Secondary Risk	-0.25***	0.072	-0.03	0.071
Perceived Cost	-0.05	0.048	-0.10**	0.049
Buyers	0.32**	0.125	0.02	0.124
GroupMember	0.28*	0.143	0.16	0.142
Labor	-0.14	0.128	0.09	0.127
Loan	-0.1	0.125	0.06	0.124
Reg:Central Valley	0.0	0.175	-0.09	0.179
Age	0.0	0.004	-0.01*	0.004
athrho	0.26***	0.076		
Constant	-1.71***	0.591	-1.41**	-0.617
Wald chi2(24)	98.62			
Prob > chi2	0			
LogLikelihood	-640.55			
Observations	519			

Notes: rob std error= Robust standard errors; *** p<0.01, ** p<0.05, * p<0.1

As for the marginal effects of joint adoption (See Appendix C6). Shows the marginal effects of joint adoption — when adaptation and mitigation technologies are equal to 1—. An increase of 1% in the perceived severity increases the probability of adopting by 7.1%. Contrary to the expectation, an increase of 1% in farmers' perceived vulnerability decreases joint adoption by 5.5%. Regarding farmers' perceived ability to perform both practices, an increase of 1% in self-efficacy increases the adoption of adaptation and mitigation technologies and practices by 5%.

Similarly, an increase of 1% in farmers' response efficacy increases the probability of adopting both types of technologies by 8.3%. The perceived cost and barriers decrease the joint adoption by 2.5%, and an increase of 1% in the secondary risk may decrease the probability of joint adoption by 4.2%. The social and demographics drivers did not show explanatory power in the case of joint adoption.

Table 4.5. Summary of significant findings and hypothesis

Number	Description	Result
H1a	Perceived severity has a significant positive effect on CSA adoption	Supported: (+) related to soil fertility practices and agroforestry Supported: (+) related to adaptation-led technologies
H1b	Perceived vulnerability has a significant positive effect on CSA adoption	Not supported: (-) related to soil conservation, agroforestry, and alternative practices Not supported: (-) related to mitigation adaptation-led technologies
H2a	Response efficacy has a significant positive effect on CSA adoption	Supported: RE *type a* is (+) related to agroforestry and RE *type b* is (+) related to agri-advisory app services Supported: (+) related to mitigation adaptation-led technologies
H2b	Self-efficacy has a significant positive effect on CSA adoption	Supported: SE *type a* (+)related to soil fertility, soil conservation practices and SE *type b* (+) related to soil fertility, soil conservation practices and the use of mobile apps Supported: (+) related to mitigation-led practices
H3	Response cost has a significant negative effect on CSA adoption	Mixed relationships: (-) related to agroforestry and (+) related to soil fertility Supported: (-) related to adaptation-led technologies
H4	Secondary risk appraisal has a significant negative effect on CSA adoption	Supported: (-) related to soil fertility practices Inconclusive: significant at 10% agroforestry and alternative practices Supported: (-) related to mitigation-led technologies

(+) Positively related (-) Negatively related

4.5 Discussion

This study aimed to identify the key risk-related drivers influencing the interrelated adoption of CSA technologies — soil conservation, soil fertility, agroforestry, agro-advisory apps, and organic/alternative practices — proposed to mitigate the negative consequences of climate change. We extended the PMT from Rogers (1983) using the cognitive component of secondary threat appraisal proposed by Cummings et al. (2020), and farmers' social and demographic characteristics to better understand their protective behaviors. In the following subsections, we elaborate on three central findings: in section 4.5.1. we connect the CSA adoption with climate risk appraisal, coping appraisal and the appraisal of potential adoption risks —secondary risk—; in section 4.5.2 we expand on the farmers' social and demographic variables driving adoption, and section 4.5.3. we unravel the interrelations among the CSA technologies.

4.5.1 Connecting climate risk, coping appraisal and secondary risk with CSA adoption

Our results revealed that risk drivers had diverse significance in explaining the adoption of CSA categories. In this section, we draw key messages related to i) climate risk perceptions (hypothesis 1a and 1b), ii) coping appraisal (hypothesis 2a, 2b, and 3), and iii) the secondary risk appraisal (hypothesis 4). We demonstrated their predicting power for some of the CSA, not across all CSA categories under study.

As for the climate risk perception, we posed two hypotheses on the influence of perceived severity (H1a) and perceived vulnerability (H1b) in explaining CSA. Our findings partially support hypothesis 1a, which positively relates the perceived severity with CSA adoption (e.g., soil fertility and agroforestry technologies) and adaptation-led technologies, consistent with other studies (e.g., Bockarjova & Steg, 2014; Bopp et al., 2019; Grothmann & Patt, 2005). Our study suggests that heightened awareness of climate change risks increases the likelihood of adopting technologies within soil fertility and agroforestry categories. However, we observed heterogeneity — i.e. how well climate change perceived severity predicts all the adoption categories — as there was no relationship between the perceived severity and the adoption of soil conservation, alternative practices, and mobile agro-advisory apps. Our findings echo Kellstedt et al. (2008) and Niles et al. (2016), who also had mixed results and pointed out that more knowledge of climate change risks is associated with a lower likelihood of taking action; thus, farmers' perceptions of climate change risk do not consistently influence behavior.

As for perceived vulnerability —hypothesis H1b—our findings show mixed and unexpected results contrary to hypothesis 1b. Our results suggest that the higher the perception of being impacted by climate change risks, the less likely to adopt soil conservation, agroforestry, and alternative practices, which is inconsistent with the literature on protection motivation (Bockarjova and Steg, 2014; Keshavarz and Karami, 2016). Paradoxically, in our case, a high vulnerability perception resulted in farmers' inaction instead of triggering the adoption, which runs counter to what earlier research has found (Arbuckle et al., 2015). Although counterintuitive, it confirms that heightened awareness of climate change might relate to a reduced sense of perceived vulnerability due to risk normalization (Luís et al., 2018), and consequently, a poor risk appraisal may result in maladaptive responses increasing their vulnerability to the impacts of climate change (Deressa et al., 2009; Ricart et al., 2023). Thus, our study adds to the existing body of literature on climate risk perception that such context-specific climate risks —i.e., coffee leaf rust disease, droughts, or heavy rainfall— relate heterogeneously within the types of technologies understudy. This challenges the underlying assumptions of a homogenous set of drivers —one size fits all— for explaining all types of climate coping mechanisms and suggests a more nuanced and context-specific approach toward explaining farmers' decision-making under risk.

As for the coping appraisal: perceived efficacy (H2a), and self-efficacy (H2b), our results align substantially with the PMT literature (Ghanian et al., 2020; Wang et al., 2019). Farmers' perceived ability to perform the protective behavior and the perceived effectiveness of the recommended behavior are positively related to CSA (supporting H2a). This information is consistent with earlier studies on the acceptance of mobile SMS in the agricultural domain (Beza et al., 2018), conservation practices under drought (Keshavarz & Karami, 2016), and other protective behaviors (Badsar et al., 2022; Bubeck et al., 2012). However, we add to these previous studies that some CSA categories are significantly explained by self-efficacy, such as soil fertility practices, soil conservation, mobile apps, and mitigation-led technologies. In contrast, others, such as agroforestry and the use of mobile apps, are significantly explained by response efficacy. The practices encompassing the agroforestry category require more radical changes in the coffee plot arrangements (Vaast et al., 2016); we argue that in the first place, higher perceived potential benefits become more relevant than self-efficacy when it comes to the adoption. The broader implication of these findings is that focusing on the coping appraisal could be key for upscaling and developing successful climate mitigation strategies since the adoption rates are still low (37.9% of adopters).

Regarding the secondary risk appraisal, our findings show the explanatory potential of secondary risk for explaining the adoption of some CSA practices (supporting H4), including mitigation-led technologies. The secondary risk was a negative predictor of soil fertility, and mitigation-led technologies. A compelling explanation here is that, even when farmers' have a positive appraisal of CSA (and their ability to perform the associated tasks), they may choose not to do so due to concerns about the secondary risks. The explanation resonates with some other adoption risk relations found by Joffre et al. (2018). Moreover, we find a low p-value—significant at 10%—to relate the secondary risk to the adoption of agroforestry and alternative practices; however, it may be valuable to further explore the relationship between the technologies and the secondary risk. In the case of the practices where the secondary risk does not have explanatory power — i.e. soil conservation — we argue that the perceived secondary risk is not strong enough to inhibit the protective behavior. Our findings echo Cummings et al. (2020); but beyond empirically testing the secondary risk theory in a different context and domain, our study adds to previous work by showing that secondary risk appraisal is not a universal driver to explain all risk-mitigating behaviors. We suggest that a higher perceived risk of the possible consequences of protective behavior may take precedence over the effects of climate threats and coping mechanisms and thus limiting the protective behavior. Moreover, our model broadens the set of explanatory drivers in climate change risk studies (Grothmann & Patt, 2005; Niles et al., 2015; Ricart et al., 2023) and other behavioral models explaining farmers' choices under risks (Bubeck et al., 2012; Joffre et al., 2018; Tabe-Ojong et al., 2020) by showing the relevance of adoption risk perception as a predictor of adoption of new technologies and practices.

4.5.2 Farmers' social and demographic characteristics and CSA adoptions

It is well known that farm and farmer characteristics influence the adoption of risk management strategies (Joffre et al., 2018; Kothe et al., 2019). Our results show that older farmers are less likely to adopt alternative farming practices consistent with Aryal et al. (2018) and Kassie et al. (2013).

Institutional variables such as being a member of an organization increase the probability of adopting soil fertility and using agro-advisory mobile apps (echoing other CSA adoption studies Aryal et al., 2020 and Kangogo et al., 2021), highlighting the importance and potential of associations and farmers' organizations in increasing farmers engagement in protective behaviors. In Costa Rica, the role of cooperatives in the coffee sector has been key for providing market access and developing and implementing more sustainable practices, e.g., voluntary certifications (Snider et al., 2017). Farmers gain access to technical assistance, training, and microcredits through cooperative networks, which have been found to play a key role in supporting farmers by reducing information and transaction costs (Wollni & Zeller, 2007). Other institutional drivers such as the number of buyers, in line with Kassie et al. (2013), our findings showed that the likelihood of a producer adopting practices from the categories of soil fertility and agroforestry increases with the number of buyers (cooperatives but also private companies). According to Wollni & Zeller (2007), having the opportunity to sell to more buyers also increases the probability of participating in specialty markets, opening space for better prices and market opportunities.

From studying farmers' social characteristics, our findings consistently concur with technology adoption studies (Prokopy et al., 2008, 2019) on the suggested signs and significances used to predict farmers' behavior. Our study suggests that while farmers' characteristics and institutional drivers play a key role in adopting CSA technologies, they do not explain all the CSA categories homogenously; thus, complemented with other behavioral drivers, they will be more likely to comprehensively explain the adoption decisions.

4.5.3 Unraveling interrelated adoption: complementarities among CSA technologies

CSA encompasses an umbrella approach with a heterogenous set of technologies key to reducing GHG and effectively adapting to climate change risks (McCarthy et al., 2018). We argue that using such an approach leads to a more fruitful understanding of adoption since it recognizes the interdependencies between technologies in the adoption process (Leeuwis & Aarts, 2021). Our findings show significant correlations between multiple CSA categories indicating that farmers' decisions to adopt one category are interrelated with adopting other technologies (consistent with Aryal et al., 2020; Makate et al., 2019). Thus, we concur with Barrett et al. (2020) that adopting a single technology will not be enough to transform agriculture toward sustainable and resilient agricultural production. Therefore, understanding how and why mutually reinforcing interrelated CSA technologies perform is key.

Understanding how this interrelation plays out gives us more insights into why some technologies have greater adoption rates than others. We found significant complementary relations among the adoption categories (e.g. soil fertility and soil conservation) similar to Kpadonou et al. (2017) and Teklewold et al. (2013). We add to these previous studies by suggesting that farmers' adoption decisions are not limited to choosing one technology in isolation. We argue that assessing technology adoption as independent decisions may lead to an over or underestimation of the drivers that explain farmer decision-making (Teklu et al., 2023), leading to a biased assessment of the drivers' significance. Instead, we show the possibilities and complementarities between CSA technology adoption and how particular drivers were key for explaining the adoption of some technologies but not others.

4.6 Conclusion: implications for theory and practice

Technology adoption studies have predominantly focused on the role of various socio-demographic and economic, social, and institutional drivers in adopting new technologies (Barham et al., 2015; Kuehne et al., 2017; Pannell et al., 2006; Wang et al., 2023). Moreover, risk management studies have portrayed the importance of cognitive processes such as climate risk and adoption risk perceptions in shaping individuals' decisions (Etumnuet al., 2023; Markanday and Galarraga, 2021; Mase et al.,2017). However, despite the potential to better understand the farmers' decision-making process, both strands remain disconnected (Streletskaya et al., 2020). In this paper, we brought these strands together, and our research shows the importance of integrating both approaches for unraveling the complexity of CSA technology adoption.

Our study's contribution engages with the technology adoption debates by broadening the scope of drivers and barriers to adopting interrelated technologies (Aryal et al., 2020). As argued by Barrett et al. (2020), Leeuwis & Aarts (2021), and Teklu et al (2023), who talk about the need to see adoption as bundled or as a package, we have empirically shown the usefulness of studying CSA technologies as interrelated. Moreover, we add to this strand of literature by pointing out that farmers' cognitive processes related to climate risk perceptions may help to understand why the final adoption of CSA technologies remains below expected levels (Moser and Barrett, 2006), even when all the extrinsic drivers seem to be present and technologies are complementary. Thus, integrating behavioral drivers — climate and secondary risks— with social and demographic characteristics gives a more comprehensive explanation of what drives farmers to protect themselves against climate change, which so far has not been widely represented in mainstream technology adoption models.

The main theoretical implications for behavioral models are based on what our study found on secondary risk appraisal. Even though we did not find negative relation to all the CSA technologies, it gives us important insights into farmers' perceived probabilities of potential losses from implementing the protective mechanism. Surprisingly, the notion of secondary risk has often been neglected in behavioral studies Click or tap here to enter text.since more focus has been placed on identifying the attitudes and choices explaining sustainable behavior under risk (Lalani et al., 2016; Wang et al., 2023). We thus contribute to the theory on PMT (e.g., Clarke et al., 2021; Wang et al., 2019) by adding a significant predictor —perceived risks of protective behavior —which shows its explanatory potential when it overshadows the threat and coping appraisal in the adoption decisions. Broadly our study adds to the existing literature on inhibitors/barriers of protective behaviors since it goes beyond the appraisal of environmental threats and coping strategies by giving a nuanced explanation of farmers' decisions under pressing climate change threats.

Our model brings opportunities to further explore why and under what circumstances the perceived adoption risk thresholds are too low or strong to inhibit behavioral change. Beyond CSA, our model has the potential for application in various domains and other types of risks (floods, droughts, wildfires) or market-related risks (Joffre et al., 2018). Firstly, the applicability of our model can be used for explaining the uptake of contested technologies with potentially higher perceived secondary risks (e.g., digital technologies or new breeds) since it will give better insights into individual adoption risks and will bring a more comprehensive explanation of what drives the individual to avoid/engage with a particular technology. Second, the extended PMT model can also be used to evaluate the relationship between adoption under other types of uncertainty and whether the secondary risk appraisal predicts the adoption of other sustainable practices.

As regards practical implications, this study reinforces that policy interventions merely relying on disaster relief programs to address disease outbreaks or extreme weather events are insufficient (Alpizar et al., 2011; Naranjo et al., 2019) to tackle the high vulnerability of coffee farmers. Thus, strengthening adaptation and risk mitigation practices will be key for the continuity of coffee farming (Harvey et al., 2014). Our study proposes a comprehensive approach to risk management interventions by suggesting the need to i) invest in climate risk awareness campaigns since the higher the climate change risk perception the more likely to adopt CSA ii) strengthen farmers perceived benefits of CSA by training, demonstrations, field experiments since a positive link between the coping appraisal and adoption was found iii) target miscommunication about the potential CSA adoption risks coupled with financial incentives to release the burden of costly or labor-intensive CSA may help to reduce the secondary risk appraisal and perceived response costs and enhance CSA adoption iv) promoting CSA adoption as bundled which might result in more effective resource allocation for the farmers (decrease in transaction cost and input efficiency) and government budgets. Thus, a well-balanced and comprehensive CSA policy mix promoting interventions supporting extension services, knowledge-sharing platforms, and regulatory schemes coupled with market support and demand-side instruments may help for effective adoption and further scaling of CSA (Harvey et al., 2021; Scherer and Verburg, 2017; Verburg et al., 2019).

CHAPTER 5

5

General discussion

5.1 Introduction

This thesis analyses three levels of CSA policy development: the macro level (where the CSA policy mix is developed); the micro level, where farmers make CSA adoption decisions, and; the meso level, which connects the two. It specifically focuses on the dynamics and relations between these three levels. Building on different strands of literature, such as sustainability transitions, agricultural innovation systems, CSA and behavioral theories, this thesis recognizes that individual choices are contingent upon the broader context (Engler et al., 2019; Upham et al., 2019). This broader context establishes the 'rules of the game' (North, 1990) in the form of standards, regulations, taxes and incentives (Flanagan et al., 2010), and in turn, individuals' behavior (which is a key driving force for social and technological change) thereby contributing (or not) to a more sustainable system (de Vries et al., 2021).

This thesis aims to address knowledge gaps within these strands by focusing on the interplay between individual actions, systemic responses and feedback mechanisms. This approach provides valuable insights into how the institutional context (i.e., policies and regulations) can influence individual behavior (the acceptance and adoption of technologies or practices) and vice versa. The main research question guiding the thesis is: *How are the interactions between CSA policies and individual farmers shaped by systemic and individual-level processes*?

This last chapter brings together the main findings from the three empirical chapters, followed by a discussion considering the broader scientific and societal context. In section 5.2 the main findings will be summarized. The theoretical implications of this research will be covered in section 5.3. Section 5.4 offers the methodological reflection. Section 5.5. outlines some limitations and directions for future research. Section 5.6 responds to the main research question. Finally, section 5.7 explores the policy and practical implications.

5.2 Summary of the findings

In this subsection, I summarize the findings according to each research question and, in Figure 5.1, I portray the main findings for each empirical chapter.

> *Research question 1 How has climate and agri-environmental policy evolved to support the emergence and implementation of CSA as a (potentially) transformative policy approach?*

Chapter 2 presented a historical and thematic content analysis of the policy mix promoting the development of CSA in Costa Rica from 2000 - 2022. I followed a top-down[20] approach to map Costa Rica's CSA strategies and instruments and describe the characteristics of the policy mix. The results showed that the CSA strategy focuses on sustainable development, food security and climate change challenges, but with differences in emphasis over time. Three phases, marked by changes in the long-term objectives, were identified. The first phase focused on environmental protection and biodiversity conservation. This was followed by a second phase where efforts were redirected toward carbon neutrality goals. In the third phase, efforts toward carbon neutrality continued but rebranded as the decarbonization of the economy by 2050. The policy instrument mix reflected a set of emerging policy elements — strategy and instruments— with (potential) transformative intentions interacting with some old classic rationale instruments (e.g., addressing market failures, information asymmetries and the externalization of costs.) There has been an imbalance between those policy instruments that aim at protecting niches and those designed to accelerate the phasing out of unwanted or counterproductive practices and technologies. Most of the programs were focused on demonstrating the effectiveness of climate change adaptation practices and low-emission technologies. This is because banning and regulating agricultural practices that have a detrimental impact (e.g., use of harmful agrochemical molecules) is very difficult to achieve, given the embeddedness of food-regime actors in policymaking and the influence that agro-industry has over the state.

This in part gave rise to problems, in terms of internal and external coherence, with tensions between the agricultural and the environmental policy domains being observed throughout the three phases, due to competing paradigms of agricultural production and climate action (e.g., prioritizing agricultural productivity and agribusiness development, often at the expense of avoiding / minimizing environmental degradation). In most phases, there was no explicit evaluation of synergies or tensions resulting from the interactions between the policy instruments (undermining consistency). In theory, Costa Rica's CSA policy is a transformative policy mix in the making. In practice, it has not met its potential because of fragmentation, a lack of policy coordination and historical legacies. In this chapter, I argue that including instruments with a transformative intention but without removing or restructuring pre-existing policies has led to a great deal of layering, drifting and the conversion of instruments and goals. In extreme cases, this has led to what could be called 'policy pandemonium'. My findings suggest that the good intentions of adopting transformative policies may result in an uncoordinated arrangement of policies

20 This implies initially identifying the main broader strategic goal guiding the policy mix (e.g. climate change adaptation or mitigation) and analyzing the specific policy instruments implemented to achieve the strategic intent (e.g. carbon pricing, emission regulations) (Ossenbrink et al., 2019).

that thwarts transformative elements and may stifle efforts to create a consistent, comprehensive and balanced transformative policy mix. This emphasizes the need to continuously scrutinize whether a policy mix is achieving its intended aims and is fit for purpose, or whether some elements need to be added or removed.

Research question 2: How is farmers' acceptance of CSA technologies influenced by policy context and behavioral drivers?

Building on the mapping and analysis of the transformative nature of the CSA policy mix, chapter 3 explores the relationship between individual farmers perception and the policy context (policies, regulations, knowledge services, etc.) in which the farm operates. This chapter shows that, besides the influence of behavioral drivers, perceptions of policy consistency, comprehensiveness and the type of instrument(s) targeting farmers' behaviors, play an important role in explaining farmers' acceptance of CSA. Farmers were targeted with a mix of instruments, such as information (e.g., extension services and the Nationally Appropriate Mitigation Actions (NAMA) program), economic support (e.g., Payment for Ecosystem Services (PES), preferential loan rates), as well as privately-led instruments such as voluntary sustainability standards (e.g., Rainforest Alliance, FairTrade and AAA Sustainable Quality). These later schemes support an array of practices and technologies focused on reducing or mitigating GHG emissions and encouraging the adoption of climate change adaptation technologies. Within the policy mix, there was an imbalance in the use of the instruments, with a preference for instruments such as extension services, preferential credit rates and private sustainability standards. This chapter reveals that, with the exception of PES and sustainability standards there was no direct link between being a beneficiary of the policy instrument and a farmer being more willing to accept CSA practices. The low participation rates suggest that a policy mix that appears comprehensive on the surface was, in practice, underutilized. This may be attributed to a lack of interlinked diffusion of the programs amongst farmers, coupled with the government´s limited capacity to rollout and support the programs.

The findings also show that the farmer's appraisal of the overall policy context, at least partially, shaped their decisions to engage with (or not) CSA. Perceptions of the consistency of the instrument mix (i.e. farmers' appraisal of the alignment of the instruments and the policy objectives) and its comprehensiveness were positively related to a higher probability of accepting the CSA technologies. Surprisingly, the study showed an inverse relation between perceived coherence of the CSA policy mix and a high technology acceptance as most farmers who ranked highly in terms of their acceptance of CSA perceived the policy mix as being relatively incoherent. The coherence of the policy mix reflects whether policymakers consistently endeavor

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to eliminate barriers associated with the uptake of CSA and/or the government was consistent in its adoption of the policies towards CSA. Farmers' appraisal of the coherence of the mix implies a low confidence in the governments' actions to promote CSA. I argue that this appraisal of policy coherence captures the broader politics of policymaking in Costa Rica and reflects farmers' (dis)satisfaction with the national government in terms of regulations, (the lack of) infrastructure and providing essential services.

These findings provide empirical insights that relate to earlier conceptualizations of the mutually responsive process of individuals choices and the policy context (e.g., Engler et al., 2019) and show that farmers' appraisal of the overall policy mix and behavioral drivers are important predictors their acceptance of CSA. Overall, the findings highlight the links between policy and individual decision-making when promoting sustainable agricultural practices, such as CSA, and emphasize the need for a comprehensive and integrated approach that addresses both systemic and individual-level determinants.

> *Research question 3 To what extent do risk-related psychological determinants drive farmers' adoption of CSA?*

Chapter 4 focused on individual behavior and explored the drivers that influence farmers' adoption of CSA. The empirical findings presented in this chapter show the key determinants that explain farmers' adoption of CSA. The study combined 1) climate change risk appraisal, 2) the perceived efficacy of the alternatives recommended to face the risks and, 3) a secondary risk appraisal (e.g., the perceived yield losses caused by implementing some CSA practices). The findings reveal that risk-related drivers had a varying significance in explaining the adoption of different categories of CSA. They suggest that heightened awareness of climate change risks increases the likelihood of adopting technologies related to soil fertility and agroforestry. They also show no relation between the perceived severity of climate change and the probability of farmers adopting soil conservation, alternative practices and mobile agro-advisory apps. Farmers with more confidence in their ability to use CSA technologies are more likely to adopt agro-advisory apps and technologies related to soil conservation and soil fertility. Farmers with a higher perception of the effectiveness of CSA technologies were more likely to adopt agroforestry and agro-advisory apps.

Thirdly the study found that the perception that CSA has, or could have, negative consequences on the farm (e.g., secondary risk appraisal) had a negative effect on the adoption of soil fertility practices and CSA technologies aimed at reducing GHG emissions reflecting farmers' fear of potential losses or additional risks associated with implementing these practices. A compelling explanation here is that, even when farmers' have a positive appraisal of CSA (and a higher perceived ability to perform the associated tasks), they may choose not to do so due to concerns about the secondary risks. The appraisal of secondary risks could include concerns about increased labor requirements, potential crop failure, or uncertainty about market demand. The chapter introduced a significant predictor to earlier research on protection motivation, which mainly focused on determining the effects of the threat and coping appraisal. I argue that a higher perceived risk of the possible consequences of protective behavior may take precedence over the effects of climate threats and the farmer's ability to cope with his or her decision to adopt CSA. Thus, a farmer's secondary risk appraisal may play a key role in influencing his or her adoption decisions.

Additionally, this chapter shows significant correlations between multiple CSA categories, indicating that farmers' decisions to adopt one category are interrelated with adopting other technologies. I found significant complementary relations among the adoption categories (e.g., soil fertility and soil conservation). Thus, this work concurs with Barrett et al. (2020) showing that CSA technology decisions are interrelated, meaning that more fruitful synergies can be achieved by promoting the bundled adoption of multiple CSA technologies.

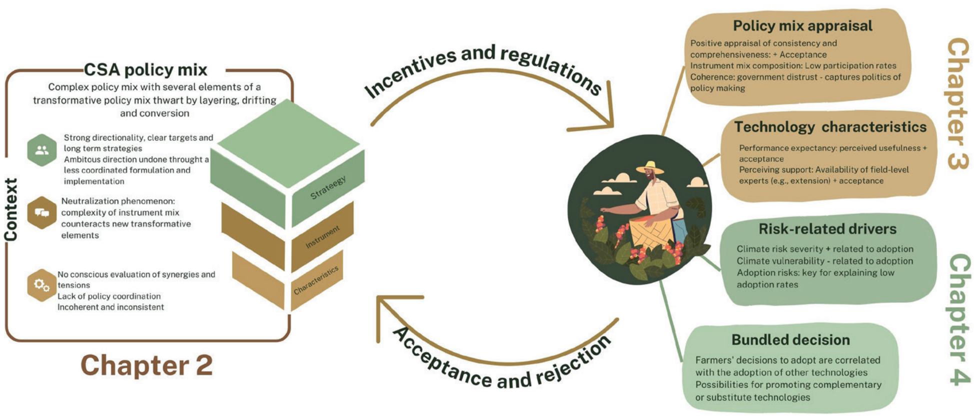

Figure 5.1 Key findings of the thesis

5.3 Theoretical contributions

This section discusses the contribution to transition research (section 5.31), behavioral theories (section 5.3.2), and CSA (section 5.3.3).

5.3.1 Contributions to transition research

The contribution of this thesis to transition research is twofold; firstly, it fills key knowledge gaps on the dynamics of transformative policy development in the agri-food sector, and; secondly, it adds to the broader discussion on the role of individual agency in sustainability transitions.

In terms of the first contribution, chapter 2 provides several contributions to the literature on transformative policy mixes. It adds new evidence that confirms that policy mixes are complex and rarely built from scratch but are incrementally developed, through layering, drifting, and conversion processes echoing Chataway et al. (2017) and Grillitsch et al. (2019). The chapter unravels the driving forces behind policy developments, such as international agreements and international cooperation interests as well gaps in implementation capacity. These influences are consistent with those in other Latin American contexts (Milhorance et al., 2022). Adding to these earlier findings, I argue the complexity of the instrument mix, resulting from policy legacies, counteracts the transformative capacity of new instruments. This is because layering, drifting and conversion in the evolving policy mix can, in some cases, have a neutralizing effect which hampers efforts to establish a coherent and consistent policy mix, resulting in less substantial changes in the policy mix than originally envisaged. This chapter also adds to the broader debates on policy development (e.g. Michael et al., 2018) and recent conceptualizations on transformative policies (Bergek et al., 2023; Parks, 2022; Scordato et al., 2021). Provides the analytical lens for the exploration of transformative policy mixes that beyond the policy instrument analysis, takes into account the synergies and tensions of the inclusion of transformative elements reflecting on their catalyzing and inhibiting forces.

Chapter 2 showed that the Costa Rican CSA policy mix can be described as incoherent (both internally and externally) and has a low level of consistency, as no purposeful attempts were made to induce synergies between policy instruments to achieve transformative outcomes. This is quite a similar pattern to that found studies of policy mixes in both the Global North (Bach & Hansen, 2023; Kivimaa & Kern, 2016; Rogge & Reichardt, 2016) and the Global South (Gomel & Rogge, 2020b; Milhorance et al., 2022). However, this thesis explores what underpins of this incoherence and inconsistency in more depth and, on the basis of these findings, argues the need for a better understanding of the sociopolitical context and how existing policy shapes influences the policy agenda (through preset priorities), the influence of lobbying (from the food regime) and limited implementation (due to the state's limited resources). Yet, the political context, i.e. the resultant policy mix for encouraging the uptake of CSA and its implementation, sets the rules of the game, in which farmers, organizations and businesses must make their decisions.

In terms of the second aspect, this thesis adds to the broader debate on the role of individual agency in sustainability transitions (de Vries et al., 2021; Gazheli et al., 2015) by providing a comprehensive explanation of the acceptance and adoption of technologies and practices by combining behavioral theories with the policy mix approach. Chapter 3 shows how individual acceptance of CSA technology is influenced by farmers' attitudes towards and beliefs concerning the technologies and their perception of the policy mix. By using well-established theories on technology acceptance (Flett et al., 2004; Venkatesh et al., 2003; T. Zhou et al., 2010), the findings add to the existing literature, indicating that individuals are willing to accept CSA if their appraisal of the policy mix, in terms of consistency and comprehensiveness, is favorable. In addition to individuals' appraisal of the policy mix, other behavioral drivers play a key role in explaining the acceptance (or not) of a technology. These include its expected performance, facilitating conditions and any (perceived) financial barriers. The model connects behavioral drivers with individuals' appraisal of the policy context and comprehensively explains what drives farmers to accept (or not) the technologies associated with CSA. This connection may be the key to facilitating the uptake of such transformative programs and minimizing the obstacles to uptake (e.g., low trust in policymakers). The chapter also shows some apparent contradictions; while the policy mix was well-appraised, there was a low level of trust in policymakers, which negatively affected the take-up of these policies. This connects with ideas on that transitions require high legitimacy of policies and policymakers (de Boon et al., 2022).

These findings follow on from earlier work on individual behavior in sustainability transitions (e.g., Upham et al., 2018, 2019), by adding insights into what drives farmers' individual behavior when considering adopting more sustainable practices. They help to bridge the gap between behavioral and transition studies by presenting a combined model using widely-recognized behavioral theories, such as the UTAUT, with policy mixes for sustainability transitions (See Table 5.1 for the potential implications). This combination suggests that efforts to promote socio-technical change may also need to consider farmers' motivations and their perceptions of the benefits, coupled with a purposeful improvement of the overall policy mix .

This thesis also adds to earlier conceptualizations on policy mixes, which have pointed to the importance of consistency, credibility, coherence and comprehensiveness in redirecting or accelerating technological change (e.g. Rogge & Dütschke, 2018; Rogge & Schleich, 2018). In so doing it deepens our understanding of the role of behavioral processes and policy contextual dynamics in influencing behavior related to the adoption of sustainable practices and technologies.

Table 5.1 Implications of behavioral drivers for transition research

Chapter	Behavioral driver	Examples of potential implications for transition research
3	Policy mix appraisal	Uncovers unexpected outcomes arising from instrument endorsement Explains how behavior is embedded, facilitated and constrained by the policy context Highlights the underutilization of policy instruments by intended recipients Provides a policy feedback mechanism (to evaluate the policy context) Captures the politics of policymaking
	Performance expectancy	Sharing and communicating the perceived usefulness of combined CSA technologies, the potential synergies and the perceived benefits that CSA might bring to the farm are key elements for mobilizing the acceptance of a technological package.
	Facilitating conditions	Perceived support from field-level experts, such as extension agents, enhances acceptance.
3/4	Perceived cost	High cost is negatively related to the acceptance of a technology and may lead to promising sustainable practices being underutilized, either due to high implementation costs and or a lack of supporting interventions.
4	Climate risk perception: severity	A heightened awareness of climate change risk positively influences individual engagement in protective behavior.
	Climate risk perception: vulnerability	A higher perception of vulnerability to climate change may (paradoxically) inhibit a farmer from adopting a technology and cause inaction.
	Coping appraisal	Farmers' perceptions of their ability to undertake the required protective behavior and the perceived effectiveness of the recommended behavior are positively related to adoption This can serve as a pivotal factor, by empowering farmers to overcome their initial resistance, embrace new techniques, and implement changes more readily and rapidly
	Secondary risk	The perceived risks of adoption negatively influence adoption Using targeted media campaigns tackling misinformation about a new technology can reduce the perceived adoption risk and thus increase the adoption of more sustainable technologies

5.3.2 Contribution to behavioral theories

This thesis contributions to adoption and behavioral theories are also twofold. Firstly, it actively integrates the study of the broader policy context – i.e. the appraisal of the policy mix, into farmers' decision-making. Chapter 3 provides empirical evidence on ways in which the policy context connects with farmers' acceptance (or not) of technology. This approach moves beyond individual-related drivers and takes into account the mutual responsiveness between the individual and the policy context. This interplay has begun to be recognized in system-oriented studies (Engler et al., 2019; Kuntosch & König, 2018) and individual-oriented studies. Individual-oriented studies focus either on the adopter or the technology, with the context being seen as a stable conditioning factor (Pannell et al., 2006). This thesis includes farmers' appraisal of the policy mix in terms of its consistency, comprehensiveness, coherence and credibility as part of the mix characteristics. In so doing it opens up the "black box'" of the contextual determinants that influence behavioral change. The findings suggest that this combination is significantly more robust and inclusive way of understanding farmers' acceptance of climate-smart technologies compared to models that only use behavioral drivers. Thus, this thesis deepens the body of work of technology adoption models (Giua et al., 2022; Teklewold et al., 2013) and behavioral models (Bopp et al., 2019; Lalani et al., 2016; Mills et al., 2018): providing insights on the operationalization of contextual drivers which had not previously been examined systematically or integrated into the existing theoretical approaches (as discussed in the next section).

A second contribution draws on the findings from chapter 4, which provide a more detailed understanding of the drivers affecting CSA adoption. While there is a long standing tradition in technology adoption studies of using socio-demographics, economic and institutional drivers to explain the uptake (Pannell & Zilberman, 2020; Prokopy et al., 2008), this puts the locus of action mainly on structural determinants and overlooks the key role of cognitive processes and individual motivations in determining adoption (Streletskaya et al., 2020). This thesis fills this gap, and chapter 4 focuses on exploring the cognitive processes that influence farmers' adoption decisions under pressing climate change threats. In this chapter I analyze the influence of risk-related drivers, climate change risks and the secondary risks associated with adopting CSA technology. The main theoretical implications are based on secondary risk appraisal, which is often neglected in behavioral and adoption studies (Bockarjova & Steg, 2014; Clarke et al., 2021; Steg & Vlek, 2009). The study showed that the secondary risk appraisal could outweigh the appraisal of climate threats and coping strategies, ultimately negatively influencing farmers' decisions regarding adoption. This combined model opens up opportunities to further explore why, and under what circumstances, the secondary risk thresholds are too low or too strong to inhibit behavioral change. For example, the findings had a predictive power for explaining the adoption of some CSA technologies, but not all, meaning that there is a threshold at which secondary risk needs becomes high enough for farmers to withdraw from the decision to adopt a new set of technologies. Thus, I argue that secondary risk has the potential to better explain the adoption of some contested technologies such as biotechnologies and artificial intelligence.

5.3.3 Contributions to CSA

The CSA literature has taken different approaches to studying the acceptance of CSA, however, it often either takes either an individualistic perspective (Kpadonou et al., 2017b; Ogada et al., 2021; Teklewold et al., 2019; Vaast et al., 2016; Westermann et al., 2018; Zougmoré et al., 2018) or a systemic perspective (Carter et al., 2018; Neufeldt et al., 2013b; Scherr et al., 2012; Totin et al., 2018; Wallbott et al., 2019), focusing for example on policy packages (Scherer & Verburg, 2017) or policy entrepreneurship (Faling & Biesbroek, 2019). I deepen this work in several ways: firstly by further exploring the development of the CSA policy mix; secondly, by connecting the macro and micro approaches of CSA and; thirdly, by adding several behavioral drivers for better explaining CSA (non) adoption.

Similar to what was found in Wallbott et al. (2019), effective CSA policy implementation in Costa Rica is limited by funds, implementation gaps, and lack of coordination between ministries, cooperation agencies and the private sector. Regarding the policy design, policy instruments were not specifically CSA-focused or carefully integrated into the existing mix. This issue was also observed in other geographical contexts by Milhorance et al. (2022), who identified concerns around the lack of tangible instruments for implementing climate adaptation, mitigation, and agricultural productivity targets, and in the case of climate change policies in other contexts beyond agriculture (see also Lesnikowski et al., 2021). This thesis deepens this work by analyzing the transformative potential of the CSA policy mix. CSA development have inherently multistakeholder (governments, organization, farmers), multiscale (international, national, regional, local), and multiobjective nature (marry climate change adaptation and mitigation with sustainable development). By analyzing the transformative potential of the CSA policy mix I argue that the transformative elements of CSA are constrained by the actors within the policy regime, and that private corporations and cooperatives that opt to support sustainability transformations are a more consistent driver of change.

In line with a number of authors (Farstad et al., 2022; Harvey et al., 2021; Scherer & Verburg, 2017; Verburg et al., 2019), this thesis emphasizes the importance of a balanced CSA policy mix. This thesis confirms this, but also explores the coherence and consistency of the mix by identifying the synergies and tradeoffs between instruments and strategies at both the macro and micro level, which has not been previously studied in CSA. The findings on the development of CSA (at the macro level) showed how directionality-shaping-oriented exercises (such as vision creation) provided a sense of purpose and long-term planning for CSA. However, these efforts were counteracted through less-coordinated policy formulation and implementation. The appraisal of the policy mix at the meso level highlight the need for a consistent and comprehensive policy mix in order for CSA to be accepted and adopted. What's more, in the Costa Rican agricultural context it is still an open question on what type of CSA transformation is being promoted, since some of the policies aim to fundamentally transform the current agricultural system while others focus on promoting incremental change.

While this thesis has taken a combined individual-systems perspective, a great part of the CSA literature has initially focused on CSA practice adoption (e.g., economic evaluations and cost-benefit analysis) and this remains an important focus. Nonetheless, the scientific community criticized such approaches for oversimplifying the complexity of adoption decisions (e.g. Leeuwis & Aarts, 2011, 2021) and argued that individual adoption decisions have broader determinants, being interconnected, for example, with other farmers, embedded in larger systems or related to decisions about adopting other technologies. This thesis adds to the body of work focused on understanding the adoption of CSA in two ways: i) by exploring CSA adoption as interrelated to other technologies and; ii) by opening up the set of behavioral drivers influencing adoption. The CSA adoption literature has been predominantly focused on exploring and understanding the determinants of CSA adoption and has methodologically used binary adoption decisions or analyzed a single farm technology. This has led to a neglect of the complex and dynamic process of making adoption decisions (Montes de Oca Munguia et al., 2021). I add to this body of work by exploring CSA adoption as being interrelated i.e. that the adoption of one technology is related to the adoption of other technology. This is in line with the arguments of Barrett et al. (2020), Leeuwis & Aarts, (2021) and Teklu et al. (2023) who discuss the need to see adoption as bundled or as a coherent package.

In chapter 4, I empirically show the usefulness of studying CSA technologies as interrelated, since understanding the factors that determine the complementary adoption of technologies deepens the debates of rethinking adoption a single decision but seeing it as a dynamic process (Kiptot et al., 2007; Sutherland et al., 2022). It shows that interdependencies among technologies and practices are an important determinant for adoption and non adoption.

5.4 Methodological reflections

5.4.1 Reflection of my role in this thesis

Throughout the thesis, I have argued that the policy context shapes farmers' — since it sets the 'rules of the game' by which these farmers make decisions — and such decisions influence their acceptance and adoption of more sustainable practices. To explain how I arrived at this position I need to explicitly reflect on my background and how this has influenced this work.

I was born and raised in Costa Rica. As a farmer's daughter I grew up weaving the duality between living in the city during school days and enjoying farm life on the weekends. This influenced the choice of choosing Costa Rica as a case study in the early research design stages. I was familiar with the context, the institutional networks, contacts and infrastructure that I had already built up whilst working at the University of Costa Rica. While coffee is part of Costa Rica's cultural identity, I had not previously had the opportunity to work in the coffee sector until the start of my PhD, which made it necessary to learn about the context, have informal conversations with farmers, cooperative members and organizations and to learn about how coffee is produced, traded and processed.

Throughout the research process, I began to notice a disconnection between science and real-life impacts (e.g., what implications does this research hold for farmers' practices?). This struggle was most evident when I was out in the field, talking to families, organizations, owners of coffee mills, extension agents and farmers who all generously shared their experiences and details about their practices and opened their doors and minds to help with this research. Whilst I tried to be very clear with participants about this study's objectives, I also tried to avoid perpetuating power imbalances from previous 'extractivist' approaches. Yet, this thesis does rely on traditional data collection methods (interviews, surveys and focus groups). I engaged with local partners such as cooperatives, farmers' organizations and regional extension agencies, and sought to involve them in several phases of the research, I aimed to actively listen to their insights and queries. In addition, throughout the timeline of the thesis, my findings on the policy process (challenges, tensions, agreements) were presented in informal meetings, organized by the Ministry of Agriculture or NGOs (e.g., workshops for co-designing the National Policy on Low Emission Coffee Systems) to which I was invited. In additionally, one workshop with local partners was organized to present the general findings of the quantitative data. To assure practical impact in my future efforts I should dedicate more attention to providing follow-up meetings, facilitating opportunities for ongoing support and preparing accessible media documents in Spanish, policy briefs for policymakers, digital communication tools for extension agents and audiovisual and multimedia material for organizations and farmers.

I consider that this thesis contributes to three areas of literature that have predominantly been conceptualized and theorized from Eurocentric and Global Northern perspectives. The thesis practical contributions hold the potential to have greater impacts by introducing elements of participatory and action-research methodologies designed at generating tangible societal impact within communities, cooperatives, and farmers. Thus, the work could be linked with broader debates such as decolonizing transition studies (e.g,. Ghosh, Ramos-Mejía, et al., 2021). Such an approach involves paying more attention to local sustainability narratives, empowering alternative systems, including a more diverse range of stakeholders and opening up to the nuanced social realities on the ground.

5.5 Limitations and directions for further research

This work was focused through three analytical lenses, I here reflect on the limitations of this approach and suggest further directions of research in relation to each of the analytical lenses.

5.5.1 The macro level

The study was confined to a single case in Costa Rica in which I gained an in-depth understanding and context-specific insights, set out in chapter 2, which focused on studying the CSA policy mix in the context of the Global South. I conclude that the policy mix is complex and contextual and is influenced by policy cultures, legacies and styles. Similar findings have been drawn in other contexts and sectors (see e.g. Lesnikowski et al., 2019). I have made, what I feel is, an important contribution to both transitions and CSA literature in analyzing a transformative policy mix in-the-making by signaling elements (e.g., strong directionality, balanced instrument mixes, and coordination) that appear to be key to enhancing the effectiveness of CSA policies. In this vein, future research would benefit from studying the policymaking process more systematically by cross-fertilizing theories on transformative policy mixes (e.g. Ghosh, Kivimaa, et al., 2021; Grillitsch et al., 2019; Scordato et al., 2018) with policy theories, using policy process frameworks, such as policy feedback, advocacy coalitions and evolutionary approaches such as punctuated equilibrium (Baumgartner et al., 2018; Béland, 2010; Herweg et al., 2018; Rosenbloom et al., 2019; Sabatier, 2019; Schmid et al., 2019). This will allow for more emphasis to be placed on identifying the fit or potential tensions of new policies, stability of actors, actor power dynamics and shared and dissonant values, and the role that these play in the policy making process.

Further research could also explore and compare the design and implementation of a transformative policy and its dynamics in different contexts, e.g., the Global North vs. the Global South or comparable cases from the Global South, incorporating elements such as the role of actors (Haelg et al., 2020; Mockshell & Birner, 2015), policy styles (Howlett & Tosun, 2021; Lesnikowski et al., 2021) and political cultures (Pfotenhauer & Jasanoff, 2017). This study of CSA policies tried to take into account scale interactions at national and international levels; future research could go deeper into cross-scale analysis and/or identify the intensity of spatial influence in determining the transformative policy mix.

5.5.2 The meso level

At the meso level, this thesis explores the embeddedness of farmers within the policy context. The findings of this thesis emphasize the significance of both behavioral and policy mix appraisal for understanding CSA acceptance, and to my knowledge it is one of the first attempts at bridging systemic and individual interactions. Chapter 3 analyses the interrelationship between farmers' appraisal of the policy mix characteristics and their behavioral drivers and shows the significance of some policy characteristics (comprehensiveness and consistency) in affecting farmers' acceptance. This said, I found contradictory and unexpected influences from other policy mix characteristics (notably coherence and credibility), an issue which is worthy of further exploration in future studies This study measured policy credibility on the ground via several items, one of the items focused on the perceived support of extension agents in implementing CSA. This underscored the significance of extension agents as influencers for CSA acceptance and leads me to suggest that extension agents may have a powerful role to play as bridging entities between the meso and micro levels. Although the chapter's main emphasis wasn't on unraveling the role of extension agents, there is potential for more comprehensive exploration of this potential (see Wiener et al. (2020).

Bridging the macro and meso levels holds substantial promise for a more comprehensive understanding of the complexity of farmer's decision-making processes and deepens our understanding of the multidimensional nature of sustainability transitions, an approach that certainly requires further exploration. Future research could benefit from a mixed method approach which could, for example, incorporate an analysis of the dynamics between farmers' behavioral drivers and the policy mix. This could be achieved through longitudinal studies, coupled with in-depth interviews, in order to see how the longer-term changes in farmers' choices result in the adoption (or not) of more sustainable practices.

5.5.3 The micro level

The findings of chapters 3 and 4 build on a cross-sectional survey study of coffee farmers in Costa Rica. As a representative study of all coffee-growing regions in Costa Rica. The study is limited by the fact that the data were captured within the constraints of a set of temporal and spatial frameworks and the data analysis only allowed for correlations, not cause-and-effect relationships. A more nuanced explanation of the complexity of technological change dynamics may be useful for understanding individual adoption paths over time (as proposed by Montes de Oca Munguia et al., 2021 and Sutherland et al., 2022). Further research could benefit from this type of long-term analysis for analyzing current technology adoption paths or modelling future pathways.

Future studies could also be based on field experiments or in the form of serious games that present farmers with hypothetical scenarios involving combinations of protective behaviors (ranging from low to higher risk behaviors) and associated determinants (secondary risks, costs, attitudes, beliefs and policy appraisals, etc.), thereby assessing farmers' willingness to engage with CSA. Such an approach might also introduce dynamic elements (e.g., extreme weather changes, market and input prices) and help farmers learn from the hypothetical situations with which they are presented.

5.6 Conclusions

This section addresses the main research question by elaborating on the three analytical levels and contributing to a better understanding of the CSA transition (Figure 5.2). The main research question guiding this study was :

> *How are the interactions between CSA policies and individual farmers shaped by systemic and individual-level processes*?

The thesis explored the complex interactions and influences between CSA policies (the macro level) and individual behaviors (the micro level) in the transition towards CSA. By examining the roles of institutions (e.g., laws, norms, organizations, policies and instruments), context (e.g. policy cultures, legacies and styles) and behavioral drivers (e.g. climate perceptions, self-efficacy and adoption risks), I unraveled how these elements collectively shape the dynamics between the system and farmers' decisions towards CSA acceptance and adoption.

At the macro level (chapter 2), it was shown that Costa Rica's policy mix faces challenges due to a weak implementation capacity, incoherence, conflicting goals and interventions with overlapping purposes. Ambitious goals and long-term visions were necessary for promoting policy changes and gave a sense of purpose but provided insufficient stimulus to transform the country's agricultural system toward CSA. The country's particular institutional context, policy cultures and legacies shaped the development of the policy mix over time. Throughout the evolution of the policy mix transformative elements faced counteractive influences due to layering, drifting, and conversion.

As the connecting device between the macro and micro levels, I build upon the meso level (chapter 3) as a nexus to capture the mutual responsiveness between the policy context and farmers' decisions toward implementing more sustainable technologies. This is because farmers' decisions towards CSA technologies are informed by their context, e.g., the type of technical assistance available, the projects and programs they are involved in and their assessment of the policy context. Individuals' perceptions of the policy mix (e.g. consistency and comprehensiveness) positively shaped their decisions to accept CSA. It was evident that farmers are willing to accept CSA if there have a favorable appraisal of the policy mix in terms of consistency and comprehensiveness. Finally, this chapter shows that the appraisal of the policy mix might also function as a feedback mechanism in which positive or negative evaluations can be used to trigger policy changes by adjusting policies, targets, and interventions which, in turn, would affect individual decision-making.

Given the dynamic relationship between the context and the individual, I zoomed in on the micro level (chapter 4) by analyzing the determinants of farmers' adoption of CSA. I revealed that individual decisions are influenced by behavioral determinants (e.g., perceptions of the technology, adoption risks and climate risk perceptions) and social and demographic characteristics. The results revealed that risk drivers had varying significance in explaining the adoption of different categories of CSA (e.g., soil conservation, soil fertility, agroforestry, agro-advisory apps, and organic/alternative practices). The main barriers include the perceived potential adoption risks which influenced the adoption of soil fertility practices and the use of agro-advisory mobile apps and perceived climate change vulnerability which influenced the adoption of soil conservation practices, agroforestry and alternative technologies. The main stimuli for CSA adoption include perceived climate change severity, self-efficacy, response efficacy and being a member of an organization.

In summary, this leads to the following key takeaways from this thesis:

- Successful transformative policy mixes require close scrutiny of the mix's balance and how fundamentally transform the mix. This entails giving greater attention to phasing out legacy policy instruments and carefully integrating new instruments.
- The policy mix appraisal highlights the mutual responsiveness between policy context and farmers' decisions, shedding light on its recursive nature and ongoing interaction.
- A more nuanced explanation of what motivates farmers to protect themselves against climate change can be obtained by combining behavioral drivers—climate and secondary risks—with social and demographic factors.

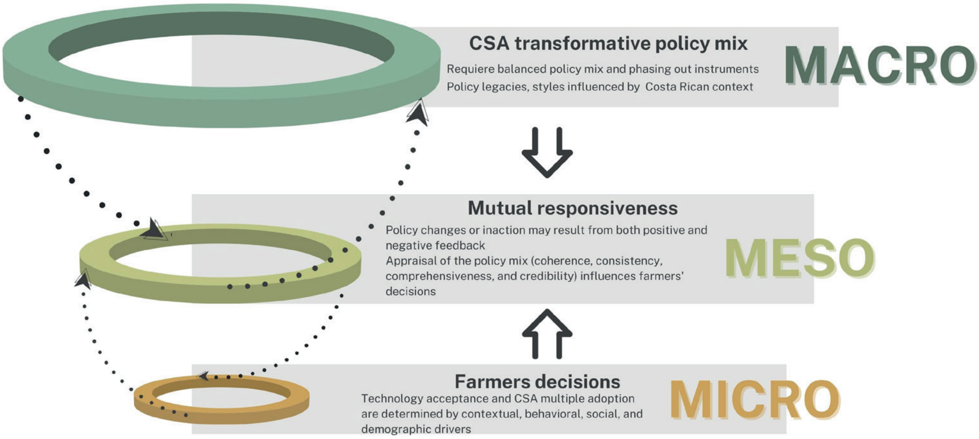

Figure 5.2 Dynamics between three analytical levels

These conclusions and takeaway messages have policy and practical implication, on which I will reflect next in the final section of this chapter.

5.7 Policy and practical implications

This thesis identifies four main challenges for policy and practice. In this section, I will elaborate on practical recommendations tailored for policymakers and other stakeholders such as organizations, cooperatives and extension agents. In Table 5.2, I offer potential policy adjustments based on the findings of each chapter.

5.7.1 Overall policy mix

While policy mix analysis offers a comprehensive overview of the broader policy landscape, controlling and analyzing the dynamics of the multi-scale and cross-sectoral instruments is complex. I suggest that existing specialized policy bureaus (such as, SEPSA —the Executive Secretariat for Agricultural and Livestock Sector Planning) could enhance their capacities by using alternative analytical lenses for policy analysis, such as the policy mix approach. This approach has the potential to provide a more holistic understanding of what is entailed when introducing new instruments and goals and a deeper understanding of the complexity of policymaking. Using the policy mix lens to analyze overall coherence, consistency and credibility may uncover tensions and possible causes of policy failure and may help to purposively promote synergies between the instruments employed (as suggested by Lesnikowski et al., 2021). The approach may help improve policy design, redesign and implementation. Considering the country's recent accession to the OECD, there is an opportunity to link SEPSA (and other bureaus) with the OECD's coordination unit for support and to further explore tools, mechanisms and actionable proposals that may strengthen policy coherence and coordination (OECD, 2014, 2019).

While a policy mix overhaul may be idealistic and unfeasible, efforts should be made to carefully integrate new instruments and goals and phase out old, counterproductive, instruments. I suggest that incorporating feedback mechanisms (e.g. from individual organizations) is pivotal here. Positive or negative feedback can be instrumental in understanding how policies once designed reshape the policymaking processes and how this, in turn affects further policy adjustments (see e.g. Béland, 2010).

5.7.2 Complex policymaking

Although the CSA strategies provide long-term direction, the actions were weakened when translating theory into practice, due to a series of political and administrative factors, e.g. policy style, context and how policy is developed in Costa Rica. Challenges facing policy development and implementation included fragmented public administration, a lack of trust in the policy process, a lack of capacity to scale up innovations and conflicting agendas between ministries.

Table 5.2 Relations between the CSA policy mix appraisal and possible policy adjustments

Level	Policy mix building block	Research findings	Possible policy adjustment
Macro	Overall policy mix	Incoherent, inconsistent policy mix	Investment in policy integration Creation of a macro level coordination body
Meso	Overall instrument mix	Balanced policy mix that is underutilized in practice	Promoting interlinked the diffusion of the programs amongst farmers Policy mix approach for policy analysis and design Creation of a meso level CSA coordination body
	Type of instrument: e.g. NAMA café	No relation to CSA acceptance	Policy implementation adjustment and scaling up of NAMA initiatives to reach more farmers
	Type of instrument: Private certification	Positive relation between implementing Sustainability standards and acceptance	Integration of public and private instruments (e.g.,market-driven)
	Type of instrument: Differential interest rates (loans)	No relation between DIR and CSA Acceptance	Coupled interventions: favorable loan rates with other interventions
	Type of instrument: PES	Negatively related to CSA acceptance	Reconcile conflicting objectives between CSA and goals in the environmental domain (e.g. through policy integration)
	Perceived coherence	Negatively related to acceptance	Efforts to build legitimacy and trust via field level agents (e.g. extension agents)
	Perceived comprehensiveness	Positively related to acceptance	Building balanced policy mix with no central and flanking policies missing
	Perceived consistency	Positively related to acceptance	Promoting intended synergies amongst instruments Overcoming policy inertia
	Perceived credibility	Not significantly related with CSA acceptance	Improvement of accountability mechanisms
Micro	Farmers behavioral drivers	Mixed results	Investment in policy integration Creation of a macro level coordination body

Thus, successful policy implementation was undermined by the lack of coordination (vertical and horizontal), reinforcing the argument to strengthen policy integration (as suggested by Biesbroek, 2021). Enhancing policy integration (e.g., resolving incoherence and inconsistency and reconciling conflicting interests) can be effectively facilitated through the strategic deployment of intermediaries. Policy intermediaries, for instance, can connect actors and stakeholders who have difficulty in collaborating with each other (Kivimaa et al., 2019; Klerkx et al., 2015). Other research (e.g., Vilas-Boas et al., 2022) has shown they can play a key role in creating linkages, mobilizing stakeholders and acting as policy network brokers (Milhorance et al., 2020). I suggest (based on the findings of chapter 3) that intermediaries may be a key for working toward a better image of the overall policy mix (e.g., by coordinating local actions with regional policy strategies) since this should improve end-user perception (e.g., higher credibility or a more positive perception of consistency), which have been shown (here and elsewhere) to be important determinants in promoting the acceptance of new technologies.

I propose the integration of intermediary bodies tailored to each level: macro, meso, micro, so called ecologies of intermediaries (Kivimaa et al., 2019; Klerkx & Aarts, 2013; Vilas-Boas et al., 2022). At the macro level, an intermediary could help to navigate the intricate dynamics inherent in the multilevel and cross-sectoral nature of CSA. A coordination body located at the national level (e.g. Ministry of Science and Technology at the Innovation agency) could take on the roles of translating global agreements, connecting policies, conciliating conflicting goals, and coordinating projects and interventions. At the meso level, I suggest creating a CSA coordination body to bridge the macro strategic policy decisions and the micro level farming practices. The CSA coordination body could orchestrate and translate local realities to policymaking and vice versa. I suggest to locate such coordination unit in an already existing NGO, such as Fundecooperación or Fundacion Aliarse, due to its strategic connecting position, neutrality and legitimacy. The unit must be allocated with resources (e.g., staff, training, budget) and have the capacities to translate strategic political decisions into actionable plans and projects within ministries and other domains. The practical recommendation echoes the OECD´s (2017) report on budgetary allocations for effective policy implementation and evaluation. This coordinating unit would be crucial in facilitating collaboration and communication between different stakeholders involved in CSA and in providing feedback to the macro level coordination body, providing a space where private companies, governmental officers, researchers, certifying agencies, extension agents and implementation officers can collaborate. This would allow for a better alignment and a more efficient and effective implementation of CSA strategies.

At the micro level, a third intermediary i.e the regional extension officer director, will be key for translating the national vision to the local narratives. Their role could be focused on coordinating with the CSA coordination body and vice versa since they can directly understand farmers' challenges and goals. These coordination efforts could enhance the quality extension services in the region and may be key for connecting farmers with other public institutions and private stakeholders (see, e.g., Kilelu et al. (2013) and Prokopy et al. (2015)).

This three-tiered intermediary structure is designed to span various scales, to enhance the effectiveness of policy implementation and a better integration of the three pillars of CSA: adaptation, mitigation and agricultural productivity.

5.7.3 Securing resources for policy implementation and learning

In economics there is the concept of a "price taker", where an individual or entity does not influence the market price of a product, Costa Rica (and other countries in the Global South are in a similar position in terms of CSA policy design and implementation (i.e., they are "policy takers"). The influence of global agreements (such as Paris Agreement, Agenda 2030) and the country's reliance on external funding for policy implementation have shown that the instrument mix is largely shaped by external drivers and pressures. Such replications of models from elsewhere have led to policies that are not well suited to the specific contexts of Costa Rica, giving rise to challenges in efficient implementation as local officials struggle with executing policies that are not aligned with local realities. Since dependence on cooperation funds is likely to continue in the foreseeable future, recommendations in this regard include:

- scaling up participatory and collaborative approaches in the policy design phase,
- the timely involvement of diverse local, regional, and national stakeholders;
- prioritizing sufficient space for flexibility and improvements, and;
- creating a conducive space for policy learning

5

Effective policy learning in such a context should incorporate effective mechanisms for policy monitoring and evaluation and refine efforts for ensure accountability. These activities may be key for identifying successful approaches and best practices and for providing open spaces for sharing experiences of policy failures in order to avoid replicating unsuccessful interventions.

5.7.4 Private efforts and incremental change

It is clear from the above that CSA policy interventions do not come only from the political domain but involve a wide variety of actors designing and implementing interventions at multiple levels Corporations, cooperatives, and transnationals play a key role in the sustainability of the coffee sector, which, although it has tended towards sustainable production, other nonsustainable practices prevail. Chapter 2 reveals a trend of incremental changes driven by initiatives led by national corporations, cooperatives, and private companies.

At the community level organizations, such as cooperatives and producer organizations, play a key role in providing inputs and credit at a lower cost, as well as market information and technical assistance. At the same time, traders also provide information, technical support and credit to farmers. Both types of actors have a key role in promoting more sustainable practices, since market-based incentives are needed to overcome the high costs of adopting alternative (and sometimes radically so) practices (Grabs, 2020; Verburg et al., 2019). Chapters 3 and 4 show how behavioral variables, such as the need to share information about technologies and the effects of climate change, tackle technology misinformation and the perception of support networks all increase farmers' acceptance and adoption of CSA practices.

Connected the meso level intermediaries suggested in section 5.7.2. I argue that extension agents roles such as ensuring empowering of farmers, providing climate advice, assessing climate vulnerabilities, building capacities, and monitoring progress on CSA are crucial for the successful implementation of CSA. I suggest that scaling-up the current efforts of CSA communities of practices promoted by the National Institute for Innovation and Transfer of Agricultural and Livestock Technology (INTA) can be a way of building social capital and promoting the sharing of knowledge and values that are favorable to more sustainable practices. As such, strengthening other existing platforms for facilitating public and private collaboration, such as innovation labs and the Carbon Neutrality Platform may also be key for mainstreaming CSA.

5.7.5 Bundled CSA interventions for promoting behavior change

This thesis suggests that policy interventions aimed at promoting CSA technologies need to consider behavioral drivers, such as the perceived cost and effort, the facilitating conditions and perceived climate risk, in policy design. For example, while policy instruments may widely support and communicate the potential benefits and usefulness of CSA technologies they also need to facilitate knowledge acquisition and sharing and provide training and organizational support. Following Barrett et al (2020), I argue that bundled interventions are needed to transform the current agricultural production system towards a more sustainable and resilient one, where a comprehensive approach to climate risk management interventions is the key to promoting investments in behavioral change and climate risk awareness campaigns. Coupled together these actions should strengthen farmers' perceived benefits of CSA (through, for example, training programs, demonstrations and field experiments) (see Wiener et al., 2020).

Rather than promoting a single technological approach I suggest that current efforts for promoting a portfolio of low carbon and resilient agricultural practices, such as the "10 Good Agricultural Practices for NAMA coffee" (Nieters et al., 2015) should play a key role in facilitating the implementation of CSA strategies in Costa Rica. This should be coupled with complementary training programs targeting miscommunication about the potential risks of CSA adoption and climate change in order to stimulate adoption rates. Financial incentives that alleviate the burden of costly or labor-intensive CSA adaptations should also be considered as a way to reduce farmers' appraisal of secondary risks and thereby enhance the adoption of CSA.

Appendix A Suplemental material Chapter 2

A1. Instrument mix categorization

Table A1. Instrument mix categorization

Type/Purpose	Regulatory	Economic	Soft	Systemic
Description	Measures are undertaken to influence people through formulating rules and directives that mandate receivers to act according to what is ordered in these rules and directives	Involve the handing out or the taking away material resources, in cash or kind.	Attempts at influencing people through the transfer of knowledge, the communication of reasoned argument, and persuasion. provide recommendations, make normative appeals, or offer voluntary or contractual agreements	Tools that focus on the organization of innovation systems, support learning and experimenting, and stimulate vision, strategy, and demand articulation
Niche creation	Regulation, tax exemptions	Financial: R&D funding, deployment subsidies, low-interest loans, venture capital	Policy instruments such as certificate trading, feed-in tariffs, public procurement, deployment subsidies, and labelling training schemes, coordination	Innovation platforms, foresight exercises, public procurement and labelling to create legitimacy for new technologies, practices and visions
Regime destabilization	Policies, such as taxes, import restrictions, and regulations. Control policies, for example, may include using carbon trading, pollution taxes or road pricing to put economic pressure on current regimes. Banning certain technologies is the strongest form of regulatory pressure (eg	Withdrawing support for selected technologies (e.g. cutting R&D funding, removing subsidies for).		Balancing involvement of incumbents for example in policy advisory councils with niche actors; formation of new organizations to take on tasks linking to system change.

Source: Adapted from Kivimaa and Kern 2016

A2. Policy documents and interviewee list included in the analysis

Table A2. Types of policy documents included in the instrument mix

Type of document	Total of documents review
Law	30
Decree	29
International Cooperation Project	19
National /Sectorial Development Plan	16
Project	13
Program	11
National/Regional Policy	10
Strategy	10
Regulation	9
Agreement	7
International Agreement	6
Agenda	4
Guideline	4
Platform	4
Climate Change National Communication	3
Public Private Initiative	3
Conference	2
National Determined Contributions	2
Costa Rica Constitution	1
National voluntary Standard	1
Other: News, Webapages, reports	30
Total	214

Table A3. Expert interviews with actors related to CSA in Costa Rica

ID	Type of Actor	Sector	Institution	Date	Duration
4	Public Sector: Policy	Agriculture	Executive Secretariat for Agricultural and Livestock Sector Planning	02/12/2020	30:03:00
2	Public Sector: Program Manager	Agriculture	Ministry of Agriculture and Livestock	07/12/2020	84:05:00
3	Public Sector: Policy	Agriculture and Climate Change	Executive Secretariat for Agricultural and Livestock Sector Planning	08/12/2020	54:37:00
7	Multilateral cooperation Agency	Agriculture	Inter-American Institute for Cooperation on Agriculture	08/12/2020	65:38:00
6	Private Sector: Program Manager	Agriculture: Coffee sector	National Coffee Institute	08/12/2020	49:09:00
10	Public Sector: Policy	Agriculture	Ministry of Agriculture and Livestock	09/12/2020	45:08:00
9	Private Sector:	Agriculture: Coffee sector	National Coffee Institute	09/12/2020	47:03:00
8	Public Sector: Research	Agri environmental Climate change	National Institute of Agricultural Innovation and Technology Transfer	09/12/2020	44:44:00
1	Research	Agriculture	University	10/12/2020	46:43:00
11	Public Sector: Policy	Agriculture and Climate Change	Ministry of Agriculture and Livestock	11/12/2020	50:58:00
12	Public Sector: program Manager	Agriculture: Coffee sector	Ministry of Agriculture and Livestock	14/12/2020	52:07:00
13	Private Sector	Agriculture: Coffee sector	National Coffee Institute	14/12/2020	51:52:00
15	Private Sector	Agriculture	Camara Nacional Agricultura y Agroindustria	15/12/2020	51:03:00
14	NGO and Public sector	Climate change	NGO / Parlament	15/12/2020	55:24:00
4	International Agency	Climate change	German Development Agency GIZ	22/12/2020	47:16:00
17	Private Sector	Agriculture	Insurance company	03/02/2021	43:29:00
16	Research	Agriculture and Policy	University	05/02/2021	53:38:00
20	NGO	Climate change and Agriculture	Fundecooperación (NGO)	01/03/2021	50:17:00
18	Public Sector: Policy	Environment / Climate Change	Ministry of Environment	10/03/2021	60:08:00
21	Public Sector	Agriculture and Climate Change	Ministry of Agriculture and Livestock	16/04/2021	61:06:00
19	Public Sector	Agriculture	Ministry of Agriculture and Livestock	19/04/2021	120:22:00
				Total	**1164:50:00**

A3. Policy mix strategic phases

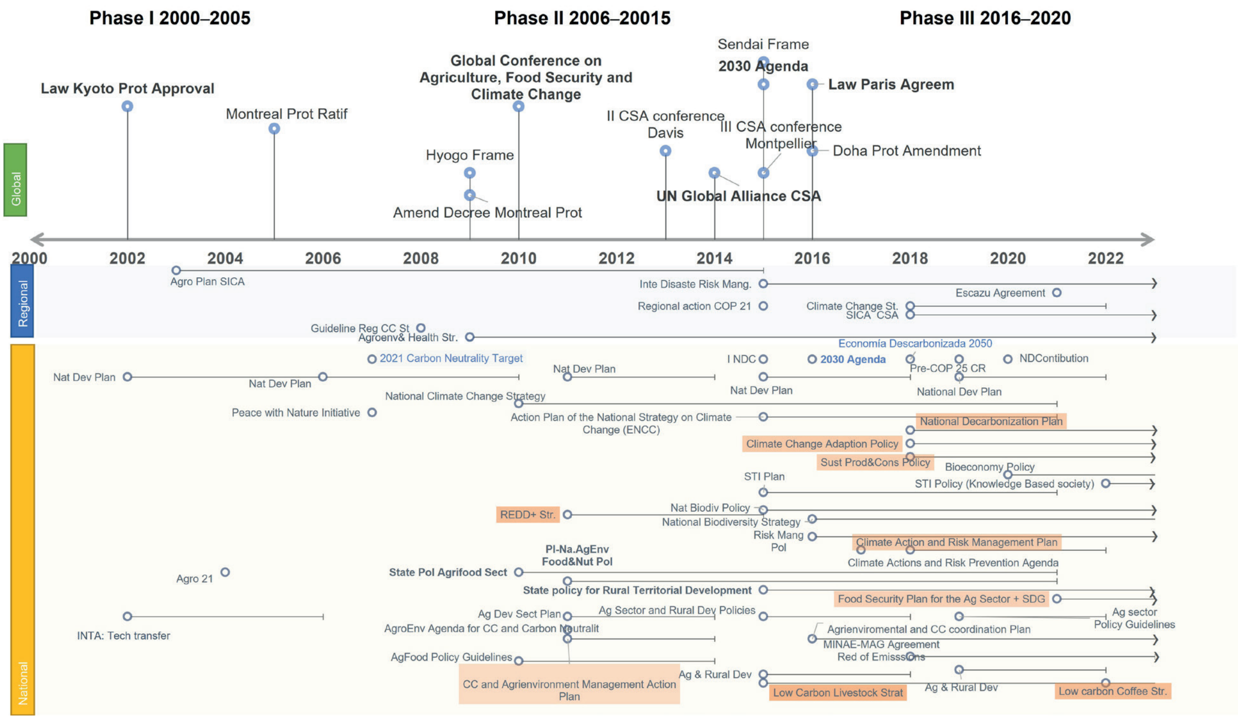

Figure A3. Climate Smart Agriculture strategic phases: Plans and guidelines. In orange squares indicate the plans and policies with transformative features

A3. Climate-Smart Agriculture instrument mix purpose categorization

Table A3. Climate Smart agriculture key instruments divided by instrument type (regulatory, economic, informative and systemic) and purpose (niche creation and regime destabilization)

Type/Purpose	Regulatory	Economic	Soft or informative	Systemic
Niche creation	Phase 1 (1994) Art 50. Constitutional Amendment, (1995) Environmental Law 7554, (1996) Forestry Law 7575, Regulation of the Use, Management and soil conservation law Phase 2 Law Organic Agriculture Promotion Amendment Law 7554 Environmental Law (inclusion of Org Agriculture) Regulation 344433 Biodiversity Law Amendment Law Soil conservation Regulation Domestic Carbon Market Phase 3 FONASCAFE Law Amendment Law 7554 Environmental Amendment Law 7778: Biodiversity Law	Phase 1 PES scheme Phase 2 Law 8634: Development Bank System Benefits for Organic Production (RBAO) for organic producers Low carbon emsission agricultural technologies project (production and processing) NAMA Agricultural Insurance premiums for Adaption and Mitigation practices Phase 3 Incubator program (low carbon and Adaptation indicators included) GEF Small Grants Program in Costa DESCUBRE program	Phase 1 (1995) Regulations: Ecological Blue Flag Program Private standard: Rain Forest Alliance Public standard: Organic Agriculture Phase 2 3xAdmendment Ecological Blue Flag Program Decree No. 34548 National Action Program to Combat Land Degradation in Costa Rica Voluntary stardard TICO-GAP (national certification program) INTE C-Neutral Standard Carbon Neutrality Country Program (Recognition) Training programs and extension on CSA NAMA coffee capacity building project Phase 3 Amendment Carbon Neutrality 2.0 Program Germoplasm R&D program CR coffee app,riceapp Free pesticide Rice standard Agroinnova: IICA	Phase 1 Advisory Commission on Land Degradation (CADETI) Cross-sectoral coordination: Risk Management program INTA creation (Institution for Innovation and technology transfer) Agricultural and Livestock Production Conversion Program Phase 2 PLATICAR PLATFORM Creation of Climate Change Bureau Interministerial Technical Committee on Climate Change (CTICC) NAMA experiments Carbon Neutrality Alliance Phase 3 Fab Lab Climate Changes Roundtables NAMA livestock experiments Cross-sectoral coordination against desertification SEPLASA Agroclimatic Boards SINAMEC: Climate change and GHG database Platform (Bio/Eco Entrepreneurship) Hub for the Development of Agribusiness and Entrepreneurship in Costa Rica IICA

A

Table A3. Continued

Type/Purpose	Regulatory	Economic	Soft or informative	Systemic
Regime destabilization	Phase 2 Amendment of the regulation for prescribed agricultural burns Phase 3 Decree Agrochemical regulation Decree on Agrochemicals (MRL)			Phase 2[21] REDD+ Exc Secretariat Phase 3 SDG secretariat NAMAs governance arrangements (rice, sugar cane, and *musaceae*) Citizen's Advisory Council Climate Change and Scientific Advisory Council

21 In Phase 2 and 3 new consultancy groups, councils and secretariats were created or amended. They all included new members of underrepresented stakeholders such as indigenous communities representatives, smallholder farmers national organization representatives. Thus, since the main aim of including new members is linked to changing and balancing the involvement of regime actors in policy decisions we categorize the instruments under regime destabilization following Kivimaa and Kern (2016) typology.

Appendix B Suplemental material Chapter 3

B1. Sample selection calculation

The target population was coffee farmers in the seven coffee regions. In order to calculate the sample size, statistics from the ICAFE were retrieved. The total number of coffee farmers in 2019-2020 was 29918 (ICAFE, 2018). To determine the sample size, we used the sample size formula for a finite population represented as

$$n = \frac{N * Z^2 * p * q}{e^2(N-1) + (Z^2 * p * q)}$$

Where N= is the population size, z = The z-score is the number of standard deviations a given proportion is away from the mean, p = represents population proportion is the percentage of the population with a specific characteristic q = (1-p) e= margin error.

The calculated minimum sample size from the interviews is 467 for a population of 29918 coffee farmers based on alpha level a priori at 0.05, level of acceptable error at 4.5%, and population proportion of 0.5.

B

B2. Socio demographics and farm characteristics

Table B2. Coffee farmers' socio-demographics and farm characteristics

Variable		Mean	SD	Frequency	%
Age		52.58	14.08		
Gender	Male			435	83
	Female			88	17
Education	No education			50	10
	Completed Primary			307	59
	Completed Secondary			46	9
	Technical Education			9	2
	Incomplete University			28	5
	Completed University			83	16
Hectares planted with coffee		5.86	24.75		
Number of varieties		2.95	1.60		
Land Tenure	Yes			510	98
	No			13	3
Credit/Loan	Yes			275	53
	No			248	47
Use of family labor	Yes			383	73
	No			140	27
Sustainability standard	Certified			197	38
	Non Certified			314	60
	Transition stage			12	2
Training	Yes			419	80
	No			104	20
Member of an Association/ Cooperative	Yes			400	76
	No			123	24
Technical Assistance	No			165	32
	Private			192	37
	Public			48	9
	Both			118	23

B3. Behavioral items measurement

Table B3. Climate Smart Technology Acceptance model behavioral items

Factor	Item	Description	Response scale
CSTA	CSTA1	I would use or will continue using the CS technologies in the future.	1= Not likely 5= Very likely
	CSTA2	I planned to use or will continue using the CS technologies more frequently in the future.	
	CSTA3	I would promote the CS technologies use to the others farmers.	
	CSTA4	I would change my practices to cope and adapt to climate change.	
PR	PR1	I'm concerned about the potential impact of climate change on my community	1= Strongly Disagree 5= Strongly Agree
	PR2	Climate change presents more risks than benefits to agriculture globally	
	PR3	I believe that extreme weather events will happen more frequently in the future	
	PR4	Climate change poses more risks than benefits to agriculture in my community	
	PR5	Climate change will lead to increased productivity losses due to diseases and pests	
	PR6	The global climate is changing	
	PR7	Climate change poses risks to agriculture globally	
PE	PE1	It is useful for my coffee plot to perform CSA technologies	1= Strongly Disagree 5= Strongly Agree
	PE2	Using the CSA technologies will increase my chances of achieving higher crop productivity.	
	PE4	If I take up CS technologies, my profits and income will increase.	
	PE5	Using CS technologies makes it easier for me to do farming activities in the coffee plantation	
FC	FC1	I have access to the necessary resources (financial, knowledge) to implement CS tech	1= Strongly Disagree 5= Strongly Agree
	FC2	I have the necessary knowledge to implement CS technologies	
	FC3	Experts are available in the area to address the problems and deficiencies of CS Tech	
	FC4	It is easy for me to get the skills to use CS technologies	
PC	PC1	Farm work is too busy; there is no extra time to commit to CS Technologies	1= Strongly Disagree 5= Strongly Agree
	PC2	Working very hard every day, no extra physical strength to commit to CS Technologies	
	PC3	I have financial constraints to implement CS technologies	
SI	SI1	People who are important to me think that I should use the CS technologies	1= Strongly Disagree 5= Strongly Agree
	SI2	The people whose opinions are valuable to me prefer to use the CS technologies.	
	SI3	The local community encourage me to adopt CST on my farm	
	SI4	The CSA practices help me to be an example for other farmers.	
CRE_Coo	CRE1	Cooperatives encourage me to adopt CST on my farm	1= Strongly Disagree 5= Strongly Agree
	CRE2	Do you think that there is a strong support of cooperatives for promoting CSA	

Table B3. Continued

Factor	Item	Description	Response scale
CON	CON1	Concerning MAG and ICAFE training programs supports the use Climate Smart or sustainable practices	1= Strongly Disagree 5= Strongly Agree
	CON2	Funding programs (grants and donations) for investment in equipment/machinery and improvement of practices reinforce each other in order to support me to use Climate Smart technologies"	
	CON3	Concerning the policy environment, there are contradictions in the programs and projects promoted by the government to promote CSA and more sustainable agriculture.	
COHE	COH1	Policy makers spot/ recognize on time the problems that arise in relation to the use of sustainable practices and CSA	1= Strongly Disagree 5= Strongly Agree
	COH2	Policy makers always strive to remove obstacles related to the use of sustainable practices and CSA.	
	COH3	Policy makers are well informed about developments in sustainable coffee farming CSA	
	COH4	The government is constantly adjusting its policies to favor of CSA.	

The items of red were deleted according to factor loading below 0.5.
CSTA= Climate Smart Technology Acceptance PR= Perceived Climate Risk, PE= Performance Expectancy, FC= Facilitating Conditions, SI= Social Influence, CRE= Credibility, CON= Consistency, PC= Perceived Cost, COH=Coherence

B4. Clustering method for selecting optimal number of clusters

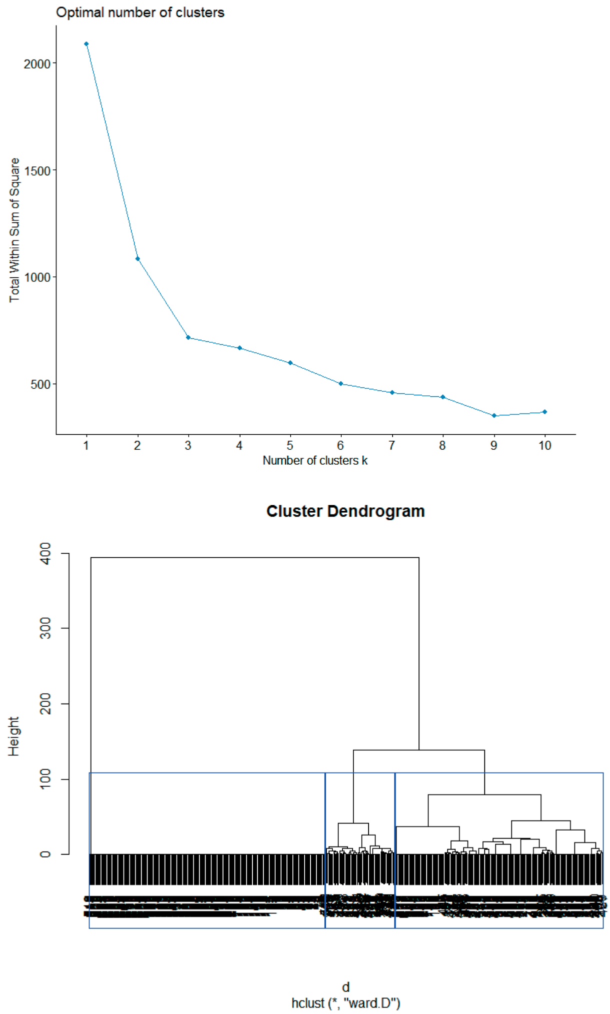

Figure B4. WSS showing the optimal number of clusters.

Appendix C Supplemental material Chapter 4

C1. Distribution of farmers sampled in each coffee region

Table C1. Number of farmers surveyed per coffee region.

	Number of farmers	Survey Sample	Sample Percentage
Tarrazú	10,212	128	24.7%
Occidental	6,278	80	15.4%
Perez Zeledón	5,639	135	26.0%
Central	2,808	88	17.0%
Coto Brus	2,457	59	11.4%
Turrialba	1,986	22	4.2%
Zona Norte	538	7	1.3%
Total	29,918	519	100%

C2. Principal Component Analysis results: Behavioral items

Table C2. Component loading: varimax rotation Var(blanks are abs(loading)<.3)

		Component						
		1	2	3	4	5	6	7
Item description	Item	PS	PV	SEa	SEb	REa	REb	SR
Drought poses a threat to the coffee plantation	PS1	0.609						
Unpredictably high rainfalls pose a threat to the coffee plantation	PS2	0.755						
More yield losses due to excessive rainfall severity	PS3	0.670						
Climate change affects the coffee bean quality	PS4	0.762						
Climate change has increase plant disease severity	PS5	0.598						
Increase of problems in blossoming (scattered flowering, flower drop, drying of buds).	PVP1		0.672					
Lower productivity and yield losses due to climate change	PVP2		0.740					
Losses of plants due to an increase in diseases and plagues (anthracnose)	PVP3		0.827					
Increase of plant diseases vulnerability (coffee rust)	PVP4		0.771					
Reduction of the quality of the coffee harvest	PVP5		0.770					
Apply fertilizers/fertilizers according to the need of the plantation/ according to demand.	SEI1			0.632				
Manage resources (e.g. labor, herbicides, fertilizers) efficiently.	SEI2			0.716				
Deliver high-quality grain	SEI3			0.774				
Meet the grain quality expectations demanded by the buyer.	SEI4			0.772				
Take actions to combat the effects of climate change (drought or excess rainfall).	SE1				0.656			
Use sensors and other tools to measure humidity and temperature.	SEI5				0.864			
Use high-tech in the coffee plantation (drones, automated fertilizer , weather stations, site-specific liming).	SEI6				0.873			
Proper/efficient use of fertilizers is useful for reducing environmental impact by reducing nitrogen emissions.	PRE5					0.653		

C

Table C2. Continued

		Component						
		1	**2**	**3**	**4**	**5**	**6**	**7**
Proper use of fertilizers reduces costs and increases productivity.	PRE6					0.684		
The use of applications with climatic information is useful to increase quality and quantity of coffee beans.	PRE8					0.686		
The use of pest resistant varieties is useful to combat climate change.	PRE9					0.610		
Soil conservation practices are useful for my coffee plantation	PRE1						0.706	
Soil conservation practices are useful to prepare for climate change/Soil conservation practices increase the resilience of the coffee plantation to extreme rainfall.	PRE2						0.779	
Shade trees are useful to prepare for drought, climate variability and disease.	PRE3						0.715	
In general, Climate Smart practices have or could have negative consequences on my farm.	SR1							0.711
Soil and water conservation practices have negative consequences on my the coffee plantation.	SR2							0.551
Climate Smart practices can lead to a reduction in yield/ production of harvested coffee.	SR3							0.675
If I use CS technologies, I run the risk of losing productivity.	SR4							0.734

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

[a.] rotation converged in 6 iterations.

The items PS6 and PRE4 were eliminated due to loadings less than 0.30.

C3. Detailed description of the behavioral components

Table C3. Description of the components and principal component analysis for the model explanatory variables

Variable	Interpretation	Source	Mean	Cronbach's Alpha	N of Items	Sampling Adequacy
Perceived severity	Farmer's appraisal of how harmful the consequences of climate change are Likert scale from 1 (very low) to 5 (very high)	(Bockarjova & Steg, 2014; Keshavarz & Karami, 2016; Z. Zhou et al., 2020)	4.25	0.76	5	KMO = 0.819 Bartlett's Test of Sphericity p< 0.000
Perceived vulnerability	The likelihood that the farmer will experience harm (negative consequences) from climate change Likert scale from 1 (not likely) to 5 (very likely)	(Bockarjova & Steg, 2014; Ghanian et al., 2020; Grothmann & Patt, 2005; Truelove et al., 2015)	3.98	0.86	5	
Response efficacy [a]	Efficacy of type a CSA to diminish the negative consequences of climate change Likert scale from 1 = strongly disagree to 5=strongly agree	(Keshavarz & Karami, 2016; Zhao et al., 2016))	4.13	0.65	4	
Response efficacy [b]	Efficacy of type b CSA to diminish the negative consequences of climate change Likert scale from 1 = strongly disagree to 5=strongly agree		4.72	0.69	3	
Self-efficacy [a]	Farmers' perceived ability to enact the type a CSA successfully Likert scale from from 1 = I feel unprepared to 5 = I feel very prepared.	(Bockarjova & Steg, 2014; Keshavarz & Karami, 2016)	4.18	0.75	4	
Self-efficacy [b]	Farmers' perceived ability to enact the type b of CSA successfully Likert scale from from 1 = I feel unprepared to 5 = I feel very prepared.		2.65	0.78	3	
Secondary risk appraisal	The magnitude of perceived harm associated with engaging with CSA We use a Likert scale from 1 (strongly disagree) to 5 (strongly agree).	(Cummings et al., 2020)	1.91	0.61	4	

C4. Descriptive statistics of CSA Technologies categories

Table C4. Descriptive statistics of CSA technologies

ID	Variable	% adoption	Mean	Std.Dev.	Median	Min	Max
Category I Soil fertility		60.10%	2.366	0.894	3	0	3
TA1	Soil analysis	82.1%				0	1
TA2	Soil amendments, e.g., lime to correct pH	86.7%				0	1
TA3	Use of fertilizers according to soil type	67.8%				0	1
Category II Soil conservation practices		60.90%	1.817	0.94	2	0	3
TA4	Soil conservation practices	86.9%				0	1
TA5	Windbreaks barriers	57.8%				0	1
TA6	Plant vegetative measures	37.0%				0	1
Category III Agroforestry		52.80%	1.559	0.946	2	0	3
TA7	Use of non-conventional shade threes	45.3%				0	1
TA8	Agroforestry	71.1%				0	1
TA9	Rainwater harvesting techniques	39.5%				0	1
Category IV Agro-advisory mobile apps		37.90%	0.453	0.628	0	0	2
TA10	Early warning apps (plagues, weather forecast)	32.8%		0.47		0	1
TA11	Harvest forecast app	12.5%		0.331		0	1
Category V Alternative farming practices		40.8%	1.252	0.801	1	0	3
TA12	Crop diversification (e.g. banana, cassava or avocado threes)	59.5%		0.491		0	1
TA13	Use of organic fertilizer	61.8%		0.486		0	1
TA14	Organic farming practices (no pesticides use)	3.9%		0.193		0	1

C5. Multivariate probit correlation error coefficients

Table C5. Correlation error coefficients MVP model

	Soil Fert	Std err	Soil Cons	Std err	Agrofor	Std err	Alternat	Std err	Apps
Soil Fert	1								
Soil_Cons	0.164**	0.074802	1						
Agrofor	0.192***	0.072	0.162**	0.074	1				
Alternat	0.188**	0.072	0.206***	0.073	0.141**	0.072	1		
Apps	0.197***	0.074	-0.006	0.076407	0.215***	0.073	0.0048	0.074	1

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0: $X^2(10) = 43.1298$ Prob > $X^2 = 0.0000$

Soil Fert = Soil fertility practices, Soil Cons =Soil conservation practices, Agrofor = Agroforestry, Alternat = Alternative farming practices, Apps = agro-advisory mobile apps

C6. Marginal Effects bivariate probit model

Table C6. Marginal effects adoption of mitigation and adaptation-led technologies

	Pr(mit=1,ad=1),			Pr(mit=1,ad=0),			Pr(mit=0,ad=1),		
	dy/dx	Std.Err.	P>z	dy/dx	Std.Err.	P>z	dy/dx	Std.Err.	P>z
P Severity	0.071	0.025	0.005	-0.015	0.025	0.560	0.027	0.019	0.144
P Vulnerability	-0.055	0.019	0.003	0.007	0.021	0.754	-0.018	0.015	0.251
Self-efficacy	0.051	0.015	0.001	0.045	0.015	0.003	-0.02	0.011	0.077
Response efficacy	0.083	0.023	0.000	0.009	0.025	0.710	0.013	0.019	0.497
Secondary Risk	-0.042	0.019	0.023	-0.059	0.021	0.005	0.032	0.015	0.038
Perceived Cost	-0.025	0.012	0.041	0.007	0.015	0.634	-0.011	0.011	0.311
Number of sellers	0.05	0.031	0.111	0.078	0.038	0.043	-0.043	0.028	0.119
GroupMember	0.071	0.037	0.052	0.04	0.042	0.346	-0.011	0.031	0.712
Labor	-0.004	0.033	0.906	-0.054	0.038	0.154	0.037	0.028	0.177
Loan	-0.002	0.032	0.943	-0.036	0.037	0.329	0.025	0.027	0.355
Central Valley	-0.017	0.045	0.702	0.017	0.053	0.744	-0.016	0.039	0.675
Age	-0.002	0.001	0.181	0.002	0.001	0.156	-0.002	0.001	0.081

Appendix D Supplemental material chapter 3 and 4

D1.Survey

Climate Smart Agriculture in coffee farms

***Own translation from the Spanish version of the survey**

Climate Change and behavioral drivers affecting the uptake of climate-smart coffee farming

General information

This study is part of a research project of Wageningen University and the University of Costa Rica. This questionnaire is designed to study how farmers perceive climate-smart or sustainable and climate-adapted technologies and to understand the motivations for using sustainable practices on their farms.

We would like to inform you that your personal data and responses are confidential, the information will be analyzed in a general way and individual responses cannot be identified. The researcher will assign you a numeric identifier and your name will not be connected to your responses, i.e. the responses will be processed anonymously without name references. It is important to us that you feel safe while answering the questionnaire, at any time you can pause or stop.

If you have any questions or comments about this study, we will be happy to clarify them at any time.

Thank you very much for being part of this study, your answers are very important to us!

Acknowledgements

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Informed Consent

CI1 I confirm that I have read and understood the information provided in the information sheet for the project activity. o Yes (1) o No (2)

C12 I give my consent to be interviewed for the activity of this project o

CI3 I give my consent for my answers to be documented on paper and/or in electronic format. Yes (1) o No (2)

Internal Use
Type of survey? o Telephone (1) o In person (2)

CF0 Coffee growing region
o Coto Brus (1)
o Los Santos (2)
o Perez Zeledón (3)
o Turrialba (4)
o Central Valley (5)
o West Valley (6)
o North (7)

CF0 Province
o Puntarenas (1)
o Alajuela (2)
o Cartago (3)
o San José (4)
o Heredia (5)
o Guanacaste (6)

CF1 Canton where the farm is located.
o Buenos Aires (4) ... Other (59)

SECTION2 SD Section 2. Sociodemographic information

D

SD1 Gender
o Male (1)
o Female (2)
o Other(2)

SD2 Age in years ____

SD3 Formal education
o Incomplete primary school (1)
o Primary school complete (2)
o Secondary incomplete (3)
o Secondary complete (4)
o Technical (5)
o University incomplete (6)
o Completed university (7)

SD4 Have you received training, courses, lectures related to coffee? . o Yes (1) o No (2)

SD6 Do you belong to an association/cooperative of producers? . o Yes (1) o No (2)

SD7 Which producer association/cooperative do you belong to? Please list all that you belong to

....

SD10 If you have children, do your children support family agricultural production?
o Yes (1)
o No (2)
o N/A (99)

SD11 The farm's labor force is
Family (1)
Hired (2)
Subcontracted (3)

SD12 Do you have any credit to finance productive activities? . o Yes (1) o No (2)

SECC3. CF Section 3. Farm characteristics

CF3 Is the farm owned, rented, borrowed, other?
o Owned (1)
o Rented (2)
o Borrowed (3)
o Other (4)

CF4 Size of the farm? Measure Size (1) o

CF5 Area of the farm planted with coffee? Measure Size (1) o

CF6 Years of producing coffee? > 1 (7) ... 173 (179)

CF7 Variety(ies) grown
Caturra (1)
Catuai (2)
Catimor/Costa Rica 95 (3)
Sarchimor (4)
Geisha (5)
Hybrid Tico (6)
Other (7)

CF8 Average annual coffee production in fanegas per hectare?
Measure Quantity

CF10 Does the crop have any quality certification or good agricultural practices? Example Organic, Rain Forest, Fair Trade, among others.
o Certified (1)
o Not certified (2)
o Transition stage (3)

CF11 What certification do you have?
Organic (1)
Fair Trade (2)
GlobalGAP (3)
Rainforest Alliance (4)
AAA Nespresso (6)
Other (5)

CF12 Is your certification group or individual?
o Group (1) o Individual (2)

CF13 Do you get technical assistance? o Yes (1) o No (2)

CF14 Technical assistance received is
o Public (MAG, ICAFE) (1)
o Private (Cooperatives, Engineer, input supplier, Company) (2)
o Both (3)

SECC 4. CC Section 4. Climate change and other risks

Climate change is the global variation of the Earth's climate. This variation is due to natural causes and to the action of man and is produced on all climatic parameters: temperature, precipitation, cloudiness, etc.

		1 = Strongly disagree	2 (2)	3 (3)	4 (4)	5 = Strongly agree
PR1	I'm concerned about the potential impact of climate change on my community	o	o	o	o	o
PR2	Climate change presents more risks than benefits to agriculture globally	o	o	o	o	o
PR3	I believe that extreme weather events will happen more frequently in the future	o	o	o	o	o
PR4	Climate change poses more risks than benefits to agriculture in my community	o	o	o	o	o
PR5	Climate change will lead to increased productivity losses due to diseases and pests	o	o	o	o	o
PR6	The global climate is changing	o	o	o	o	o
PR7	Climate change poses risks to agriculture globally	o	o	o	o	o

PS Please indicate how serious/harmfull the following events 1 (very low) to 5 (very high)

	1 Very low				5 Very high
	1	2	3	4	5
PS1Drought poses a threat to the coffee plantation					
PS2Unpredictably high rainfalls pose a threat to the coffee plantation					
PS3 Yield losses due to excessive rainfall severity ()					
PS4Climate change affects the coffee bean quality					
PS5Climate change has increase plant disease severity ()					
PS6 Rise in temperatures					

PV Of the following risks please indicate how likely/possible it is that they could affect your farm (1= not likely 5= very likely)

	1 = Strongly disagree	2 (2)	3 (3)	4 (4)	5 = Strongly agree
Increase of problems in blossoming (scattered flowering, flower drop, drying of buds).	o	o	o	o	o
Lower productivity and yield losses due to climate change	o	o	o	o	o
Losses of plants due to an increase in diseases and plagues (anthracnose)	o	o	o	o	o
Increase of plant diseases vulnerability (coffee rust)	o	o	o	o	o
Reduction of the quality of the coffee harvest	o	o	o	o	o
Increase of problems in blossoming (scattered flowering, flower drop, drying of buds).	o	o	o	o	o
Lower productivity and yield losses due to climate change	o	o	o	o	o

SEC 6. CSC: Section 6. Climate-Smart Coffee CSC

CSC.0. Do you know about CSA or CSF? . o Yes (1) o No (2)

CSC.0.1 Can you provide and example? ________

Internal use

Climate-smart coffee growing is known as sustainable and climate-adapted coffee growing. . It aims to sustainably increase productivity, improve resilience to climate risk while reducing greenhouse gases.

Examples of practices are: reduction of fertilizer use, use of climate information applications, soil conservation practices, crop diversification, shade management. [For example, soil conservation practices such as mulching, terracing or live fences improve the sustainable use of soil, in turn fixing carbon and giving your farm an advantage in extreme rainfall events because the soil is not washed away].

CSC.0.1 According to the above definition, could you mention any practice that you consider as sustainable or Climate Smart?

Please indicate to what extent you agree or disagree with the following statements (1 = Strongly Disagree 5 = Strongly Agree)

PE1	It is useful for my coffee plot to perform CSA technologies
PE2	Using the CSA technologies will increase my chances of achieving higher crop productivity.
PE4	If I take up CS technologies, my profits and income will increase.
PE5	Using CS technologies makes it easier for me to do farming activities in the coffee plantation
PRE5	Proper/efficient use of fertilizers is useful for reducing environmental impact by reducing nitrogen emissions.
PRE6	Proper use of fertilizers reduces costs and increases productivity.
PRE8	The use of applications with climatic information is useful to increase quality and quantity of coffee beans.
PRE9	The use of pest resistant varieties is useful to combat climate change.
PRE1	Soil conservation practices are useful for my coffee plantation
PRE2	Soil conservation practices are useful to prepare for climate change/Soil conservation practices increase the resilience of the coffee plantation to extreme rainfall.
PRE3	Shade trees are useful to prepare for drought, climate variability and disease.

FC Indicate to what extent you agree or disagree with the following statements (1 = Strongly Disagree 5 = Strongly Agree)

FC1	I have access to the necessary resources (financial, knowledge) to implement CS tech	
FC2	I have the necessary knowledge to implement CS technologies	
FC3	Experts are available in the area to address the problems and deficiencies of CS Tech	
FC4	It is easy for me to get the skills to use CS technologies	
SI1	People who are important to me think that I should use the CS technologies	
SI2	The people whose opinions are valuable to me prefer to use the CS technologies.	
SI3	The local community encourage me to adopt CST on my farm	
SI4	The CSA practices help me to be an example for other farmers.	
PC1	Farm work is too busy; there is no extra time to commit to CS Technologies	
PC2	Working very hard every day, no extra physical strength to commit to CS Technologies	
PC3	I have financial constraints to implement CS technologies	

CSTA Please indicate how likely it is that you would do any of the following

Recuerde CI =climáticamente inteligente o practicas sostenibles y adaptadas al clima

		1 = Very unlikely;				5 = Very likely
		1	2	3	4	5
CSTA1	I would use or will continue using the CS technologies in the future.					
CSTA2	I planned to use or will continue using the CS technologies more frequently in the future.					
CSTA3	I would promote the CS technologies use to the others farmers.					
CSTA4	I would change my practices to cope and adapt to climate change.					

SEC Indicate how prepared you are to perform the following practices (1 = I feel unprepared to perform the practice; 5 = I feel very prepared to perform the practice).

Apply fertilizers/fertilizers according to the need of the plantation/ according to demand.	☆	☆	☆	☆	☆
Manage resources (e.g. labor, herbicides, fertilizers) efficiently.	☆	☆	☆	☆	☆
Deliver high-quality grain	☆	☆	☆	☆	☆
Meet the grain quality expectations demanded by the buyer.	☆	☆	☆	☆	☆
Take actions to combat the effects of climate change (drought or excess rainfall).	☆	☆	☆	☆	☆
Use sensors and other tools to measure humidity and temperature.	☆	☆	☆	☆	☆
Use high-tech in the coffee plantation (drones, automated fertilizer , weather stations, site-specific liming).	☆	☆	☆	☆	☆
Apply fertilizers/fertilizers according to the need of the plantation/ according to demand.	☆	☆	☆	☆	☆

SRP Indicate to what extent you agree or disagree with the following statements (1 = Strongly Disagree 5 = Strongly Agree)

In general, Climate Smart practices have or could have negative consequences on my farm.	o	o	o	o	o
Soil and water conservation practices have negative consequences on my the coffee plantation.	o	o	o	o	o
Climate Smart practices can lead to a reduction in yield/production of harvested coffee.	o	o	o	o	o
If I use CS technologies, I run the risk of losing productivity.	o	o	o	o	o
In general, Climate Smart practices have or could have negative consequences on my farm.	o	o	o	o	o

SECC 7. CSA Section 7 CSA practices- technologies

AT_P **Set 1**

Have you performed soil analysis on the farm (AT_P1_1)?	yes (1)	no (2)
Do you make amendments? Example: Use of lime to correct acidity in the soil (AT_P_19)	yes (1)	no (2)
Do you use chemical fertilizers (AT_P_3_1)?	yes (1)	no (2)
Do you use organic fertilizer such as compost, boccashi or biochar or others? (AT_P_20)	yes (1)	no (2)
Do you use specific fertilizers/fertilizers according to the type of soil? (PEnvB5_1)	yes (1)	no (2)
Do you use organic products to control pests and diseases such as repellents or biols? (AT_P_P_4_1)	yes (1)	no (2)

AT_GC **Set 2**

Do you use shade threes in the coffee plantation (AT_GC_3_1)?	yes (1)	no (2)
Have you renewed the coffee plantation (AT_GC_5_1)?	yes (1)	no (2)
Do you use improved varieties that are resistant to pests and diseases? (AT_GC_10_1)	yes (1)	no (2)
Do you use improved varieties that are more productive (AT_GC_11_1)?	yes (1)	no (2)
Do you apply weed management (mowing or herbicides)? (AT_GC_6_1)	yes (1)	no (2)
Do you use soil conservation practices (AT_GC_7_1)?	yes (1)	no (2)
Has the use of herbicides increased in recent years in your coffee plantation to control weeds? (AT_GC_29)	yes (1)	no (2)
Has the use of pesticides or fungicides increased in recent years in your coffee plantation to control pests and diseases? (PEnvB15_1)	yes (1)	no (2)
Do you implement integrated pest management, for example: pest sampling (sticky traps, pest sampling, protective barriers, manual control and biological controllers) (AT_GC_9_1)?	yes (1)	no (2)

AT_GC_3_2 ¿Type of shade?

- o Banana (1)
- o Avocado (2)
- o Guaba (3)
- o Poro (4)
- o Other (5)

....

AT_GC_7_2 What soil conservation practices do you use?

- o Contour seeding (1)
- o Vegetative barriers (2)
- o Terraces (3)
- o Ditches (4)
- o Diversion channels (5)
- o Gully correction (6)
- o Other (7)

....

D

AT_CA_1_2 Have you reforested near water sources?
o Yes (1)
o No (2)

....

PEnvB_8_1 Do you use any water harvesting practices?
o Yes (1)
o No (2)

PEnvB **Set 3**

Do you use cell phone applications for disease prediction or early warning? E.g. CR-CAFE or messages from the cooperatives with alerts (PEnvB_8_1)	yes (1)	no (2)
Do you use on-farm sensors to measure air and soil temperature (PEnvB_17_1)?	yes (1)	no (2)
Do you use systems and/or applications for crop estimation (AT_GC_12_1)?	yes (1)	no (2)
Do you use windbreaks (PEnvB_11_1)?	yes (1)	no (2)
Do you implement Agroforestry Systems (PEnvB_2_1)?	yes (1)	no (2)
Have you stopped cultivating certain areas of the farm? (PEnvB_13_1)	yes (1)	no (2)
Have you planted crops that you did not plant before? (PEnvB_14_1)	yes (1)	no (2)

SECC 8. PM Section 8. Programs and Projects

Q_P The following questions refer to programs/projects to promote Climate Smart practices

CONCOH 7.1 Please rate the following statements using a scale of. 1 = Strongly Disagree to 5 = Strongly Agree

		1 = SD 1 (1)	2 (2)	3 (3)	4 (4)	5 = SA (5)
CON1	Concerning MAG and ICAFE training programs supports the use Climate Smart or sustainable practices	o	o	o	o	o
CON2	Funding programs (grants and donations) for investment in equipment/machinery and improvement of practices reinforce each other in order to support me to use Climate Smart technologies"	o	o	o	o	o
CON3	Concerning the policy environment, there are contradictions in the programs and projects promoted by the government to promote CSA and more sustainable agriculture.	o	o	o	o	o

COH1	Policy makers spot/ recognize on time the problems that arise in relation to the use of sustainable practices and CSA	o	o	o	o	o
COH2	Policy makers always strive to remove obstacles related to the use of sustainable practices and CSA.	o	o	o	o	o
COH3	Policy makers are well informed about developments in sustainable coffee farming CSA	o	o	o	o	o
COH4	The government is constantly adjusting its policies to favor of CSA.	o	o	o	o	o
COM1	Important flanking policies are missing that promote the adoption of CS	o	o	o	o	o

CRE 7 Please rate the following statements using a scale of. 1 = Strongly Disagree to 5 = Strongly Agree

	(1)	(2)	(3)	(4)	(5)
CRE0: Do you think that there is a strong support from the central government for promoting CSA.	o	o	o	o	o
CRE3: Do you think that there is a strong support from extension agencies for promoting CSA	o	o	o	o	o
CRE4: Do you think that there is a strong support private companies for promoting CSA.	o	o	o	o	o
CRE1Cooperatives encourage me to adopt CST on my farm	o	o	o	o	o
CRE2 Do you think that there is a strong support of cooperatives for promoting CSA	o	o	o	o	o

IMIX Do you participate in any of the following programs or projects ?

- Coffee NAMA Program (IMIX_1_1) o Yes (1) o No (2)
- Organic Agriculture Program (IMIX_2_1) o Yes (1) o No (2)
- Environmental Services Recognition Program (IMIX_3_1) o Yes (1) o No (2)
- Private certifications (GLOBAL GAP, Rain Forest Alliance, Fair Trade) (IMIX_4_1) o Yes (1) o No (2)
- Agricultural Insurance (IMIX_5_1) o Yes (1) o No (2)
- Blue Flag Certification Program (IMIX_6_1) o Yes (1) o No (2)
- Credits/Loans with differentiated interest (cooperatives lower rates or payment of inputs with the harvest) (IMIX_7_1) o Yes (1) o No (2)
- Field days and demonstration plots (IMIX_8_1) o Yes (1) o No (2)

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English summary

The predominant agricultural production model characterized by intensive use of inputs and strong reliance on agrochemicals contributes to soil and water degradation, biodiversity loss, and greenhouse gas emissions (Crippa et al., 2021). Such complex and interlinked societal challenges call for transforming the current agricultural system. In response, practitioners, development agencies, and scientists promoted Climate Smart Agriculture (CSA) as an integrated approach to tackle climate change threats encompassing changes at the farm level but also efforts for redirecting financial resources and orchestrating policies and regulations (Lipper et al., 2015). Given the complexity of CSA, the transition requires systemic changes (e.g., policies, legislation, and infrastructures) (Scherer & Verburg, 2017; Zilberman et al., 2018) but also changes at the individual level (e.g., farmers and consumers). To change the existing agricultural system and build a 'Climate Smart system' no single policy instrument, intervention, or technology suffices (Edmondson et al., 2019; Kivimaa & Kern, 2016; Rosenow et al., 2017; Turnheim & Geels, 2013), but requires a policy mix to restrict prevailing unsustainable practices and support the development of new technologies (Flanagan et al., 2011; Kivimaa & Kern, 2016; Rogge & Reichardt, 2016).

In the four strands of the literature where this thesis is situated -sustainability transitions, agricultural innovation systems, CSA, and behavioral theories- it is recognized that individual choices are interconnected with a broader context, as individuals are not passive recipients but active participants driving technological change, and their behavior collectively contributes (or not) to a more sustainable system (de Vries et al., 2021; Upham et al., 2019). Transition and agricultural innovation theories overlook individual agents' role in change, while behavioral theories focus on cognitive processes without considering institutional context as an external determinant. Building on these different strands of literature, this thesis recognizes that individual choices are contingent upon the broader context (Engler et al., 2019; Upham et al., 2019). This broader context establishes the 'rules of the game' (North, 1990) in the form of standards, regulations, taxes, and incentives (Flanagan et al., 2010), and in turn, individuals' behavior (which is a key driving force for social and technological change) thereby contributing (or not) to a more sustainable system (de Vries et al., 2021). Therefore, the main research question guiding the research project is: *How are the interactions between CSA policies and individual farmers shaped by systemic and individual-level processes*?

As a starting point, this thesis uses the macro-level CSA policy developments to unravel the dynamics of implementing CSA as a potentially transformative policy mix

(chapter 2). At the meso level, the study examines how farmers' appraisal of the policy environment and behavioral drivers influence the acceptance of CSA technologies (chapter 3). At the micro level (chapter 4), this study focuses on farmers' CSA adoption by identifying the key risk-related drivers influencing the interrelated adoption of CSA technologies. To answer the research questions, we consider qualitative and quantitative primary and secondary data, including in-depth interviews, observations, focus group discussions, surveys, and policy documents.

Chapter 2 presents a historical and thematic content analysis of the policy mix promoting the development of CSA in Costa Rica from 2000 – 2022. The results showed that the CSA strategy focuses on sustainable development, food security, and climate change challenges, but with differences in emphasis over time. The policy mix's transformative potential was inhibited by weak implementation capacity and internal and external incoherence between sectors and governance levels, leading to tensions resulting from policy-element interactions such as conflicting goals and interventions with overlapping purposes. In theory, Costa Rica's CSA policy is a transformative policy mix in the making. In practice, it has not met its potential because of fragmentation, a lack of policy coordination, and historical legacies.

Chapter 3 explores the relationship between individual farmers and the policy context in which the farm operates. The chapter asses how farmers' behavioral drivers and their appraisal of the policy mix (consistency, coherence, credibility, and comprehensiveness) influence the acceptance of CSA technologies and practices. These findings show that, besides the influence of behavioral drivers, perceptions of policy consistency, comprehensiveness, and the type of instrument(s) targeting farmers' behaviors play an important role in explaining farmers' acceptance of CSA. Perceptions of the consistency of the instrument mix (i.e., farmers' appraisal of the alignment of the instruments and the policy objectives) and its comprehensiveness were positively related to a higher probability of accepting the CSA technologies. Overall, the findings highlight the links between policy and individual decision-making when promoting sustainable agricultural practices, such as CSA, and emphasize the need for a comprehensive and integrated approach that addresses both systemic and individual-level determinants.

Chapter 4 focused on individual behavior and explored the drivers that influence farmers' adoption of CSA. The chapter conceptualizes a model that integrates 1) climate change risk appraisal, 2) the perceived efficacy of the alternatives recommended to face the risks, 3) a secondary risk appraisal (e.g., the perceived threats caused by implementing some CSA practices), and 4) social and demographics. Focused on risk-related appraisals, the analysis reveals how the influence of perceived climate risk severity, perceived vulnerability, response efficacy, self-efficacy, and perceived cost had varying significance in explaining the adoption of different categories of CSA. Additionally, this chapter shows significant correlations between multiple CSA technologies, indicating that farmers' decisions to adopt one technology (or CSA category) are interrelated with adopting other technologies. I found significant complementary relations among the adoption categories (e.g., soil fertility and soil conservation).

This thesis contributes to a better understanding of CSA policy developments and has shown the dynamics between the system and farmers' choices. Three key contributions are made to the literature by improving the understanding of the farmer-system interactions. Each contribution is positioned at a different analytical level based on the strands of the literature where this thesis is situated: sustainability transitions, behavioral theories, and CSA.

First, this thesis contributes to transition studies by showing the developments of transformative policy mixes in practice and identifying key features that positively or negatively reinforce one another to promote the intended change. Chapter 2 pays sufficient attention to what underpins policy coherence and consistency in more depth and, based on these findings, argues the need for a better understanding of the sociopolitical context by signaling that institutional context, policy cultures, and legacies shaped the development of the policy mix over time. Thus, transformative elements (such as guiding long-term vision) faced counteractive influences due to layering, drifting, and conversion processes.

Second, it contributes to transition and behavioral theories by capturing the mutual responsiveness between the policy context and farmers' decisions toward implementing more sustainable technologies. Chapter 3 adds to the broader debate on the role of individual agency in sustainability transitions by providing a comprehensive explanation of the acceptance and adoption of technologies and practices by combining behavioral theories with the policy mix approach. Moreover, it adds to behavioral theories since it moves beyond focusing on individual-related drivers explaining technology acceptance and adoption. This thesis opens the' black box' of the contextual determinants influencing behavioral change. Chapter 3 shows how individuals' perceptions of the policy mix (e.g., consistency and comprehensiveness) positively shaped their decisions to accept CSA, and it was evident that farmers are willing to accept CSA if they have a favorable appraisal of the policy mix in terms of consistency and comprehensiveness. The findings suggest that this combination is a significantly more robust and inclusive way of understanding farmers' acceptance of climate-smart technologies than models that only use behavioral drivers.

Third, it contributes to CSA by taking a combined individual-systems perspective. First, I explored the development of the CSA policy mix; secondly, I connected the macro and micro approaches of CSA and added several behavioral drivers to better explain CSA adoption. As for the CSA policy mix, the policy instruments were not specifically CSA-focused or carefully integrated transformative elements into the existing mix, resulting in what could be called a "policy pandemonium". Second, at the individual level, this thesis adds to the body of work focused on understanding the adoption of CSA in two ways: i) by exploring CSA adoption as interrelated to other technologies and ii) by opening up the set of behavioral drivers influencing adoption. The finding challenges the underlying assumptions of a homogenous set of drivers -one size fits all for explaining all climate coping mechanisms and suggests a more nuanced and context-specific approach for promoting CSA adoption.

Finally, this thesis identifies challenges for policy and practice and offers practical recommendations tailored for policymakers and other stakeholders such as organizations, cooperatives and extension agents. There is a need to work toward policy integration. Enhancing policy integration can be effectively facilitated through the strategic deployment of intermediaries. I propose the integration of intermediary bodies tailored to each level: macro, meso, and micro. At the macro level, an intermediary could help to navigate the intricate dynamics inherent in the multilevel and cross-sectoral nature of CSA (e.g., by an innovation agency located at the Ministry of Science and Technology). At the meso level, I suggest creating a CSA coordination body to bridge the macro-strategic policy decisions and the micro level farming practices (e.g., chaired by a NGO with representation at both levels). At the micro level, I suggest designating a coordination extension agent in each region to connect with the CSA coordination unit and other extension services scattered across the public and private agencies. This three-tiered intermediary structure may be designed to span various scales to enhance the effectiveness of policy implementation and better integrate the three pillars of CSA: adaptation, mitigation, and agricultural productivity.

At the community level, organizations, such as cooperatives and producer organizations, play a key role in providing inputs and credit at a lower cost, as well as market information and technical assistance. Thus I argue that providing information about technologies and climate change risk, assessing farmer vulnerability to climate risk, and tackling technology misinformation may increase farmers' acceptance and adoption of CSA practices. Thus, investing in effective communication channels between farmers, cooperatives, technicians, and extension agents may be a way to promote more sustainable practices.

Resumen

El modelo de producción agrícola predominante, caracterizado por el uso intensivo de insumos y la fuerte dependencia de los productos agroquímicos, contribuye a la degradación del suelo y el agua, la pérdida de biodiversidad y las emisiones de gases de efecto invernadero (Crippa et al., 2021). Estos retos sociales complejos e interrelacionados exigen transformar el sistema agrícola actual. En respuesta, los profesionales, las agencias de desarrollo y los científicos han promovido la Agricultura Climáticamente Inteligente (CSA, por sus siglas en inglés) como un enfoque integrado para hacer frente a las amenazas del cambio climático, que abarca cambios en las explotaciones agrícolas, pero también esfuerzos para reorientar los recursos financieros, orquestar políticas y normativas (Lipper et al., 2015). Dada la complejidad de la agricultura climáticamente inteligente , la transición requiere cambios sistémicos (por ejemplo, políticas, legislación e infraestructuras) (Scherer y Verburg, 2017; Zilberman et al., 2018) pero también cambios a nivel individual (por ejemplo, agricultores y consumidores). Para cambiar el sistema agrícola existente y construir un "sistema climáticamente inteligente" no basta con un único instrumento político, intervención o tecnología (Edmondson et al., 2019; Kivimaa & Kern, 2016; Rosenow et al., 2017; Turnheim & Geels, 2013), sino que requiere una combinación de políticas para restringir las prácticas insostenibles imperantes y apoyar el desarrollo de nuevas tecnologías (Flanagan et al., 2011; Kivimaa & Kern, 2016; Rogge & Reichardt, 2016).

En las cuatro vertientes de la literatura en las que se sitúa esta tesis -transiciones hacia la sostenibilidad, sistemas de innovación agrícola, CSA y teorías del comportamiento-se reconoce que las elecciones individuales están interconectadas con un contexto más amplio, ya que los individuos no son receptores pasivos sino participantes activos que impulsan el cambio tecnológico. Por ende el comportamiento contribuye colectivamente (o no) a un sistema más sostenible (de Vries et al., 2021; Upham et al., 2019). Las teorías de la transición y la innovación agrícola pasan por alto el papel de los agentes individuales en el cambio, mientras que las teorías del comportamiento se centran en los procesos cognitivos consideran el contexto institucional como un determinante externo.

Basándose en estas diferentes corrientes de la literatura, esta tesis reconoce que las elecciones individuales están supeditadas al contexto más amplio (Engler et al., 2019; Upham et al., 2019). Este contexto más amplio establece las "reglas del juego" (North, 1990) en forma de normas, reglamentos, impuestos e incentivos (Flanagan et al., 2010), y, a su vez, el comportamiento de los individuos (que es una fuerza motriz clave para el cambio social y tecnológico), contribuye así (o no) a un sistema más sostenible

(de Vries et al., 2021). Por lo tanto, la principal pregunta de investigación es: ¿Cómo se configuran las interacciones entre las políticas de CSA y los agricultores individuales mediante procesos a nivel sistémico e individual?

Como punto de partida, esta tesis utiliza la evolución de las políticas de CSA a nivel macro para explorar las dinámicas de la implementación de CSA como una combinación de políticas potencialmente transformadora (capítulo 2). A nivel meso, el estudio examina cómo influyen en la aceptación de las tecnologías de CSA la valoración que hacen los agricultores del entorno político y los impulsores del comportamiento (capítulo 3). A nivel micro (capítulo 4), este estudio se centra en la adopción de CSA por parte de los agricultores, identificando los principales factores relacionados con el riesgo que influyen en la adopción interrelacionada de tecnologías CSA (e.g., prácticas de conservación de suelo, fertilización, agroforestería)

Para responder a las preguntas de la investigación, se consideran datos cualitativos y cuantitativos primarios y secundarios, incluidas entrevistas en profundidad, observaciones, debates de grupos focales, encuestas y documentos políticos.

El Capítulo 2 presenta un análisis de contenido histórico y temático de la combinación de políticas que promueven el desarrollo de la CSA en Costa Rica entre 2000 y 2022. Los resultados mostraron que la estrategia de CSA se centra en los retos del desarrollo sostenible, la seguridad alimentaria y el cambio climático, pero con diferencias de énfasis a lo largo del tiempo. El potencial transformador de la combinación de políticas es innhibido por la escasa capacidad de implementación y la incoherencia interna y externa entre los sectores y los niveles de gobernanza, lo que provocó tensiones derivadas de las interacciones entre las políticas y los elementos transformadores, como objetivos contrapuestos e intervenciones con fines superpuestos. En teoría, la política de CSA de Costa Rica es una combinación de políticas transformadoras, pero en la práctica, no ha alcanzado su potencial debido a la fragmentación, la falta de coordinación política y los legados históricos.

El capítulo 3 explora la relación entre los agricultores individuales y el contexto político en el que opera la finca. El capítulo evalúa cómo influyen en la aceptación de las tecnologías y prácticas de CSA los impulsores del comportamiento de los agricultores y su valoración de la combinación de políticas (consistencia, coherencia, credibilidad y exhaustividad). Estos resultados muestran que, además de la influencia de los factores de comportamiento, las percepciones de la coherencia de las políticas, la exhaustividad y el tipo de instrumento(s) dirigido(s) a los comportamientos de los agricultores desempeñan un papel importante a la hora de explicar la aceptación de la CSA por parte de los agricultores. La percepción de la coherencia de la combinación de instrumentos (es decir, la valoración por parte de los agricultores de la alineación de los instrumentos y los objetivos políticos) y su exhaustividad se relacionaron positivamente con una mayor probabilidad de aceptación de las tecnologías de CSA. En general, los resultados ponen perspectiva los vínculos entre la política y la toma de decisiones individuales a la hora de promover prácticas agrícolas sostenibles, como la CSA, y hacen hincapié en la necesidad de un enfoque global e integrado que aborde los factores determinantes tanto a nivel sistémico como individual.

El capítulo 4 se centra en el comportamiento individual y explora los factores que influyen en la adopción de la CSA por parte de los agricultores. El capítulo conceptualiza un modelo que integra 1) la valoración del riesgo del cambio climático, 2) la eficacia percibida de las alternativas recomendadas para hacer frente a los riesgos, 3) una valoración secundaria del riesgo (por ejemplo, las amenazas percibidas causadas por la aplicación de algunas prácticas de CSA), y 4) aspectos sociales y demográficos. Centrándose en las valoraciones relacionadas con el riesgo, el análisis revela cómo la influencia de la gravedad percibida del riesgo climático, la vulnerabilidad percibida, la eficacia de la respuesta, la autoeficacia y el coste percibido mostraron heterogeneidad a la hora de explicar la adopción de diferentes categorías de CSA. Además, este capítulo muestra correlaciones significativas entre múltiples tecnologías de CSA, lo que indica que las decisiones de los agricultores de adoptar una tecnología (o categoría de CSA) están interrelacionadas con la adopción de otras tecnologías. Se encontraron relaciones complementarias significativas entre las categorías de adopción (por ejemplo, fertilidad del suelo y conservación del suelo).

Esta tesis contribuye a una mejor comprensión de la evolución de las políticas de la CSA así como la dinámica entre el sistema y las elecciones de los agricultores.

Se hacen tres contribuciones al mejorar la comprensión de las interacciones entre el agricultor y el sistema. Cada contribución se sitúa en un nivel analítico diferente en función de la literatura en las que se sitúa esta tesis: transiciones hacia la sostenibilidad, teorías del comportamiento y CSA.

En primer lugar, esta tesis contribuye a los estudios sobre la transición mostrando la evolución de las combinaciones de políticas transformadoras en la práctica e identificando las características clave que se refuerzan positiva o negativamente entre sí para promover el cambio pretendido. En el capítulo 2 se presta suficiente atención a lo que subyace a la coherencia y consistencia de las políticas en mayor profundidad y, basándose en estos hallazgos, se argumenta la necesidad de comprender mejor el contexto sociopolítico al señalar que el contexto institucional, las culturas políticas y los legados moldearon el desarrollo de la combinación de políticas a lo largo del tiempo. Así, los elementos transformadores (como la visión orientadora a largo plazo) se enfrentaron a influencias contrapuestas debido a los procesos de estratificación, drifting y conversión.

En segundo lugar, contribuye a las teorías de la transición y el comportamiento al captar la capacidad de respuesta mutua entre el contexto político y las decisiones de los agricultores hacia la aceptación de tecnologías más sostenibles. El capítulo 3 contribuye al debate más amplio sobre el rol de la agencia individual en las transiciones hacia la sostenibilidad al ofrecer una explicación exhaustiva de la aceptación y adopción de tecnologías y prácticas combinando las teorías del comportamiento con el enfoque de la combinación de políticas. Además, agrega a las teorías del comportamiento, ya que va más allá de centrarse en los factores individuales que explican la aceptación y la adopción de tecnologías. Esta tesis abre la "caja negra" de los determinantes contextuales que influyen en el cambio de comportamiento. El capítulo 3 muestra cómo las percepciones de los individuos sobre la combinación de políticas (por ejemplo, coherencia y exhaustividad) influyeron positivamente en sus decisiones de aceptar la CSA, y se puso de manifiesto que los agricultores están dispuestos a aceptar la CSA si tienen una valoración favorable de la combinación de políticas en términos de coherencia y exhaustividad. Los resultados sugieren que esta combinación es una forma significativamente más sólida e inclusiva de entender la aceptación de los agricultores de las tecnologías climáticamente inteligentes que los modelos que sólo utilizan factores relacionados con el comportamiento.

En tercer lugar, contribuye a la literatura de CSA adoptando una perspectiva combinada individual- sistémica. Primero, se exploró el desarrollo de la combinación de políticas de CSA; Segundo, se conectaron los enfoques macro y micro de CSA, añadiendo varios factores del comportamiento que explicaron de mejor forma la adopción de CSA. En cuanto a la combinación de políticas de CSA, los instrumentos políticos no se centraban específicamente en la CSA ni integraban cuidadosamente elementos transformadores en la combinación existente, lo que dio lugar a lo que podría denominarse un "pandemónium político". Tercero, a nivel individual, esta tesis se suma al conjunto de trabajos centrados en la comprensión de la adopción de la CSA de dos maneras: i) explorando la adopción de la CSA como interrelacionada con otras tecnologías y ii) abriendo el conjunto de factores del comportamiento que influyen en la adopción. Los resultados ponen en tela de juicio los supuestos subyacentes de un conjunto homogéneo de factores que explican todos los mecanismos de adaptación al cambio climático y sugieren un enfoque más matizado y específico del contexto para promover la adopción de la CSA.

Por último, esta tesis identifica retos para la política y la práctica y ofrece recomendaciones prácticas adaptadas a los responsables políticos y otras partes interesadas, como organizaciones, cooperativas y agentes de extensión. Es necesario trabajar por la integración de las políticas. La mejora de la integración de políticas (por ejemplo, resolviendo incoherencias e incoherencias y conciliando intereses contrapuestos) puede facilitarse eficazmente mediante el despliegue estratégico de intermediarios. Como resultado de la investigación se propone la integración de organismos intermediarios adaptados a cada nivel: macro, meso y micro. A nivel macro, un intermediario podría ayudar a coordinar la intrincada dinámica inherente a la naturaleza multinivel e intersectorial de la CSA (por ejemplo, mediante una agencia de innovación ubicada en el Ministerio de Ciencia y Tecnología). A nivel meso, se sugiere crear un órgano de coordinación de la CSA que sirva de puente entre las decisiones políticas estratégicas y las prácticas agrícolas a nivel micro (por ejemplo, presidido por una ONG con representación en ambos niveles). A nivel micro, se propone designar un agente de extensión de coordinación en cada región para conectar con la unidad de coordinación de la CSA y otros servicios de extensión dispersos por los organismos públicos y privados. Esta estructura intermediaria de tres niveles está diseñada para abarcar varias escalas con el fin de mejorar la eficacia de la aplicación de las políticas e integrar mejor los tres pilares de la CSA: adaptación, mitigación y productividad agrícola.

A nivel comunitario, las organizaciones, como las cooperativas y las organizaciones de productores, desempeñan un papel clave a la hora de proporcionar insumos y créditos a un coste menor, así como información de mercado y asistencia técnica. Por ello, proporcionar información sobre tecnologías y riesgos del cambio climático, evaluar la vulnerabilidad de los agricultores ante el riesgo climático y abordar la desinformación tecnológica puede aumentar la aceptación y adopción de prácticas de CSA por parte de los agricultores. Así, invertir en canales de comunicación eficaces entre agricultores, cooperativas, técnicos y agentes de extensión puede ser una forma de promover prácticas más sostenibles.

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About the author

Maria Fernanda Rodriguez Barillas, born and raised in Costa Rica. She holds a Master of Science degree in International Agribusiness and Rural Development from Göttingen University, Germany, and the University of Talca, Chile and a bachelor degree in Agricultural Economics from Universidad de Costa Rica where she graduated in 2012.

Prior to her Ph.D. studies, Maria Fernanda worked as an Agricultural Economics Lecturer at the University of Costa Rica during this time, she contributed to the courses on Agricultural Economic Analysis and Principles of Agricultural Economics. She was actively engaged in action research projects within indigenous communities, working towards the promotion of traditional agricultural cultivation practices to enhance food security.

Upon completing her Ph.D., she will join the Department of Agricultural Economics at the Universidad de Costa Rica. In this next phase, she aspires to integrate her passion for research with the opportunity to teach, further contributing to the her personal and professional growth but also aligning with the vision of the department.

María Fernanda Rodríguez-Barillas
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Wageningen School of Social Sciences

Name of the learning activity	Department/Institute	Year	ECTS*
A) Project related competences			
A1 Managing a research project			
WASS introduction course	WASS	2021	1.0
Scientific writing	Wageningen in'to Languages	2020	1.8
Writing Research Proposal	WUR	2020	6.0
'How transformative is the Climate-Smart Agriculture policy mix in Costa Rica? Early insights through the perspective of policy mix building blocks'	EUSPRI Conference	2020	1.0
'Mapping the Climate Smart Agriculture policy mix for the Costa Rican coffee sector: What transformative instruments does it have?'	Globelics international conference	2022	1.0
Skill session: Publishing and reviewing	KTI	2022	0.3
Reviewing a Scientific Manuscript	WGS	2023	0.1
A2 Integrating research in the corresponding discipline			
Qualitative Data Analysis: Procedures and Strategies MAT-50806	WUR	2020	6.0
Generalized Linear Models	PE&RC	2022	0.9
Analysing Discourse: Theories, Methods and Techniques CPT56306	WUR	2020	6.0
Research Methodology: from topic to proposal	WASS	2020	4.0
B) General research related competences			
B1 Placing research in a broader scientific context			
Innovation and Sustainable transition	Western Norway University of applied Sciences	2020	5.0
Systems Thinking in Practice	PhD course 14th European IFSA Conference, Portugal	2022	4.0
B2 Placing research in a societal context			
Workshop "Sustainability indicators" Sustainable Coffee and Cacao Discussion Group. Wageningen University	SCCDG WUR	2023	0.5
Workshop organized for extension agents and policymakers "Climate-smart agriculture transition in the coffee sector in CR". Ministry of Agriculture and Livestock, Perez Zeledón, Costa Rica	Ministry of Agriculture and Livestock, Perez Zeledón, Costa Rica	2022	0.5

C1 Employing transferable skills in different domains/careers			
Competence Assessment	WGS	2020	0.3
PhD workshop carousel	WGS	2021	0.3
Critical Thinking and Argumentation	WGS	2023	0.3
Total			**39.0**

*One credit according to ECTS is on average equivalent to 28 hours of study load

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