INCORPORATING LIVELIHOOD CHANGE IN FOREST CARBON OFFSET PROJECT IMPLEMENTATION AND SPILLOVER MONITORING: INSIGHTS FROM EASTERN PANAMA

Marie-Claude Carignan

Department of Geography
McGill University, Montreal

August 2024

A thesis submitted to McGill University
in partial fulfillment of the requirements of
the degree of Master of Science (M.Sc.)

ACKNOWLEDGEMENTS

Je souhaite débuter par exprimer ma gratitude pour mon superviseur de recherche, le professeur Yann le Polain de Waroux, pour son encadrement et son support constant tout au long de ma maîtrise. Yann, je suis extrêmement reconnaissante du soutien, de la compréhension, de la flexibilité et du mentorat dont tu m'as si généreusement fait part au cours des trois dernières années. Je tiens également à remercier le professeur Oliver Coomes qui, en tant que second membre de mon comité de supervision, m'a appuyé grâce à son expérience et ses recommandations, et ce, à de nombreuses étapes du processus de recherche et de rédaction. Oliver et Yann, je veux aussi vous remercier de m'avoir offert de nombreuses opportunités de partager ma passion pour la recherche de terrain en tant qu'auxiliaire d'enseignement, car ces expériences se sont révélées être des moments phares de mon parcours. Finalement, je tiens particulièrement à exprimer mon immense reconnaissance à la docteure Catherine Potvin qui, en plus d'avoir financé mon travail de terrain et la première année de ma maîtrise, est aussi devenue une mentor et modèle clé dans mon développement en tant que jeune femme en début de carrière de recherche. Catherine, cela aura été un réel privilège de pouvoir te côtoyer et d'apprendre de ton expérience et ton éthique de travail inspirantes. Merci de m'avoir prise sous ton aile, et de m'avoir guidée et appuyée lors des trois dernières années. Je t'en suis très reconnaissante.

Bia bua a la comunidad de Ipetí-Emberá por recibirme con brazos abiertos cada vez en su pueblo, por siempre hacerme sentir bienvenida en su hogar, y por compartir su idioma, su comida y más que nada su tiempo conmigo. *Bia bua* a las autoridades tradicionales por su colaboración y su apoyo con mi investigación, especialmente al señor Cacique del congreso general Emberá de Alto-Bayano Carlos Gil, al señor Noko del congreso local Ipetí-Emberá Nesor Tumasa, y al señor Secairo Dogirama, el residente del congreso local Ipetí-Emberá. Quisiera agradecer especialmente a Icel Ruiz, mi asistente, quién me apoyó en cada etapa de mi investigación de campo, a Vivián Ibarra y Lucelys Flaco por su ayuda tan crítica con la animación de mis talleres, y a Elionel Ortega y Ariosto Guainora por las visitas de campo y por compartir de su pericia sobre los bosques y su territorio, y a AMARIE por su apoyo logístico durante mi tiempo en Ipetí. A mis participantes: *bia bua* por compartir sus conocimientos y sus historias conmigo y por su paciencia infinita con mis preguntas. Conocerlos ha sido un privilegio increíble y ya tengo ganas de volver a visitar de nuevo.

Quiero dar un agradecimiento muy especial desde el fondo de mi corazón a Secairo Dogirama, Elena Dogirama, y a sus hijos por su hospitalidad y por hacerme parte de su familia desde mi primera visita en Ipetí. Gracias por cuidarme como a uno de los suyos, por mostrarme tanta generosidad y humanidad, y, lo más importante, por enseñarme cómo cocinar el patacón y la hojaldra perfectos. Las palabras no alcanzan para expresar mi gratitud hacia su familia.

Quisiera también expresar mi gratitud a Lady Mancilla por su apoyo y sus consejos sobre el trabajo de campo, los proyectos de reforestación y como navegar STRI y Panamá. Gracias a Juan Soteras, a Elena Soteras, y a Claudia Arami Nuñez por su ayuda con la transcripción de mis entrevistas. Cristina Herrera, gracias por los cientos de horas que pasamos trabajando juntas y por tu ayuda durante cada una de esas horas.

Brais Marchena, gracias por tu amistad y tu apoyo inquebrantable. I hope we keep hissing at each other for many, many years to come. Katia Forgues, thank you for sharing a tent, a grocery list, and a gut biome with me. Je n'aurais pas pu imaginer une meilleure personne avec qui partager toutes ces aventures. Sharing a home with you two (and too many critters to count) has been one of the highlights of my degree. I'll keep the memories we shared behind that Holiday Inn close to my heart for a very long time.

Thank you to Kumari Karunaratne for your insightful mentorship and for supporting me through the highs and lows of writing a thesis and navigating early academia, 50 minutes at a time.

Back in Burnside Hall, I want to thank Patrice Matthews, Olivia del Giorgio, Michelle Hahn-Baker, Saman Rais-Ghasem, and Morgan Sleeth for your unwavering support, advice, friendship, and sports breaks. You made this experience so much more special, and I consider myself very lucky to have had you by my side for the ride.

Finalement, merci du fond du cœur à ma famille pour vos encouragements, votre soutien, et les nombreuses pauses FaceTime (sauf Charlotte Carignan – tu ne réponds presque jamais à mes appels, mais tu as compensé en messages qui m'ont fait pleurer de rire à plusieurs reprises).

Cette recherche a été rendue possible grâce à la Chaire de recherche du Canada sur l'atténuation des changements climatiques et la forêt tropicale, à la bourse de formation à la maîtrise des Fonds de recherche du Québec, à la bourse d'études supérieures à la maîtrise du Conseil de recherche en science humaines du Canada, ainsi que par la bourse Rathlyn en recherche de terrain.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS .... **i**
LIST OF FIGURES .... **vi**
LIST OF ABBREVIATIONS .... **vii**
ABSTRACT .... **ix**
RÉSUMÉ .... **xi**
RESUMEN .... **xiii**
CONTRIBUTION OF AUTHORS .... **xv**
CHAPTER 1: INTRODUCTION **16**
CHAPTER 2: LITERATURE REVIEW **19**
2.1 Sustainable Livelihoods *19*
2.2 Forest-Based Carbon Sequestration Projects *20*
2.3 Land-Use Spillovers *22*
2.3.1 Leakage and other spatial spillovers in forest carbon offset projects 23
2.3.2 Permanence in forest carbon offset projects 25
2.4 Livelihoods and Forest Carbon Offset Projects *26*
CHAPTER 3: INCORPORATING LOCAL COMPLEXITIES FOR IMPROVED FOREST CARBON PROJECTS: INSIGHTS FROM A COMMUNITY INITIATIVE IN PANAMA **28**
3.1 Introduction *28*
3.2 Background and Theoretical Framework *30*
3.2.1 Forest-based carbon measures and co-benefits 30
3.2.2 Sustainable livelihoods and carbon capture projects 32
3.2.3 The Emberá in the Bayano Region 34
3.3 Methods *34*
3.3.1 Study Site 34
3.3.2 REDD+ in Ipetí 36
3.3.3 Data Collection and Analysis 38
3.4 Results *39*
3.4.1 Ups and downs of crop production 41
3.4.2 Changes in cattle ranching practices 46
3.4.3 Renting out land 48
3.4.4 Participation in forest carbon projects 50
3.5 Discussion *53*

3.5.1 Livelihood transitions and the limitations of local carbon storage projects 53
3.5.2 Conducting forest carbon projects among change 56
3.6 References *58*
BRIDGING STATEMENT: FROM LIVELIHOOD TRAJECTORIES TO SPILLOVER ANALYSIS 66
CHAPTER 4: ADAPTING THE SUSTAINABLE LIVELIHOODS FRAMEWORK TO DIAGNOSE AND MITIGATE LAND-USE SPILLOVERS IN FOREST CARBON PROJECTS 67
4.1 Introduction *67*
4.2 A Livelihoods Framework for Land-Use Spillovers *70*
4.2.1 Sustainable livelihoods and forest carbon offset projects 70
4.2.2 Conceptual framework 71
4.3 Methods *75*
4.3.1 Study site 75
4.3.2 Data collection and analysis 77
4.4 Results *79*
4.4.1 Defining the scope 79
4.4.2 Examining spillover pathways 81
4.4.2.1 Simple activity shifting 81
4.4.2.2 Activity adoption through generated income effects 82
4.4.2.3 Temporal leakage via institutional interactions 85
4.4.2.4 Baseline agent behaviour change through community-wide participatory planning 87
4.4.2.5 Hyper-adoption through kin-mediated knowledge diffusion 90
4.5 Discussion *92*
4.5.1 Towards context-specific solutions to handling spillovers 92
4.5.2 Spillover management in swidden landscapes 94
4.5.3 Tailoring leakage evaluations to local contexts 95
4.6 Conclusion *96*
4.7 References *96*
CHAPTER 5: GENERAL DISCUSSION AND CONCLUSION 102
5.1 Recommendations for the McGill-Bayano Project *104*
5.2 Study Limitations *107*
5.3 Conclusion and Summary *109*
BIBLIOGRAPHY 112
APPENDICES 126

LIST OF FIGURES

Figure 1. **The Sustainable Livelihoods Framework** (Ellis, 2000, p. 30) 20

Figure 2. **Map of Ipetí-Emberá in Panama's Upper Bayano watershed**. 35

Figure 3. **Adapted sustainable livelihoods framework for spillover analysis**. 73

Figure 4. **Map of Ipetí-Emberá in Panama's Alto Bayano watershed**. 75

Figure 5. **Coffee-to-carbon leakage pathway**. 84

Figure 6. **Institutional leakage**. 86

Figure 7. **Spillovers on land management and swidden-fallow cycles**. 89

Figure 8. **Hyper-adoption of FCOPs through knowledge spillovers**. 91

LIST OF ABBREVIATIONS

CDM	Clean Development Mechanism
DFID	Department for International Development
REDD+	Reducing emissions from deforestation and forest degradation in developing countries
FCOP	Forest carbon offset project
PES	Payments for ecosystem service
UNFCCC	United Nations Framework Convention on Climate Change
FAO	Food and Agriculture Organization of the United Nations
IPLC	Indigenous Peoples and local communities
STRI	Smithsonian Tropical Research Institute
IPCC	Intergovernmental Panel on Climate Change
A/R	Afforestation/Reforestation
NEO	Neotropical Ecology Laboratory
NGO	Non-governmental organization
BAU	Business-as-usual
AMPYME	Autoridad de la Micro, Pequeña y Mediana Empresa
ANCON	Asociación nacional para la conservación de la naturaleza
MiAMBIENTE	Ministerio Del Ambiente
BDA	Banco de Desarrollo Agropecuario

En honor a Bonarge Pacheco,
Cuya visión y obra de toda una vida lo hicieron todo posible.

ABSTRACT

Forest carbon projects require careful design tailored to the local context where they are implemented to ensure the delivery of positive livelihood and carbon sequestration outcomes. However, little attention has been paid to the effects that changing local livelihoods can have on the successful implementation of forest-based initiatives over time. Variations in the local socio-ecological context can alter the intervention's initial fit and compromise its success. From the participant's perspective, misfits between the intervention and its implementation context can dampen community co-benefits or, in worse-case scenarios, lead to adverse socio-economic outcomes. Considering biophysical factors, forest carbon offset projects ill-fitted to their implementation context can compromise adoption and compliance or be subject to carbon leakage, which occurs when an intervention induces an increase in carbon emissions outside its operational jurisdiction, undermining its net outcomes.

This thesis explores the importance of livelihood changes on carbon leakage and socio-economic outcomes using the 15-year-old Ipetí-STRI Carbon Sequestration Project as a case study. Ipetí-Emberá, an indigenous community located in Eastern Panama, has been engaged in conservation and carbon offset reforestation projects for over three decades. Based on a collection of individual and communal oral history interviews, we aim to better understand how a 15-year community-level reforestation project has interacted with and impacted local livelihoods over time, with special attention to how these interactions may have caused unanticipated outcomes and land-use spillovers.

The first chapter examines the evolution of land-based livelihood strategies over the past two decades and the project's role in facilitating these changes. We identify interactions between features of the STRI-Ipetí Project originating from early community consultations, such as the benefit-sharing mechanism and the inclusion of agroforestry, and aspects of local livelihood strategies that have emerged since the project's establishment. We also draw connections between these interactions and wider internal and external factors like climate change, inflation, social organization, and the COVID-19 pandemic. Maintaining community consultations and flexible

governance are crucial to addressing misfits and ensuring local community representation in project design, thereby mitigating policy risks over time.

The second chapter focuses on land-use spillovers, using a qualitative approach to assess and mitigate leakage in forest carbon offset projects. We adapt the Sustainable Livelihoods Framework to analyze causal connections between participants' livelihood strategies and project implementation, identifying four spillover pathways, two of which are positive. By tracking capital flows and mediating factors, we pinpoint key leverage points for effective monitoring and mitigation. Context-specific solutions are proposed, including addressing income effects and institutional interactions undermining land-use policies. The study highlights the importance of monitoring baseline drivers and motivations to enhance project design and leakage management, demonstrating the framework's effectiveness in addressing leakage in forest-based climate mitigation projects.

RÉSUMÉ

Les projets de reboisement pour fins de séquestration du carbone implantés dans des communautés rurales dépendantes des ressources naturelles nécessitent une conception adaptée aux communautés locales impliquées afin de garantir la réalisation de résultats positifs, tant au niveau humain qu'environnemental. Cependant, peu d'attention a été accordée aux effets qu'un contexte local dynamique peut avoir sur le succès de ces initiatives forestières. Les variations dans le contexte socio-écologique local, notamment dans les stratégies de subsistance, peuvent causer des décalages entre les réalités des participant·e·s et l'intervention qui compromettent le succès de cette dernière. D'un point de vue humain, ces incohérences peuvent réduire les co-bénéfices perçus et même, dans les pires cas, causer des impacts socio-économiques néfastes. Quant à leur performance environnementale, les projets mal adaptés à leur contexte peuvent être sujets à des fuites de carbone, qui se produisent lorsque l'intervention induit une augmentation des émissions de gaz à effet de serre en dehors de sa juridiction opérationnelle, compromettant ainsi ses résultats nets.

Ce mémoire explore l'importance des changements de moyens de subsistance sur les impacts socio-économiques et les fuites de carbone du projet de séquestration du carbone Ipetí-STRI, un projet de reboisement initié en 2008. Ipetí-Emberá, une communauté autochtone située dans l'est du Panama, est directement impliquée dans des projets de conservation de la forêt tropicale et de compensation carbone forestier depuis plus de trois décennies. À l'aide d'une collection d'entretiens individuels et collectifs, nous visons à mieux comprendre comment le projet de reforestation communautaire a influencé et interagi avec les moyens de subsistance locaux au fil du temps, en accordant une attention particulière à la manière dont ces interactions ont pu entraîner des résultats inattendus et des changements indirects sur les processus d'affectation des terres.

Le premier manuscrit (chapitre 3) examine l'évolution des stratégies de moyens de subsistance liées aux ressources naturelles et à l'utilisation des terres au cours des 25 dernières années, ainsi que le rôle que la projet Ipetí-STRI a joué dans ces changements. Nous identifions des interactions entre des caractéristiques du projet initialement conçues lors de consultations

communautaires, telles que le mécanisme de distribution des bénéfices et l'adoption de l'agroforesterie comme méthode de reboisement, et certains aspects des stratégies économiques poursuivies par les ménages d'Ipetí depuis l'établissement du projet. Nous connectons ces interactions et dissonances à un nombre de facteurs socio-écologiques locaux, tels que les changements climatiques, l'inflation et la pandémie de COVID-19. Le maintien de consultations communautaires et d'une gouvernance flexible est crucial, non seulement pour garantir la représentation des communautés locales dans la conception des projets, mais également pour identifier et répondre aux décalages qui émergent au fil du temps.

Le deuxième manuscrit (chapitre 4) développe une approche qualitative pour identifier et atténuer les fuites dans les projets de compensation carbone forestière. Nous adaptons le c*adre des moyens d'existence durables* pour analyser les liens causaux entre les stratégies de subsistance des participant·e·s et la mise en œuvre du projet. Nous identifions quatre types de débordements, dont deux causant des fuites de carbone et deux entraînant des effets positifs. Le suivi des flux de capitaux nous permet d'identifier des points d'intervention stratégique pour un suivi et une atténuation efficaces des fuites de carbone, nos permettant ainsi de présenter des solutions spécifiques au contexte. L'étude souligne l'importance de surveiller l'évolution des facteurs d'utilisation et d'attribution des terres et les motivations des participant·e·s dans l'amélioration de la conception de projets de carbone forestier et la gestion des effets secondaires néfastes.

RESUMEN

Los proyectos de carbono forestal requieren un diseño cuidadoso y adaptado a las comunidades locales involucradas en ellos, a fin de garantizar resultados positivos tanto en el plano biofísico como en el de los medios de subsistencia. Sin embargo, se ha prestado poca atención a los efectos que pueden tener los cambios en los medios de subsistencia locales sobre el éxito de las iniciativas forestales a lo largo del tiempo. Las variaciones en el contexto socioecológico local pueden alterar el ajuste inicial de la intervención y comprometer su éxito. Desde el punto de vista de los participantes, los desajustes pueden mermar los cobeneficios comunitarios o, en el peor de los casos, provocar resultados socioeconómicos adversos. Teniendo en cuenta los factores biofísicos, los proyectos de compensación de carbono forestal mal adaptados a su contexto pueden comprometer la adopción y el cumplimiento, y potencialmente generar fugas de carbono, que ocurren cuando una intervención induce un aumento de las emisiones de carbono fuera de su área de operación, socavando así sus resultados netos.

Esta tesis investiga cómo los cambios en los medios de subsistencia influyen en las fugas de carbono y en los resultados socioeconómicos, tomando como caso de estudio el Proyecto de Fijación de Carbono Ipetí-STRI, que lleva 15 años en funcionamiento. Ipetí-Emberá es una comunidad indígena situada en el este de Panamá que ha participado durante más de tres décadas en proyectos de conservación y reforestación mediante esquemas de compensación por captura de carbono. A partir de una serie de entrevistas de historia oral, tanto individuales como comunitarias, buscamos entender mejor cómo un proyecto de reforestación comunitario de 15 años ha interactuado con los medios de subsistencia locales y los ha impactado a lo largo del tiempo, prestando especial atención a los resultados imprevistos y efectos secundarios en el uso de la tierra que estas interacciones puedan haber causado.

En el primer capítulo se examina la evolución de las prácticas de subsistencia agrícolas a lo largo de las dos últimas décadas y el papel del proyecto en la facilitación de estos cambios. Identificamos interacciones entre unos aspectos del Proyecto STRI-Ipetí que surgen de características inicialmente diseñadas a través de consultas comunitarias tempranas, como el mecanismo de reparto de beneficios y la adopción de la agrosilvicultura, y estrategias de

subsistencia adoptadas por los participantes desde el inicio del proyecto. Estos desajustes están vinculados a varios factores internos y externos del contexto socio-ecológico local, así como el cambio climático, la inflación, la organización social, y la pandemia de COVID-19. Mantener las consultas comunitarias y una gobernanza flexible son cruciales para abordar estos desajustes y garantizar la representación de la comunidad local en el diseño de los proyectos, mitigando así los riesgos políticos a lo largo del tiempo.

El segundo capítulo se centra en el fenómeno de los efectos secundarios sobre el uso de la tierra, utilizando un enfoque cualitativo para evaluar y mitigar las fugas en los proyectos de compensación de carbono forestal. Adaptamos el marco de los Medios de Vida Sostenibles para analizar las conexiones causales entre las estrategias de subsistencia de los participantes y la ejecución de los proyectos, identificando cuatro causas de efectos secundarios, dos de las cuales son positivas. Mediante el seguimiento de flujos de capital y factores mediadores, señalamos los puntos clave de apalancamiento para una supervisión y mitigación eficaces. Se proponen soluciones específicas para cada contexto, que incluyen abordar los efectos en los ingresos y las interacciones institucionales que socavan las políticas de uso de la tierra. Este estudio subraya la importancia de supervisar los factores y las motivaciones base con el fin de mejorar el diseño de los proyectos y lograr una gestión más adecuada de las fugas, lo cual evidencia la eficacia del marco de los Medios de Vida Sostenibles para abordar las fugas en los proyectos forestales de mitigación del cambio climático.

CONTRIBUTION OF AUTHORS

This thesis is the original work of the author. Marie-Claude Carignan was responsible for formulating the research questions, collecting and analyzing the data, analyzing the data, and writing the thesis. However, it comprises two manuscripts to be submitted to peer reviewed journals which will be co-authored with Yann le Polain de Waroux. Prof. le Polain de Waroux contributed to all stages of the work through his role as the author's thesis supervisor. This includes the conceptualization of the research and the elaboration of the research methods prior to data collection, supporting data analysis by providing regular feedback, and editing the manuscript drafts. For simplicity, Chapters 1, 2, 5 and 6 use an active voice of the author ("I"/ "my"), whereas "we"/ "our" is used in the manuscripts in Chapter 3 and 4.

CHAPTER 1: INTRODUCTION

Forest and other land-based ecosystems have a crucial role to play in the battle against climate change. Tropical forests, in particular, are especially significant: they represented 55% of the world's forest carbon stocks and accounted for 70% of the gross annual sink between 1990 and 2007, but tropical land-use change and deforestation nearly completely offset their sink capacity over the same period (Pan et al., 2011). More recently, the agriculture, forestry, and land use sectors collectively accounted for 22% of global greenhouse gas emissions between 2010 and 2019, with land use change representing over half of these emissions (IPCC, 2022).

Forest and land-based climate change mitigation measures are included in virtually all modelled scenarios allowing the limiting of global warming to 2°C (Griscom et al., 2017; IPCC, 2023), including reforestation, afforestation, improved land management, and reduced emissions from deforestation and degradation. Their popularity has exploded since the launch of the Clean Development Mechanism (CDM) in 2005, which supports Annex-I countries in meeting their Kyoto carbon emissions reductions commitments by purchasing certified carbon reductions from developing countries implementing various forms of approved carbon reduction projects, including reforestation and afforestation. The CDM was quickly followed by the UNFCCC's REDD+ platform, which provided a similarly structured framework to "help implement forests solutions addressing the climate emergency by avoiding carbon emissions and supporting carbon sequestration" in developing countries (UN-REDD, 2022, p. 14).

Besides constituting foundational parts of the nature-based compliance market, these policy frameworks also contributed to the development and explosion of voluntary carbon markets (Fujii et al., 2024). While the former is associated with publicly-regulated trading systems, such as jurisdictional cap-and-trade programs, the latter correspond to the unregulated markets where companies and individuals can purchase carbon credits to offset their carbon footprint (ICAP, 2024). The UN-REDD program oversaw more than 700 million tCO2 of emissions reductions between 2009 and 2020 (UN-REDD, 2022), and nearly 715 million carbon offset credits were issued from forestry and land use projects by the world's four leading carbon credit verification standards[1] during the same period, making these pathways the most important contributor to the voluntary market by credits issued (Haya et al., 2024).

McGill University, based in Montreal, Canada, is one of countless institutions incorporating the purchase of carbon offsets to its actions to achieve its greenhouse gas emissions reduction goals, namely, to become carbon neutral by 2040. Its flagship initiative is the Bayano-McGill Reforestation Project, a fair-trade carbon offset agreement co-led with a women-led local non-governmental organization. As part of this project, 44 Indigenous Emberá households in Eastern Panama's Alto Bayano watershed are each being financially compensated to reforest one hectare of land with native timber trees (McGill Office of Sustainability, 2020). The university offsets 925 tCO_2 per year until 2040 through this initiative (McGill University, 2023).

Prior to the Bayano project, McGill University scientists have been collaborating with Bayano communities for nearly 30 years on several participatory action research projects focused on tropical forest conservation and restoration (Shinbrot et al., 2022). Specifically, the first decade of collaborative research between the Neotropical Ecology Laboratory and the community of Ipetí-Emberá culminated in one of Panama's first carbon sequestration projects (Holmes, Potvin, et al., 2017), the Ipetí-STRI Reforestation Project, a contract signed in 2008 in partnership with the Smithsonian Tropical Research Institute (STRI, 2018).

Building on existing local expertise following the STRI project and its own research capabilities, McGill University has decided to forgo the contracting of third-party carbon credit certification. The rationale behind this decision is that monitoring can be accomplished by trained community members, and that McGill will be supporting the project's implementation and monitoring with scientific and technical knowledge. However, greenhouse gas inventory standards such as the GHG Protocol (World Resources Institute, 2003) require that offset quantification methodologies address a suite of issues, including the potential reversibility of the carbon

[1] The American Carbon Registry, the Climate Action Reserve, the Gold Standard, and the Verified Carbon Standard.

removals, and the demonstration of the intervention's additionality, and the identification and quantification of relevant secondary effects which may dampen the project's net impacts by inducing new carbon emissions elsewhere.

This thesis focuses on the characterization of forest carbon offset projects' secondary effects. Now in effect for 15 years, the STRI project had so far been exempt of active spillover monitoring and quantification due to its small size and the local context, which together made the risk of significant leakage highly unlikely (Coomes et al., 2008). However, the new McGill project brought this question back to light. The McGill Office of Sustainability, which signed the McGill-Bayano agreement, has been seeking to inform the design and management of the McGill-Bayano project to reduce the potential risks of leakage and other negative spillovers. The present thesis is the outcome of this inquiry.

I use the STRI project as a case study to see whether any unanticipated forms of leakage or other land-use spillovers have taken place during the project's first 15 years to evaluate the leakage risk of a forest carbon offset projects in the Bayano. I employ a qualitative approach focused on enhancing our understanding of local spillover mechanisms to allow the development of mitigation strategies and monitoring practices that are transferable from one project to another.

This broad objective will be accomplished in two steps, each of which is covered by a manuscript in this thesis. The first chapter aims to describe the livelihood transitions experienced in Ipetí since the beginning of the STRI project. This enabled the untangling of the intervention's interactions with its changing social-ecological context, which potentially affect its outcomes over time. The second chapter builds on these interactions to describe spillover mechanisms resulting from the project's implementation. Finally, I review the implications of my findings and discuss its implications for the McGill-Bayano project.

CHAPTER 2: LITERATURE REVIEW

2.1 Sustainable Livelihoods

Sustainable livelihoods approaches first rose to prominence in mainstream development studies in the 1990s as a people-centered, bottom-up approach to studying rural livelihoods and sustainable development (Bennett, 2010; Turner, 2017). Scoones (2015, p. 5) describes the livelihoods framework as offering "diverse insights into the way complex, rural livelihoods intersect with political, economic and environmental processes." Drawing from Chambers and Conway's (1992) seminal article on the approach, Ellis (2000, p.10) defines livelihoods as comprising "the assets (natural, physical, human, financial and social capital), the activities, and the access to these (mediated by institutions and social relations) that together determine the living gained by the individual or household." Livelihoods approaches examine how households mobilize and channel their assets towards the adoption of specific combinations of livelihood strategies in pursuit of the tangible improvement of their livelihood outcomes over time, a process taking place within a broader context where institutions, social processes and other contextual factors, mediate the households' access to resources, strategies, and outcomes (Bayrak et al., 2014; Scoones, 1998). Livelihoods are considered sustainable when they are resilient to shocks and stresses (social sustainability), and maintain or enhance the natural resource base to provide for future generations (environmental sustainability) (Chambers and Conway, 1992).

The main categories of capitals described by livelihoods scholars are *natural capital* (resources and services derived from nature), *human capital* (available labor, including its capabilities, knowledge, and skills), *financial capital* (economic assets through cash, savings, access to credit, etc.), *physical capital* (assets used to generate more assets, such as buildings, roads, water infrastructure, tools, and machinery), and *social capital* (one's social networks and what these can procure through reciprocity and trust-based relationships) (e.g., Chambers and Conway, 1992; Ellis, 2000; Scoones, 1998). In addition to these capitals, the various processes mediating the interactions between assets and livelihood strategies include formal and informal institutions, organizations. Contextual factors that shape livelihood dynamics range from politics, history, social relations, agroecology, economic, and demographic trends. For example, Ellis's sustainable livelihoods framework, shown in Figure 1, considers how social relations, institutions, and organizations modify the access to capital in the context of trends and shocks. Finally, livelihood outcomes are often assessed through changes in well-being, employment quality, livelihood security, and environmental sustainability (Ellis, 2000; Scoones, 1998).

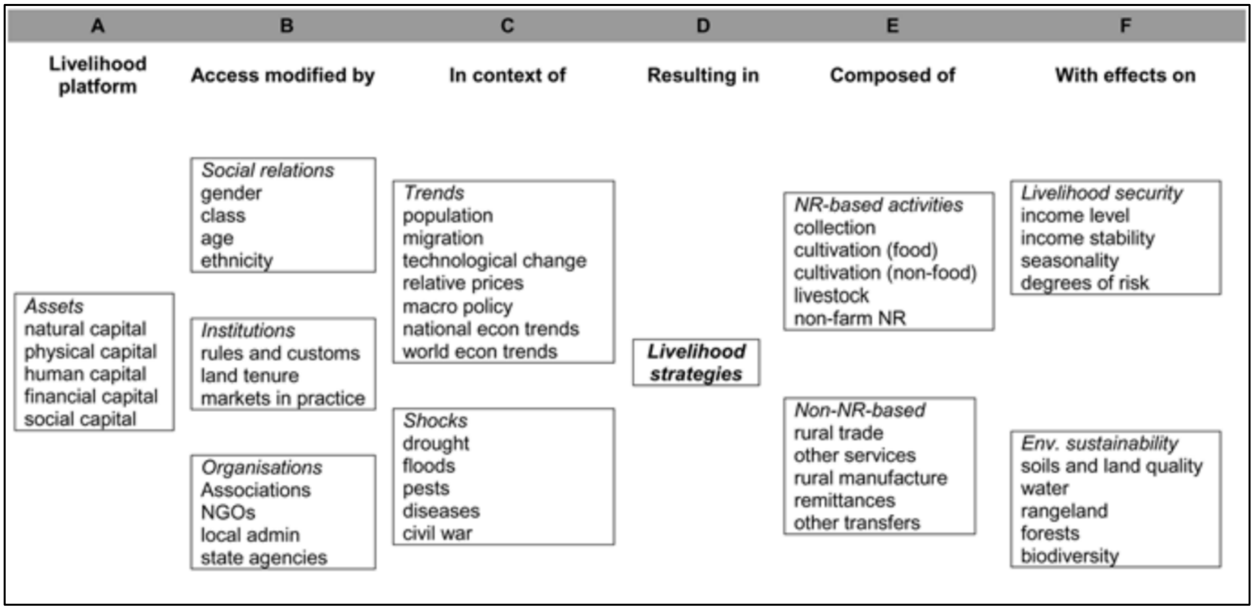

Figure 1. **The Sustainable Livelihoods Framework** (Ellis, 2000, p. 30)

2.2 Forest-Based Carbon Sequestration Projects

Forest and land-based carbon ‘farming’ is part of the broader natural climate solutions portfolio, the land-based actions that can be employed to capture carbon from the atmosphere or avoid its future release (Griscom et al., 2017, p. 11645). Afforestation, the planting of new forests, and reforestation, the replanting of degraded or harvested forestlands (A/R), are the two natural mechanisms proposed by Kyoto Protocol’s CDM, the most prominent international carbon compliance mechanism (Hultman et al., 2020; UNFCCC, 2021). CDM-A/R allows developed countries to offset their Kyoto emission reduction targets by purchasing carbon credits from A/R projects in developing countries. In 2007, partly responding to CDM's limited scope of action, the UNFCCC put forward a new framework focused on Reducing Emissions from Deforestation and forest Degradation, fostering conservation, sustainable management of forests, and enhancing forest carbon stocks (REDD+) (Streck, 2021). Using a similar financing mechanism, REDD+ also includes a wider range of forest conservation and improved management measures. These policy frameworks also contributed to the development and explosion of voluntary carbon markets (Fujii et al., 2024), which correspond to the unregulated markets where private companies and individuals can purchase carbon credits to offset their carbon footprint (ICAP, 2024).

The UNFCCC's REDD+ framework has been described as the world's largest Payments for Ecosystem Services (PES) scheme (Bayrak et al., 2014; Corbera, 2012; Wunder et al., 2020). PES schemes describe transactions where the providers of an ecosystem service (e.g., watershed management, ecotourism, carbon sequestration) seek remuneration for providing said service by selling units to one of more buyers as a way to ensure its continued supply. The ecosystem service in question must be well defined and measurable to allow units to be verified and sold, and the purchase of units is usually conditional to the provision (Engel et al., 2008). In this thesis, I refer to PES projects where carbon sequestration units are being produced by the implementation of forest-based measures and sold through voluntary carbon markets as Forest Carbon Offset Projects (FCOPs).

National REDD+ regimes and voluntary subnational interventions often co-occur and interact in the policy realm over space and time; already implemented FCOPs are often used as pilot projects to inform national REDD+ readiness and implementation, and vice versa (Caplow et al., 2011; Streck, 2021; Wunder et al., 2020). A notable significant difference between voluntary FCOPs and international compliance frameworks such as REDD+ and CDM-A/R is the former's higher flexibility in project designs. To address the authentication issues of credits due to the lack of validation processes in compliance markets' regulatory frameworks, voluntary FCOPs often use third-party carbon crediting standards to validate and certify their carbon offset units. Negotiations tailored to the needs of both buyers and providers, along with a broader range of mechanisms approved by carbon standards, enable the implementation of more diverse carbon sequestration activities. For example, activities such as avoided deforestation and agroforestry are frequently rejected from more standard credit validation schemes due to concerns over non-additionality (Streck, 2021), namely that such projects may not actually yield sufficient emission reductions relative to the baseline (additional reductions) (Streck, 2011). This uncertainty regarding the additionality of emission reduction credits is especially questioned when accounting for the displacement of emissions over space and time; even the more regulated and larger-scale nature-based frameworks face intense scrutiny from scholars, policymakers, media, and other stakeholders alike, due to the risks related to land-use spillovers, specifically leakages and non-permanence (see Brown et al., 2000; Caplow et al., 2011; Engel et al., 2008; Murray et al., 2004; Pagiola et al., 2016). A glaring example of this scrutiny is the article published in early 2023 in The Guardian reviewing VERRA's accounting and validation methodologies revealed that over 90% of their certified carbon offsets are not additional, making them effectively 'worthless' (Greenfield, 2023).

2.3 Land-Use Spillovers

Spillovers describe any unintended effect triggered by an intervention occurring outside of its operational scope (Bastos Lima et al., 2019; Meyfroidt et al., 2018). Where carbon sequestration is concerned, carbon leakage refers to the overall reduction of the carbon sequestration produced by an intervention due to its unanticipated secondary land-use spillovers (Aukland et al., 2003). While leakage typically refers to spillovers with overall negative effects, boosting effects, also known as positive spillovers, may also occur (Bastos Lima et al., 2019). Land-use spillovers are not limited to forest carbon projects; they have been documented in the context of protected areas (Ewers and Rodrigues, 2008; Fuller et al., 2019), international trade agreements (Branger and Quirion, 2014; Murray et al., 2004), and other forestry and agricultural policies (Heilmayr et al., 2020; Kuschnig et al., 2021; Miranda et al., 2019), including where policy interactions can lead to deforestation havens (see le Polain de Waroux et al., 2016).

Land-use spillovers happen through several channels. For example, Lima et al. (2019) describe nine general spillover types that may arise in land use systems (activity displacement, market-mediated effects, informational spillovers, motivational leakage, and institutional interplay and policy interactions), and Sonderegger et al. (2022) compiled a comprehensive list of 25 socio-economic and environmental spillover pathways of agricultural crop production.

Quantitative approaches are the most frequent tools used in the academic literature to evaluate leakages and its effects on an intervention' net outcomes (Henders and Ostwald, 2012). For example, some use econometric models to estimate secondary leakage through market effects (Murray et al., 2004). Others quantify it by calculating deforestation in buffer zones around a project against a pre-determined baseline (Ewers and Rodrigues, 2008), or on smaller scales by including the participants' non-project lands in carbon accounting to account for potential activity shifting (De Jong et al., 2007; Pagiola et al., 2007). While scarce in the literature in comparison, qualitative and human-centered approaches can detect potential leakage pathways that are too complex or too small in scale to detect quantitatively (Atmadja and Verchot, 2012; Aukland et al., 2003). These include the use of project narratives (Brown et al., 2000) or the inclusion of qualitative data to inform quantification; for instance, De Jong *et al.* (2007) interviewed participants of a carbon PES project on their understanding of the project and their land-use decisions as a way to better explain the land-use changes observed on their plots.

2.3.1 Leakage and other spatial spillovers in forest carbon offset projects

Evaluating and mediating leakage and other spillovers is an essential part of FCOP credit validation; if left unaccounted for, emission reductions credits may be certified and traded without any net carbon sequestration taking place, that is, if CO_2 emissions are merely displaced rather than reduced.

Land system scholars and project stakeholders typically restrict their consideration of leakage pathways to two categories. The first, *primary leakage,* refers to cases where the carbon benefits gained from an intervention are partially or fully cancelled out by increased emissions off-site. Primary leakage can happen when carbon-emitting activities are displaced outside the intervention's boundary (activity displacement) or if forest users outsource their access to goods and resources initially obtained from the intervention site (outsourcing) (Aukland et al., 2003; Wunder, 2008). On the other hand, *secondary leakage* occurs when the environmental intervention creates new incentives for third parties to alter their land use, resulting in increased emissions (Streck, 2021).

Forms of secondary leakage include market effects, where third parties respond to changing supply chains and commodity and land markets affected by a land-use intervention (Heilmayr et al., 2020; S. K. Sharma et al., 2012). Secondary positive spillover pathways include, for example, the hyper-adoption of intervention practices by non-target agents due to information sharing and neighbor effects (Bastos Lima et al., 2019; Robalino and Pfaff, 2012). Hyper-adoption outcomes depend on new adopters' initial land practices: it can potentially yield a net positive impact if more carbon is stored as a result, resulting in a positive land-use spillover.

Leakage processes in FCOPs are highly specific to their implementation context. Factors such as project scale, market integration, and project design (e.g., land-use activities and livelihood alternatives introduced, payment scheme and disbursement mechanism) affect land-use decisions, potentially resulting in different forms of primary and secondary leakages (Atmadja and Verchot, 2012). Smaller-scale projects typically do not impact land and commodity supplies enough to induce market-mediated effects and, the smaller the scale of an FCIO, the lower its likelihood of significant primary displacement (Coomes et al., 2008; De Jong et al., 2007; Pagiola et al., 2007). Additionally, primary leakage is more likely in projects where communities with a high reliance on forest resources are not supported with the necessary starting capital to pursue alternative sources of income (Atmadja and Verchot, 2012; Bayrak et al., 2014). On a similar note, FCOPS that restrict access to natural capital (e.g., forest protection and avoided deforestation) are more likely to induce leakage (Nunez et al., 2020).

Enabled by qualitative inquiries, exploring actor motivations and social processes is critical to explaining land-use decisions and the resulting leakage-related mechanisms. For example, studies find that participants are more likely to enroll their low-pressure lands in PES (Giudice et al., 2019; Pagiola et al., 2007), such that while leakage is unlikely, fewer additional benefits occur. Regarding hyper-acceptance, Giudice et al. (2019) detect positive forest and conservation gains on a community's non-enrolled lands in Peru's national PES program, which likely results from information spillovers on the introduced sustainable land management practices. Similar information-sharing and motivation spillovers are documented in Mexico's Scolel Té project (De Jong et al., 2007).

2.3.2 Permanence in forest carbon offset projects

In the context of carbon sequestration, permanence refers to the long-term sustainability of the carbon stored as part of the intervention. Carbon credits are only permanent if the stocks can be maintained and preserved through time. Permanence can be a critical concern in FCOPs due to the highly reversible nature of biological carbon sinks such as biomass and soils. Unintentional non-permanence occurs when carbon sinks are compromised by events such as by biomass mortality due to fires, droughts, or other significant disturbances such as wars or conflicts (Baker et al., 2010; Baldocchi and Penuelas, 2019; Kerr, 2013). On the other hand, carbon sink reversal can be intentional if carbon sequestration enhancing practices adopted as part of the FCOP are abandoned after the implementation phase or payment cessation (Pagiola et al., 2016; Rasch et al., 2021). Some scholar conceptualize the intentional reversal of carbon stocks as temporal leakage, especially if the intervention is designed to induce trade-offs or other adverse incentives for the abandonment of the intervention practices over time (Bastos Lima et al., 2019; Kerr, 2013).

Uncovering the nature of these non-permanence mechanisms can have important ethical implications, especially if the distribution of payments is conditional on the permanence of the carbon offsets. As noted by Tacconi et al. (2013, p. 742), "where carbon-emitting events are beyond the control of the individuals or communities involved in the scheme, it would be inappropriate to attempt to recover payments from them." Further, understanding processes that lead to intentional carbon stock reversal can lead to the identification of effective mitigation strategies over the mere policing of compliance through payment withholding.

The combination of the FCOP's design and payment disbursement mechanism play a crucial part in the prediction and prevention of intentional permanence: asset-building projects (e.g., sustainable land management), even if payments only occur in the short term, tend to be more permanent than access-restricting ones (e.g., avoided deforestation). This is because capacity-building and early payments help overcome the initial adoption barriers and thus 'tip the balance' from more damaging towards sustainable practices. On the other hand, participants in access-restricting projects are more likely to return to pre-FCOP land uses if the opportunity cost of FCOP activities without payments is too high (Rasch et al., 2021). Supporting this, Pagiola et al. (2016) found that the beneficial land uses adopted during a sustainable land management PES in Colombia were maintained by participants after payment cessation, but not spontaneously without payments by non-participants. In addition to arriving at similar conclusions, Rasch et al. (2021, p. 12) also uncovered a positive relationship between permanence and social capital, such that "farmers [who] are well connected among each other (...) could have experimented and exchanged information among themselves about which set of practices leads to satisfying, and thus permanent, results." The latter study shows the potentially crucial role of social relations and processes in land-use decisions and permanence.

2.4 Livelihoods and Forest Carbon Offset Projects

Scholars support the use of livelihoods approaches to improve the understanding the interactions of rural livelihoods and FCOPs at various stages of the interventions, from informing project design to evaluating their long-term impacts (see Holmes and Potvin, 2014). When conceptualized within the sustainable livelihoods framework, FCOPs are created and enforced by institutions and organizations that modify the access and the use of capitals, for example limiting access to natural capital by barring forest conversion, or by providing by providing human capital in the form of agricultural training and capacity-building, altering local livelihood opportunities, strategies, and their associated livelihood outcomes as a result (Atela et al., 2015; Bayrak and Marafa, 2016; Philemon, 2021).

While the context-specificity of the results greatly limit generalizations, studies that assess the impacts of forest-based measures on assets generally find that participation enhances the ownership and access to social, financial, and physical (mainly through seedling provision) capital (Caplow et al., 2011; Peras et al., 2016; Philemon, 2021; Sunderlin et al., 2017). On the other hand, while natural resources can be enhanced through improved management, the users' access to these assets is generally negatively impacted (Bayrak et al., 2014; Bayrak and Marafa, 2016). The impacts on human capital, measured through indicators of nutrition and food security, health, and knowledge, are conflicting (Bayrak and Marafa, 2016; Peras et al., 2016; Philemon, 2021; Tacconi et al., 2013). The studies evaluating the FCOP's outcomes on participant livelihood are also mixed, some finding a general decrease (Larson et al., 2018; Peras et al., 2016) or no significant impact (Sunderlin et al., 2017).

These impacts are not uniformly spread across the participating communities, and that local institutions and social relations play an important role in these distributional issues (Caplow et al., 2011). For instance, Aggarwal and Brockington (2020) detected a correlation between household wealth and financial disadvantages from a CDM-A/R pilot project in India. Similarly, Bayrak *et al.* (2014) found that only elite households received payments from a local REDD+ program in Vietnam, leaving the poorer ones more vulnerable to food insecurity. They also described wealth-differentiated social capital gains where wealthier households were disproportionately able to expand their social networks, which were critical in accessing additional financial benefits from the project. Philemon (2021) found similar results on the role of social relations and financial benefits in a PES project in the Philippines. The literature also suggests that poorer households overall are less likely to participate in FCOPs, which enhances the potential of FCOPs furthering the wealth gap in forest-based communities (Atela et al., 2015; Engel et al., 2008; Pagiola et al., 2007). As a solution, authors overwhelmingly mention the importance of community involvement, prior and informed consent, and cultural sensitivity in project design as safeguards for equitable participation and distribution of benefits (e.g., Asquith et al., 2002; Bayrak et al., 2014; Larson et al., 2018; Philemon, 2021).

CHAPTER 3: INCORPORATING LOCAL COMPLEXITIES FOR IMPROVED FOREST CARBON PROJECTS: INSIGHTS FROM A COMMUNITY INITIATIVE IN PANAMA

3.1 Introduction

Forest ecosystems have a crucial role to play in climate change mitigation. The IPCC estimates that the agriculture, forestry, and land use sectors were responsible for 22% of worldwide greenhouse gas emissions in 2019, with deforestation being the main contributor. Even so, land systems, and particularly forests, still constitute a crucial net carbon sink. As of 2011, tropical forests accounted for 55% of the world's forests carbon stocks (Pan et al., 2011). This storage capacity could be doubled by implementing forest-based solutions like reforestation, afforestation, and other measures to avoid deforestation and degradation (Griscom et al., 2017; IPCC, 2023).

Forest ecosystems are also central to the livelihoods of Indigenous Peoples and Local Communities (IPLCs) who rely directly on forests for food, shelter, and other resources ranging from traditional medicine to marketable products (Holmes and Potvin, 2014; Paredes and Kaulard, 2022). A quarter of the world's forests, including 36% of the areas considered intact, fall under indigenous tenure or management (Garnett et al., 2018). Despite high surrounding deforestation pressures, forests under indigenous jurisdiction exhibit lower degradation rates than non-indigenous lands across the Tropics (Sze et al., 2022), and in some cases, even more so than non-indigenous protected areas (e.g., Jusys, 2018; Nolte et al., 2013). Due to their role as both users and stewards of forests, IPLCs are considered critical stakeholders in global efforts to halt forest loss (e.g., Fa et al., 2020; Garnett et al., 2018).

The natural resource-dependent livelihoods of IPLCs around the world are already affected by not only climate change, but myriad other complex interacting political, social, economic, and environmental factors (Reyes-García et al., 2024; Zant et al., 2024). Forest Carbon Offset Projects (FCOPs) are powerful tools that can simultaneously increase carbon stocks, empower participants, and enhance their livelihoods. However, they have the potential to harm their participants and their local communities' well-being when poorly designed and implemented (Bayrak and Marafa, 2016) or, at the very least, introduce significant livelihood trade-offs (Blundo-Canto et al., 2018). This highlights the imperative of ensuring an appropriate contextual fit between a forest-based intervention and the social-ecological context where it is carried out, as well as the inclusion of local realities and needs in project design (Dawson et al., 2018).

It is generally accepted that FCOPs "are taken up differentially across the landscape depending on biophysical and socioeconomic characteristics and political climate" (Caplow et al., 2011, p. 153). The question of policy design fit with the local context has been explored theoretically (e.g., Boyd et al., 2007), but empirical case studies are still lacking. Similarly, the differential outcomes FCOPs generate in different livelihood contexts is seldom studied directly (e.g., Zhang et al., 2020). Instead, it is usually highlighted as a factor limiting the generalization of empirical study results (e.g., Blundo-Canto et al., 2018; Jack and Cardona Santos, 2017; Nantongo et al., 2024).

Beyond static context-specificity, how the livelihood context transforms and interacts with FCOPs and their impact on the intervention's effectiveness over time is also under-studied. Relevant contextual factors that may interact and transform FCOPs include, but are not limited to, existing market processes and policies (Corbera and Schroeder, 2011) and agroecological conditions (Nantongo et al., 2024), and the resulting opportunity cost of land use (Blundo-Canto et al., 2018). As community members' livelihood circumstances evolve, so does the way they engage with FCOPs (K C et al., 2021; Laudari et al., 2024). Such concerns are especially significant in forest-based initiatives due to the reversible nature of carbon stocks through land-use decisions.

This study aims to understand better how community-level FCOP initiatives interact with and impact local livelihoods, and what livelihood transitions over the long term mean for the design and successful implementation of FCOPs. It does so by examining livelihood transitions in Ipetí-Emberá, an Indigenous community in Panama that has been conducting forest conservation projects for over 30 years, through the lived experiences of households participating in a 15-year-old timber reforestation and agroforestry project. The broad focus on interactions rather than on unidirectional cause-and-effect chains between the project and livelihoods is intentional; such a flexible, all-encompassing approach allows the detections of mechanisms where the project may have impacted livelihood opportunities, but also where livelihood decisions (some directly related to the project, some seemingly not) may have impacted the STRI project's success. Specifically, we ask the following questions: What have been the livelihood trajectories of project participants over the last two decades, particularly in terms of land-based activities? And how, if at all, have changes in the local livelihood context over the project's duration affected its carbon sequestration outcomes and its successful delivery of co-benefits? To answer these questions, we analyze a series of household livelihood trajectory interviews to describe Ipetí's land-based livelihood trends since the project's start and examine the implications of these trajectories for the project's outcomes. Doing this allows us to understand better the complex and subtle ways the STRI project and the participant's broader livelihood strategies have shaped and impacted each other over time, and how the role wider contextual factors have played in mediating these interactions. Finally, we conclude with reflections on what can be learned from this experience for the adaptive management of community-based REDD+ projects more broadly.

3.2 Background and Theoretical Framework

3.2.1 Forest-based carbon measures and co-benefits

People have long recognized the importance of forest- and other nature-based actions in greenhouse gas emission abatement efforts. The Kyoto Protocol's Clean Development Mechanism (CDM) was the first global policy platform to recognize forest-based mitigation tools by allowing developed nations to finance reforestation and afforestation projects in developing countries to meet their Kyoto emission reduction targets (Bhullar, 2013; Pan et al., 2022). Partly responding to CDM's limited scope and adoption of forest solutions, the UNFCCC proposed REDD in 2008, a policy framework focused on reducing emissions from deforestation and forest degradation, the enhancement and conservation of forest carbon stocks, and sustainable forest management practices (REDD+) (Bhullar, 2013; Streck, 2021). Since then, the UN-REDD programme has overseen more than 700 million tCO_2 in emissions reductions by its 65 partner countries and $350M transferred in results-based payments between 2009 and 2020, making it the most prominent international platform for REDD+ development and financing (UN-REDD, 2022, p.

16). It provides developing countries with technical support in planning and implementing a REDD+ national strategy, including various policies nested at different scales, financing strategies, safeguard information systems, and monitoring forest reference levels (UN-REDD, 2022).

Since its early days, REDD+ has faced criticism and opposition from many experts and civil society groups regarding IPLC rights infringements and restrictions in resource access, tenure, and governance (Paredes and Kaulard, 2022). Responding to these claims, the UNFCCC released the 2010 Cancún Safeguards to promote and protect the role of IPLCs in its activities (Corbera and Schroeder, 2011). However, UNFCCC safeguards are voluntary, and their implementation remains at the discretion of lower jurisdictional levels, leading to inconsistent efforts and accountability (Rey Christen et al., 2020). For example, Panama’s National Coordinating Body of Indigenous Peoples withdrew from UN-REDD due to similar concerns in 2012 (Potvin and Mateo-Vega, 2013) but has since then re-joined talks and contributed to the elaboration of Panama’s national REDD+ strategy (MiAMBIENTE, 2022).

In parallel to public initiatives, the explosive popularity of voluntary carbon markets post-Kyoto also led to an explosion of FCOPs, widely viewed as local-scale REDD+ projects (Wunder et al., 2020). Voluntary carbon markets are decentralized markets often regulated by third-party certification schemes where private buyers can purchase carbon offsets from voluntary carbon capture providers. Between 2006 and 2020, over 650 million tCO_2 of offsets were issued by the four largest voluntary project registries (Fujii et al., 2024). Free from the UN-REDD programme’s policy framework regulations and bureaucratic burden, these projects are often able to employ more flexible designs, including variations in the forest-based activities adopted, the scale of implementation, the nature of the actors involved, the type and distribution of incentives, and the inclusion of local communities (Angelsen et al., 2008; Streck, 2021; Wunder et al., 2020). These voluntary projects are also subject to different social and equity standards, with approaches to co-benefits varying from ‘pro-poor’ to ‘do no harm’ (Bayrak et al., 2014; Pan et al., 2022), and they vary in their monitoring and reporting practices (Caplow et al., 2011).

This complex mosaic of forest-based policies, diverging governance structures and regulatory frameworks, can complicate the delivery of positive outcomes to IPLCs involved in

REDD+ or FCOPs as part of voluntary carbon markets (Dawson et al., 2018). The context-specificity of forest degradation and deforestation drivers and of the multi-scalar institutional and regulation landscapes make planning and implementing beneficial on-the-ground activities a complex task (Corbera and Schroeder, 2011; Paredes and Kaulard, 2022). As such, a better integration of local livelihood and experiences in FCOP design and implementation, and an enhanced understanding of how policy and context interact with one another over time, are increasingly recognized as solutions to address this challenge (Aukland et al., 2003; Dang et al., 2023). This has also led to the adoption of livelihood perspectives in the monitoring and evaluation FCOPs and their socio-economic outcomes and of the integration of social learning in the implementation process, namely through adaptive management practices (Caplow et al., 2011; Holmes and Potvin, 2014).

3.2.2 Sustainable livelihoods and carbon capture projects

Sustainable livelihoods approaches provide a people-centered framework to "help understand what is and what could be done to make livelihoods sustainable as an overall developmental objective" (Turner, 2017, p. 2). They are well-suited to FCOP evaluation because such projects unavoidably reshape the way people use, access, and govern resources, and create and restrict livelihood strategies at the same time (Bayrak et al., 2014; Coomes et al., 2004; Scoones, 2015).

Drawing from Chambers and Conway's (1992) seminal article on the approach, Ellis (2000, p.10) defines *livelihoods* as comprising "the assets (natural, physical, human, financial and social capital), the activities, and the access to these (mediated by institutions and social relations) that together determine the living gained by the individual or household." In short, livelihood approaches examine how households mobilize their assets to adopt specific livelihood strategies leading to tangible livelihood outcomes. These processes occur over time within a broader context where institutions, social processes, and other contextual factors mediate the households' access to resources, strategies, and outcomes (Bayrak et al., 2014; Scoones, 1998, p. 199). Livelihood strategies are dynamic, because people "respond to changing contexts, and because they wish to change their circumstances" (Rigg, 2007, p. 92).

The existing livelihoods literature on FCOPs mostly focuses on the one-directional impacts of these interventions on the social-ecological context where they are implemented, mostly by monitoring changes in asset endowment at the household and community level. However, they do not examine the ways the two-way interactions between the FCOPs and the livelihood activities themselves and its implications for project outcomes. Of the studies focusing on the impacts of FCOPs on their participants' assets, many find that participation enhances the ownership and access to social, financial, and physical capital (Caplow et al., 2011; Peras et al., 2016; Philemon, 2021; Sunderlin et al., 2017), while others show restrictions in access to these capitals (Bayrak et al., 2014; Bayrak and Marafa, 2016). Findings on human capital (nutrition and food security, health, knowledge, etc.) are conflicting (Bayrak and Marafa, 2016; Peras et al., 2016; Philemon, 2021; Tacconi et al., 2013). Studies evaluating livelihood outcomes found a decrease (Larson et al., 2018; Peras et al., 2016) or no significant impact on participant's subjective (Sunderlin et al., 2017) and objective well-being, the latter measured using holistic livelihood indices (Dube and Chatterjee, 2022). Regarding resource and outcomes distribution within communities, findings often point to wealth-differentiated impacts favoring wealthier and male participants in the access to resources and co-benefits from REDD+ (Aggarwal and Brockington, 2020; Atela et al., 2015; Pagiola et al., 2007; Philemon, 2021).

To our knowledge, there are no studies that employ the sustainable livelihoods approach to evaluate how FCOPs change and interact with rural livelihoods, and how deeper fundamental changes in the landscape influence this relationship over time and thus potentially create constraints and trade-offs as a result. Adjacent studies using different approaches include Laudari et al (2024) who, using the social-ecological systems framework (Ostrom, 2009), investigate the jeopardized engagement and effectiveness of community forestry management in Nepal due to long-term local social-ecological shifts using. Similarly, Dang et al. (2023) used a structural equation model to unveil the feedbacks effects between changes in rural livelihood activities and ecological restoration projects in China, and the way the latter's effectiveness is affected as a result.

3.2.3 The Emberá in the Bayano Region

The Emberá of Panama are a forest and river-based indigenous group whose livelihoods have historically revolved around subsistence agriculture, hunting, and fishing (Dalle and Potvin, 2004; Taylor, 2016). Originating from the Brazilian Amazon, most Emberá had migrated north-westward into Colombia's Choco region following Spanish colonization by the 16th century (Taylor, 2016) and further into Panama's Darién to flee forced mining labor by the late 18th century (Wali, 1989, p. 26). Today, with a population nearing 40,000, the Emberá form the fifth most important indigenous group in Panama (MiAMBIENTE, 2022).

Between the 1940s and 1960s, motivated by the better access to markets guaranteed by the road, waves of Emberá families moved further into Panama and settled along the Bayano River and its tributaries, an area already populated by indigenous Guna groups and colonists (Potvin et al., 2007; Wali, 1989). At this point, the Bayano region knew little to no administrative presence from Panamanian authorities. By 1970, approximately 350 Emberá lived in the Bayano region in distant family-based settlements, following Emberá's historical settlement pattern (Wali, 1989). In the mid-1970s, President Omar Torrijos's industrialization plan and the consequent construction of the Bayano Hydroelectric Basin forced the relocation of the Bayano's indigenous and colonist populations. By 1977, following a series of unsuccessful attempts by the government, the vast majority of the Emberá had been relocated into the new villages of Piriatí and Ipetí. These villages, along with the community of Majé, today form the *Tierras Colectivas Alto Bayano*. Following decades of legal battles with the government, Ipetí's land title was officially recognized by Panama's Law 72 in 2015 (Vergara-Asenjo et al., 2017).

3.3 Methods

3.3.1 Study Site

This study focuses on the community of Ipetí-Emberá (hereafter Ipetí), situated on a collectively owned Indigenous territory located 150 kilometers east of Panama City on the Pan-

American Highway in the Alto Bayano Watershed (Figure 2). Annual temperatures in Ipetí average 25°C, and precipitations reach 2,000 to 2,500mm, the vast majority of which falls between May and December (Köppen classification Am) (Potvin et al., 2007). Ipetí's mosaic of soils, originally covered by tropical rainforests, ranges from highly fertile to highly infertile (Nortcliff, 1998; Tschakert et al., 2007). Approximately half of the territory is crossed by a mountain ridge. (D. Sharma et al., 2016).

After the community's formal establishment in 1975, the *Tierra Colectiva*'s 3,191 ha were progressively divided into 1 to 100-ha *parcelas*[2] (lot) by the local authorities and assigned for households based on their size. Now that all land has been allocated, acquisition occurs only through inheritance, gifting, or sale between Emberá. Land use decisions are made by households or kin groups. The land-use cycle in the early 2000s was described by Potvin et al. (2007, p. 1355) as a swidden agriculture system where forests were cleared and burned for cropping and then left in fallow for some time (1-30 years), after which it is cleared again for cropland or pasture conversion. According to a participatory mapping workshop conducted in Ipetí in 2004 (Potvin et

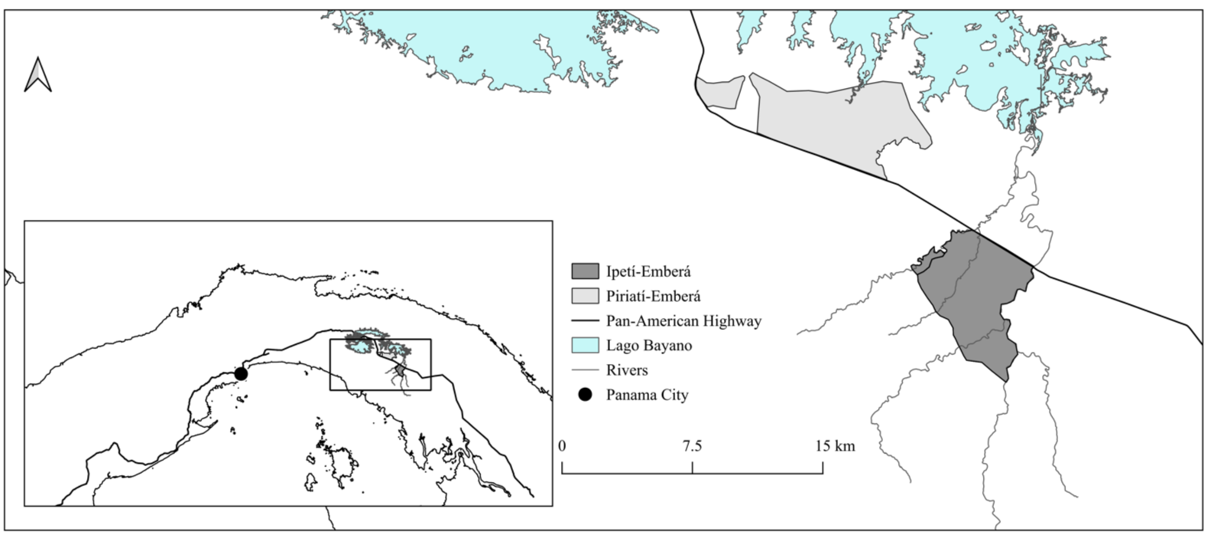

Figure 2. **Map of Ipetí-Emberá in Panama's Upper Bayano watershed**.

[2] We use '*parcelas'* to refer to a household's total land holdings and 'plot' when speaking of a portion of the *parcela* dedicated to a specific land use.

al., 2007), the main land-use change drivers upon settlement were demographic growth, which led to forest clearing for subsistence agriculture, and the completion of the Pan-American Highway, which resulted in the expansion of commercial agriculture. Simultaneously, the introduction and expansion of cattle ranching in the 1990s had caused a significant pressure on the *Tierra Colectiva*'s forest cover. As a result, by the early 2000s, about half the *Tierra Colectiva's* original forest had been converted to a mosaic of croplands, pasture, and fallows at various stages.

In 2004, when Potvin et al. conducted their study, all households relied on a diverse livelihood portfolio comprised of farm and non-farm activities, including farm labor, crop sale, small livestock, cattle ranching, service provision, and tourism-related activities. The transition from a purely subsistence cultivation-based economy to more diversified livelihood portfolios had started at the turn of the century in response to a heightened need for cash income to pay for education and other consumer goods. The median annual income was US $1,236 (Tschakert et al., 2007, p. 809). Today, Ipetí's local authorities estimate the population at 800 individuals, an increase of around 250 since 2004 (Tschakert et al., 2007, p. 808).

3.3.2 REDD+ in Ipetí

Ipetí's engagement in participatory action research began in the mid-1990s through a partnership with McGill University's Neotropical Ecology (NEO) Lab in Canada. After their first project revealed that over two-thirds of the territory's culturally significant plant species were locally endangered or now absent (Dalle and Potvin, 2004), the community turned to the newly developing voluntary carbon market for opportunities to fund conservation initiatives.

Following many years of planning, including the development of a participatory land-use/land-cover baseline in 2004 with the NEO lab's support (Potvin et al., 2007), the first carbon offset contract was signed between a community-based NGO and the buyer, the Smithsonian Tropical Research Institute (STRI), thus marking the beginning of the Ipetí-STRI carbon offset project (hereafter STRI project). The contract specified that STRI would purchase 3600 tCO2e from reforestation activities at a price of $10.22 USD/tCO2e from the NGO, who would oversee the project's implementation with the participating families. In addition, an external NGO (ANCON) was contracted to support the community NGO with technical and managerial assistance and external monitoring. The contract also entailed an avoided deforestation component, but it was quickly abandoned due to land invasions and conflicts by colonists (Holmes, Kirby, et al., 2017).

The amount allocated to each family was calculated based on 25-year carbon sequestration projections for each plot design. The payment and benefit-sharing mechanisms were informed by community consultations during the planning and early implementation phases. Various financial incentive options were proposed, including result-based payments, compensations matching alternative plot uses, and flat payments addressing households' basic living expenses. In the end, the signing parties agreed that 80% of the payments would be given to the participants over the first eight years following planting, the most labor-intensive period of the contract, and the remaining 20% would be dedicated to a community fund.

Between 2008 and 2010, 20 plots between 0.25 and 1 ha were committed to the project by 19 participants. STRI accepted to include agroforestry as a reforestation option in 2009, responding to concerns that only wealthier families could afford timber reforestation, which implied forgoing any returns from a portion of their *parcela* for the 17 years following the end of payments, the time needed for trees to reach the appropriate maturity for harvesting. Combining timber with fruit trees and shrubs was, therefore, meant to provide short-term benefits through fruit sale and consumption, even if the total carbon offset payments were lower. Two participants abandoned the project after their plot was completely devastated by a brush fire that had escaped a neighbor's control. Two intentionally left the project and converted their plot to another land use, leaving a total 16 participants still the project by the 15th year.

More recently, a second FCOP contract was signed in 2020 between McGill University and another local, women-led NGO. This new project comprises 44 households in three communities dedicating 1ha to timber-only reforestation, 20 of which are in Ipetí. Planting took place between 2020 and 2022, and the compensations increased to represent the current cost of labor.

3.3.3 Data Collection and Analysis

Data was collected by me during five months of intermittent fieldwork from April to September of 2022 with the support of three local field assistants (Icel Ruiz, Vivian Ibarra, and Lucelys Flaco), followed by preliminary result dissemination, member-checking, and follow-up interviews in June and July of 2023. This research was approved by McGill University's Research Ethics Board I (REB file #22-03-112).

We began by running four exploratory focus groups to get more insight into Ipetí's recent history and inform the subsequent household interviews. Informants, including both reforestation participants and non-participants, were recruited upon local authority recommendations and subsequent snowballing, and were divided into four age and gender-based groups of three to six people. The focus groups were structured around a community timeline activity (Geilfus, 2002, p. 53), but intentionally remained flexible to follow the informants' lead. They lasted between one and two hours.

We then conducted twenty-one in-depth household interviews (40 minutes to 2.5 hours) which constitute the bulk of our data. We interviewed 15 of the 17 active STRI project participants, one former participant who has left the project, and four additional households to integrate non-STRI perspectives and experiences, including two participating in the McGill project. The interviews were mostly unstructured to leave room for informants to dictate the topics and rhythm of the discussion. We used a topic checklist as an interview guide (see Appendix I) to ensure thematic consistency. The general interview structure was as follows: After covering the family's history and the community's foundation when applicable, the conversation was stirred towards the household's livelihood trajectories. We only brought up the reforestation projects at the end to avoid them taking over the interview. We also conducted eight key informant interviews with STRI project stakeholders and community leaders to better understand and contextualize their perspective regarding the planning and implementation processes, as well as the project's outcomes.

Following the household interviews, we facilitated two participatory mapping workshops (n=5 and n=7). Recruitment was based on the local authorities' recommendation, snowballing, and involvement in previous research activities. Participants were asked to represent the current state of the *Tierra Colectiva* by dividing 30 tokens into land cover categories (forest, short fallow, high fallow, crops, mechanized crops, pasture, reforestation, newly cleared land, and agroforestry). By doing so, we replicated a similar exercise performed in 2004 to evaluate the land cover history and likely land cover pathways under business-as-usual and REDD+ scenarios, the former constituting the STRI project's baseline (see (Potvin et al., 2007) for more details). The main source of data from these workshops came from the discussions resulting from presenting the participants with the REDD+ and BAU scenarios for 2025 (as projected in 2004) side by side with their estimation of Ipetí's current land cover. The discussions focused on the land-based livelihood trajectories to which the informants attributed the discrepancies between the different scenarios.

All focus groups, interviews, and workshops were recorded with a smartphone and a recorder (model SONY ICD PX333). The recordings were then uploaded and transcribed into the qualitative analysis software MaxQDA2022. We coded the interview and workshop transcripts and our field notes using two sets of pre-established codes: the first one using concepts from the Sustainable Livelihood Framework (Ellis, 2000, p. 30), and the second set covering FCOP dimensions such as 'implementation', 'motivation and incentives', 'outcomes', 'future plans', 'governance and management', and 'problems and solutions'. The segments for each provisional code were categorized into sub-codes where appropriate, and interactions between the STRI-Ipetí project and livelihood transitions were extracted were the two code sets overlapped. Causation coding was applied to segments describing livelihood transitions to identify the drivers, mediating factors, assets mobilized, the informant's level of agency, and the outcomes.

3.4 Results

Our results describe a livelihood context continually changing with and around the implementation of the FCOP, having implications for its efficacy. To answer our research questions, we begin by reviewing the dominant livelihoods transitions in the region over the past 15 years, including those related to the STRI Project's implementation. We then show how the potential and intended objectives of the FCOP's initial design can change in relation to changing livelihood dynamics. Finally, we discuss the significance of these interactions and of their impacts in the context of FCOP design and governance.

Our interviews and workshops show that the early diversification of Ipetí households' livelihoods away from a quasi-exclusive reliance on subsistence agriculture documented in the early 2000s has continued since then. The households we interviewed reported engaging in various land-based activities to make a living, including subsistence cropping, larger-scale agricultural production destined for sale, small and large livestock rearing, participation in reforestation projects, farm labor, and land rental. Non-farm activities include gold panning, business endeavors (e.g., owning a kiosk*,* small hustles), tourism-related activities (including craft making and the coordination of tourist visits), and short-term contractual labor or stable employment, to relying on remittances from close relatives who migrated out of Ipetí to pursue new livelihood opportunities. While all households still engage in some form of subsistence agriculture, their direct dependency on natural resources varies widely from one family to another. Livelihood portfolios range from near-full reliance on crops to, for example, planting just enough plantain (which has low labor requirements relative to other staple crops) to meet one's needs and counting on non-farm income sources to purchase everything else.

These changes arose in response to a series of underlying trends and factors considered in livelihood decisions in the last 20 years, mainly relating to environmental and climate changes, social transformation, and economic disruptions and pressures. All but two interviewed households reported changes in land productivity caused by environmental and climate changes, such as increased seasonal variability, land degradation, and biotic invasions. Economically speaking, 15 households highlighted a significant increase in the cost of living and a remarkable decline in unskilled labor demand, accentuating the need for reliable sources of cash. Half the households interviewed also noted a deterioration of social cohesion within the community, which some tied to the collapse of previously community-run tourism activities and lower levels of mutual support and collaboration between families. Furthermore, questions of land access were recurring, specifically regarding growing land scarcity driven by demographic pressures. All the drivers of change were mentioned across all household FCOP design types and participation profiles (agroforestry, timber, non-participants).

Overall, that the most important trends could be described in terms of these four livelihood activities: cropland farming, cattle ranching, renting of land, and reforestation. In what follows, we expand on how and why these livelihood strategies have evolved over time, and then further on the interactions and feedbacks between these livelihood trends and the reforestation project.

3.4.1 Ups and downs of crop production

Ipetí has experienced several swings in agricultural production since its foundation, starting from the cultivation of staple foods aimed for household consumption to an initial rapid expansion of crop farming in the early 1980s, then followed by a consistent decrease since the late 1990s due to unstable yields and fluctuating market conditions, except for select newer, more reliable market crops, particularly coffee. All of Ipetí's households were exclusively self-reliant for food production when the *Tierra Colectiva* was first settled. Agricultural activities were mostly limited to small-scale subsistence crops (rice, corn, and plantain) due to the restricted access to external markets. Households supplemented this occasional agricultural income with day labor, gold panning, and the vast majority selling timber from their plots as they cleared the forest for crop production.

Improvements in accessibility tied with early settlement development incentivized a shift towards production of food crops for the market. Increased road infrastructure, first with the completion of the Pan-American Highway in 1980 and subsequently with additional roads going to the village and into the territory, facilitated the sale of crop surpluses. This led to the gradual expansion of staple crop cultivation such as corn towards market production, paired with the adoption of new of subsistence staples, like yam and yuca, in the 1980s. For example, two neighbors and friends, Michel (60s) and Roberto (50s), recalled teaming up upon receiving

AMPYME[3] seed capital of $800 to start large-scale market production of yam in the late 1990s, reaching annual yields of 15,000 quintals on average after three years. This level of production was not possible for everyone though, as households face unequal opportunities due to their *parcela*'s characteristics, including its distance from the village, topography, and soil fertility, the latter seeming to specifically restrict the production of tuber crops. Participants whose *parcelas* were composed of 'red soil' (ultisols) described fertility issues as well as challenges meeting market standards:

> "I started to clear the land here; I planted corn and rice, but neither produced well. The only thing that produced a little was the yuca, but the rest doesn't. Not even plantains, it's no good: they sprout nicely, but after a while, the leaves turn yellow and dry out. We still produce yuca, but only to eat. For selling, that's also a problem because in Panama, they don't want yuca from red soil. It's not good for selling because it's red." (Gerardo[4], 50s, 30/08/2022)

The steady expansion of subsistence crop production for surplus sale was eventually met with considerable agrological challenges. Since the 1990s, many producers have been gradually abandoned the commercial production of staple crops, especially tubers, and sought alternative income sources. Whereas some informants cite employment opportunities brought on by higher education levels and extended social connections as the main reason for the abandonment of cropland farming, many also bring up other social-ecological factors that have increased the vulnerability of strictly agriculture-dependent livelihoods. Among these was the higher incidence of pests and crop diseases, mentioned by all but three of the interviewed households. In fact, our two interviewees mentioned above who had originally been successful selling yams had to abandon their production shortly after that due to the regional spread of a yam fungal infection and the subsequent drop in yam prices. The sale of their harvest barely allowed them to cover their

[3] Autoridad de la Micro, Pequeña, Y Mediana Empresa (Micro, Small, and Medium Enterprise Authority)
[4] All the names used are pseudonyms.

operating costs, leaving each with barely $10 in profit after the third year. Seven of the 20 households interviewed gave up large-scale yam production following that yam epidemic. More recently, 12 households reported an increased prevalence of pests, specifically rodents and birds, which cause severe damage to rice and corn crops. As a result, half of these households have abandoned cultivating these staples in the last decade.

Additionally, half the households brought up climate change and extreme seasonal variability as considerable factors behind the decline of crop farming. Several informants explained that the climate had been generally warmer and drier, compromising crop yields, but that the directionality of changes can vary drastically from year to year. For example, the 2022 rainy season began much earlier, causing important disturbances in people's ability to clear fallow for cultivation. Such variations make traditional practices based on local ecological knowledge increasingly unreliable, such as the swidden-fallow calendar usually followed in Ipetí:

> "Traditionally, we are accustomed to burning on Holy Saturday, that's the exact date. People relied on it, waited for the burning date, and in waiting for that, it turned out to be... nothing. Because the rain came earlier during Holy Week, and no one could burn anything for their crops." (Arturo, 50s, 08/07/2022)

Informants repeatedly reported that their crop yields had been increasingly unpredictable and that land productivity, especially when cultivating in fallows, was much lower than before. They tied these changes to the factors mentioned earlier, but also to land degradation caused from nearby intensification, both in and around the territory, especially upstream on the Bayano River. They listed chemical run-off, hydrological disturbances due to deforestation, as well as weed issues, such as invasions of wild sugarcane *(Saccharum spontaneum L.),* a grass that quickly colonizes open lands. For example, two informants estimated that rice yields had decreased by half over the last 20 years under these combined pressures.

Households have adopted various coping strategies to confront these mounting issues. According to a community leader, people have started to clear more forested land instead of using fallows, hoping for better outcomes. A few of those who had sufficient success in agricultural endeavors eventually purchased a vehicle and started working as intermediaries between local producers and buyers in Panama City to internalize the external intermediaries' profit margin. Others have abandoned subsistence cropping altogether (except for plantain, which all interviewed households still cultivated) and turned to other sources of cash income that allow them to purchase food, such as investing in more resilient market crops like coffee.

More recently, coffee production has seen a massive gain in popularity and uptake, namely due to its high economic potential and relatively quick output; coffee shrubs start producing fruit approximately 5 years after planting, after which yields consistently increase every year. Its demand is high, its price stable, and harvests are almost guaranteed, provided good management. Moreover, stable and predictable production of any marketable crop can be used to secure loans from Panama's *Banco de Desarrollo Agropecuario*[5] (BDA), making it an interesting alternative to cattle. While cattle ranching has high capital requirements at the outset, capital needs for coffee production were lessened for some by the physical resources provided through the STRI project's agroforestry component (such as coffee, shade tree seedlings, carbon payments to cover the initial labor investment). Many of the participants described getting initiated to coffee through the STRI project. Interest has been further spiked more recently as training seminars were offered in 2022 to all community interested members by the FAO, in collaboration with one of Panama's leading coffee producers. Given the relatively recent adoption and expansion of coffee in Ipetí, producers are yet to harvest at scales sufficient to rely solely on coffee income to meet their needs, but many aspire to such affluence. As expressed by an informant who had just reaped from his first coffee harvest: "Here, no one makes more than $2,000 or $3,000 from their crops. (...) Whereas with coffee... If you have enough, $10,000, $8,000, $12,000… you will make money! That's why I tell you, the coffee project is very important." Other 'new' market crops mentioned during interviews include tomatoes, cucumber, turmeric, and chilis.

[5] Agricultural Development Bank

This massive adoption of new market crops has also had its downsides, particularly price volatility, which was mentioned in more than half of the interviews. For instance, many people (including 11 of our interviewees) had started or intensified ginger production in 2021 due to its high demand during the COVID-19 pandemic, only to see ginger prices fall from approximately $50 per 100lbs in 2021 to $8 by 2022, which informants attributed to an excess in supply. Since root crops can be kept in the ground for long periods, people postponed harvesting until the price recovers, but as of writing, it had remained low. The issue was not limited to new crops. A woman reported a comparable situation with plantain:

> "Due to the pandemic, plantain ended up costing four dollars per 100, so people stopped planting and abandoned the crop. So now that the pandemic has ended, they face the consequences because nobody has planted. Now, a plantain in Panama costs one dollar, the large ones!" (Diana, 40s, 14/08/2022)

This quote also adds the COVID-19 pandemic as yet another factor that shook Ipetí's livelihood system, leading households towards a temporary return to subsistence agriculture. As people's movement within and outside the *Tierra Colectiva* was tightly restricted by public health rules, people were unable to seek out labor opportunities, leading to extreme cash shortages. As a result, many households temporarily returned to subsistence cropping or intensified their already existing practices:

> "I always knew that the crisis was coming when the pandemic began, so I started planting more to provide for my family through it, both to eat and to sell." (Álvaro, 40s, 17/08/2022)

> "We had some little crops here and there, and we consumed those; that's how we sustained ourselves. We had the river nearby where we could catch fish, we could go and harvest plantains, all that. If we had been living like people in the city… It's a good thing that we live here in the countryside." (Marco, 40s, 28/08/2022)

However, as mentioned earlier, the abnormal rainy season that followed considerably limited Ipetí households' ability to grow crops for subsistence and market production. This, coupled with the 2022 political crisis and hyperinflation caused by roadblocks, highlights the vulnerability of farming to compound crises.

> I wanted to plant this year because hard times are coming. There's going to be a shortage of food. It's going to be very high, very expensive. (…) I think I'm going to die of hunger!" (Lisa, 40s, 13/08/2022)

Farming, thus, went from being an essential part of livelihood strategies in Ipetí to an increasingly volatile activity. While it can still account for a significant proportion of some households' livelihood portfolios, revenues from crop farming are still limited and uncertain. Households who still mostly rely on staple crops for a living are among the poorer ones in the community and, beyond coffee production, opportunities for socio-economic advancement are sought in other land-based livelihoods.

3.4.2 Changes in cattle ranching practices

Livestock rearing is not historically part of Emberá culture. Respondents reflected this by repeatedly associating cattle ranching and the forest clearing for pastures with colonist practices in interviews and informal conversations. However, as a community elder explained, the adoption of cattle ranching in Ipetí has occurred out of necessity, and despite the knowledge that such practices damage the ecosystem.

> "No more medicine will grow anymore where we plant pasture, we will not find it again. That is not our tradition. But we must do it anyway because if we don't, there won't be any food, and even if there is, we will struggle and struggle to grow that food. That is why many people in our community do not have many possessions: everything depends on bananas, yucca, yams… Small things that do not move us forward. To have a future, one has to do something good that one can rely on tomorrow, like raising livestock." (Rafael, 70s, 26/08/2022)

A government development program initially introduced cattle ranching to Ipetí in the early 1990s, and the activity subsequently underwent further expansion. According to the local authorities, approximately 5% of Ipetí's households currently own cattle. Of the 21 households interviewed, six engaged in cattle ranching, another six had done so in the past, and four expressed the desire to adopt or re-engage (two) in the activity. Because non-cattle owners identified land-related limitations (size or distance from the village) and the high capital investment required at the start (improved pasture, fencing, animals, veterinary expenses, etc.) as the main barriers to entry, we suspect our participant pool being mostly composed of older households who owned land in the early 2000s skews our sample towards individuals more likely to own cattle than less resource-endowed households at earlier stages of their life-cycles.

Cattle are a source of both physical and financial capital. Larger-scale livestock breeders (herds of 50-100 heads of cattle) generate regular income from selling finished 'fattened' cows born from the existing herd. However, smaller herds (fewer than ten heads) also benefit owners in two ways. First, they were highly liquid assets used in cases of emergency. For example, interviewees have reported selling cattle to invest the income and freed land in other livelihoods (mentioned by four households), to pay for children's higher education (two) or relatives' healthcare-related fees (two). Others have also gifted cows to children as inheritance (two) or plan to do so in the future (two). But cattle were also one of the few assets accepted for bank loan warranties, along with large ready-to-reap harvests and new agricultural machinery (which no-one owns in Ipetí), since collectively owned land does not qualify. To our knowledge, at least three informants had or were in the process of securing loans from the BDA using their cattle as a warranty.

Cattle ranching requires significant starting capital investments. Beyond the livestock itself, the labor required to clear fallow land and prepare the pasture, along with the purchase of improved turf seeds and materials to build and maintain fences, results in steep entry costs for new adopters. Four interviewees overcame barriers to entry by inheriting their first cattle from their parents or collaborating with them before becoming independent. Others started herding livestock with the support of a government development program (n=2) and earned the initial capital through work outside Ipetí (n=2) or the sale of land-based products (crops and forest products) (n=2). Eight households have, at some point, cooperated with extended family members or non-kin partners to split the labor and resources (including land) and then share the outputs. Only three have engaged without any form of external collaboration.

Cattle ranching has had a significant impact on Ipetí's land cover. On average, the participants of the participatory mapping workshops agreed that the extent of pastures had increased by 20% since the early 2000s. This expansion is now not solely linked to an expansion of cattle ownership among the people of Ipetí, however. Families, including three of our informants, are now increasingly selling their herds in order to rent out their pastures to *campesinos*, or even converting fallows to pasture for that purpose without having previously owned cattle themselves.

3.4.3 Renting out land

Land leasing to non-Emberá individuals or companies has become an increasingly common livelihood strategy in the past two decades. According to a member of the traditional authorities, about 15% of Ipetí's landowners rent out part of their land to *campesinos* (mostly cattle ranchers) or large-scale rice producers. This alternative source of land-derived income has gained popularity in response to most agricultural crops' lower yields, volatile demand, and the increasing labor inputs required to deal with weeds and pests. As the older generations (currently heading most land-endowed households) face challenges finding alternative sources of income through stable or wage employment, renting land becomes one of the few options available to provide for their families.

The most popular land use for which land is rented out, by area, is mechanized rice production (with an estimated 230 ha). This land use is restricted to flat plots with appropriate road infrastructure so machinery can access the plot, which limits adoption to households whose land holdings fit these criteria. Three of the households we interviewed rent part of their plots to rice producers. Two of them are siblings who inherited land already leased out by their deceased parent for that purpose (50 and 62 ha, respectively). In contrast, the third one only recently started converting fallow for that purpose (approximately 8 ha). Alternatively, many also lease out land to colonists who use the plots as pastures for their cattle (two interviewees) or sometimes for crop production (two interviewees). Renting contracts vary in duration, price, and type of rental services, and Ipetí's traditional authorities must approve any agreement. For example, one of our informants offers renting-adjacent where he cares for many *colonists'* herds on his pastures for a few weeks to a few months. Others alternate between renting a given plot to *arroceros* (rice farmers) and cattle ranchers within the same year. Prices fluctuate, with rice paddies ranging from $200 to $300 per ha and per year, contingent on the land's preparedness for cultivation. Improved pasture is assessed at approximately $200 per ha per year, while unprepared fallow costs around $100 per ha per year.

Mechanized agriculture had important consequences on the land in the medium term, as interviewees and workshop participants described:

> "And the others as well, they plow the land, but by cleaning it with a tractor, they immediately damage the soil, and the land will never be the same. For example, there's a low area down here where they plant rice; that land is useless now. It's only suitable for mechanized work. Mechanized in the sense that if you want to plant rice, you have to improve it with a lot of fertilizer and chemicals to have a harvest." (Rafael, 70s, 26/08/2022)

> "When they [the rice producers] leave, they leave behind all the chemicals in the soil, and that land will not have the same yields. It won't produce anymore." (Boris, 30s, 26/08/2022)

According to our participatory workshop attendees, this degradation of the land produced a land use lock-in that explained why most mechanized rice fields have been continuously rented out for the last 20 to 30 years.

The COVID-19 pandemic and the subsequent 2022 economic crisis, however, had serious impacts on land rental in Ipetí. Three of the seven interviewees who leased out plots in 2021 lost their renters in 2022, two of which linked it explicitly to the economic crisis. Those renting out pastures were more heavily affected than the ones renting to rice enterprises. One told us that he could not find anyone to whom he could lease out his combined 20ha of rice paddies and pasture:

> “I rented it the year before the pandemic. Last year I rented too. This year, people don't have the budget to rent. Right now… there is nothing, I’m not renting anything.” (Álvaro, 40s, 17/08/2022)

Luckily, Álvaro was able to fall back on the ginger, turmeric, and chili he had planted in larger quantities during the pandemic in prevision of economic hardship (see his previous quote in 4.1) until he found renters again. Even as land rents are perceived as a low-risk-high-reward option to capitalize on one’s land holdings, this sharp decline of the land market illustrates the strategy’s vulnerability of land rents to external economic disruptions which, especially when renting to neighboring colonists, will coincide with those affecting Ipetí’s landholders in their other livelihoods as well.

3.4.4 Participation in forest carbon projects

Of the STRI project participants we interviewed during household interviews, seven took part in timber reforestation (one using a lower density silvopastoral design), and ten enlisted in the agroforestry component, with one participating in both. Motivations and incentives to get involved in the project fell into three broad categories: conservation, based on the prospect of owning timber, and of producing and selling fruit.

We noted that participants were highly conservation-driven across all reforestation designs, with multiple participants bringing up the cultural value of forests and the importance of species recovery and emphasizing the significance of reforestation in preserving ecological knowledge for future generations. One articulated this concern poignantly:

> "In reality, all the wood is gone now... The *cedro espinoso*, the *espave*, the *bálsamo*, nothing is left. So, I started to analyze: What will my children see? My

children won't know what a *cedro espinoso* is anymore, none of those. That's why I started planting." (Marco, 40s, 28/08/2022)

Several participants also saw an opportunity to develop their own timber supply, either to use directly in crafts or to be able to build traditional Emberá houses again (palm-frond-roofed platforms elevated on posts), as large enough trunks required to support the structures are now either unavailable in the *Tierra Colectiva,* or too expensive to afford by most. The sale potential of grown timber trees was also a considerable factor. Of the participants who chose the agroforestry option over planting only timber species, five mentioned choosing the later thanks to the prospect of shorter-term benefits associated with the consumption and sale of fruit, predominantly coffee. The theme of leaving a legacy for future generations emerged in the context of conservation, timber, and fruit-related incentives. Participants saw reforesting as a means to generate natural, cultural, and economic capital for their children and grandchildren, which they will be able to fall back on in emergency situations or, as many mentioned, to access higher education. The project providing seedlings and paying participants for plot maintenance significantly eased the barriers typically associated with the activity's adoption.

Agroforestry participants generally perceived more benefits from their participation in the project than those engaged in timber-based reforestation. Direct benefits beyond the payments they received in the first eight years include the harvesting and sale of fruit from the plot, especially coffee (mentioned by eight out of ten agroforestry participants). Many have since expanded coffee production from their original STRI plot, often citing the project as their first step in the coffee market. However, many noted that the now larger timber and fruit trees cast too much shade over their coffee plants, limiting their productivity. Several of those who were now participating in the FAO's coffee workshop series also complained that the project did not provide them with such training, thus restricting their ability to fully capture benefits from their plot. Other critiques point to pests eating and damaging their fruit and preventing their sale, especially avocados and mangos, and to market access issues. Notably, a former coordinator from the community NGO and agroforestry participant noted that he could not find a profitable market for the fruit (in this case, achiote) he had grown once it was ready for harvest, causing him to lose most of his production.

While timber participants generally recognized the natural capital they had gained and were yet to capture in the future, they otherwise struggled to find other direct ways the project has benefitted them. Both timber and agroforestry participants in fact critiqued the project for the compensation and its disbursement mechanism, namely payments were too low and stopped too early. Specifically, any work involved in protecting the plots beyond the active implementation period was not rewarded, nor was the opportunity cost of maintaining these plots beyond the implementation. The payments the participants received were equivalent to the daily wage at the time, which has since increased from $6 to $20. Since the interviews, the participants have initiated a dialogue with STRI to adjust the carbon price to the current cost of living.

Responding to this lack of short-term benefits, people looked for alternative ways to make the plots more productive or increase their potential. Many are turning to coffee intensification and expansion as a more secure revenue source, for example by exclusively replacing trees that had died on agroforestry plots with coffee plants, regardless of the species. Others were also considering cutting down some of the taller timber trees to remove the excess shade, per the FAO workshop facilitators' recommendations. Notably, the participant who had opted for the silvopastoral system told us he had been successfully harvesting coffee he had planted between his timber trees, which had been placed at a density low enough not to compromise coffee growth. While his objectives were lower than other participants due to his plot's lower timber tree density, the trees he planted as part of the STRI project had stored 179% of the carbon stocks expected by the 10th year mark, making it the project's most successful plot so far[6].

Besides these coffee-related strategies, participants have been requesting formal reforestation certificates, which they received a few months after we conducted our interviews. These certificates are necessary for many of the expected initial incentives to eventually concretize (direct use and sale of timber). Participants mentioned a recent moratorium on the emission of tree

[6] Based on the 10-year carbon monitoring report produced in 2021 by Brais Marchena, Lady Mancilla, and Catherine Potvin

felling permits, which can be by-passed if one can prove that the trees were planted. Further, a few also claimed that the BDA newly allowed individuals with a certified reforestation to use their trees as guarantee for bank loans and credit, although no-one could point to official documentation confirming it.

3.5 Discussion

3.5.1 Livelihood transitions and the limitations of local carbon storage projects

Our study described a combination of transitions in Ipetí's livelihood context that together have affected its population's relationship with their land assets and activities over time, including forest-based carbon interventions. In particular, the culmination of socioeconomic and ecological pressures (i.e., lower land productivity, social fragmentation, crop price volatility, pests, and crop diseases) and shocks (i.e., the COVID-19 pandemic, the 2022 shortage of cleared land due to the early rains, the political and economic crisis) in recent years has changed the way the participants perceive and interact with the project. The trends we described in Ipetí's main land-based livelihood activities demonstrate the importance community members increasingly place on the generation of cash income, namely by channeling their land assets towards quick and high-return activities (i.e. market crop production, rents) or, at the very least, ensuring they remain accessible for this purpose during times of hardship. Now that the STRI project does not fulfil that function, it is relegated to a lower priority. This changing relationship has been manifesting as misfits between certain parameters of the intervention and the new local context, specifically the agroforestry reforestation component and the payment disbursement mechanism, compromising the project's efficacy as a result. We focus the following discussion on two specific points of contention: 1) the interactions between FCOPs and the evolving local context and 2) some ways the STRI project fell short in its response.

The rise of coffee production in Ipetí's agricultural landscape and shifts in the agroforestry participants' priorities ended up causing significant trade-offs between its biophysical and socioeconomic outcomes or, in other words, the project's effectiveness and its co-benefits. Of all the trees planted in the STRI project, coffee and other fruit shrubs store the least carbon by far (Holmes, Kirby, et al., 2017). With respect to their income generation potential, agroforestry plots were not designed to maximize fruit yields, and no training was offered as part of the STRI project to maximize crop production. As a result, participants must now choose between prioritizing either coffee or carbon. Coffee yields can be increased by felling the largest trees to remove the excess growth-inhibiting shade, which coincidently store the most carbon. However, prioritizing carbon implies forgoing otherwise easily attainable high harvest levels without any compensation for the sacrifice made. The fact that participants are encouraged to adopt the former strategy by FAO development program technicians shows the interplay between the STRI project and national land-based development programs. Even if seemingly anecdotal, this interaction suggests the existence of nesting issues between national programs and local-scale private initiatives (Dawson et al., 2018; Wunder et al., 2020), as it was not predicted nor detected on either side until our study, even though the FAO is Panama's main REDD+ enacting agency. Participants prioritizing the survival of their coffee plants over the other species and replacing any dead trees with coffee shrubs only further accentuated the problem, such that the agroforestry plots, on average, only stored 60% of the carbon predicted by the 15-year projections (Forgues et al., 2024).

Further, the increased prevalence of land-based passive income through land rentals is, in fact, a key emerging factor influencing the way community members engage with FCOPs. The distribution of non-conditional payments based on the cost of labor over the project's first eight years only offset the opportunity cost of labor during that period, rather than the full opportunity cost of participation over the 25-year period. Since the end of the implementation period, participants have been more acutely aware of the foregone profits they could now earn with a given area of land, even if noncompliance is involved. In addition to the mostly marginal income so far earned from fruit sale and the distant prospect of timber ownership, FCOP plots are now perceived by many as unproductive assets they must still contractually maintain beyond the payment period. This issue has become much more tangible now, especially given the mismatch between early compensations and the current cost of labor ($25 in 2022, versus $6 in 2008), the variable but overall expanding land renting market, and the ever-increasing cost of living and cash income requirements that other strategies often fail to cover. This corroborates the results of a meta-analysis of 59 REDD+ case studies conducted by Hajjar et al (2021), in which they signalled that a majority of projects saw an increase in opportunity costs associated with lost revenues during the REDD+ monitoring period, and that inflexible forest management rules tend to risk preventing community social-ecological resilience to shocks and uncertainty.

The end of the active implementation period also led to fewer community consultations and follow-up meetings taking place and coincided with the dismantling of the local NGO contractually in charge of the project. This, in addition to the COVID-19 pandemic more recently, made matters worse as it prevented STRI project stakeholders from taking stock of the local context's evolution, severely limiting their ability to work together with local stakeholders to adapt the project to better fit the participants' new realities over time. In addition, any further FCOP negotiations, planning, and implementation have been further complicated by social fragmentation in Ipetí, which has increased markedly since the early 2010s. This increased the number of disagreements over it and led to allegations of unequal direct and indirect benefit capture related to the project. This was a reminder that, as discussed by Andersson et al. (2018), FCOPs do not take place in a vacuum; by interacting with community groups and institutions, they unavoidably play into existing internal dynamics and may unknowingly feed into existing social inequalities and political conflicts. Overall, even though the STRI project's adaptive approach to governance yielded important early project improvements and community-informed decisions during the active implementation phase to respond to livelihood needs (agroforestry component and compensation front-loading), it may not have been enough to fully prevent important livelihood trade-offs and constraints further down the line due to changes in the local context. This led to the degradation of the project's initial fit.

Addressing such issues of fit is especially relevant in land-based projects involving non-conditional payments and reforestation and afforestation, since the carbon already purchased is stored over long periods of time, and any gains are easily reversible in the plot is altered or fully converted to another land use (Tacconi et al., 2013). Such noncompliance is likely, even when penalties are in place, if sufficient short-term benefits cannot be earned from FCOPs resource-dependent contexts (Boyd et al., 2007). This reality means that FCOPs find ways to track local social-ecological trends which impact forest use drivers or participant motivations and incentives, so as to ensure that the project's incentive scheme remains relevant to the local context and avoids the introduction of trade-offs between an FCOP's effectiveness and its socio-economic outcomes (Schweikart et al., 2022). Even if initially unanticipated, the success met by the participant who opted for the alternative silvopastoral design suggests that such trade-offs are indeed avoidable.

As a new and larger project contracted by McGill University in Ipetí and Piriatí is currently being implemented, and as forest-based measures both in REDD+ and the voluntary carbon market are still gaining popularity in other parts of the world, resolving questions of policy fit and governance, and finding ways to make to scale these solutions is particularly important. While claiming the universality of our findings would defeat the core argument of our paper that context matters, the fact that similar procedural failures emerge in other REDD+ analyses suggests that solutions might be at least partly transferable (Dawson et al., 2018; Schweikart et al., 2022).

3.5.2 Conducting forest carbon projects among change

Adaptive management, a natural resource management approach allowing for simultaneous learning about the resource itself, is, in theory, well-suited to FCOPs and REDD+ more widely. It relies on iterative cycles of learning, collaboration, reflections over resources and management tools to recognize and account for the dynamic nature of the resource system, including its management and environmental conditions (Williams, 2011). It has already been identified as a key best practice in REDD+, specifically in informing implementation, and as a way to reinforce other best practices such as capacity-building and collaboration among stakeholder groups (Holmes and Potvin, 2014). However, discussing emerging resource management challenges, Williams argues that the multiplicity and directionality of evolving ecological drivers leading to non-stationary resource behavior is a "new and serious challenge to adaptive decision making, one that requires new approaches that go beyond the standard ways of framing and addressing learning-based management" (Williams, 2011, p. 1351). Our study further demonstrates the role of the compound effect of both resource drivers and resource user behavior in these non-stationary resource use dynamics, which are due to contextual factors that fall outside the scope of traditional resource monitoring typical of adaptive natural resource management.

Addressing such governance problems is most relevant in forest-based interventions, especially those involving reforestation and afforestation or non-conditional payments, since long periods of time are required for the purchased carbon to be stored, and any gains are easily reversible in cases of failure (Tacconi et al., 2013). This would require expanding 'traditional' adaptive management into the implementation phase and long-term monitoring as well as expanding monitoring from resources only to the wider livelihood context and stakeholders' evolving incentives (Schultz et al., 2015). This is, however, not an easy task: as demonstrated by our case study, monitoring itself relies heavily on stakeholder relationships, structures and procedures which also need to evolve over time to prevent failures induced by the same institutional and wider contextual changes it is meant to survey (Corbera and Schroeder, 2011; Hajjar et al., 2021). In other words, not only does the adaptive governance structure need to monitor natural resource responses to management, but it must also track the multi-dimensional context in which resources are managed and the institutional and social context in which the monitoring process itself is conducted (Dang et al., 2023). However, as Schultz (2015) warns, overly flexible governance structures may lead to cause failure if monitoring and accountability to stakeholders is disrupted.

The way such practices can be scaled from local projects to larger policies such as national REDD+ strategies remain to be explored. UN-REDD's Cancún safeguards do not mention adaptive approaches to management (Holmes and Potvin, 2014), limiting the usefulness of developing standards and indicators in that direction. Improving land-based policy nesting and improving cross-institutional awareness and partnerships can be a way to limit the livelihood constraints faced by local participants. The increased participation of IPLCs at all phases and levels of the policy process goes beyond adaptive management. Meaningful participation that recognizes and promotes the agency, background, and context of all actors and groups involved is one of many steps necessary for the development of successful and socio-economically beneficial FCOPs and REDD+ initiatives.

3.6 References

Aggarwal, A., and Brockington, D. (2020). Reducing or creating poverty? Analyzing livelihood impacts of forest carbon projects with evidence from India. *Land Use Policy*, *95*. https://doi.org/10.1016/j.landusepol.2020.104608

Andersson, K. P., Smith, S. M., Alston, L. J., Duchelle, A. E., Mwangi, E., Larson, A. M., de Sassi, C., Sills, E. O., Sunderlin, W. D., and Wong, G. Y. (2018). Wealth and the distribution of benefits from tropical forests: Implications for REDD+. *Land Use Policy*, *72*, 510–522. https://doi.org/10.1016/j.landusepol.2018.01.012

Angelsen, A., Streck, C., Peskett, L., Brown, J., and Luttrell, C. (2008). *What is the right scale for REDD?: The implications of national, subnational and nested approaches*. Center for International Forestry Research (CIFOR). https://doi.org/10.17528/cifor/002595

Atela, J. O., Minang, P. A., Quinn, C. H., and Duguma, L. A. (2015). Implementing REDD+ at the local level: Assessing the key enablers for credible mitigation and sustainable livelihood outcomes. *Journal of Environmental Management*, *157*, 238–249. https://doi.org/10.1016/j.jenvman.2015.04.015

Aukland, L., Costa, P. M., and Brown, S. (2003). A conceptual framework and its application for addressing leakage: The case of avoided deforestation. *Climate Policy*, *3*, 123–136. https://doi.org/10.3763/cpol.2003.0316

Bayrak, M. M., and Marafa, L. M. (2016). Ten years of REDD+: A critical review of the impact of REDD+ on forest-dependent communities. *Sustainability*, *8*(7), Article 7. https://doi.org/10.3390/su8070620

Bayrak, M. M., Tu, T. N., and Marafa, L. M. (2014). Creating social safeguards for REDD+: Lessons learned from benefit sharing mechanisms in Vietnam. *Land*, *3*, Article 3. https://doi.org/10.3390/land3031037

Bhullar, L. (2013). REDD+ and the Clean Development Mechanism: A comparative perspective. *International Journal of Rural Law and Policy*. https://doi.org/10.5130/ijrlp.i1.2013.3229

Blundo-Canto, G., Bax, V., Quintero, M., Cruz-Garcia, G. S., Groeneveld, R. A., and Perez-Marulanda, L. (2018). The different dimensions of livelihood impacts of Payments for Environmental Services (PES) schemes: A systematic review. *Ecological Economics*, *149*, 160–183. https://doi.org/10.1016/j.ecolecon.2018.03.011

Boyd, E., Gutierrez, M., and Chang, M. (2007). Small-scale forest carbon projects: Adapting CDM to low-income communities. *Global Environmental Change*, *17*, 250–259. https://doi.org/10.1016/j.gloenvcha.2006.10.001

Caplow, S., Jagger, P., Lawlor, K., and Sills, E. (2011). Evaluating land use and livelihood impacts of early forest carbon projects: Lessons for learning about REDD+. *Environmental Science and Policy*, *14*(2), 152–167. https://doi.org/10.1016/j.envsci.2010.10.003

Chambers, R., and Conway, G. (1992). *Sustainable rural livelihoods: Practical concepts for the 21st century*. Institute of Development Studies (UK). https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/775

Coomes, O. T., Barham, B. L., and Takasaki, Y. (2004). Targeting conservation–development initiatives in tropical forests: Insights from analyses of rain forest use and economic reliance among Amazonian peasants. *Ecological Economics*, *51*(1), 47–64. https://doi.org/10.1016/j.ecolecon.2004.04.004

Corbera, E., and Schroeder, H. (2011). Governing and implementing REDD+. *Environmental Science and Policy*, *14*(2), 89–99. https://doi.org/10.1016/j.envsci.2010.11.002

Dalle, S., and Potvin, C. (2004). Conservation of useful plants: An evaluation of local priorities from two Indigenous communities in Eastern Panama. *Economic Botany*, *58*, 38–57. https://doi.org/10.1663/0013-0001(2004)058[0038:COUPAE]2.0.CO;2

Dang, D., Li, X., Li, S., Li, X., Lyu, X., Dou, H., Li, M., Liu, S., Xuan, X., and Wang, K. (2023). Changing rural livelihood activities may reduce the effectiveness of ecological restoration projects. *Land Degradation and Development*, *34*(2), 362–376. https://doi.org/10.1002/ldr.4465

Dawson, N. M., Mason, M., Mwayafu, D. M., Dhungana, H., Satyal, P., Fisher, J. A., Zeitoun, M., and Schroeder, H. (2018). Barriers to equity in REDD+: Deficiencies in national interpretation processes constrain adaptation to context. *Environmental Science and Policy*, *88*, 1–9. https://doi.org/10.1016/j.envsci.2018.06.009

Dube, L. C., and Chatterjee, S. (2022). Assessing livelihood impact of forest carbon projects using sustainable livelihood framework. *Mitigation and Adaptation Strategies for Global Change*, *27*(8), 49. https://doi.org/10.1007/s11027-022-10022-9

Ellis, F. (2000). *Rural livelihoods and diversity in developing countries*. Oxford University Press. http://catdir.loc.gov/catdir/enhancements/fy0610/00035692-t.html

Fa, J. E., Watson, J. E., Leiper, I., Potapov, P., Evans, T. D., Burgess, N. D., Molnár, Z., Fernández-Llamazares, Á., Duncan, T., Wang, S., Austin, B. J., Jonas, H., Robinson, C. J., Malmer, P., Zander, K. K., Jackson, M. V., Ellis, E., Brondizio, E. S., and Garnett, S. T. (2020). Importance of Indigenous Peoples' lands for the conservation of Intact forest landscapes. *Frontiers in Ecology and the Environment*, *18*(3), 135–140. https://doi.org/10.1002/fee.2148

Forgues, K., Carignan, M.-C., Marchena, B., Mancilla, Lady, Pacheco Ortega, E., Guaynora, A., Pacheco, C., and Potvin, C. (2024). Comparing the long-term carbon offsets and livelihood benefits of a reforestation project with agroforestry, enrichment planting in fallows, native timber mixtures and monocultures [Manuscript submitted for publication]. *Department of Biology, McGill University*.

Fujii, H., Webb, J., Mundree, S., Rowlings, D., Grace, P., Wilson, C., and Managi, S. (2024). Priority change and driving factors in the voluntary carbon offset market. *Cleaner Environmental Systems*, 100164. https://doi.org/10.1016/j.cesys.2024.100164

Garnett, S. T., Burgess, N. D., Fa, J. E., Fernández-Llamazares, Á., Molnár, Z., Robinson, C. J., Watson, J. E. M., Zander, K. K., Austin, B., Brondizio, E. S., Collier, N. F., Duncan, T., Ellis, E., Geyle, H., Jackson, M. V., Jonas, H., Malmer, P., McGowan, B., Sivongxay, A., and Leiper, I. (2018). A spatial overview of the global importance of Indigenous lands for conservation. *Nature Sustainability*, *1*(7), 369–374. https://doi.org/10.1038/s41893-018-0100-6

Geilfus, F. (2002). *80 Herramientas para el desarollo participativo: Diagnóstico, planificación monitoreo y evaluación*. Instituto Interamericano de Cooperación para la Agricultura. https://repositorio.iica.int/handle/11324/4129

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W. H., Shoch, D., Siikamäki, J. V., Smith, P., Woodbury, P., Zganjar, C., Blackman, A., Campari, J., Conant, R. T., Delgado, C., Elias, P., Gopalakrishna, T., Hamsik, M. R., … Fargione, J. (2017). Natural climate solutions. *Proceedings of the National Academy of Sciences*, *114*(44), 11645–11650. https://doi.org/10.1073/pnas.1710465114

Hajjar, R., Engbring, G., and Kornhauser, K. (2021). The impacts of REDD+ on the social-ecological resilience of community forests. *Environmental Research Letters*, *16*(2), 024001. https://doi.org/10.1088/1748-9326/abd7ac

Holmes, I., Kirby, K. R., and Potvin, C. (2017). Agroforestry within REDD+: Experiences of an indigenous Emberá community in Panama. *Agroforestry Systems*, *91*(6), 1181–1197. https://doi.org/10.1007/s10457-016-0003-3

Holmes, I., and Potvin, C. (2014). Avoiding re-inventing the wheel in a people-centered approach to REDD+. *Conservation Biology*, *28*(5), 1380–1393. https://doi.org/10.1111/cobi.12301

IPCC. (2023). *Climate change 2023: Synthesis report* (pp. 35–115). IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647

Jack, B. K., and Cardona Santos, E. (2017). The leakage and livelihood impacts of PES contracts: A targeting experiment in Malawi. *Land Use Policy*, *63*, 645–658. https://doi.org/10.1016/j.landusepol.2016.03.028

Jusys, T. (2018). Changing patterns in deforestation avoidance by different protection types in the Brazilian Amazon. *PLOS ONE*, *13*(4), e0195900. https://doi.org/10.1371/journal.pone.0195900

K C, B., Race, D., Fisher, R., and Jackson, W. (2021). Changing rural livelihoods and forest use transition in the Middle Hills of Nepal. *Small-Scale Forestry*, *20*(3), 479–501. https://doi.org/10.1007/s11842-021-09477-6

Larson, A. M., Solis, D., Duchelle, A. E., Atmadja, S., Resosudarmo, I. A. P., Dokken, T., and Komalasari, M. (2018). Gender lessons for climate initiatives: A comparative study of REDD+ impacts on subjective wellbeing. *World Development*, *108*, 86–102. https://doi.org/10.1016/j.worlddev.2018.02.027

Laudari, H. K., Sapkota, L. M., Maraseni, T., Subedi, P., Pariyar, S., Kaini, T. R., Lopchan, S. B., Weston, C., and Volkova, L. (2024). Community forestry in a changing context: A perspective from Nepal's mid-hill. *Land Use Policy*, *138*, 107018. https://doi.org/10.1016/j.landusepol.2023.107018

MiAMBIENTE. (2022). *Estrategia nacional para la Reducción de Emisiones por Deforestación y Degradación de los bosques (Estrategia nacional REDD+)* (p. 137). ENREDD+.

Nantongo, M., Vatn, A., and Soka, G. (2024). REDD+: The perfect marriage between conservation and development? A comparative study of the impacts of REDD+ on livelihoods and deforestation in Tanzania. *World Development*, *173*, 106432. https://doi.org/10.1016/j.worlddev.2023.106432

Nolte, C., Agrawal, A., Silvius, K. M., and Soares-Filho, B. S. (2013). Governance regime and location influence avoided deforestation success of protected areas in the Brazilian Amazon. *Proceedings of the National Academy of Sciences*, *110*(13), 4956–4961. https://doi.org/10.1073/pnas.1214786110

Nortcliff, S. (1998). Human activity and the tropical rainforest: Are the soils the forgotten component of the ecosystem? In *Human Activities and the Tropical Rainforest* (pp. 49–64). Kluwer Academic Publishers.

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science*, *325*(5939), 419–422. https://doi.org/10.1126/science.1172133

Pagiola, S., Ramírez, E., Gobbi, J., de Haan, C., Ibrahim, M., Murgueitio, E., and Ruíz, J. P. (2007). Paying for the environmental services of silvopastoral practices in Nicaragua. *Ecological Economics*, *64*(2), 374–385. https://doi.org/10.1016/j.ecolecon.2007.04.014

Pan, C., Shrestha, A., Innes, J. L., Zhou, G., Li, N., Li, J., He, Y., Sheng, C., Niles, J.-O., and Wang, G. (2022). Key challenges and approaches to addressing barriers in forest carbon offset projects. *Journal of Forestry Research*. https://doi.org/10.1007/s11676-022-01488-z

Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., Phillips, O. L., Shvidenko, A., Lewis, S. L., Canadell, J. G., Ciais, P., Jackson, R. B., Pacala, S. W., McGuire, A. D., Piao, S., Rautiainen, A., Sitch, S., and Hayes, D. (2011). A large and persistent carbon sink in the world's forests. *Science*, *333*(6045), 988–993. https://doi.org/10.1126/science.1201609

Paredes, M., and Kaulard, A. (2022). Forest as 'nature' or forest as territory? Knowledge, power, and climate change conservation in the Peruvian Amazon. *The Journal of Peasant Studies*, *0*(0), 1–22. https://doi.org/10.1080/03066150.2022.2134010

Peras, R. J., Pulhin, J., Inoue, M., Mohammed, A. J., Harada, K., and Sasaoka, M. (2016). The sustainable livelihood challenge of REDD+ implementation in the Philippines. *Environment and Natural Resources Research*, *6*(3), Article 3. https://doi.org/10.5539/enrr.v6n3p91

Philemon, T. (2021). The Uluguru Payment for Ecosystem Services (PES) Programme in Tanzania: Can Livelihoods Benefits between PES Participants and Non-participants Go Beyond Implementation? *Tanzania Journal of Development Studies*, *19*(1), Article 1.

Potvin, C., and Mateo-Vega, J. (2013). Curb indigenous fears of REDD+. *Nature*, *500*(7463), 400–400. https://doi.org/10.1038/500400e

Potvin, C., Tschakert, P., Lebel, F., Kirby, K., Barrios, H., Bocariza, J., Caisamo, J., Caisamo, L., Cansari, C., Casamá, J., Casamá, M., Chamorra, L., Dumasa, N., Goldenberg, S., Guainora, V., Hayes, P., Moore, T., and Ruíz, J. (2007). A participatory approach to the establishment of a baseline scenario for a reforestation Clean Development Mechanism project. *Mitigation and Adaptation Strategies for Global Change*, *12*(8), 1341–1362. https://doi.org/10.1007/s11027-006-9056-3

Rey Christen, D., García Espinosa, M., Reumann, A., and Puri, J. (2020). Results based payments for REDD+ under the Green Climate Fund: Lessons learned on social, environmental and governance safeguards. *Forests*, *11*(12), Article 12. https://doi.org/10.3390/f11121350

Reyes-García, V., García-del-Amo, D., Álvarez-Fernández, S., Benyei, P., Calvet-Mir, L., Junqueira, A. B., Labeyrie, V., Li, X., Miñarro, S., Porcher, V., Porcuna-Ferrer, A., Schlingmann, A., Schunko, C., Soleymani, R., Tofighi-Niaki, A., Abazeri, M., Attoh, E. M. N. A. N., Ayanlade, A., Ávila, J. V. D. C., … Zakari, I. S. (2024). Indigenous Peoples and local communities report ongoing and widespread climate change impacts on local social-ecological systems. *Communications Earth and Environment*, *5*(1), Article 1. https://doi.org/10.1038/s43247-023-01164-y

Rigg, J. (2007). Making a living in the Global South: Livelihood transitions. In *An Everyday Geography of the Global South*. Routledge.

Schultz, L., Folke, C., Österblom, H., and Olsson, P. (2015). Adaptive governance, ecosystem management, and natural capital. *Proceedings of the National Academy of Sciences*, *112*(24), 7369–7374. https://doi.org/10.1073/pnas.1406493112

Schweikart, M., Mertz, O., and Müller, D. (2022). Adaptive approaches to REDD+ are needed for countries with high forest cover and low deforestation rates. *Environmental Research Letters*, *17*(11), 114011. https://doi.org/10.1088/1748-9326/ac9827

Scoones, I. (1998). *Sustainable rural livelihoods: A framework for analysis* (IDS Working Paper 72). IDS. https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/3390

Scoones, I. (2015). *Sustainable livelihoods and rural development*. Fernwood Publishing.

Sharma, D., Holmes, I., Vergara-Asenjo, G., Miller, W. N., Cunampio, M., B. Cunampio, R., B. Cunampio, M., and Potvin, C. (2016). A comparison of influences on the landscape of two social-ecological systems. *Land Use Policy*, *57*, 499–513. https://doi.org/10.1016/j.landusepol.2016.06.018

Streck, C. (2021). REDD+ and leakage: Debunking myths and promoting integrated solutions. *Climate Policy*, *21*(6), 843–852. https://doi.org/10.1080/14693062.2021.1920363

Sunderlin, W. D., De Sassi, C., Ekaputri, A. D., Light, M., and Pratama, C. D. (2017). REDD+ Contribution to Well-Being and Income Is Marginal: The Perspective of Local Stakeholders. *Forests*, *8*(4), Article 4. https://doi.org/10.3390/f8040125

Sze, J. S., Carrasco, L. R., Childs, D., and Edwards, D. P. (2022). Reduced deforestation and degradation in Indigenous Lands pan-tropically. *Nature Sustainability*, *5*(2), Article 2. https://doi.org/10.1038/s41893-021-00815-2

Tacconi, L., Mahanty, S., and Suich, H. (2013). The livelihood impacts of Payments for Environmental Services and implications for REDD+. *Society and Natural Resources*, *26*(6), 733–744. https://doi.org/10.1080/08941920.2012.724151

Taylor, S. (2016). *Environmental conservation as an instrument of national political economy: Culture, livelihoods, and territorial rights of the Emberá of Panama* [Clark University]. https://commons.clarku.edu/idce_masters_papers/41

Tschakert, P., Coomes, O. T., and Potvin, C. (2007). Indigenous livelihoods, slash-and-burn agriculture, and carbon stocks in Eastern Panama. *Ecological Economics*, *60*(4), 807–820. https://doi.org/10.1016/j.ecolecon.2006.02.001

Turner, S. (2017). Livelihoods. In *International Encyclopedia of Geography* (pp. 1–9). John Wiley and Sons, Ltd. https://doi.org/10.1002/9781118786352.wbieg0838

UN-REDD. (2022). *2022 consolidated annual progress report of the UN-REDD Programme Fund* (Annual Report 14). https://www.un-redd.org/sites/default/files/2023-08/UNREDD_AnnualReport2022_10Aug_FINAL.pdf

Vergara-Asenjo, G., Mateo-Vega, J., Alvarado, A., and Potvin, C. (2017). A participatory approach to elucidate the consequences of land invasions on REDD+ initiatives: A case study with Indigenous communities in Panama. *PLOS ONE*, *12*(12), e0189463. https://doi.org/10.1371/journal.pone.0189463

Wali, Alaka. (1989). *Kilowatts and crisis: Hydroelectric power and social dislocation in eastern Panama*. Westview Press.

Williams, B. K. (2011). Adaptive management of natural resources—Framework and issues. *Journal of Environmental Management*, *92*(5), 1346–1353. https://doi.org/10.1016/j.jenvman.2010.10.041

Wunder, S., Duchelle, A. E., Sassi, C. de, Sills, E. O., Simonet, G., and Sunderlin, W. D. (2020). REDD+ in theory and practice: How lessons from local projects can inform jurisdictional approaches. *Frontiers in Forests and Global Change*, *3*. https://www.frontiersin.org/article/10.3389/ffgc.2020.00011

Zant, M., Schlingmann, A., Reyes-García, V., and García-del-Amo, D. (2024). Incremental and transformational adaptation to climate change among Indigenous Peoples and local communities: A global review. *Mitigation and Adaptation Strategies for Global Change*, *28*(8), 57. https://doi.org/10.1007/s11027-023-10095-0

Zhang, Q., Wang, Y., Tao, S., Bilsborrow, R. E., Qiu, T., Liu, C., Sannigrahi, S., Li, Q., and Song, C. (2020). Divergent socioeconomic-ecological outcomes of China's conversion of cropland to forest program in the subtropical mountainous area and the semi-arid Loess Plateau. *Ecosystem Services*, *45*, 101167. https://doi.org/10.1016/j.ecoser.2020.101167

BRIDGING STATEMENT: FROM LIVELIHOOD TRAJECTORIES TO SPILLOVER ANALYSIS

While the first chapter identified policy misfits that arose between STRI project and its livelihood context over time, the second chapter focuses on how these changes can lead to unintended consequences that impact the project's effectiveness, known as leakage, in carbon offset projects.

Examining the evolution of land-based livelihood strategies in Ipetí, and of the interactions between this dynamic context and the Ipetí-STRI project, began shedding light on the broader implications of such interventions, particularly regarding land-use spillovers. I demonstrated that the unanticipated mismatches that arose from the interactions between the changing context and the project's initial design have the potential to reduce the project's efficiency over time. This suggests that, despite the initial assessment made that carbon leakage from the project is unlikely to be significant due to its small size and its local land tenure and livelihood context (Coomes et al., 2008), a new evaluation may be useful to identify novel forms of spillovers that could have emerged as a result of the changing livelihood context's new fit with the project.

Building on the insights gained from the first chapter's analysis of livelihood strategy shifts and the local socio-ecological context, the second chapter utilizes a qualitative approach to describe these spillovers mechanisms. I do so by adapting the Sustainable Livelihoods framework (DFID, 1999), which provides the necessary building blocks to trace the causal connections between the STRI project's implementation and its cascading effects on livelihood strategies. This holistic approach not only provides a comprehensive understanding of the underlying drivers behind leakage, but also it facilitates the elaboration of context-specific solutions to enhance project design and to improve leakage management. It informs locally relevant leakage mitigation strategies by identifying leverage points along the causal chain leading to the displacement of carbon emissions outside the intervention's direct scope of action. Such an approach would not be possible without the in-depth understanding of the local livelihood context and its dynamism described in the previous chapter.

CHAPTER 4: ADAPTING THE SUSTAINABLE LIVELIHOODS FRAMEWORK TO DIAGNOSE AND MITIGATE LAND-USE SPILLOVERS IN FOREST CARBON PROJECTS

4.1 Introduction

Natural climate solutions, which aim to protect or enhance the carbon storage capacity of the Earth's ecosystems, are increasingly considered a critical component of the global climate change mitigation portfolio. Estimates suggest that nature-based solutions could contribute over 20% of the efforts required to curb global warming to below 2°C by 2050, of which two-thirds are made up by forest-based interventions such as reforestation, reducing deforestation and degradation (REDD) and improving forest management (Griscom et al., 2017).

Forest-based solutions have been occupying an increasingly large space in emissions abatement discussions. Following the inclusion of reforestation and afforestation mechanisms in the Kyoto Protocol's Clean Development Mechanism in 2006, the UNFCCC's REDD+ programme became in 2008 the main platform through which developed countries could offset their Kyoto targets through forest-based mechanisms, specifically by funding developing countries in their efforts to reduce deforestation and forest degradation, support conservation, sustainable management of forests, and the enhancement of their forest carbon stocks (Aukland et al., 2003; Streck, 2021). These two policy frameworks coincided with expansions of the voluntary carbon markets, leading to an explosion of voluntary Forest Carbon Offset Projects (FCOPs) (Fujii et al., 2024). These projects present quasi-infinite variations, ranging from extra-local private initiatives to national programs as part of corporate net-zero strategies or international offsetting agreements.

Despite their popularity, the efficiency of FCOPs has been under constant scrutiny by policymakers and the scientific community. One of the prime concerns they highlight is the induction of land-use spillovers, more precisely in the form of leakage (Brown et al., 1997; Engel et al., 2008; Pan et al., 2022). While spillovers describe any unintended effect triggered by an intervention occurring outside of its operational scope, carbon leakage refers specifically to spillovers that cause an increase in off-site emissions, resulting in less overall carbon sequestration than anticipated (Bastos Lima et al., 2019; Meyfroidt et al., 2018).

Land-use spillovers happen through several channels. For example, Lima et al. (2019) describe nine general spillover types that may arise in land-use systems (activity displacement, market-mediated effects, informational spillovers, motivational leakage, and institutional interplay and policy interactions), and Sonderegger et al. (2022) compiled a comprehensive list of 25 socio-economic and environmental spillover pathways of agricultural crop production. Despite the diversity of land-use spillovers described in other intervention contexts, FCOP implementers and the corresponding academic literature have so far maintained their focus on two categories (Atmadja and Verchot, 2012; Bastos Lima et al., 2019; Henders and Ostwald, 2012). The first one, known as market effects, occurs when large-scale FCOPs trigger significant changes in commodity supply and price in a way that may incentivize production elsewhere by third parties (Atmadja and Verchot, 2012). The second category is activity shifting, also known as displacement, which happens when the actors targeted by an FCOP, or baseline agents, merely move the carbon-emitting activities outside the intervention area, leading to a geographical shift of the emissions rather than a reduction (Aukland et al., 2003). All carbon credit certifiers require some form of risk assessment or mitigation measures for these mechanisms, although the importance varies (Henders and Ostwald, 2012; Pan et al., 2022).

While challenging to avoid, activity shifting has been characterized as a symptom of deficient policy design or a misfit with the intervention context, as it signals a failure of FCOPs to provide adequate livelihood alternatives to the baseline agents when access to productive land is restricted (e.g., through REDD) (Bastos Lima et al., 2019; Brown et al., 1997). It is likely to occur where livelihoods rely on subsistence agriculture and forest products, and multiple land uses compete under pressures such as population growth and land scarcity (De Jong et al., 2007). Activity displacement is often detected and quantified through spatial monitoring or follow-use surveys designed to identify land-use changes on the participants' non-treatment land during the implementation against controls or a baseline (Alix-Garcia et al., 2012; De Jong et al., 2007; Jack and Cardona Santos, 2017; Pagiola et al., 2007). However, these methods present important limitations in terms of attribution, that is, the establishment of causal mechanisms between the intervention and the induction of the land-use changes detected. For example, using nearby controls assumes the absence of social interaction spillovers to the control area, which have been shown to significantly influence land-use decisions in some FCOP contexts (Robalino and Pfaff, 2012; Wang et al., 2021).

Qualitative assessments evaluating the relative risk or magnitude of activity leakage can enable a more comprehensive understanding of how leakage may arise on the ground, especially in subsistence contexts where market leakage is unlikely (Atmadja and Verchot, 2012). Because primary leakage and spillovers arise from the combination and re-configuration of context-specific drivers, mediating processes, and individuals exercising their political agency over time and at multiple scales (Bastos Lima et al., 2019; Swingland et al., 2002), a better understanding of the local context can help unveil the unexpected pathways through which leakage may manifest, enable effective mitigation and, ultimately, inform the improvement of FCOPs (De Jong et al., 2007). However, despite multiple calls for in-depth qualitative, socially-focused evaluations of FCOP-induced leakage (Atmadja and Verchot, 2012; Aukland et al., 2003; Caplow et al., 2011; Corbera and Schroeder, 2011), studies adopting this approach are, to our knowledge, still largely absent from the literature.

In this paper, we suggest a way to fill this gap and implement such qualitative assessments of leakage in FCOPs through an approach centered on local livelihoods. We demonstrate this approach this by adapting the sustainable livelihoods framework (Scoones, 1998) to analyze FCOP spillovers and applying the framework to a 15-year community-based FCOP run by an Emberá community in Eastern Panama. We show that applying the tried-and-true sustainable livelihoods perspective to spillover analysis can facilitate the diagnosis of leakage pathways during FCOP planning and monitoring and support the development of targeted and effective mitigation strategies (De Jong et al., 2007; Swingland et al., 2002).

4.2 A Livelihoods Framework for Land-Use Spillovers

4.2.1 Sustainable livelihoods and forest carbon offset projects

Livelihoods comprise "the assets (natural, physical, human, financial and social capital), the activities, and the access to these (mediated by institutions and social relations) that together determine the living gained by the individual or household" (Ellis, 2000, p. 20). Livelihood studies emerged as a response to structural perspectives on development by proposing an "integrated, holistic, bottom-up perspective centered on the understanding of what people do to make a living in diverse social contexts and circumstances" (Scoones, 2015, p. 1). The most widely used theoretical tool for livelihood analysis is the Institute of Development Studies' sustainable livelihoods framework (Scoones, 1998), from which multiple popular variations have emerged since (i.e., Bebbington, 1999; DFID, 1999; Ellis, 2000).

Many studies have employed a general livelihoods lens to evaluate the outcomes of payment-for-ecosystem-services schemes (see (Blundo-Canto et al., 2018) for a systematic review). However, when isolating FCOPs, we find that fewer apply the sustainable livelihoods framework for that purpose (i.e., Atela et al., 2015; Bayrak and Marafa, 2016; Peras et al., 2016; Philemon, 2021). Those doing so focus on the intervention's socio-economic outcomes by quantifying changes in the participants' asset endowments and using qualitative data to explain the observed trends based on the framework. While not explicitly addressing them as such, applying the livelihoods approach to FCOP evaluation has yielded the detection of socio-economic spillovers in some studies. For example, Peras *et al.* (2016) describe improvements in infrastructure and service delivery as an indirect consequence of increased visits of external project stakeholders, which Sonderegger et al. (2022)'s spillover typology would categorize as 'service and infrastructural access spillovers' and 'stakeholder interactions'. Again using Sonderegger's typology, Philemon (2021) details 'disposable income spillovers' on housing conditions as participants reinvested their savings from a sustainable land management project into housing improvements. This shows the potential of a livelihoods approach to track the mechanisms through which land-use spillovers and leakage occur. However, it has yet to be used to explore them explicitly, especially not regarding land-use pathways, which translate into carbon leakage.

4.2.2 Conceptual framework

Our livelihoods and land-use spillover framework (**Error! Reference source not found.**) combines Frank Ellis' and the DFID's iterations of the sustainable livelihoods framework (DFID, 1999; Ellis, 2000, p. 30). It displays how, within and given a certain social, economic, political, and environmental *context*, and households make use of the *assets* (human, natural, financial, physical, and social) at their disposal to adopt a set of *livelihood strategies*, which range land-based and non-land-based activities. *Local institutions, social relations and norms, and organizations*, are among the myriad factors that may influence a household's ability to access and utilize capital and, consequently, to adopt certain activities. The adoption of a given livelihood portfolio results in *outcomes* (e.g., income, changes in well-being, food security) which further inform the household's ability to adopt new strategies in the future by building up their assets. The added *land use sub-dimension* (see shaded boxes) brings to light the otherwise implicit relationship between livelihood strategies and land use decisions prevalent in rural resource-dependent contexts.

Our framework's focus on household-level livelihoods strategies and agency facilitates the identification of the drivers motivating the baseline agents' land-use decisions and the degree to which these decisions are linked with the implementation of an FCOP. It supports the description of land-use spillover pathways by providing a structure supporting the establishment of causal chains between an FCOP its indirect impacts on livelihoods and land use. Due to the focus on household-level decision-making, the framework focuses on the identification of primary leakage pathways, namely mechanisms where "interventions cause people/entities responsible for [deforestation and degradation] and other activities that generate emissions prior to the intervention (i.e., baseline agents of [deforestation and degradation]) to move their activities outside the intervention boundary and continue to cause emissions or cause new emissions there" (Atmadja and Verchot, 2012, p. 314).

FCOPs present themselves in our framework most importantly as a transforming process modifying access and use of forests and land resources (see green text and arrows in **Error! Reference source not found.**) (Bayrak et al., 2014). The precise way they do so is specific to each intervention. For example, **Error! Reference source not found.** shows an afforestation and reforestation project scenario where participants engage in

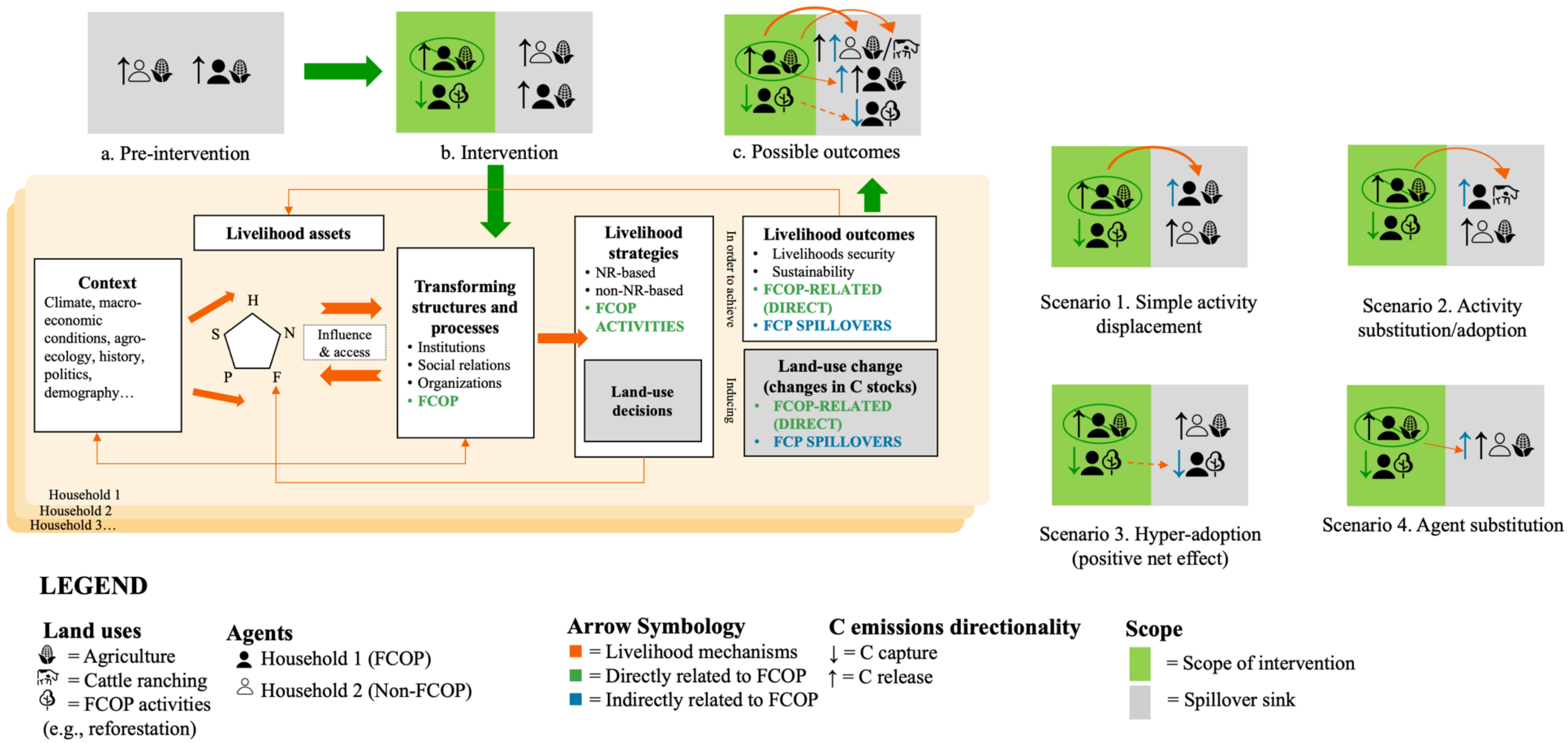

Figure 3. **Adapted sustainable livelihoods framework for spillover analysis**.

reforestation as a new livelihood activity, likely in exchange of an incentive (see b. intervention). Upon the FCOP's implementation, households negotiate and rework their livelihood strategies in response to the novel opportunities and trade-offs created by the project. This reshuffling of activity portfolios and the trickle-down effects it induces is the stage at which land-use spillovers arise (Dyer and Nijnik, 2014).

To be considered a spillover, a land-use change must 1) be caused by the implementation of the FCOP (attribution), and 2) fall outside the intervention's scope for at least one of these parameters. Land-use leakage specifically refers to spillovers that have a negative impact on an intervention's original aim, namely carbon stocks in FCOPs (Meyfroidt et al., 2018), but positive spillovers can also occur if secondary effect lead to higher-than-anticipated carbon sequestration. Since spillovers can "take place across ('over') established governance boundaries, be they geographical, temporal, jurisdictional, sectoral, or political" (Lima et al., 2019, p. 3), their analysis requires delimiting the FCOP's scope (spillover source) and of the scope over which its indirect influence is most likely to manifest, that is, the spillover sink (Atmadja and Verchot, 2012). Our framework therefore demands the explicit and case-specific definition of the spillover source and sink. In this case study, we do so along their respective spatial and temporal scales, as well as by the agents and activities involved. Well-defined scope boundaries also respond to baseline shifts (changes in deforestation and degradation drivers, or baseline agent behavior) to avoid the emergence of policy misfits over time between the scopes and the local context they represent.

Once a land-use change is deemed a spillover, they can then be characterized more precisely by their distinctive characteristics and causal mechanism. Our framework lists a few spillover pathways as examples. Scenario 1 displays the most conventional form of leakage, activity shifting, which occurs when a project participant displaces a high-emission activity restricted by the FCOP to a region external to the intervention's direct scope of operation. Scenario 2 shows an alternative form activity shifting, where a participant substitutes a restricted high-emission activity by adopting another one. This pathway would be treated as a leakage if the new activity if the causal relationship is established. Primary leakage also can be caused by include non-intervention baseline agents (non-participants) if their livelihood decisions are linked to the FCOP. For example, this could occur cause positive effects if technologies and practices introduced by an FCOP are adopted by non-participants, also known as hyper-adoption (Scenario 3).

Adversely, akin to small-scale market effects, non-participants may expand their involvement in barred activities to provide for their participating peers' foregone livelihood opportunities (Scenario 4).

4.3 Methods

4.3.1 Study site

This study focuses on the community of Ipetí-Emberá (hereafter Ipetí), situated on a collectively owned Indigenous Emberá territory located 150 kilometers east of Panama City on the Pan-American Highway (Figure 2). The area has a tropical monsoon and trade-wind littoral climate (Köppen classification Am) and its original vegetation cover is a tropical moist forest (Kirby and Potvin, 2007). Upon the community's establishment in 1975, Ipetí's traditional authorities divided the *Tierra Colectiva*'s 3,191 hectares into *parcelas*[7] (land parcels) and allocated them based on household size. Current land holdings vary between 1 and 100 ha and are managed by individual

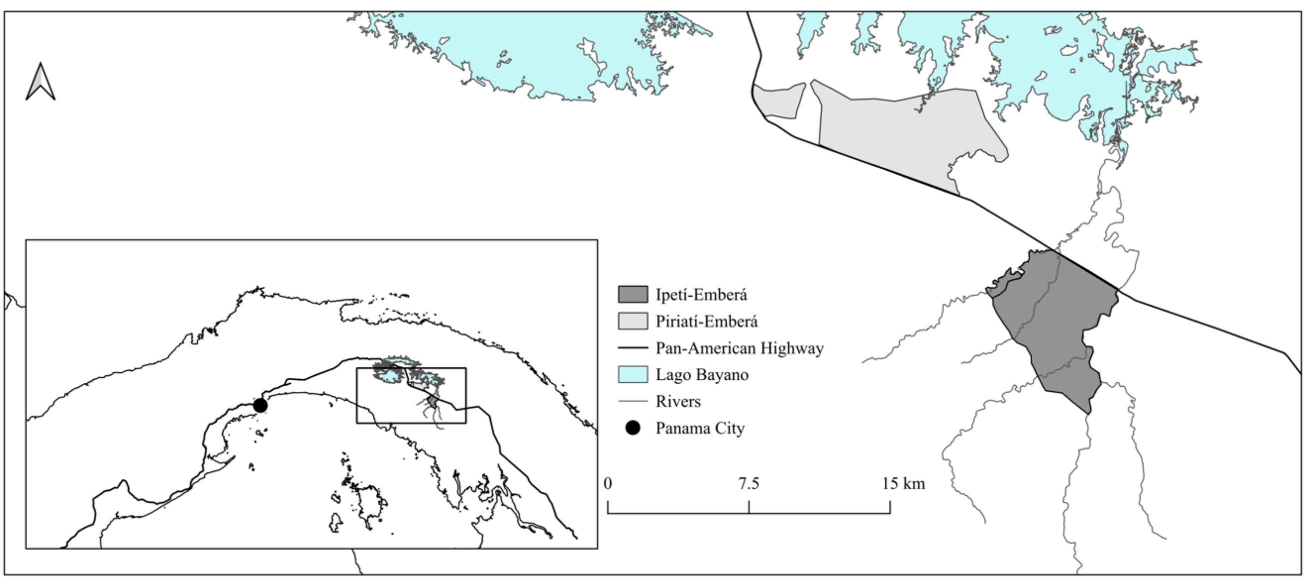

Figure 4. **Map of Ipetí-Emberá in Panama's Alto Bayano watershed**.

---

[7] We use '*parcelas'* to refer to a household's total land holdings and 'plot' when speaking of a portion of the *parcela* dedicated to a specific land use.

households or close kin groups. Land acquisition now only occurs through inheritance, gifting, or sale between Emberá. By 2004, half the *Tierra Colectiva's* original forest had been converted to a mosaic of croplands, pasture, and fallows at various stages (Potvin et al., 2007). Ipetí's local authorities currently estimate the population at 800 individuals, an increase of around 250 since 2004 (Tschakert et al., 2007, p. 808).

All Ipetí's households' livelihood portfolio comprise a combination of various on-farm and non-farm strategies. Common activities include agricultural production for household consumption and sale of surpluses, unskilled farm labor, small livestock rearing, cattle ranching, service provision, and tourism-related activities such as handicraft sale. Since the early 2000s, following decreasing crop yields due to climate and environmental changes such as an increased prevalence of pests and invasive plants, and following marked increases in the relative cost of living, Ipetí's livelihood profile has progressively shifted away from a heavily subsistence-based economy (Tschakert et al., 2007) to one prioritizing more guaranteed sources of cash income. For example, there has been a significant increase in the leasing out of land to non-Emberá cattle ranchers and to companies who use the rented plots for mechanized rice production. This has also coincided with the gradual abandonment, either partial or full depending on the household, of subsistence staples (e.g., rice, corn, yam, etc.) in favor of market crops, such as coffee and ginger. Following the COVID-19 pandemic, many community members have been increasingly re-adopting their nature-based livelihoods (subsistence agriculture and fishing), namely in response to a significant reduction in tourism-related income, the unreliable sale of some cash crops due to volatile prices and difficulties in market access, and scarce day labor opportunities.

In 2008, the community, through its community-run NGO, signed its first carbon offset contract with the Smithsonian Tropical Research Institute (STRI) following five years of collaborative project planning and research with a tropical ecology research group based at Canada's McGill University, including a participatory land-use/land-cover baseline produced in 2004 (Potvin et al., 2007). As part of this intervention (hereafter called the STRI project), 19 households reforested small sections of their *parcela* (0.25 and 1-ha plots), either with native timber species or following an agroforestry design (timber plots, fruit trees and shrubs, and crops).

Participants received the carbon payments over the contract's first eight years to mitigate the high labor demand for maintenance. Each household's payments were valued using 25-year carbon sequestration projections for each design (timber and agroforestry), with carbon priced at \$10.22 USD/tCO2e. The payments and benefit-sharing mechanisms were elected during the community planning phase. A portion of the project funds had also initially been dedicated to a pilot REDD+ project on some areas of the *Tierra Colectiva*, with payments to be given to the households managing these lands. However, this option was quickly abandoned after the forest was cleared by colonists invading the territory at the borders (Holmes, Kirby, et al., 2017).

To safeguard the participants' rights on their land and their autonomy, the contract only bound the participants to maintain their plots for 25 years and they could leave the project at any point. Since the project's onset, two participants have abandoned the project after their plot had been completely devastated by fires that has spread from neighboring plots being burned for cultivation. Many of the remaining plots have been partially damaged by fires. Finally, one other participant left the project and felled the trees they had planted.

In 2020, a second local NGO signed a new FCOP with McGill University. This new project involves 44 households spread between three communities, including 20 from Ipetí. 44 hectares of native timber reforestation were planted between 2020 and 2022, and the compensations increased to represent the current cost of labor.

4.3.2 Data collection and analysis

Data collection took place during five months of intermittent fieldwork from April to September of 2022 followed by preliminary result dissemination, member-checking, and follow-up interviews in June and July of 2023. With the help of local field assistants, we conducted exploratory focus groups, in-depth interviews focusing on household and community livelihood trajectories, participatory mapping workshops, and semi-structured interviews with key project stakeholders. More information on the context and content of each method can be found in Chapter 1. This research was approved by McGill University's Research Ethics Board I (REB file #22-03-112).

All focus groups, interviews, and workshops recordings, as well as my field notes, were transcribed and coded using MaxQDA2022. The coding process rested on two sets of pre-established codes: the first one, relying on concepts from the Sustainable Livelihood Framework (Ellis, 2000, p. 30), served to identify any livelihood change and its related 'context', 'capitals', 'mediating processes', 'activities' and 'land use decisions', and 'outcomes'. The second code set covered aspects of FCOPs such as 'motivation and incentives', 'implementation', 'direct outcomes', 'future plans', 'governance and management', and 'problems and solutions.' We identified spillovers by searching for overlaps between FCOP-related codes and those associated livelihood and land-use changes not directly related to the household's participation in the FCOP (i.e., STRI timber reforestation or STRI agroforestry). Other cooccurring codes in these segments were used to establish the causal chains between the FCOP implementation and the indirect outcome described.

While we do not quantify the magnitude of the leakage, we rely on above-ground carbon stock measurements of each of Ipetí's land uses (Potvin et al., 2007) to determine whether land use transitions are associated with a positive or negative gain in carbon stocks and the relative magnitude of that change (see Table 1. Relative magnitude of carbon fluxes resulting from land-use changes in Ipetí.

	NEW LAND USE									
FORMER LAND USE	**Forest**	**Refor.**	**Agrofor.**	**T. fallow**	**Cropl.**	**Sh. fallow**	**Plant.**	**Coffee**	**Pasture**	**Mech. rice**
Forest	NA	NA	NA	NA	- -	NA	- -	- -	- -	- -
Reforestation	NA	NA	- -	NA	- -	- -	- -	- -	- -	- -
Agroforest	NA	+ +	NA	NA	-	-	-	-	-	-
Tall fallow	NA	+ +	+	NA	-	NA	-	-	-	-
Cropland	NA	+ +	+	NA	NA	-	-	-	-	-
Short fallow	NA	+ +	+	+	+	NA	-	-	-	-
Plantain	NA	+ +	+	NA	+	+	NA	-	-	-
Coffee	NA	+ +	+	NA	+	+	+	NA	=	=
Pasture	NA	+ +	+	NA	+	+	+	=	NA	=
Mechanized rice	NA	+ +	+	NA	+	+	+	=	=	NA

Table 1. Relative magnitude of carbon fluxes resulting from land-use changes in Ipetí

4.4 Results

Applying the adapted sustainable livelihoods framework to the livelihood trajectories of Ipetí-Emberá's households enhances our understanding of the project's collateral effects on land use and allows the diagnosis of distinct spillover pathways. More specifically, the participants' livelihood strategies following the adoption of the project have triggered trickle-down effects on their livelihood outcomes and capital endowment, which in turn influence their other land-use decisions. Our framework provides the structure necessary to establish a causal chain of events leading from implementation to specific leakage pathways or boosting effects. Additionally, centering the participants' agency and motivations in the leakage evaluation reveals the nature of the misfits between the project's design and the local livelihood landscape that give rise to leakage. This level of understanding of how and why different spillovers arise points us potential courses of action to mitigate these unanticipated losses in the STRI project's net performance.

In the following section, we begin by defining and discussing the intervention's jurisdiction and the leakage sink, that is, the scale over which relevant spillovers should manifest. Then, we describe four leakage pathways and boosting effects revealed by the in-depth interviews we conducted with 21 households, including 13 STRI project participants, four McGill project participants (with one involved in both), three involved in project management, and two non-involved households.

4.4.1 Defining the scope

In order to isolate the interventions' direct outcomes from any collateral impacts it may induce, we need to define the project's operational jurisdiction in space, time, and in terms of activities and agents. We rely on the information on the STRI project contract provided by its participants and the stakeholders involved in its planning and implementation to delineate the intervention's jurisdictional scope. When left unclear, we use the carbon offset payment's coverage of each factor to better detail its direct jurisdiction. The spillover sink is delimited based on the livelihood context.

We define the intervention's *spatial* scope as the reforestation plots, to isolate the direct effect of the project's payments, which were meant to cover the labor required for these plots' maintenance. Given the tight relationship the baseline agents have with their territory and the resulting low mobility for land-based livelihoods, we can safely limit the geographical spillover sink to the *Tierra Colectiva,* as has been confirmed by past research in the community (Coomes et al., 2008) and confirmed by our own fieldwork. While some spillovers materializing outside the community may fall outside of the spatial monitored scope, they are likely to be anecdotal and negligible. Per our framework, any significant pathway would still and likely be identifiable from its source, for example, if a participant significantly altered their land use or access outside the *Tierra Colectiva* following project adoption.

The project's *temporal* scope can be framed in two different ways. Per the contract, it officially corresponds to the 25 years during which the participants are contractually required to keep their plot. Following this logic, any land-use change attributed to the intervention occurring after 25 years within the *Tierra Colectiva,* including the STRI plots, is considered a temporal land-use spillover. However, our interviews revealed widespread confusion among the participants regarding the obligation period, namely that many thought the project had ended at the same time as the payments. The lower frequency of project-related follow-ups made detecting and clarifying the issue even more difficult on the external stakeholders' part. Building on this ambiguity, while the contract dictates that any felling taking place within active reforestation plots between the end of payments and the 25-year mark corresponds to a contract breach (i.e., direct project failure/non-additionality), it could be deemed 'lawful' temporal leakage according to the participants' perceptions of the projects' temporal boundaries.

In-intervention *agents* include project participants, while potential spillover agents extend to the rest of the population. The nature of the community's collective and collaborative land tenure system suggests that spillovers can spread through social relations via kin or kindred interactions and land use arrangements. Following the same logic, *activities* are in-project if they are directly targeted by the payments or the baseline drivers they directly sought to prevent. Therefore, this corresponds to reforestation, agroforestry, and crop cultivation, the latter being the only land use for which forest is cleared (cropland is then either left in fallow or converted to other uses). We consider any other livelihood strategy associated with a change in land use as potential spillovers provided the establishment of a causal chain.

4.4.2 Examining spillover pathways

4.4.2.1 Simple activity shifting

The simplest leakage mechanisms to possibly occur are the direct displacement of activities or the reinvestment of carbon offset payments into carbon-emitting activities (Scenario 1 in Figure 3). We found little to no evidence for either of them. Very little displacement of activities from one place to another following the project's implementation shifting occurred at the project's immediate onset because most participants decided to reforest on plots they did not use at the moment (short fallow). Only two participants mentioned having planted on land that was in use prior to planting, and one of them told us that he moved his production to another plot on his land:

> MCC: What was on your plot before the project?
>
> Carlos (M40s): Well, before it was just plantains, right? [wife nods] Plantains, yuca, and such. For our own consumption and for sale. But no, we had never thought of having a farm before. I was very happy after I saw my large farm…mangoes, everything!
>
> MCC: (…) After you planted the trees, did start planting the yuca and plantains in another place?
>
> Susana (F40): Yes, exactly. We always had to do that because we had children in school, and we planted every year to sell, to have it, to help the kids in school. (10/09/2024)

As for reinvesting the payments, the participants described them as too low to be reinvested in other activities; households mostly used them to pay for their children's education or to cover basic expenses:

> "When they paid us, we didn't look for workers; we kept the money ourselves to buy food. (…) It wasn't much, it was just a little, and what was left was for us, so we made the effort ourselves to maintain the plot." (Marco, 40s, 28/08/2022)

> "Well, it was very important because all my children were in school, I had to pay for school, snacks, clothes, and transportation. So, it was very important. (…) It was all used up." (Flor, 50s, 30/08/2022)

Beyond exploring these more straight-forward leakage pathways, our framework has allowed us to detect four other, better concealed forms of spillover. Two of these pathways are causing leakage and the remaining two are boosting effects. The first leakage mechanism, specific to agroforestry participants, occurs through reinvestment the income generated from the agroforestry harvests. The second one arises from institutional interactions with Panama's forest protection laws. The two boosting effects occur through motivational and informational spillovers, respectively, following knowledge diffusion in the community.

4.4.2.2 Activity adoption through generated income effects

The first spillover pathway we uncovered using the sustainable livelihoods framework is triggered by the production and sale of coffee from the STRI project's agroforestry plots (see **Error! Reference source not found.**). This new access to natural and financial capital resulting from adoption STRI agroforestry has prompted the participants to adapt their livelihood strategies to maximize the potential earnings from coffee production, sparking interest in cattle ranching.

One of the primary motivations for engaging in any livelihood activity, including the STRI project, is the generation of cash income: eight of the ten agroforestry participants we interviewed mentioned selling coffee as the main livelihood outcome they had achieved thus far from the STRI project (#3 and #4 in **Error! Reference source not found.**) – much higher than the carbon payments themselves, and half told us that the opportunity to grow and sell coffee as the primary motivation behind their engagement in the FCOP. Many were first able to adopt this crop thanks to the STRI project's easing of the capital entry barriers, namely by providing the seedlings and by compensating the costs of early plot maintenance before the shrubs start producing fruit, leaving participants needing to provide the land and any additional labor required outside the FCOP payments' coverage (#2 in **Error! Reference source not found.**).

Coffee is one of few highly profitable market crops with reliable yields currently under cultivation in Ipetí. Following the yield failures and market instability of other, previously reliable staples, many participants have been responding to these market and agrological context cues and started seeking ways to increase their coffee production since the project's onset. One produced his own seedlings from the seeds he obtained from his STRI plot, and another replaced with coffee the planted trees that had not survived within his plot, regardless of the original species or seedling category (timber, fruit tree, shrub). However, others are still limited by the high costs required for expansion, namely the seedling production, pest, weed, and disease control and, most importantly, the high labor requirements for maintenance and harvest. However, the agroforestry plots were not designed with coffee production maximization in mind. The excess shade provided by the carbon-storing timber trees limits the participants' ability to expand relying uniquely on current STRI coffee earnings.

In search for alternatives, some have been considering seeking financing through loans provided by Panama's *Banco de Desarrollo Agropecuario*[8]. Without private land holdings to use as guarantee, however, Emberá living in collective lands are left with very few options for securing financial services such as loans. Of the capitals accepted as collateral, those available in Ipetí are limited to livestock or large, ready-to-pick harvests of market crop (#5 in **Error! Reference source not found.**). The harvest size required being one that no coffee producers in Ipetí have yet attained, purchasing and rearing cattle is one of the few options for Ipetí's landowners to access bank loans, making cattle ranching an important complementary activity to coffee production (#6 and #7 in **Error! Reference source not found.**). Stating this precise motivation, one participant we interview had already purchased their first cow with the income earned from coffee. They planned to subsequently grow their herd enough to qualify as a bank collateral so they can further invest in

[8] Agricultural Development Bank

coffee production. At least one other participant signaled planning to do the same in the coming years.

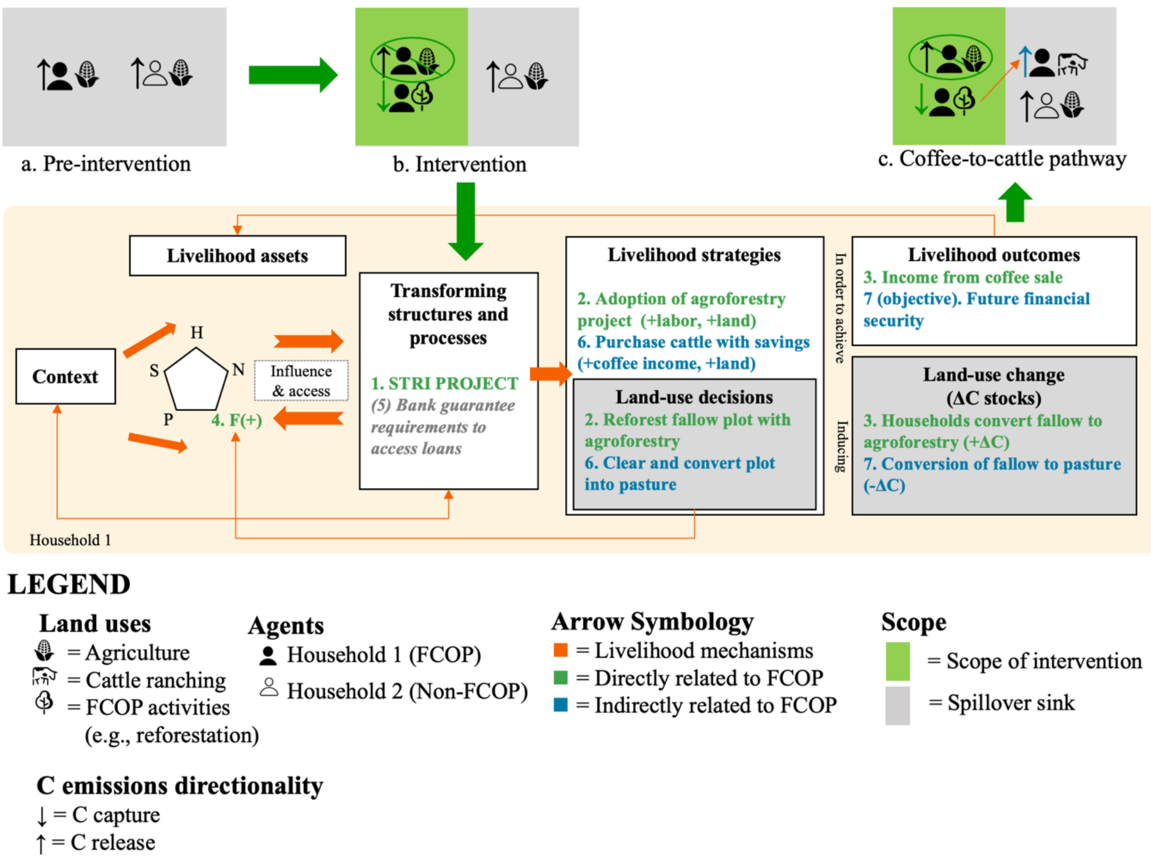

Figure 5. **Coffee-to-carbon leakage pathway**.
The adoption of agroforestry as part of the STRI project creates incentives for the expansion of coffee production. To support that expansion, some people invest their coffee income in cattle, which they can use as collateral to obtain larger bank loans.

This situation therefore leads to leakage in two different ways. First, the conversion of land left in fallow to pasture also triggers positive emissions as participants open up new pastures to accommodate for their new and growing cattle herds (#7 in **Error! Reference source not found.**) (Table 1). Further, as coffee plantations store very little carbon (anywhere between 10 and 50 tCO2/ha depending on plot configuration (Polzot, 2004)[9]), converting tall fallow to coffee

[9] We estimate that the plantation design suggested by FAO coffee production workshop facilitator would store approximately 10 tCO_2/ha (1625 coffee shrubs per hectare at 2.8 $kgCO_2$ each (Segura et al., 2006) and shade timber tree of planted every 25m with average CO_2 content of 342 $kgCO_2$ at 25 years (Holmes, Kirby, et al., 2017)).

plantations is likely to cause a net release of atmospheric carbon over time and, to a smaller extent, when converting young fallow plots and pastureland to coffee.

4.4.2.3 Temporal leakage via institutional interactions

Institutions play an important role in the mediation of livelihoods. They dictate the rules which influence the access and use of certain households to livelihood capitals, directly impacting the strategies available for adoption. FCOPs are themselves such an institution, but their interactions with other similar structures and processes in the policy space, and the way households then exploit or suffer from these interactions, may generate unanticipated effects on the way the original rules imposed by an intervention play out on the ground. Our interviews revealed such an effect, a high-risk future leakage mechanism enabled by institutional interactions (**Error! Reference source not found.**). To our knowledge, it is yet to materialize, but we estimate it likely that it does so especially from 2033 onwards, which marks the end of the 25-year contracts signed in 2008.

Nearly all the participants we spoke with signaled us their interest in obtaining an official reforestation certificate. Having a formal reforestation proof is not only a way to prove ownership and rights over the trees planted, but it would also allow participants to circumvent national legislations aimed at restricting forest loss and secure government incentives associated with reforestation (#5 in **Error! Reference source not found.**). This would enable participants to access additional income, both from timber sale and from these additional incentives (#7 in **Error! Reference source not found.**). For example, one participant who formerly worked in the processing and resale of timber products (M40s) told us that felling permits for non-planted trees had increased by approximately ten-fold in price following a near-complete moratorium on tree-felling permits, effectively kicking him and most small-scale producers out of the market. However, should the financial need eventually arise, owning a reforestation certificate would allow him to log and sell the trees planted by his family as part of the STRI project, which is not possible under this moratorium. This incentive was similarly expressed by two other, order participants:

> “That's not for me, it's for the day when I die, so my daughter can claim it. She will be able to say, ‘We are going to sell that wood, here is the certificate, my dad left it to us as an inheritance’. (…) And she's not going to pay much, only about

$15. Now, to get those permits, it gets up to $3,000, but if you don't have the money for it…" (Michel, 60s, 12/08/2022)

"If there is still forest in my parcela where there are some trees that are already old and I want to take advantage of them, I need to request a permit to log this timber (…) Here in Panama, if you cut down a tree, you have to plant ten trees to replace it, but if you were in a project (…) and you have a certificate of that reforestation, you can say "Look, I have reforestation." So, they will not demand that I plant here, nor will they be able to deny me the permit saying that I do not reforest." (Rafael, 70s, 26/08/2022)

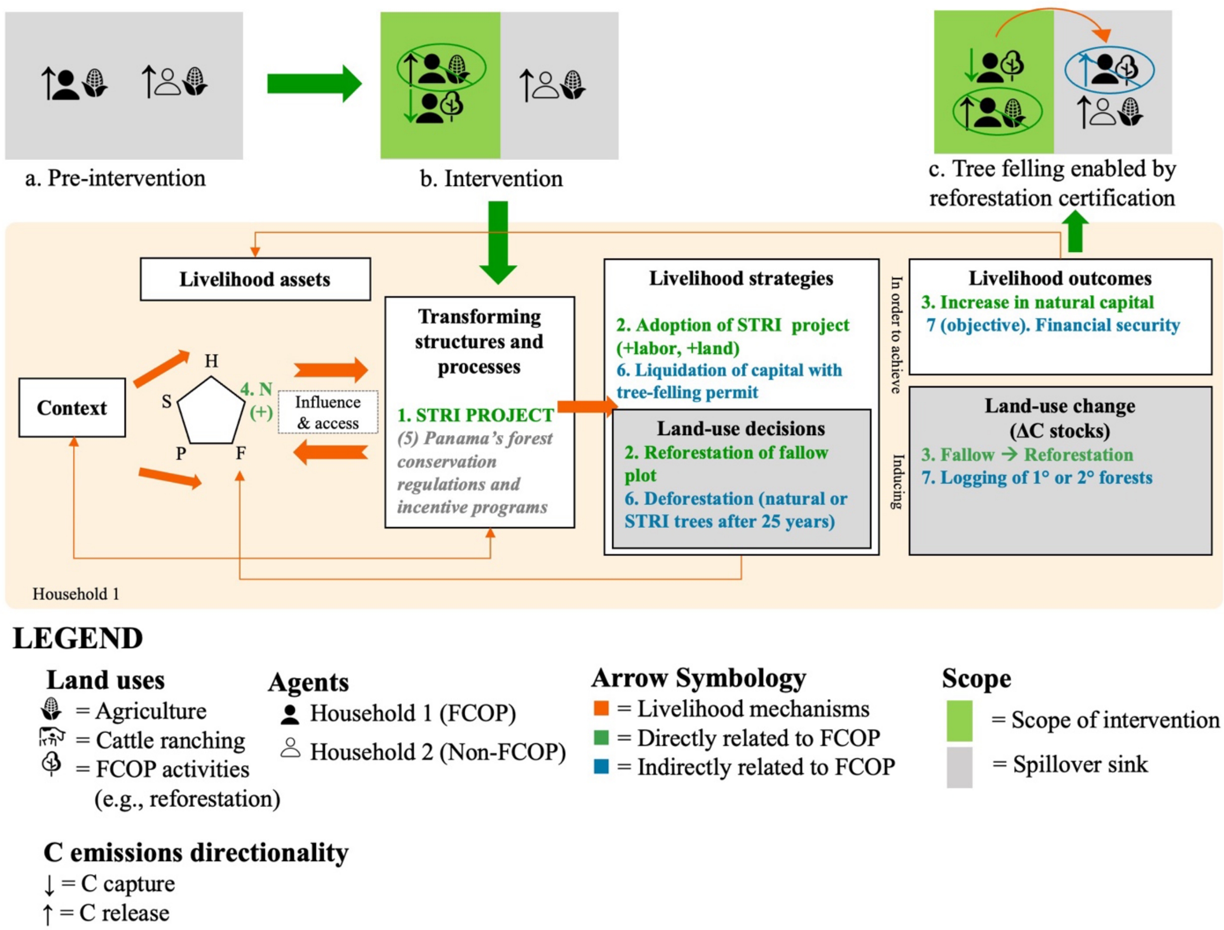

Figure 6. **Institutional leakage**.
Depending on the future regulations in place, official reforestation certificates may allow STRI participants to work around other pro-carbon government policies by enabling them to engage some level of timber logging.

While participants had not yet received certificates at the time of the interviews, the way they may be utilized within national regulatory frameworks sheds light on the role of institutional interactions in the mediation of land-use spillovers. Based on these two quotes outlined above, leakage may occur as the act of reforestation facilitates logging beyond the FCOP's temporal scope through legal mechanisms, or in space by effectively permitting participants to log elsewhere during the project's duration.

4.4.2.4 Baseline agent behaviour change through community-wide participatory planning

We detected signals of positive land-use spillovers also tied to transforming structures and processes, this time tied with the STRI project's interactions with the local community members, participant or not, and their influence on their land uses practices outside the project (**Error! Reference source not found.**). Our results revealed that the FCOP had impacts on local swidden-fallow practices extending to non-participants by influencing intrinsic attitudes towards forest and associated cultural conservation. Specifically, many interviewees recalled the discussions and the awareness land- motivating them to prioritize clearing fallow instead of primary forest when freeing land for crop cultivation (#1 and #2 in **Error! Reference source not found.**). This means that the STRI project indirectly avoided deforestation outside its spatial operational scope (#3 in **Error! Reference source not found.**). Importantly, the collaborative planning process spread awareness and better land management practices beyond its participant pool and facilitated the knowledge spillover over agent boundaries. The workshops' effect was well described by a couple during their household interview, both of whom are now involved in the McGill project, one as a participant and the other as a field coordinator, after having involved in developing the STRI project:

> Arturo (M50s): Almost the majority here, since the community started the reforestation projects in 2008, what we do is clear the fallows. Tall fallow, short fallow... (...) Now, very few [cut down primary forest]. Some do but very little… like I said, half a hectare, a quarter of a hectare.
>
> MCC: Because there's no space left?

> Arturo: No, it's not that, but (because of) the trainings on the role of trees in our region given when we started with the project. If we hadn't started like this, I tell you, this wouldn't be here...
>
> Maya (F50s): There wouldn't even be forests left around here, I believe. (08/07/2022)

However, several interviewees have signalled to us that these avoided deforestation gains described above are now being compromised. In a context of population growth where land is becoming scarcer, the combination of climate change and pest-induced crop insecurity, and the degradation of fallows, pushes households towards opening croplands by once again felling forests to ensure better harvests. Additionally, the community has witnessed the emergence of new land-based passive revenue streams, specifically the renting of pastures and rice paddies to non-Emberá. By setting a concrete opportunity cost on any land deemed unproductive, this has created an incentive to convert unused plots to these land uses for rent, including forests. As expressed by a member of the Neotropical Ecology Laboratory when reflecting on early leakage management:

> "We thought, and I believe we were right, that the participants themselves were not going to start opening other fields, that they themselves were not going to start cutting down more forests. But we had not considered the fact that perhaps they could rent the land to other people who would be interested in cutting down the forest." (External project stakeholder, 20/06/2022)

The matter of rising incentives and perceived opportunity cost becomes salient when considering the STRI project's payments disbursement mechanism. The completion of financial compensations by the eighth year has left the participants struggling to find benefits until the moment they are freed from their contractual obligations. The majority have expressed that the project is not financially benefitting them anymore, and that they should be compensated for their reforestation plot's foregone potential revenues if used for other purposes. Consequently, while attribution may be ambiguous, any conversion of unproductive land to a more lucrative use by a participant past the eighth-year mark could be considered leakage, as they could be doing so to offset the above-mentioned foregone revenues.

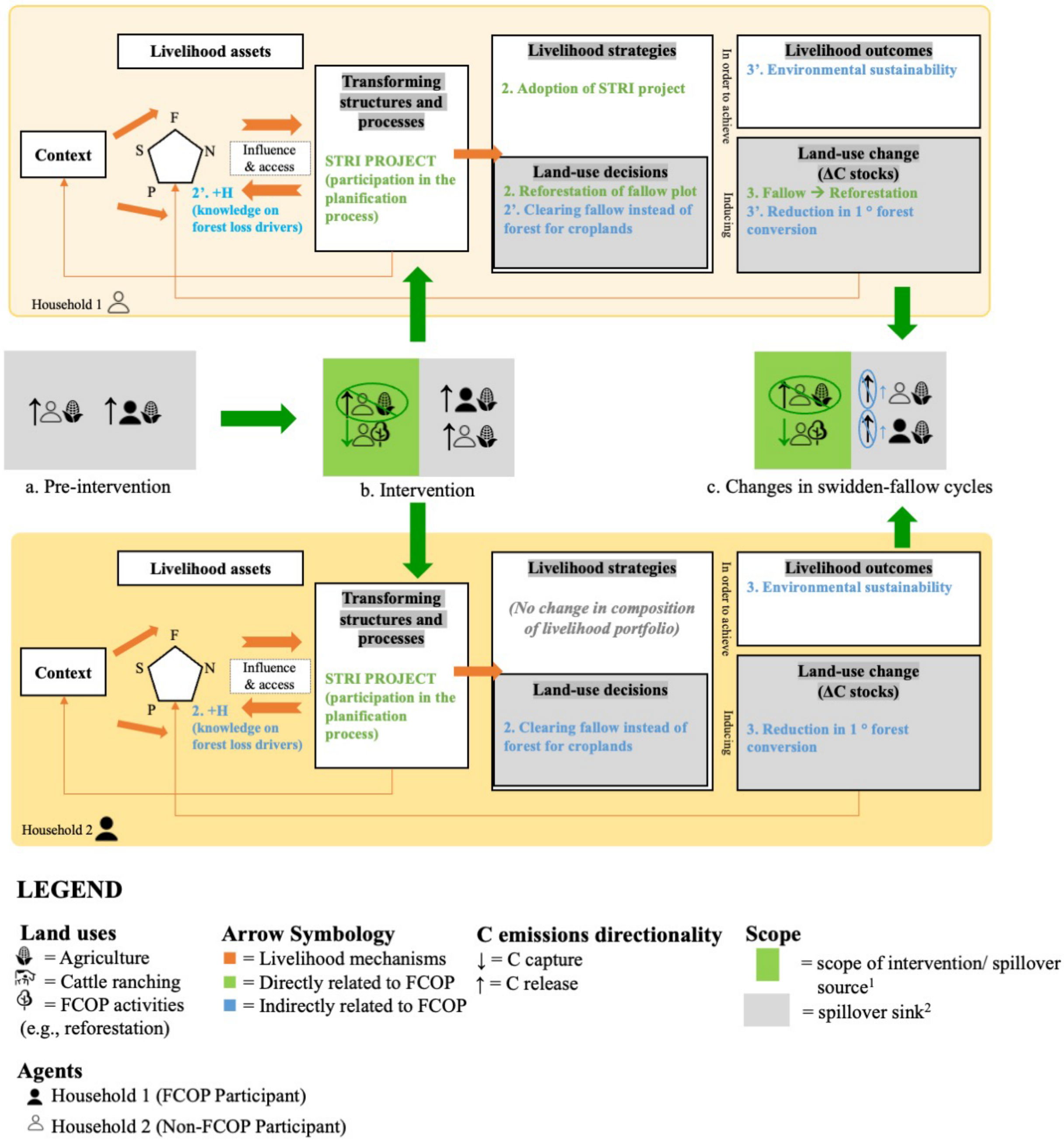

Figure 7. **Spillovers on land management and swidden-fallow cycles**.
Following the community's participation in visioning workshops during the STRI project's planning phase, many participants and non-participants both have altered their land use by prioritizing clearing land in fallow rather than forest to open new croplands.

4.4.2.5 Hyper-adoption through kin-mediated knowledge diffusion

We found a strong signal for knowledge diffusion within social networks, specifically by reducing fears and uncertainty around involvement and the delivery of benefits (#1 to #4 in Figure 8), resulting in the enhanced adoption of reforestation practices by influencing the FCOPs' enrolment trends over time (#5 and #6 in Figure 8). A former community chief and participant specifically stressed the role of kin networks in information-sharing regarding FCOPs, highlighting that 'reforestation is a family affair'. Many of the later STRI adopters (years 2009 and 2010) entered the project after witnessing the first generation of participants successfully entering the project and retaining rights over their land:

> At first, many didn't want the project because they thought it was bad. (…) Many believed they were coming to take our lands. (…) If you're coming to take over my land, I'd rather not have anything to do with that, it's best to stay out of it. Many believed that, but others thought that it was good to reforest. About eight families initially accepted the project. After that, the rest said, "alright, let's do it!" (Jorge, 40s, 30/08/2022)

We suspect that this pioneer effect from the STRI project at least partially explains the McGill-Bayano project's adoption. Reforestation indeed seems to be a familial affair; of Ipetí's 20 households participating in the McGill project, one participated in the STRI project, eight are the children or siblings of STRI participants, and seven are closely related to local STRI or McGill project managers.

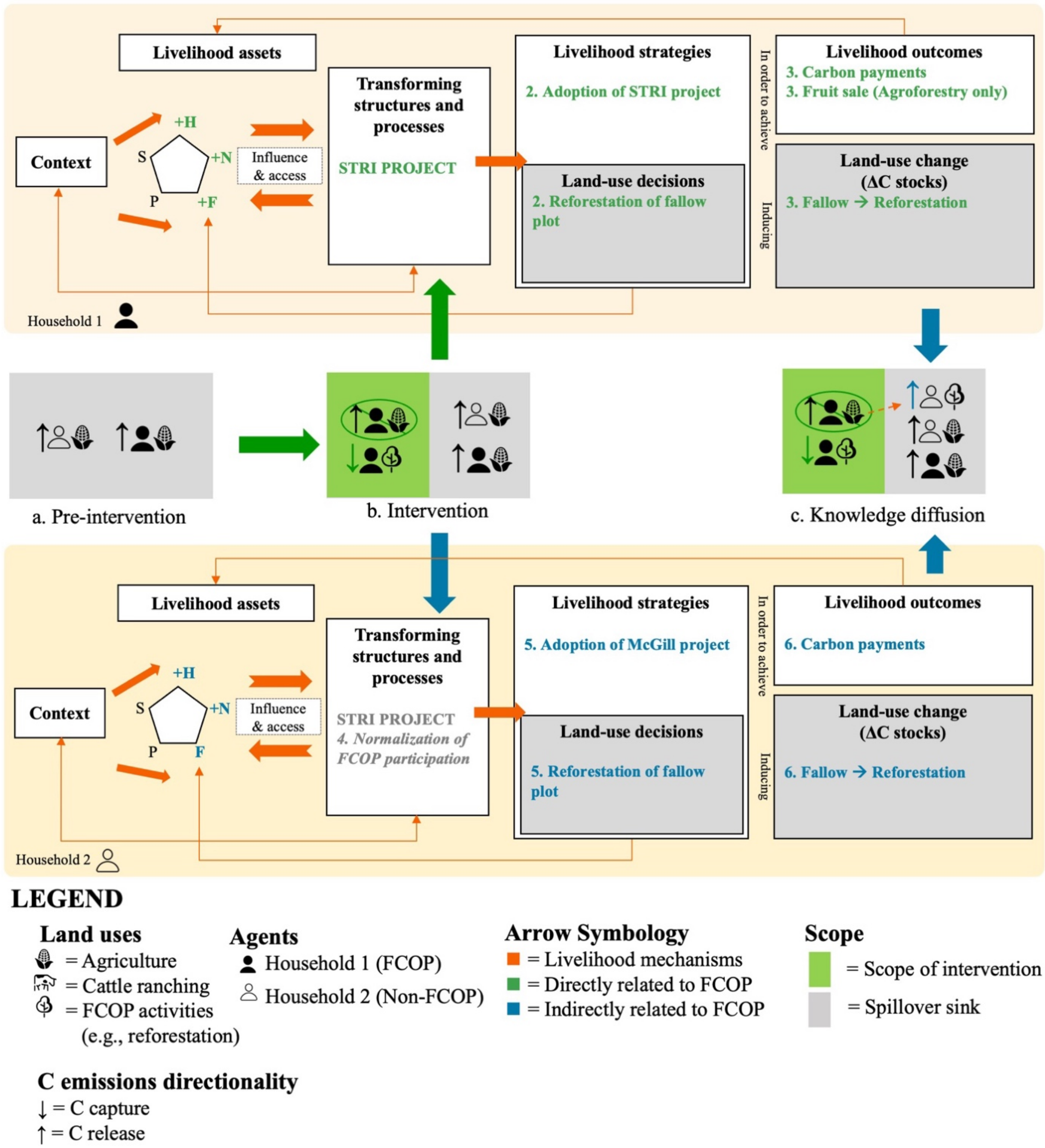

Figure 8. **Hyper-adoption of FCOPs through knowledge spillovers**.
Early STRI project adopters have motivated other community members to also engage in reforestation, either by also joining the STRI project or by later joining the McGill-Bayano Reforestation project.

4.5 Discussion

The adapted sustainable livelihoods framework we developed allowed the diagnosis of spillovers, including leakage pathways and boosting effects caused by the 15-year Ipetí-STRI project. Many are more complex than the relatively straightforward activity displacement typically associated with primary leakage. The sustainable livelihoods framework can provide the necessary structure to track the role of capital flows and mediating factors in facilitating land-use spillovers from FCOPs. By better establishing and understanding the causal chains leading to spillovers, leverage points which can be mobilized to mitigate leakage or boost positive spillovers can more readily be identified.

4.5.1 Towards context-specific solutions to handling spillovers

A nuanced understanding of the motivations driving decision-making leading to spillovers, especially leakage, and of the contextual factors enabling these mechanisms is key to the formulation of locally adapted, people-centered management measures. For example, the first mechanism we describe differs from other income effects more commonly discussed in the literature, namely the "use of program payments to finance production of goods and services on farm" (Dyer and Nijnik, 2014, p. 229). In our case study, the income effects behind the leakage are sourced from the livelihood alternative rather than from the carbon offset payment itself as the agroforestry adopters reinvest the income generated by coffee cultivation into the adoption of cattle ranching and convert additional land into pastures as a result. This mechanism is operating through restrictions on economic capital and access to bank services, as well as crop market variability, which markedly narrow down the financially worthwhile crop options. Methodologically speaking, while it is impossible to prove that these effects would have not occurred without the FCOP (that is, as a result of economic growth and other coffee production incentives) without the inclusion of counterfactuals in our study, the participants' testimonies describing the project as enabling the adoption of coffee production by easing entry barriers and explaining the rationale behind coffee's complementarity with cattle ranching allow us to establish strong causal links inferring leakage.

Mitigating the cattle-to-coffee pathway could be approached by seeking ways to facilitate access to other forms of savings or financial services, or by helping lower the barriers to coffee cultivation expansion and intensification, which participants seek to alleviate by investing in cattle to secure loans. Further, incentivizing participants who opt to purchase cattle with their agroforestry earnings to exclusively rely on existing pastures to avoid additional clearing, and to adopt improved pasture technologies to improve land efficiency, could reduce the magnitude of leakage. Doing so would require monitoring the progressive adoption of cattle ranching as the coffee yields from agroforestry plots increase over time. However, in this context, rebound effects will remain difficult to avoid and to control equitably.

While they have not taken place yet, we estimate that there is a high risk of institutional leakage associated with the distribution of official reforestation certificates. The role of institutional interactions has rarely been discussed in the context of land-use spillovers (Bastos Lima et al., 2019). Panama is already known for its paradoxical land use policies, namely its land titling efforts and reforestation incentives, which are both linked with increased deforestation rates (Walker, 2021). In this case, the leakage generated by the antagonistic interactions of public and private incentive schemes is closely related with the issue of double crediting often raised in REDD+ nesting discussions (Atmadja et al., 2022). While spillovers induced by national legislations are more difficult to mitigate at the project scale, better nesting of jurisdictional projects into national initiatives could reduce the risk of double accounting and leakage. This is possible; some of Panama's reforestation incentives already exclude reforestation activities having previously been part of compensation programs (Ley 69 Del 30 de Octubre de 2017, 2017). Detecting these pathways would require both land cover and institutional monitoring; the status of forest protection incentives in Panama is still changing, and different legislation combinations would facilitate distinct pathways to materialize.

Additionally, socially mediated spillovers promoting the adoption of reforestation projects is not unique. Other studies found similar peer effects to be influential in the adoption of low-emission farming practices (Wang et al., 2021) and pesticide-free agriculture in Switzerland (Kreft et al., 2023), but also of deforestation rates (Robalino and Pfaff, 2012). To further increase the uptake of FCOPs, ways to capitalize on such boosting effects include the active recruitment of individuals from "new" families in future projects to widen the social basin through which knowledge is spread.

Finally, social learning and peer influence may have also played a role in the changes participants described in their swidden-fallow cycles, which they have shortened to spare older fallows and primary forests from conversion. While we consider these changes a form of motivational spillover resulting from a solidified environmental awareness (Bastos Lima et al., 2019), fallow length constriction and land sparing in shifting agriculture landscapes can on their own constitute cost-effective forms of FCOP, perhaps even more so than A/R mechanisms, but only if the opportunity cost of such land management is priced accurately (Morton et al., 2020).

4.5.2 Spillover management in swidden landscapes

Swidden-fallow agriculture, practiced by many Indigenous Peoples and local communities in tropical agroecosystems around the world, produces landscapes that form an ever-evolving mosaic of plots varying in size, use, and age (Coomes et al., 2016). The dynamic nature of land use in swidden-fallow landscapes can complicate the attribution process in FCOP spillover analysis. Not only does land conversion continuously happen regardless of the intervention, the rate at which cycling occurs, which can be modeled as part of a baseline, may change because of shifts in baseline drivers unrelated to the project (Morton et al., 2020). As a result, extensive quantitative and qualitative monitoring of both land cover change and local livelihoods are needed to parse out which of the many changes in land-use are caused by an intervention.

Using Ipetí as an example, all households have, since the project's onset, kept clearing fallows and, occasionally, forests, to access new croplands. Whether any of the additional clearing could have taken place on the plot dedicated to the project in a business-as-usual scenario is likely, but to say that any clearing was caused by the project is difficult to prove. Further, the high prevalence of pest and weeds, climate variability, and general soil degradation, is currently driving forest clearing to replace less productive old fallows. While the project may have indirectly halted deforestation for some time, the degradation of soils currently in rotation is likely partially a result of the shortened fallow cycles indirectly induced by the project. However, given the multiplicity and complexity of external factors driving Ipetí's households' land use decisions, assuming that the STRI project is the driver causing participants to cut down tall fallow or forest that would not have been felled otherwise (i.e. attribution), whether before or after the emergence of these external pressures, is difficult to prove. While it may simply correspond to a dampening of the project's boosting effects and not be causing any net leakage in this context, the thought experiment has important implications for policy improvements.

4.5.3 Tailoring leakage evaluations to local contexts

Many methodologies for measuring leakage, such as the use of leakage belts around interventions and monitoring via remote sensing, rely on matching methods or baselines based on historical trends to evaluate whether the spillover sink's land conversion rate displays leakage effects (Ewers and Rodrigues, 2008; Guizar-Coutiño et al., 2022; West et al., 2020). However, matching methods using non-participants are unsuitable given the existence of land-use spillovers involving non-participants (Jack and Cardona Santos, 2017), and using neighboring communities as controls (i.e. Piriatí-Emberá, the best option in our case) is complicated by the local nature of significant land use drivers (D. Sharma et al., 2016). In addition, baselines are not always reliable;, they often fail to account for changes in socio-economic (West et al., 2023) and natural conditions (Pan et al., 2022) driving land use, and can be intentionally inflated by project promoters for their benefit (West et al., 2020). Default or risk-associated leakage discount factors may be a simpler solution to accounting for leakage, but they are not conducive to the identification of leakage pathways and appropriate mitigation strategies.

While the pathways identified in this paper are specific to Ipetí's social-ecological context, our study suggests that monitoring changes in baseline drivers and in baseline agent motivations through the FCOP planning and implementation process are an effective way to identify spillovers as well as avenues to improve project design. The sustainable livelihoods framework offers a useful structure to do so. While in-depth qualitative investigations are time and resource-intensive and cannot are insufficient for post-hoc quantification, such approaches can inform leakage quantification by identifying both existing pathways and ones that are likely to arise, point to potential leakage risk indicators to improve monitoring (Swingland et al., 2002), while also informing mitigation strategies to improve FCOP design. Finding ways to scale this approach to larger-scale FCOPs is the next step to incorporating appropriate, locally relevant ways to incorporate leakage monitoring and mitigation in forest-based climate mitigation projects.

4.6 Conclusion

Our study confirms that employing a qualitative approach rooted in sustainable livelihoods to the analysis of FCOP primary spillovers provides several critical benefits. First, as seen with the STRI project, smaller-scale FCOPs will have even smaller and difficult-to-detect land-use spillovers. It is unlikely that any of the pathways we described thanks to the sustainable livelihoods approach would have been captured by traditional land use monitoring. Descriptive approaches are often the only way to meaningfully evaluate leakage. Second, by centering participant agency and decision-making, it provides the necessary building blocks to establish clear causal chains between the implementation of an intervention and its ripple down effects on land use, unveiling sometimes complex attribution mechanisms. Third, the establishment of these detailed causal chains not only meets the attribution criteria of leakage evaluation, but also allows the identification of several leverage points which can be mobilized in the elaboration of efficient and context-specific leakage mitigation strategies, or in the enhancement of positive spillover effects. Finally, it can allow the early diagnosis of future sources of leakage, allowing the early adoption of preventative measures. While quantification is still required for the completion of a full analysis of FCOP leakages and spillovers, beginning with an in-depth qualitative inquiry will allow the efficient focusing of monitoring efforts towards the relevant scales, actors and activities, and offer avenues for transformative mitigation strategies that go beyond discounting and penalties.

4.7 References

Alix-Garcia, J., Shapiro-Garza, E., and Sims, K. (2012). Forest conservation and slippage: Evidence from Mexico's national payments for ecosystem services program. *Land Economics*, *88*, 613–638. https://doi.org/10.3368/le.88.4.613

Atela, J. O., Minang, P. A., Quinn, C. H., and Duguma, L. A. (2015). Implementing REDD+ at the local level: Assessing the key enablers for credible mitigation and sustainable livelihood outcomes. *Journal of Environmental Management*, *157*, 238–249. https://doi.org/10.1016/j.jenvman.2015.04.015

Atmadja, S., Duchelle, A. E., Sy, V. D., Selviana, V., Komalasari, M., Sills, E. O., and Angelsen, A. (2022). How do REDD+ projects contribute to the goals of the Paris Agreement? *Environmental Research Letters*, *17*(4), 044038. https://doi.org/10.1088/1748-9326/ac5669

Atmadja, S., and Verchot, L. (2012). A review of the state of research, policies and strategies in addressing leakage from reducing emissions from deforestation and forest degradation (REDD+). *Mitigation and Adaptation Strategies for Global Change*, *17*(3), 311–336. https://doi.org/10.1007/s11027-011-9328-4

Aukland, L., Costa, P. M., and Brown, S. (2003). A conceptual framework and its application for addressing leakage: The case of avoided deforestation. *Climate Policy*, *3*, 123–136. https://doi.org/10.3763/cpol.2003.0316

Bastos Lima, M. G., Persson, U. M., and Meyfroidt, P. (2019). Leakage and boosting effects in environmental governance: A framework for analysis. *Environmental Research Letters*, *14*(10), 105006. https://doi.org/10.1088/1748-9326/ab4551

Bayrak, M. M., and Marafa, L. M. (2016). Ten years of REDD+: A critical review of the impact of REDD+ on forest-dependent communities. *Sustainability*, *8*(7), Article 7. https://doi.org/10.3390/su8070620

Bayrak, M. M., Tu, T. N., and Marafa, L. M. (2014). Creating social safeguards for REDD+: Lessons learned from benefit sharing mechanisms in Vietnam. *Land*, *3*, Article 3. https://doi.org/10.3390/land3031037

Bebbington, A. (1999). Capitals and capabilities: A framework for analyzing peasant viability, rural livelihoods and poverty. *World Development*, *27*(12), 2021–2044. https://doi.org/10.1016/S0305-750X(99)00104-7

Blundo-Canto, G., Bax, V., Quintero, M., Cruz-Garcia, G. S., Groeneveld, R. A., and Perez-Marulanda, L. (2018). The different dimensions of livelihood impacts of Payments for Environmental Services (PES) schemes: A systematic review. *Ecological Economics*, *149*, 160–183. https://doi.org/10.1016/j.ecolecon.2018.03.011

Brown, P., Cabarle, B., and Livernash, E. R. (1997). *Carbon counts estimating climate change mitigation in forestry projects*. World Resources Institute.

Caplow, S., Jagger, P., Lawlor, K., and Sills, E. (2011). Evaluating land use and livelihood impacts of early forest carbon projects: Lessons for learning about REDD+. *Environmental Science and Policy*, *14*(2), 152–167. https://doi.org/10.1016/j.envsci.2010.10.003

Coomes, O. T., Grimard, F., Potvin, C. J., and Sima, P. (2008). The fate of the tropical forest: Carbon or cattle? *Ecological Economics*, *65*(2), 207–212. https://doi.org/10.1016/j.ecolecon.2007.12.028

Coomes, O. T., Takasaki, Y., and Rhemtulla, J. (2016). Forests as landscapes of social inequality: Tropical forest cover and land distribution among shifting cultivators. *Ecology and Society*, *21*(3). https://doi.org/10.5751/ES-08684-210320

Corbera, E., and Schroeder, H. (2011). Governing and implementing REDD+. *Environmental Science and Policy*, *14*(2), 89–99. https://doi.org/10.1016/j.envsci.2010.11.002

De Jong, B., Bazán, E., and Montalvo, S. (2007). Application of the "Climafor" baseline to determine leakage: The case of Scolel Té. *Mitigation and Adaptation Strategies for Global Change*, *12*, 1153–1168. https://doi.org/10.1007/s11027-006-9068-z

DFID. (1999). *DFID sustainable livelihoods guidance sheets*. Emergency Nutrition Network (ENN). https://www.ennonline.net/www.ennonline.net/dfidsustainableliving

Dyer, G. A., and Nijnik, M. (2014). Implications of carbon forestry for local livelihoods and leakage. *Annals of Forest Science*, *71*(2), 227–237. https://doi.org/10.1007/s13595-013-0293-9

Ellis, F. (2000). *Rural livelihoods and diversity in developing countries*. Oxford University Press. http://catdir.loc.gov/catdir/enhancements/fy0610/00035692-t.html

Engel, S., Pagiola, S., and Wunder, S. (2008). Designing payments for environmental services in theory and practice: An overview of the issues. *Ecological Economics*, *65*(4), 663–674. https://doi.org/10.1016/j.ecolecon.2008.03.011

Ewers, R. M., and Rodrigues, A. S. L. (2008). Estimates of reserve effectiveness are confounded by leakage. *Trends in Ecology and Evolution*, *23*(3), 113–116. https://doi.org/10.1016/j.tree.2007.11.008

Fujii, H., Webb, J., Mundree, S., Rowlings, D., Grace, P., Wilson, C., and Managi, S. (2024). Priority change and driving factors in the voluntary carbon offset market. *Cleaner Environmental Systems*, 100164. https://doi.org/10.1016/j.cesys.2024.100164

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W. H., Shoch, D., Siikamäki, J. V., Smith, P., Woodbury, P., Zganjar, C., Blackman, A., Campari, J., Conant, R. T., Delgado, C., Elias, P., Gopalakrishna, T., Hamsik, M. R., … Fargione, J. (2017). Natural climate solutions. *Proceedings of the National Academy of Sciences*, *114*(44), 11645–11650. https://doi.org/10.1073/pnas.1710465114

Guizar-Coutiño, A., Jones, J. P. G., Balmford, A., Carmenta, R., and Coomes, D. A. (2022). A global evaluation of the effectiveness of voluntary REDD+ projects at reducing deforestation and degradation in the moist tropics. *Conservation Biology*, *36*(6), e13970. https://doi.org/10.1111/cobi.13970

Henders, S., and Ostwald, M. (2012). Forest carbon leakage quantification methods and their suitability for assessing leakage in REDD. *Forests*, *3*(1), Article 1. https://doi.org/10.3390/f3010033

Holmes, I., Kirby, K. R., and Potvin, C. (2017). Agroforestry within REDD+: Experiences of an indigenous Emberá community in Panama. *Agroforestry Systems*, *91*(6), 1181–1197. https://doi.org/10.1007/s10457-016-0003-3

Jack, B. K., and Cardona Santos, E. (2017). The leakage and livelihood impacts of PES contracts: A targeting experiment in Malawi. *Land Use Policy*, *63*, 645–658. https://doi.org/10.1016/j.landusepol.2016.03.028

Kirby, K. R., and Potvin, C. (2007). Variation in carbon storage among tree species: Implications for the management of a small-scale carbon sink project. *Forest Ecology and Management*, *246*(2), 208–221. https://doi.org/10.1016/j.foreco.2007.03.072

Kreft, C., Angst, M., Huber, R., and Finger, R. (2023). Farmers' social networks and regional spillover effects in agricultural climate change mitigation. *Climatic Change*, *176*(2), 8. https://doi.org/10.1007/s10584-023-03484-6

Ley 69 Del 30 de Octubre de 2017, 69, República de Panamá (2017). https://www.sala-seem.org/index.php?preview=1andformat=andoption=com_dropfilesandtask=frontfile.downloadandcatid=79andid=412andItemid=1000000000000

Meyfroidt, P., Roy Chowdhury, R., de Bremond, A., Ellis, E. C., Erb, K.-H., Filatova, T., Garrett, R. D., Grove, J. M., Heinimann, A., Kuemmerle, T., Kull, C. A., Lambin, E. F., Landon, Y., le Polain de Waroux, Y., Messerli, P., Müller, D., Nielsen, J. Ø., Peterson, G. D., Rodriguez García, V., … Verburg, P. H. (2018). Middle-range theories of land system change. *Global Environmental Change*, *53*, 52–67. https://doi.org/10.1016/j.gloenvcha.2018.08.006

Morton, O., Borah, J. R., and Edwards, D. P. (2020). Economically viable forest restoration in shifting cultivation landscapes. *Environmental Research Letters*, *15*(6), 064017. https://doi.org/10.1088/1748-9326/ab7f0d

Pagiola, S., Ramírez, E., Gobbi, J., de Haan, C., Ibrahim, M., Murgueitio, E., and Ruíz, J. P. (2007). Paying for the environmental services of silvopastoral practices in Nicaragua. *Ecological Economics*, *64*(2), 374–385. https://doi.org/10.1016/j.ecolecon.2007.04.014

Pan, C., Shrestha, A., Innes, J. L., Zhou, G., Li, N., Li, J., He, Y., Sheng, C., Niles, J.-O., and Wang, G. (2022). Key challenges and approaches to addressing barriers in forest carbon offset projects. *Journal of Forestry Research*. https://doi.org/10.1007/s11676-022-01488-z

Peras, R. J., Pulhin, J., Inoue, M., Mohammed, A. J., Harada, K., and Sasaoka, M. (2016). The sustainable livelihood challenge of REDD+ implementation in the Philippines. *Environment and Natural Resources Research*, *6*(3), Article 3. https://doi.org/10.5539/enrr.v6n3p91

Philemon, T. (2021). The Uluguru Payment for Ecosystem Services (PES) Programme in Tanzania: Can Livelihoods Benefits between PES Participants and Non-participants Go Beyond Implementation? *Tanzania Journal of Development Studies*, *19*(1), Article 1.

Polzot, C. L. (2004). *Carbon storage in coffee agroecosystems of Southern Costa Rica: Potential applications for the Clean Development Mechanism*. York University.

Potvin, C., Tschakert, P., Lebel, F., Kirby, K., Barrios, H., Bocariza, J., Caisamo, J., Caisamo, L., Cansari, C., Casamá, J., Casamá, M., Chamorra, L., Dumasa, N., Goldenberg, S., Guainora, V., Hayes, P., Moore, T., and Ruíz, J. (2007). A participatory approach to the establishment of a baseline scenario for a reforestation Clean Development Mechanism project. *Mitigation and Adaptation Strategies for Global Change*, *12*(8), 1341–1362. https://doi.org/10.1007/s11027-006-9056-3

Robalino, J. A., and Pfaff, A. (2012). Contagious development: Neighbor interactions in deforestation. *Journal of Development Economics*, *97*(2), 427–436. https://doi.org/10.1016/j.jdeveco.2011.06.003

Scoones, I. (1998). *Sustainable rural livelihoods: A framework for analysis* (IDS Working Paper 72). IDS. https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/3390

Scoones, I. (2015). *Sustainable livelihoods and rural development*. Fernwood Publishing.

Segura, M., Kanninen, M., and Suárez, D. (2006). Allometric models for estimating aboveground biomass of shade trees and coffee bushes grown together. *Agroforestry Systems*, *68*(2), 143–150. https://doi.org/10.1007/s10457-006-9005-x

Sharma, D., Holmes, I., Vergara-Asenjo, G., Miller, W. N., Cunampio, M., B. Cunampio, R., B. Cunampio, M., and Potvin, C. (2016). A comparison of influences on the landscape of two social-ecological systems. *Land Use Policy*, *57*, 499–513. https://doi.org/10.1016/j.landusepol.2016.06.018

Sonderegger, G., Heinimann, A., Diogo, V., and Oberlack, C. (2022). Governing spillovers of agricultural land use through voluntary sustainability standards: A coverage analysis of sustainability requirements. *Earth System Governance*, *14*, 100158. https://doi.org/10.1016/j.esg.2022.100158

Streck, C. (2021). REDD+ and leakage: Debunking myths and promoting integrated solutions. *Climate Policy*, *21*(6), 843–852. https://doi.org/10.1080/14693062.2021.1920363

Swingland, I. R., Bettelheim, E. C., Grace, J., Prance, G. T., Saunders, L. S., Schwarze, R., Niles, J. O., and Olander, J. (2002). Understanding and managing leakage in forest–based greenhouse–gas–mitigation projects. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, *360*(1797), 1685–1703. https://doi.org/10.1098/rsta.2002.1040

Tschakert, P., Coomes, O. T., and Potvin, C. (2007). Indigenous livelihoods, slash-and-burn agriculture, and carbon stocks in Eastern Panama. *Ecological Economics*, *60*(4), 807–820. https://doi.org/10.1016/j.ecolecon.2006.02.001

Walker, K. L. (2021). Effect of land tenure on forest cover and the paradox of private titling in Panama. *Land Use Policy*, *109*, 105632. https://doi.org/10.1016/j.landusepol.2021.105632

Wang, Y., Möhring, N., and Finger, R. (2021). When my neighbors matter: Spillover effects in the adoption of large-scale pesticide-free wheat production. *Agricultural Economics*, *n/a*(n/a). https://doi.org/10.1111/agec.12766

West, T. A. P., Börner, J., Sills, E. O., and Kontoleon, A. (2020). Overstated carbon emission reductions from voluntary REDD+ projects in the Brazilian Amazon. *Proceedings of the National Academy of Sciences*, *117*(39), 24188–24194. https://doi.org/10.1073/pnas.2004334117

West, T. A. P., Wunder, S., Sills, E. O., Börner, J., Rifai, S. W., Neidermeier, A. N., Frey, G. P., and Kontoleon, A. (2023). Action needed to make carbon offsets from forest conservation work for climate change mitigation. *Science*, *381*(6660), 873–877. https://doi.org/10.1126/science.ade3535

CHAPTER 5: GENERAL DISCUSSION AND CONCLUSION

In the two manuscripts of this thesis, I examined the complexities and implications of the Ipetí-STRI project's evolving relationship with the local context where it was implemented. Together, this work highlights the intricate interplay between livelihood transitions, socio-economic pressures, and forest-based interventions, underscoring the necessity for adaptive, context-sensitive forest carbon offset projects to effectively achieve their goals, both in terms of livelihood improvements and carbon sequestration.

The first manuscript delved into the socio-economic and ecological pressures that have reshaped the livelihoods of the Ipetí community. Its key findings, which lay the groundwork for the second manuscript, point to a decline in soil productivity, crop price volatility, and an increase in the prevalence of pests and diseases, as having collectively influenced the way community members engage with their land. These new sources of variability, paired with social fragmentation, economic and political unrest, and the recent public health crisis, have led households to seek secure more sources of cash income. This has translated into a preference to cultivate market-stable cash crops, such as coffee, over subsistence staples, and into the increased prevalence of land rentals, which our informants perceived as a passive form of land-based income. Then, the second manuscript narrowed down on the indirect land use changes linked to the Ipetí-STRI project, resulting in the description of four complex pathways of leakage and boosting effects. Our use of the sustainable livelihoods framework reveals nuanced mechanisms beyond mere activity shifting where, through intricate causal chains involving capital asset accumulation, institutional interplay, and social relations, land-use decisions seemingly unrelated to the Ipetí-STRI project are connected back to its implementation.

The results outlined in each chapter are heavily interrelated. The first paper's broader examination of the project's interactions with these livelihood trajectories revealed the emergence of policy misfits from these interactions, specifically in connection with agroforestry component's coffee-or-carbon dilemma and issues with the payment distribution mechanism, both of which initially carefully designed through community consultations to maximize livelihood outcomes and avoid such trade-offs. While the first manuscript identified misfits between the FCOP and its local livelihood context that may cause direct project failure through non-compliance, similar misfits are also at the source of the spillovers identified through the second chapter's narrower focus on the projects' land use change. These relationships between the two chapters' findings support the idea that, as proposed by Dyer and Nijnik, "the context's influence on the effectiveness and equitability of carbon forestry cannot be considered separately since both livelihood impacts and leakage arise from the same processes" (2014, p. 233).

While considered separately in our chapters, direct non-compliance and leakage are heavily related concepts. The coffee-carbon trade-off introduced in the first chapter and the coffee-to-cattle leakage pathway are useful examples to demonstrate this conceptual duality: whether a project's impacts are deemed direct or indirect relies on the way its operational scope is defined. The changes in Ipetí's land use practices described in the first chapter (i.e. the increased adoption of coffee cultivation following its introduction via the STRI project) are examples of the changes in baseline drivers discussed in the context of leakage monitoring. Following the first chapter's framing, the primary consequence of this induced trade-off on the project is potential non-compliance if participants decide to log shade-casting timber trees to optimize their STRI agroforestry plot's coffee production. However, as discussed in chapter two's discussion surrounding the project's temporal scope definition, this form of non-compliance constitutes temporal leakage (or non-permanence) if the project's temporal boundaries are defined according to the participants' perspective, namely with the payment window. Further, considering the coffee-to-cattle leakage pathway, extending the project's operational scope to the participant's full *parcela* rather than their reforestation plot would effectively absorb the leakage as a form of direct non-additionality.

Overall, these examples reflect the conceptual duality discussed by Filewod and McCarney (2023) between leakage and additionality in the context of market leakage, or between leakage and permanence when considering the project's temporal dimensions. To summarize, whether the given outcomes of such misfits constitute direct non-compliance, a spillover, or fall fully outside the project's scope, is truly a conceptual matter of scale. Consequently, the explicit and informed definition of a FCOP's operational and spillover scope are essential to the accurate reporting of secondary effects, but also to the selection of appropriate direct monitoring methodologies.

5.1 Recommendations for the McGill-Bayano Project

Building on this investigation, I carefully extrapolate my findings from the STRI project to the McGill-Bayano Reforestation Project and identify potential misfits between the project and the current context in the Alto-Bayano watershed. While the newer project extends to Piriatí-Emberá as well, I consider its livelihood context to heavily reflect Ipetí-Emberá's situation since the beginning of the COVID-19 pandemic, which coincided with the beginning of the McGill-Bayano project's implementation. I also identify promising leakage detection and mitigation strategies.

The payment distribution mechanism as currently designed should be revised to reduce risks of non-compliance and leakage. McGill project participants receive tri-annual payments based on the number of days of labor required for plot maintenance, with daily wages fixed at the 2020 price of labor ($25). As of the current agreement, these payments are to last during the project's first five years. To reduce the risk of non-compliance and leakage, our findings suggest that financial incentives should minimally cover the opportunity cost of land use, but ideally including any further necessary plot maintenance during the project's 25-year compliance period.

The McGill-Bayano project's exclusion of agroforestry as a reforestation mechanism option, motivated by its demonstrated risk of carbon sequestration under-performance (Forgues et al., 2024), effectively eliminates the agroforestry-specific risks of leakage and non-compliance. However, this omission has re-introduced the original trade-off identified during the first year of the STRI project, namely that short-term benefits are more difficult to perceive in timber reforestation systems (Holmes, Kirby, et al., 2017). Among many consequences, this may have discouraged some less well-off households from participating. More importantly, extrapolating from the findings outlined in the first chapter, it also likely accentuates the future risk of non-compliance caused by the lack of tangible benefits from reforestation after the completion of the payment period.

Concretely, the simplest way to mitigate the risk of non-compliance and leakage associated with the current payment mechanism is the distribution of annual lump-sum payments of $300, equivalent to the income a household can receive by renting out 1 ha of pasture or rice paddy in

2025. Alternatively, a more flexible approach would be to set the value of the annual payment to the land's rent, an easy value to collect on an annual basis, to ensure the continual fit between the incentive scheme and the land rental market.

Careful attention will have to be paid to the way participants respond to the approach adopted by the McGill-Bayano project following the end of the payment period, especially if the project's incentives fall below its opportunity cost. The evolving resource dynamics described in Ipetí in the last 15 years (e.g. pests, climate variability) suggest that participants may need to adapt their plot maintenance practices over time to respond to these changes, for examples to prevent the propagation of brush fires by maintaining a fire break, by irrigating the seedlings in the event of a drought, or by implementing weed control measures if the wild sugarcane *(Saccharum spontaneum L.)* takes over. Despite the provision of fixed lump-sum payments, the need for any additional capital inputs not covered by the incentive scheme may lead to discouragement and ultimately to plot abandonment, compromising the carbon's permanence as a result. In this scenario, an even more proactive solution would be to not only offset the annual opportunity cost of rent, but to also compensate the participants for any further investment needed to ensure proper tree growth. This could include providing continued technical and material support, or by compensating the labor inputted in additional maintenance. This would require McGill University to continue working closely with local coordinators to monitor the risks faced by the participants in the maintenance of their plot, whether they be of environmental, climatic, or socio-economic nature, to devise mitigation plans in collaboration with local communities, and to shoulder the economic burden associated with risk mitigation.

Importantly, such pricing schemes would more accurately represent the actual investment required to offset ones' carbon emissions through forest-based projects. Improving the quality of the information held by both carbon offset buyers and sellers would allow both sides to make more informed decisions in future negotiations or projects. In practice, it would also play a non-negligible role in protecting McGill's initial investment made during the most payment-heavy period the project. Obviously, such an approach would significantly increase the cost of carbon paid by the buyer, especially in a context where unexpected maintenance costs may arise due to the constant shifts in baseline drivers due to livelihood pressures other unintentional non-permanence threats (e.g. fires, pests, weeds). However, one can argue that any other payment scheme assuming, expecting, or requiring that plots will be maintained without the presence of incentives effectively puts the economic burden of maintenance on the participants, which carries serious social justice implications.

The McGill-Bayano Project should ensure the maintenance of open communication channels with the participants and the transparency of governance mechanisms. These efforts to maintain open communication channels with participants and other local stakeholders should expand to beyond 2025, which marks the end of the project's active maintenance phase. Doing so would support the prompt identification of emerging issues and the development locally relevant solutions. Co-developing the approach to the payment distribution mechanism is a concrete example of how open communication and transparent participatory governance can be implemented.

Such continuous communication was compromised in the Ipetí-STRI project by (1) the payment disbursement design reducing the frequency of external visits, (2) issues with ANCON, the Panamanian NGO involved with monitoring as an third-party intermediary (Holmes, Potvin, et al., 2017), (3) the dissolution of the local NGO contractually in charge of the project, and (4) the difficulty to re-organize effectively due to the increasing social fragmentation in Ipetí. The McGill-Bayano project already has a direct communication channel between the project's internal and external decisionmakers, including a continuous, direct line between the local project coordinator and the McGill Office of Sustainability. Informed by the STRI participants' experiences, potential avenues to informally promote the maintenance and diversification of means of communication include ensuring regular exchanges between the McGill and Bayano communities, and between these groups and other external stakeholders. While a break in communications was partially unavoidable with the COVID-19 pandemic, many STRI participants shared with me their relief to see someone working on the STRI project was finally coming back after several years to take the time to get acquainted with the community and survey the participants about their experiences and opinions on the project, that is, even if these topics were often secondary in my formal interviews. In the McGill-Bayano context, this can be accomplished (and has been done so far) with regular student visits as part of McGill's Panama's Field Study Semester and McGill-STRI Neotropical Environment Program, and by the continuous and more in-depth involvement of new faculty and graduate student researchers (such as myself) to support the project's monitoring and improvement.

5.2 Study Limitations

This thesis presents unavoidable limitations which need be mentioned when discussing the findings and their implications. First, the timing of my fieldwork may have influenced my findings due to the socio-economic context in which I collected my data. As mentioned in the first manuscript, the period between April and September of 2022 was one filled with many disruptions in Panama. Specifically, as the country was experiencing unprecedented levels of political unrest, the local economy was facing sharp local hyper-inflation resulting from the road blocks dispersed on the Pan-American Highway, blocking access to food supplies (Martínez, 2022). These hardships, paired with the aftermath of the pandemic still heavily felt in 2022, may have distorted the informants' recalling and reporting of longer-term changes and challenges they faced over time.

The second limitation relates to our household sample, which was mostly composed of the STRI project's participants. This means that our participant pool was generally limited to land-owning families at more advanced stages of the household cycle, since the household heads were old enough to manage their family *parcela* 15 years ago. While I tried to correct this inclination by actively engaging younger household members in interviews whenever they were present, by critically discussing the universality of the livelihood trajectories experienced by our informants with my field assistants, who were respectively 32, 31, and 19 years old in 2022, and by diversifying data collection methods, this sample bias has likely skewed our data towards a limited range of lived experiences within Ipetí's community.

The third significant limitation which warrants discussion is tied with my positionality as a McGill student working in Ipetí. Leakages from a FCOP can be a sensitive topic to investigate because participants could be misled to expect negative repercussions following my investigation. Some other livelihood trajectories I explored in my interviews, such as land rents, are perceived as polarizing, and are causing disagreements within the community. Therefore, it is possible that some participants decided against disclosing some information with me, or to distort facts to avoid retributions or judgement from peers. To mitigate these limitations, I stated before every interview and workshop that my role as a graduate student researcher was to provide information for project planning, but that I had no executive decision-making on the projects myself. I also repeatedly clarified that I was not supervised by Dr. Catherine Potvin, who participants perceive as both projects' main external stakeholder, and that she did not have access to my data and had no say over my investigation. We decided on these parameters early on in my research to minimize the perceived risks participants may have associated with the disclosure of non-compliance with the reforestation projects. Still, many participants have approached me during my time in the Bayano to share their grievances about various aspects of the projects as if I was a project representative. This leads me to believe that participants could have been strategically selective about the facts they shared with me to promote their interests by influencing my findings, for example by amplifying the challenges they face as part of the project. On the other end of the spectrum, others may have defaulted to what they thought I expected to hear as a conservation-loving McGill student representing – and potentially seemingly promoting – reforestation project.

The fourth and perhaps most important limitation in this thesis is the potential for bias arising by my positionality as a graduate student at McGill University engaging in project evaluation and research that directly informs the McGill's own FCOP in Bayano. The two substantive chapters of the thesis, chapters 3 and 4, focus on the STRI project, in which McGill has been involved in the planning and implementation third-party supporting stakeholders. However, there is still a level of conflict of interest that ought to be addressed when McGill researchers such as myself are conducting research informing McGill's own in-house project. Specifically, the fact that my informants and I were aware from the beginning that my research would result in recommendations for the McGill project could have impacted the outcomes of my research, for example by selectively deciding to include specific results over others, importance of some findings, or by stakeholders strategically providing information to further their own interests.

To ensure my impartiality throughout the process, I was supervised by a professor who was not involved in either FCOP prior to my joining his research group instead of the other obvious option, Dr. Catherine Potvin, who has been deeply embedded within the development of FCOPs and the lives of Bayano's Emberá communities for decades. I made sure to consistently consult with all stakeholder groups (STRI, local coordinators, participants, third-party McGill researchers), with whom I also underwent thorough follow-ups and member-checking at various stages of my research to minimize biases for any party. Finally, by including the McGill-Bayano project recommendations in the final discussion chapter rather than the thesis' stand-alone manuscripts, I hope to separate the sections where biases are likeliest from the body of the thesis. However, the purpose of the research being to inform the McGill-Bayano Project is stated in both manuscripts to transparently and properly position the research's position the greater social, institutional, and academic context in the Bayano.

5.3 Conclusion and Summary

In conclusion, the findings from this thesis highlight the necessity of adaptive, context-sensitive approaches in FCOPs. The insights from both manuscripts underscore the critical importance of context-specific solutions in FCOP design and implementation. The use of the sustainable livelihoods framework, as applied in the first chapter, and its adapted version developed in the second chapter, serves a dual purpose: it offers a robust structure for improving one's understanding of the local livelihood context to which the intervention needs tailoring, and it enables the description of the causal chains behind both direct and indirect outcomes, allowing the identification of leverage points to mitigate or promote these outcomes when needed.

The first manuscript presented in this thesis underscores the importance of gaining a deep understanding of the day-to-day livelihoods of the communities participating in FCOPs. I demonstrate that misfits between a land-based intervention and its social-ecological context may induce trade-offs between livelihood outcomes and carbon sequestration. I show that, despite the STRI-Ipetí project's effective pursuit of an adequate fit through collaborative FCOP planning, the livelihood trajectories experienced by my informants since the project's planning and early implementation phase have created such trade-offs between livelihoods and carbon. Similar conclusions are attained in the second manuscript, namely that intervention misfits, both emerging and current but originally unanticipated, may also compromise the project by causing leakage.

To keep track of the changing context, FCOPs implemented in forest-dependent areas need mechanisms to continuously track and adapt to socio-ecological changes, ensuring the relevance of incentive schemes and preventing the introduction of trade-offs between carbon effectiveness and socio-economic outcomes. For instance, this could mean the incorporation of baseline driver monitoring via the baseline agents' livelihood trajectories and motivations, preferably through qualitative or mixed methods, into the carbon stock measurements already integral to virtually all FCOPs. Such monitoring would support the identification of emerging misfits between the intervention and its social-ecological context. Emerging challenges, such as baseline shifts driven by ecological and social changes, call for novel and constructive leakage and non-compliance mitigation strategies that go beyond those initially tailored to the local livelihood context at the project's onset, as local dynamics taking place over time can render them ineffective.

Finally, transformative solutions to FCOP-induced trade-offs go beyond the implementation of additional monitoring strategies. Adaptive project management, characterized by iterative cycles of social learning and collaboration between different stakeholder groups, can be well-suited to FCOP governance. The participants' embedded and in-depth understanding of local dynamics can hardly be matched by external stakeholder monitoring alone. By tailoring leakage and non-compliance mitigation strategies to local contexts through adaptive management and governance, FCOPs can more effectively identify approaches to balance carbon storage goals with socio-economic outcomes, fostering sustainable livelihoods and resilient communities.

I acknowledge the specificity of each intervention and of its implementation context, an idea at the core of the previous chapter. This includes the significant distinctions between the STRI project and the McGill-Bayano Reforestation Project, which differ in the communities involved, the reforestation designs deployed, the scale of the project, and the payment disbursement mechanism. However, I believe that some lessons learned from the STRI project identified in this thesis can be transferred to the McGill-Bayano project. Specifically, the application of the framework developed in Chapter 4 to the Bayano-McGill project can inform effective leakage monitoring and the development of mitigation strategies fitted to the newer intervention's context.

Future projects, both in the Alto Bayano watershed and elsewhere, should incorporate adaptive and adapted approaches to FCOP design, implementation, and monitoring. This should not only include quantitative measurements of carbon stocks and the project's direct socio-economic outcomes but also the participants' day-to-day livelihoods. Doing so would provide the necessary backbone to identify the mechanics of emerging misfits between the intervention and its evolving social-ecological context, identifying leverage points for the mitigation of adverse impacts through transformative project adaptation. Future research should investigate ways to scale these approaches to other FCOP contexts to enhance the effectiveness and socio-economic benefits of forest-based climate mitigation initiatives.

BIBLIOGRAPHY

Aggarwal, A., and Brockington, D. (2020). Reducing or creating poverty? Analyzing livelihood impacts of forest carbon projects with evidence from India. *Land Use Policy*, *95*. https://doi.org/10.1016/j.landusepol.2020.104608

Alix-Garcia, J., Shapiro-Garza, E., and Sims, K. (2012). Forest conservation and slippage: Evidence from Mexico's national payments for ecosystem services program. *Land Economics*, *88*, 613–638. https://doi.org/10.3368/le.88.4.613

Andersson, K. P., Smith, S. M., Alston, L. J., Duchelle, A. E., Mwangi, E., Larson, A. M., de Sassi, C., Sills, E. O., Sunderlin, W. D., and Wong, G. Y. (2018). Wealth and the distribution of benefits from tropical forests: Implications for REDD+. *Land Use Policy*, *72*, 510–522. https://doi.org/10.1016/j.landusepol.2018.01.012

Angelsen, A., Streck, C., Peskett, L., Brown, J., and Luttrell, C. (2008). *What is the right scale for REDD?: The implications of national, subnational and nested approaches*. Center for International Forestry Research (CIFOR). https://doi.org/10.17528/cifor/002595

Asquith, N. M., Vargas Ríos, M. T., and Smith, J. (2002). Can forest-protection carbon projects improve rural livelihoods? Analysis of the Noel Kempff Mercado climate action project, Bolivia. *Mitigation and Adaptation Strategies for Global Change*, *7*(4), 323–337. https://doi.org/10.1023/A:1024712424319

Atela, J. O., Minang, P. A., Quinn, C. H., and Duguma, L. A. (2015). Implementing REDD+ at the local level: Assessing the key enablers for credible mitigation and sustainable livelihood outcomes. *Journal of Environmental Management*, *157*, 238–249. https://doi.org/10.1016/j.jenvman.2015.04.015

Atmadja, S., Duchelle, A. E., Sy, V. D., Selviana, V., Komalasari, M., Sills, E. O., and Angelsen, A. (2022). How do REDD+ projects contribute to the goals of the Paris Agreement? *Environmental Research Letters*, *17*(4), 044038. https://doi.org/10.1088/1748-9326/ac5669

Atmadja, S., and Verchot, L. (2012). A review of the state of research, policies and strategies in addressing leakage from reducing emissions from deforestation and forest degradation (REDD+). *Mitigation and Adaptation Strategies for Global Change*, *17*(3), 311–336. https://doi.org/10.1007/s11027-011-9328-4

Aukland, L., Costa, P. M., and Brown, S. (2003). A conceptual framework and its application for addressing leakage: The case of avoided deforestation. *Climate Policy*, *3*, 123–136. https://doi.org/10.3763/cpol.2003.0316

Baker, T. R., Jones, J. P. G., Rendón Thompson, O. R., Cuesta, R. M. R., Del Castillo, D., Aguilar, I. C., Torres, J., and Healey, J. R. (2010). How can ecologists help realise the potential of payments for carbon in tropical forest countries? *Journal of Applied Ecology*, *47*(6), 1159–1165. https://doi.org/10.1111/j.1365-2664.2010.01885.x

Baldocchi, D., and Penuelas, J. (2019). The physics and ecology of mining carbon dioxide from the atmosphere by ecosystems. *Global Change Biology*, *25*(4), 1191–1197. https://doi.org/10.1111/gcb.14559

Bastos Lima, M. G., Persson, U. M., and Meyfroidt, P. (2019). Leakage and boosting effects in environmental governance: A framework for analysis. *Environmental Research Letters*, *14*(10), 105006. https://doi.org/10.1088/1748-9326/ab4551

Bayrak, M. M., and Marafa, L. M. (2016). Ten years of REDD+: A critical review of the impact of REDD+ on forest-dependent communities. *Sustainability*, *8*(7), Article 7. https://doi.org/10.3390/su8070620

Bayrak, M. M., Tu, T. N., and Marafa, L. M. (2014). Creating social safeguards for REDD+: Lessons learned from benefit sharing mechanisms in Vietnam. *Land*, *3*, Article 3. https://doi.org/10.3390/land3031037

Bebbington, A. (1999). Capitals and capabilities: A framework for analyzing peasant viability, rural livelihoods and poverty. *World Development*, *27*(12), 2021–2044. https://doi.org/10.1016/S0305-750X(99)00104-7

Bennett, N. (2010). *Sustainable livelihoods from theory to conservation practice: An extended annotated bibliography for prospective application of livelihoods approaches in protected area community research* [Working Paper]. Marine Protected Areas Research Group (MPARG), University of Victoria Protected Areas and Poverty Reduction (PAPR) Canada-Africa Research and Learning Alliance, Vancouver Island University. https://dspace.library.uvic.ca/handle/1828/4461

Bhullar, L. (2013). REDD+ and the Clean Development Mechanism: A comparative perspective. *International Journal of Rural Law and Policy*. https://doi.org/10.5130/ijrlp.i1.2013.3229

Blundo-Canto, G., Bax, V., Quintero, M., Cruz-Garcia, G. S., Groeneveld, R. A., and Perez-Marulanda, L. (2018). The different dimensions of livelihood impacts of Payments for Environmental Services (PES) schemes: A systematic review. *Ecological Economics*, *149*, 160–183. https://doi.org/10.1016/j.ecolecon.2018.03.011

Boyd, E., Gutierrez, M., and Chang, M. (2007). Small-scale forest carbon projects: Adapting CDM to low-income communities. *Global Environmental Change*, *17*, 250–259. https://doi.org/10.1016/j.gloenvcha.2006.10.001

Branger, F., and Quirion, P. (2014). Would border carbon adjustments prevent carbon leakage and heavy industry competitiveness losses? Insights from a meta-analysis of recent economic studies. *Ecological Economics*, *99*, 29–39. https://doi.org/10.1016/j.ecolecon.2013.12.010

Brown, P., Cabarle, B., and Livernash, E. R. (1997). *Carbon counts estimating climate change mitigation in forestry projects*. World Resources Institute.

Brown, S., Delaney, M., Powell, M., Burnham, M., Vaca, R., and Moreno, A. (2000). Issues and challenges for forest-based carbon-offset projects: A case study of the Noel Kempff climate action project in Bolivia. *Mitigation and Adaptation Strategies for Global Change*, *5*. https://doi.org/10.1023/A:1009620903231

Caplow, S., Jagger, P., Lawlor, K., and Sills, E. (2011). Evaluating land use and livelihood impacts of early forest carbon projects: Lessons for learning about REDD+. *Environmental Science and Policy*, *14*(2), 152–167. https://doi.org/10.1016/j.envsci.2010.10.003

Chambers, R., and Conway, G. (1992). *Sustainable rural livelihoods: Practical concepts for the 21st century*. Institute of Development Studies (UK). https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/775

Coomes, O. T., Barham, B. L., and Takasaki, Y. (2004). Targeting conservation–development initiatives in tropical forests: Insights from analyses of rain forest use and economic reliance among Amazonian peasants. *Ecological Economics*, *51*(1), 47–64. https://doi.org/10.1016/j.ecolecon.2004.04.004

Coomes, O. T., Grimard, F., Potvin, C. J., and Sima, P. (2008). The fate of the tropical forest: Carbon or cattle? *Ecological Economics*, *65*(2), 207–212. https://doi.org/10.1016/j.ecolecon.2007.12.028

Coomes, O. T., Takasaki, Y., and Rhemtulla, J. (2016). Forests as landscapes of social inequality: Tropical forest cover and land distribution among shifting cultivators. *Ecology and Society*, *21*(3). https://doi.org/10.5751/ES-08684-210320

Corbera, E. (2012). Problematizing REDD+ as an experiment in payments for ecosystem services. *Current Opinion in Environmental Sustainability*, *4*(6), 612–619. https://doi.org/10.1016/j.cosust.2012.09.010

Corbera, E., and Schroeder, H. (2011). Governing and implementing REDD+. *Environmental Science and Policy*, *14*(2), 89–99. https://doi.org/10.1016/j.envsci.2010.11.002

Dalle, S., and Potvin, C. (2004). Conservation of useful plants: An evaluation of local priorities from two Indigenous communities in Eastern Panama. *Economic Botany*, *58*, 38–57. https://doi.org/10.1663/0013-0001(2004)058[0038:COUPAE]2.0.CO;2

Dang, D., Li, X., Li, S., Li, X., Lyu, X., Dou, H., Li, M., Liu, S., Xuan, X., and Wang, K. (2023). Changing rural livelihood activities may reduce the effectiveness of ecological restoration projects. *Land Degradation and Development*, *34*(2), 362–376. https://doi.org/10.1002/ldr.4465

Dawson, N. M., Mason, M., Mwayafu, D. M., Dhungana, H., Satyal, P., Fisher, J. A., Zeitoun, M., and Schroeder, H. (2018). Barriers to equity in REDD+: Deficiencies in national interpretation processes constrain adaptation to context. *Environmental Science and Policy*, *88*, 1–9. https://doi.org/10.1016/j.envsci.2018.06.009

De Jong, B., Bazán, E., and Montalvo, S. (2007). Application of the "Climafor" baseline to determine leakage: The case of Scolel Té. *Mitigation and Adaptation Strategies for Global Change*, *12*, 1153–1168. https://doi.org/10.1007/s11027-006-9068-z

DFID. (1999). *DFID sustainable livelihoods guidance sheets*. Emergency Nutrition Network (ENN). https://www.ennonline.net/www.ennonline.net/dfidsustainableliving

Dube, L. C., and Chatterjee, S. (2022). Assessing livelihood impact of forest carbon projects using sustainable livelihood framework. *Mitigation and Adaptation Strategies for Global Change*, *27*(8), 49. https://doi.org/10.1007/s11027-022-10022-9

Dyer, G. A., and Nijnik, M. (2014). Implications of carbon forestry for local livelihoods and leakage. *Annals of Forest Science*, *71*(2), 227–237. https://doi.org/10.1007/s13595-013-0293-9

Ellis, F. (2000). *Rural livelihoods and diversity in developing countries*. Oxford University Press. http://catdir.loc.gov/catdir/enhancements/fy0610/00035692-t.html

Engel, S., Pagiola, S., and Wunder, S. (2008). Designing payments for environmental services in theory and practice: An overview of the issues. *Ecological Economics*, *65*(4), 663–674. https://doi.org/10.1016/j.ecolecon.2008.03.011

Ewers, R. M., and Rodrigues, A. S. L. (2008). Estimates of reserve effectiveness are confounded by leakage. *Trends in Ecology and Evolution*, *23*(3), 113–116. https://doi.org/10.1016/j.tree.2007.11.008

Fa, J. E., Watson, J. E., Leiper, I., Potapov, P., Evans, T. D., Burgess, N. D., Molnár, Z., Fernández-Llamazares, Á., Duncan, T., Wang, S., Austin, B. J., Jonas, H., Robinson, C. J., Malmer, P., Zander, K. K., Jackson, M. V., Ellis, E., Brondizio, E. S., and Garnett, S. T. (2020). Importance of Indigenous Peoples' lands for the conservation of Intact forest landscapes. *Frontiers in Ecology and the Environment*, *18*(3), 135–140. https://doi.org/10.1002/fee.2148

Filewod, B., and McCarney, G. (2023). Avoiding carbon leakage from nature-based offsets by design. *One Earth*, *6*(7), 790–802. https://doi.org/10.1016/j.oneear.2023.05.024

Forgues, K., Carignan, M.-C., Marchena, B., Mancilla, Lady, Pacheco Ortega, E., Guaynora, A., Pacheco, C., and Potvin, C. (2024). Comparing the long-term carbon offsets and livelihood benefits of a reforestation project with agroforestry, enrichment planting in fallows, native timber mixtures and monocultures [Manuscript submitted for publication]. *Department of Biology, McGill University*.

Fujii, H., Webb, J., Mundree, S., Rowlings, D., Grace, P., Wilson, C., and Managi, S. (2024). Priority change and driving factors in the voluntary carbon offset market. *Cleaner Environmental Systems*, 100164. https://doi.org/10.1016/j.cesys.2024.100164

Fuller, C., Ondei, S., Brook, B. W., and Buettel, J. C. (2019). First, do no harm: A systematic review of deforestation spillovers from protected areas. *Global Ecology and Conservation*, *18*, e00591. https://doi.org/10.1016/j.gecco.2019.e00591

Garnett, S. T., Burgess, N. D., Fa, J. E., Fernández-Llamazares, Á., Molnár, Z., Robinson, C. J., Watson, J. E. M., Zander, K. K., Austin, B., Brondizio, E. S., Collier, N. F., Duncan, T., Ellis, E., Geyle, H., Jackson, M. V., Jonas, H., Malmer, P., McGowan, B., Sivongxay, A., and Leiper, I. (2018). A spatial overview of the global importance of Indigenous lands for conservation. *Nature Sustainability*, *1*(7), 369–374. https://doi.org/10.1038/s41893-018-0100-6

Geilfus, F. (2002). *80 Herramientas para el desarollo participativo: Diagnóstico, planificación monitoreo y evaluación*. Instituto Interamericano de Cooperación para la Agricultura. https://repositorio.iica.int/handle/11324/4129

Giudice, R., Börner, J., Wunder, S., and Cisneros, E. (2019). Selection biases and spillovers from collective conservation incentives in the Peruvian Amazon. *Environmental Research Letters*, *14*(4), 045004. https://doi.org/10.1088/1748-9326/aafc83

Greenfield, P. (2023, January 18). Revealed: More than 90% of rainforest carbon offsets by biggest certifier are worthless, analysis shows. *The Guardian*. https://www.theguardian.com/environment/2023/jan/18/revealed-forest-carbon-offsets-biggest-provider-worthless-verra-aoe

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W. H., Shoch, D., Siikamäki, J. V., Smith, P., Woodbury, P., Zganjar, C., Blackman, A., Campari, J., Conant, R. T., Delgado, C., Elias, P., Gopalakrishna, T., Hamsik, M. R., … Fargione, J. (2017). Natural climate solutions. *Proceedings of the National Academy of Sciences*, *114*(44), 11645–11650. https://doi.org/10.1073/pnas.1710465114

Guizar-Coutiño, A., Jones, J. P. G., Balmford, A., Carmenta, R., and Coomes, D. A. (2022). A global evaluation of the effectiveness of voluntary REDD+ projects at reducing deforestation and degradation in the moist tropics. *Conservation Biology*, *36*(6), e13970. https://doi.org/10.1111/cobi.13970

Hajjar, R., Engbring, G., and Kornhauser, K. (2021). The impacts of REDD+ on the social-ecological resilience of community forests. *Environmental Research Letters*, *16*(2), 024001. https://doi.org/10.1088/1748-9326/abd7ac

Haya, B. K., Abayo, A., So, I. S., and Elias, M. (2024). *Voluntary Registry Offsets Database v11* (Berkeley Carbon Trading Project, University of California, Berkeley) [dataset]. https://gspp.berkeley.edu/research-and-impact/centers/cepp/projects/berkeley-carbon-trading-project/offsets-database

Heilmayr, R., Carlson, K. M., and Benedict, J. J. (2020). Deforestation spillovers from oil palm sustainability certification. *Environmental Research Letters*, *15*(7), 075002. https://doi.org/10.1088/1748-9326/ab7f0c

Henders, S., and Ostwald, M. (2012). Forest carbon leakage quantification methods and their suitability for assessing leakage in REDD. *Forests*, *3*(1), Article 1. https://doi.org/10.3390/f3010033

Holmes, I., Kirby, K. R., and Potvin, C. (2017). Agroforestry within REDD+: Experiences of an indigenous Emberá community in Panama. *Agroforestry Systems*, *91*(6), 1181–1197. https://doi.org/10.1007/s10457-016-0003-3

Holmes, I., and Potvin, C. (2014). Avoiding re-inventing the wheel in a people-centered approach to REDD+. *Conservation Biology*, *28*(5), 1380–1393. https://doi.org/10.1111/cobi.12301

Holmes, I., Potvin, C., and Coomes, O. T. (2017). Early REDD+ implementation: The journey of an Indigenous community in Eastern Panama. *Forests*, *8*(3), Article 3. https://doi.org/10.3390/f8030067

Hultman, N., Lou, J., and Hutton, S. (2020). A review of community co-benefits of the clean development mechanism (CDM). *Environmental Research Letters*, *15*(5), 053002. https://doi.org/10.1088/1748-9326/ab6396

ICAP. (2024). *Emissions trading worldwide: Status report 2024*. International Carbon Action Partnership. https://icapcarbonaction.com/system/files/document/240522_report_final.pdf

IPCC. (2022). *Climate Change 2022: Summary for policymakers*. Cambridge University Press.

IPCC. (2023). *Climate change 2023: Synthesis report* (pp. 35–115). IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647

Jack, B. K., and Cardona Santos, E. (2017). The leakage and livelihood impacts of PES contracts: A targeting experiment in Malawi. *Land Use Policy*, *63*, 645–658. https://doi.org/10.1016/j.landusepol.2016.03.028

Jusys, T. (2018). Changing patterns in deforestation avoidance by different protection types in the Brazilian Amazon. *PLOS ONE*, *13*(4), e0195900. https://doi.org/10.1371/journal.pone.0195900

K C, B., Race, D., Fisher, R., and Jackson, W. (2021). Changing rural livelihoods and forest use transition in the Middle Hills of Nepal. *Small-Scale Forestry*, *20*(3), 479–501. https://doi.org/10.1007/s11842-021-09477-6

Kerr, S. C. (2013). The Economics of International Policy Agreements to Reduce Emissions from Deforestation and Degradation. *Review of Environmental Economics and Policy*, *7*(1), 47–66. https://doi.org/10.1093/reep/res021

Kirby, K. R., and Potvin, C. (2007). Variation in carbon storage among tree species: Implications for the management of a small-scale carbon sink project. *Forest Ecology and Management*, *246*(2), 208–221. https://doi.org/10.1016/j.foreco.2007.03.072

Kreft, C., Angst, M., Huber, R., and Finger, R. (2023). Farmers' social networks and regional spillover effects in agricultural climate change mitigation. *Climatic Change*, *176*(2), 8. https://doi.org/10.1007/s10584-023-03484-6

Kuschnig, N., Cuaresma, J. C., Krisztin, T., and Giljum, S. (2021). Spatial spillover effects from agriculture drive deforestation in Mato Grosso, Brazil. *Scientific Reports*, *11*(1), 21804. https://doi.org/10.1038/s41598-021-00861-y

Larson, A. M., Solis, D., Duchelle, A. E., Atmadja, S., Resosudarmo, I. A. P., Dokken, T., and Komalasari, M. (2018). Gender lessons for climate initiatives: A comparative study of REDD+ impacts on subjective wellbeing. *World Development*, *108*, 86–102. https://doi.org/10.1016/j.worlddev.2018.02.027

Laudari, H. K., Sapkota, L. M., Maraseni, T., Subedi, P., Pariyar, S., Kaini, T. R., Lopchan, S. B., Weston, C., and Volkova, L. (2024). Community forestry in a changing context: A perspective from Nepal's mid-hill. *Land Use Policy*, *138*, 107018. https://doi.org/10.1016/j.landusepol.2023.107018

le Polain de Waroux, Y., Garrett, R. D., Heilmayr, R., and Lambin, E. F. (2016). Land-use policies and corporate investments in agriculture in the Gran Chaco and Chiquitano. *Proceedings* *of the National Academy of Sciences*, *113*(15), 4021–4026. https://doi.org/10.1073/pnas.1602646113

Ley 69 Del 30 de Octubre de 2017, 69, República de Panamá (2017). https://www.sala-seem.org/index.php?preview=1andformat=andoption=com_dropfilesandtask=frontfile.downloadandcatid=79andid=412andItemid=1000000000000

Martínez, K. (2022, July 19). ¿Qué desató las mayores protestas en años en Panamá? *Los Angeles Times*. https://www.latimes.com/espanol/internacional/articulo/2022-07-19/que-desato-las-mayores-protestas-en-anos-en-panama

McGill Office of Sustainability. (2020). McGill establishes fair-trade carbon offsetting project in Panama with new partnership. *McGill Reporter*. https://reporter.mcgill.ca/mcgill-establishes-fair-trade-carbon-offsetting-project-in-panama-with-new-partnership/

McGill University. (2023). *Greenhouse Gas Inventory: 2022 Reporting Year*. McGill University. https://www.mcgill.ca/sustainability/files/sustainability/greenhouse_gas_inventory_report_2022.pdf

Meyfroidt, P., Roy Chowdhury, R., de Bremond, A., Ellis, E. C., Erb, K.-H., Filatova, T., Garrett, R. D., Grove, J. M., Heinimann, A., Kuemmerle, T., Kull, C. A., Lambin, E. F., Landon, Y., le Polain de Waroux, Y., Messerli, P., Müller, D., Nielsen, J. Ø., Peterson, G. D., Rodriguez García, V., … Verburg, P. H. (2018). Middle-range theories of land system change. *Global Environmental Change*, *53*, 52–67. https://doi.org/10.1016/j.gloenvcha.2018.08.006

MiAMBIENTE. (2022). *Estrategia nacional para la Reducción de Emisiones por Deforestación y Degradación de los bosques (Estrategia nacional REDD+)* (p. 137). ENREDD+.

Miranda, J., Börner, J., Kalkuhl, M., and Soares-Filho, B. (2019). Land speculation and conservation policy leakage in Brazil. *Environmental Research Letters*, *14*(4), 045006. https://doi.org/10.1088/1748-9326/ab003a

Morton, O., Borah, J. R., and Edwards, D. P. (2020). Economically viable forest restoration in shifting cultivation landscapes. *Environmental Research Letters*, *15*(6), 064017. https://doi.org/10.1088/1748-9326/ab7f0d

Murray, B. C., McCarl, B. A., and Lee, H.-C. (2004). Estimating leakage from forest carbon sequestration programs. *Land Economics*, *80*(1), 109–124. https://doi.org/10.2307/3147147

Nantongo, M., Vatn, A., and Soka, G. (2024). REDD+: The perfect marriage between conservation and development? A comparative study of the impacts of REDD+ on livelihoods and deforestation in Tanzania. *World Development*, *173*, 106432. https://doi.org/10.1016/j.worlddev.2023.106432

Nolte, C., Agrawal, A., Silvius, K. M., and Soares-Filho, B. S. (2013). Governance regime and location influence avoided deforestation success of protected areas in the Brazilian Amazon. *Proceedings of the National Academy of Sciences*, *110*(13), 4956–4961. https://doi.org/10.1073/pnas.1214786110

Nortcliff, S. (1998). Human activity and the tropical rainforest: Are the soils the forgotten component of the ecosystem? In *Human Activities and the Tropical Rainforest* (pp. 49–64). Kluwer Academic Publishers.

Nunez, S., Verboom, J., and Alkemade, R. (2020). Assessing land-based mitigation implications for biodiversity. *Environmental Science and Policy*, *106*, 68–76. https://doi.org/10.1016/j.envsci.2020.01.006

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science*, *325*(5939), 419–422. https://doi.org/10.1126/science.1172133

Pagiola, S., Honey-Rosés, J., and Freire-González, J. (2016). Evaluation of the permanence of land use change Induced by payments for environmental services in Quindío, Colombia. *PLOS ONE*, *11*(3), e0147829. https://doi.org/10.1371/journal.pone.0147829

Pagiola, S., Ramírez, E., Gobbi, J., de Haan, C., Ibrahim, M., Murgueitio, E., and Ruíz, J. P. (2007). Paying for the environmental services of silvopastoral practices in Nicaragua. *Ecological Economics*, *64*(2), 374–385. https://doi.org/10.1016/j.ecolecon.2007.04.014

Pan, C., Shrestha, A., Innes, J. L., Zhou, G., Li, N., Li, J., He, Y., Sheng, C., Niles, J.-O., and Wang, G. (2022). Key challenges and approaches to addressing barriers in forest carbon offset projects. *Journal of Forestry Research*. https://doi.org/10.1007/s11676-022-01488-z

Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., Phillips, O. L., Shvidenko, A., Lewis, S. L., Canadell, J. G., Ciais, P., Jackson, R. B., Pacala, S. W., McGuire, A. D., Piao, S., Rautiainen, A., Sitch, S., and Hayes, D. (2011). A large and persistent carbon sink in the world's forests. *Science*, *333*(6045), 988–993. https://doi.org/10.1126/science.1201609

Paredes, M., and Kaulard, A. (2022). Forest as 'nature' or forest as territory? Knowledge, power, and climate change conservation in the Peruvian Amazon. *The Journal of Peasant Studies*, *0*(0), 1–22. https://doi.org/10.1080/03066150.2022.2134010

Peras, R. J., Pulhin, J., Inoue, M., Mohammed, A. J., Harada, K., and Sasaoka, M. (2016). The sustainable livelihood challenge of REDD+ implementation in the Philippines.

Environment and Natural Resources Research, *6*(3), Article 3. https://doi.org/10.5539/enrr.v6n3p91

Philemon, T. (2021). The Uluguru Payment for Ecosystem Services (PES) Programme in Tanzania: Can Livelihoods Benefits between PES Participants and Non-participants Go Beyond Implementation? *Tanzania Journal of Development Studies*, *19*(1), Article 1.

Polzot, C. L. (2004). *Carbon storage in coffee agroecosystems of Southern Costa Rica: Potential applications for the Clean Development Mechanism*. York University.

Potvin, C., and Mateo-Vega, J. (2013). Curb indigenous fears of REDD+. *Nature*, *500*(7463), 400–400. https://doi.org/10.1038/500400e

Potvin, C., Tschakert, P., Lebel, F., Kirby, K., Barrios, H., Bocariza, J., Caisamo, J., Caisamo, L., Cansari, C., Casamá, J., Casamá, M., Chamorra, L., Dumasa, N., Goldenberg, S., Guainora, V., Hayes, P., Moore, T., and Ruíz, J. (2007). A participatory approach to the establishment of a baseline scenario for a reforestation Clean Development Mechanism project. *Mitigation and Adaptation Strategies for Global Change*, *12*(8), 1341–1362. https://doi.org/10.1007/s11027-006-9056-3

Rasch, S., Wünscher, T., Casasola, F., Ibrahim, M., and Storm, H. (2021). Permanence of PES and the role of social context in the Regional Integrated Silvo-pastoral Ecosystem Management Project in Costa Rica. *Ecological Economics*, *185*, 107027. https://doi.org/10.1016/j.ecolecon.2021.107027

Rey Christen, D., García Espinosa, M., Reumann, A., and Puri, J. (2020). Results based payments for REDD+ under the Green Climate Fund: Lessons learned on social, environmental and governance safeguards. *Forests*, *11*(12), Article 12. https://doi.org/10.3390/f11121350

Reyes-García, V., García-del-Amo, D., Álvarez-Fernández, S., Benyei, P., Calvet-Mir, L., Junqueira, A. B., Labeyrie, V., Li, X., Miñarro, S., Porcher, V., Porcuna-Ferrer, A., Schlingmann, A., Schunko, C., Soleymani, R., Tofighi-Niaki, A., Abazeri, M., Attoh, E. M. N. A. N., Ayanlade, A., Ávila, J. V. D. C., … Zakari, I. S. (2024). Indigenous Peoples and local communities report ongoing and widespread climate change impacts on local social-ecological systems. *Communications Earth and Environment*, *5*(1), Article 1. https://doi.org/10.1038/s43247-023-01164-y

Rigg, J. (2007). Making a living in the Global South: Livelihood transitions. In *An Everyday Geography of the Global South*. Routledge.

Robalino, J. A., and Pfaff, A. (2012). Contagious development: Neighbor interactions in deforestation. *Journal of Development Economics*, *97*(2), 427–436. https://doi.org/10.1016/j.jdeveco.2011.06.003

Schultz, L., Folke, C., Österblom, H., and Olsson, P. (2015). Adaptive governance, ecosystem management, and natural capital. *Proceedings of the National Academy of Sciences*, *112*(24), 7369–7374. https://doi.org/10.1073/pnas.1406493112

Schweikart, M., Mertz, O., and Müller, D. (2022). Adaptive approaches to REDD+ are needed for countries with high forest cover and low deforestation rates. *Environmental Research Letters*, *17*(11), 114011. https://doi.org/10.1088/1748-9326/ac9827

Scoones, I. (1998). *Sustainable rural livelihoods: A framework for analysis* (IDS Working Paper 72). IDS. https://opendocs.ids.ac.uk/opendocs/handle/20.500.12413/3390

Scoones, I. (2015). *Sustainable livelihoods and rural development*. Fernwood Publishing.

Segura, M., Kanninen, M., and Suárez, D. (2006). Allometric models for estimating aboveground biomass of shade trees and coffee bushes grown together. *Agroforestry Systems*, *68*(2), 143–150. https://doi.org/10.1007/s10457-006-9005-x

Sharma, D., Holmes, I., Vergara-Asenjo, G., Miller, W. N., Cunampio, M., B. Cunampio, R., B. Cunampio, M., and Potvin, C. (2016). A comparison of influences on the landscape of two social-ecological systems. *Land Use Policy*, *57*, 499–513. https://doi.org/10.1016/j.landusepol.2016.06.018

Sharma, S. K., Telfer, M., Phua, S. T. G., and Chandler, H. (2012). A pragmatic method for estimating greenhouse gas emissions from leakage for Improved Forest Management projects under the Verified Carbon Standard. *Greenhouse Gas Measurement and Management*, *2*(1), 22–32. https://doi.org/10.1080/20430779.2012.696237

Shinbrot, X. A., Holmes, I., Gauthier, M., Tschakert, P., Wilkins, Z., Baragón, L., Opúa, B., and Potvin, C. (2022). Natural and financial impacts of payments for forest carbon offset: A 14 year-long case study in an indigenous community in Panama. *Land Use Policy*, *115*, 106047. https://doi.org/10.1016/j.landusepol.2022.106047

Sonderegger, G., Heinimann, A., Diogo, V., and Oberlack, C. (2022). Governing spillovers of agricultural land use through voluntary sustainability standards: A coverage analysis of sustainability requirements. *Earth System Governance*, *14*, 100158. https://doi.org/10.1016/j.esg.2022.100158

Streck, C. (2011). Ensuring New Finance and Real Emission Reduction: A Critical Review of the Additionality Concept Thematic Focus: Climate Change Governance - The International Regime Complex. *Carbon & Climate Law Review*, *2011*(2), 158–168.

Streck, C. (2021). REDD+ and leakage: Debunking myths and promoting integrated solutions. *Climate Policy*, *21*(6), 843–852. https://doi.org/10.1080/14693062.2021.1920363

STRI. (2018, June 27). *Reducing our carbon footprint*. Smithsonian Tropical Research Institute; Smithsonian Tropical Research Institute. https://stri.si.edu/story/reducing-our-carbon-footprint

Sunderlin, W. D., De Sassi, C., Ekaputri, A. D., Light, M., and Pratama, C. D. (2017). REDD+ Contribution to Well-Being and Income Is Marginal: The Perspective of Local Stakeholders. *Forests*, *8*(4), Article 4. https://doi.org/10.3390/f8040125

Swingland, I. R., Bettelheim, E. C., Grace, J., Prance, G. T., Saunders, L. S., Schwarze, R., Niles, J. O., and Olander, J. (2002). Understanding and managing leakage in forest–based greenhouse–gas–mitigation projects. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, *360*(1797), 1685–1703. https://doi.org/10.1098/rsta.2002.1040

Sze, J. S., Carrasco, L. R., Childs, D., and Edwards, D. P. (2022). Reduced deforestation and degradation in Indigenous Lands pan-tropically. *Nature Sustainability*, *5*(2), Article 2. https://doi.org/10.1038/s41893-021-00815-2

Tacconi, L., Mahanty, S., and Suich, H. (2013). The livelihood impacts of Payments for Environmental Services and implications for REDD+. *Society and Natural Resources*, *26*(6), 733–744. https://doi.org/10.1080/08941920.2012.724151

Taylor, S. (2016). *Environmental conservation as an instrument of national political economy: Culture, livelihoods, and territorial rights of the Emberá of Panama* [Clark University]. https://commons.clarku.edu/idce_masters_papers/41

Tschakert, P., Coomes, O. T., and Potvin, C. (2007). Indigenous livelihoods, slash-and-burn agriculture, and carbon stocks in Eastern Panama. *Ecological Economics*, *60*(4), 807–820. https://doi.org/10.1016/j.ecolecon.2006.02.001

Turner, S. (2017). Livelihoods. In *International Encyclopedia of Geography* (pp. 1–9). John Wiley and Sons, Ltd. https://doi.org/10.1002/9781118786352.wbieg0838

United Nations Framework Convention on Climate Change. (2021). *CDM Methodology Booklet* (13; p. 286). UNFCCC. https://cdm.unfccc.int/methodologies/documentation/meth_booklet.pdf

UN-REDD. (2022). *2022 consolidated annual progress report of the UN-REDD Programme Fund* (Annual Report 14). https://www.un-redd.org/sites/default/files/2023-08/UNREDD_AnnualReport2022_10Aug_FINAL.pdf

Vergara-Asenjo, G., Mateo-Vega, J., Alvarado, A., and Potvin, C. (2017). A participatory approach to elucidate the consequences of land invasions on REDD+ initiatives: A case study with

Indigenous communities in Panama. *PLOS ONE*, *12*(12), e0189463. https://doi.org/10.1371/journal.pone.0189463

Wali, Alaka. (1989). *Kilowatts and crisis: Hydroelectric power and social dislocation in eastern Panama*. Westview Press.

Walker, K. L. (2021). Effect of land tenure on forest cover and the paradox of private titling in Panama. *Land Use Policy*, *109*, 105632. https://doi.org/10.1016/j.landusepol.2021.105632

Wang, Y., Möhring, N., and Finger, R. (2021). When my neighbors matter: Spillover effects in the adoption of large-scale pesticide-free wheat production. *Agricultural Economics*, *n/a*(n/a). https://doi.org/10.1111/agec.12766

West, T. A. P., Börner, J., Sills, E. O., and Kontoleon, A. (2020). Overstated carbon emission reductions from voluntary REDD+ projects in the Brazilian Amazon. *Proceedings of the National Academy of Sciences*, *117*(39), 24188–24194. https://doi.org/10.1073/pnas.2004334117

West, T. A. P., Wunder, S., Sills, E. O., Börner, J., Rifai, S. W., Neidermeier, A. N., Frey, G. P., and Kontoleon, A. (2023). Action needed to make carbon offsets from forest conservation work for climate change mitigation. *Science*, *381*(6660), 873–877. https://doi.org/10.1126/science.ade3535

Williams, B. K. (2011). Adaptive management of natural resources—Framework and issues. *Journal of Environmental Management*, *92*(5), 1346–1353. https://doi.org/10.1016/j.jenvman.2010.10.041

World Resources Institute. (2003). *A Corporate Accounting and Reporting Standard*. World Resources Institute.

Wunder, S. (2008). How do we deal with leakage? *Moving Ahead with REDD Issues, Options and Implications*.

Wunder, S., Duchelle, A. E., Sassi, C. de, Sills, E. O., Simonet, G., and Sunderlin, W. D. (2020). REDD+ in theory and practice: How lessons from local projects can inform jurisdictional approaches. *Frontiers in Forests and Global Change*, *3*. https://www.frontiersin.org/article/10.3389/ffgc.2020.00011

Zant, M., Schlingmann, A., Reyes-García, V., and García-del-Amo, D. (2024). Incremental and transformational adaptation to climate change among Indigenous Peoples and local communities: A global review. *Mitigation and Adaptation Strategies for Global Change*, *28*(8), 57. https://doi.org/10.1007/s11027-023-10095-0

Zhang, Q., Wang, Y., Tao, S., Bilsborrow, R. E., Qiu, T., Liu, C., Sannigrahi, S., Li, Q., and Song, C. (2020). Divergent socioeconomic-ecological outcomes of China's conversion of cropland to forest program in the subtropical mountainous area and the semi-arid Loess Plateau. *Ecosystem Services*, *45*, 101167. https://doi.org/10.1016/j.ecoser.2020.101167

APPENDICES

Appendix 1. Household interview topic check-list

Family

- Where and when were you born?
- and migration history
- How, when, and why did you come to Ipetí? How was the village then?
- Children?
- Family members' education history

Land and livelihood-related

- How did you secure your *parcela?* What was on it then?
- What did you do on it first? What does it look like now? *(sketch)*
- What crops have you cultivated? How has that changed over time?
- Are specific crops for household consumption or destined for sale?
- Have cultivation methods changed?
- What sells well and poorly? How are crops sold?
- Do you get help for farmwork? Do you work on other people's farm?
- Do you rent land out to other people? How does that work?
- Have you ever had livestock?
- What land covers can be found on your *parcela* now?¿qué otros trabajos han tenido los miembros de su familia?
- Do you engage in…
    - Day labor?
    - Salaried work in our outside the community?
    - Craft sale?

FCOP

- Why did you decide to participate (or not)?
- How did you first hear of the project?

- (for participants) What was there on your reforestation plot before you planted the trees? If you were using that plot, how did you replace that source of income or food?
- How has been your experience with the project?

SOCIO-ECOLOGICAL CHANGES

- How has life in the community changed in the last few decades?
    - Environment and climate change?
    - Health?
    - Socially?
    - Economically?
- How did that happen? How were you affected?

TO CONCLUDE

- Would you say your well-being as a household has increased, remained stable, or decreased since 2000? How so?
- What’s your dream for your family?