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The Potential of Certification for Climate Change Mitigation in the Agri-Food Sector

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A case study of carbon neutral certified coffee from Costa Rica

Dissertation
Submitted in fulfilment of the requirements for the degree of
"Doktor der Agrarwissenschaften"
(Dr. sc. agr./Ph.D. in Agricultural Sciences)

To the Faculty of Agricultural Sciences

Presented by

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Born in Meersburg, Germany

- November 2017 -

This thesis was accepted as a doctoral dissertation in fulfillment of the requirements for the degree "Doctor of Agricultural Sciences" (Dr. sc. agr.) by the Faculty of Agricultural Sciences at the University of Hohenheim.

Date of oral examination: 25 July 2018

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This study was financed by

UNIVERSITY OF HOHENHEIM

Baden-Württemberg
MINISTERIUM FÜR WISSENSCHAFT, FORSCHUNG UND KUNST

Promotionsstipendium der Fakultät Agrarwissenschaften der Universität Hohenheim nach dem Landesgraduiertenförderungsgesetz (LGFG) des Landes Baden-Württemberg

DAAD
Deutscher Akademischer Austausch Dienst
Servicio Alemán de Intercambio Académico

Grant No. 50015186 GRAFÖG - Aufstockung auf die

Stiftung fiat panis

Financial support of field research.

FAZIT-STIFTUNG

Abschlussstipendium

I dedicate this thesis to my beloved daughter Gianna, who shared in every step of this journey, and whose great patience and strength lit my path all along the way.

Ich widme diese Arbeit meiner wundervollen, liebenswürdigen und starken Tochter Gianna, die mich in allen Schritten auf dieser Reise begleitet hat!

Acknowledgements

This thesis is the product of the dedication, hard work, and commitment from many besides me. First, I would like to thank Professor Regina Birner for her incredible and endless support, guidance, helpful suggestions, and optimism. Her personal interest in my work provided me the opportunity to explore topics which motivate me as well as to explore, experience, and research new avenues. I would also like to thank Dr. Thomas Hilger for his encouragement, valuable presence at the institute, and for his pointed questions, his thoughtful insight and guidance. Moreover, I thank Professor Ulrike Grote and Professor Georg Cadisch for taking the time to review my dissertation and being part of the committee. I express my gratitude to the Faculty of Agricultural Sciences at the University of Hohenheim for accepting me as a scholarship holder of the program Landesgraduiertenförderungsgesetz, Baden-Württemberg. I'm also very grateful to the FAZIT-foundation for providing me a scholarship to finalize my dissertation. I thank the German Academic Exchange Service (DAAD) for supporting my field research in Costa Rica and for enabling the empirical data collection. I'm especially thankful to the foundation fiat panis, for providing me with field research funds and their constant financial support throughout my research career.

I wish to acknowledge the excellent collaboration and outstanding assistance with Dr. Olman Quirós Madrigal and Luis Losilla from the Universidad de Costa Rica (UCR), which was essential for this study. This study would not have been possible without the outstanding support of Roberto Mata and Daniel Ureña from Coopedota R.L. I'm particularly thankful for Daniela Ureña, who supported me with my daughter in the field. I am also profoundly appreciative of the coffee farmers and villagers of Santa Maria de Dota, and all respondents for allowing me into their homes and for continuing to take part in the survey. I could never have anticipated their kindness, hospitality, warm smiles, and sincerity. I'm very grateful to Olivier Roupsard from CATIE-CIRAD for spending time with me, discussing my research and for providing me the valuable insights on their activities regarding NAMA at the hazienda Aquiares, Turialba.

I also wish to acknowledge the excellent collaboration with Josue Ruiz and Martina Hunzelmann from Hochland Kaffee Hunzelmann GmbH, and the kind staff of the roastery.

I thank my colleagues Sigrun Wagner, who joint me in the field, and Bettina Reiser and Manuel Narjes for their time, support and essential contributions to this dissertation.

I would like to express my heartfelt thanks to Semra Fetahovic, Sandhya Kumar, Katie Mackie-Haas, Lilli Scheiterle, Verena Gründler, Johannes Mössinger and Christine Bosch for their critical comments and editorial support.

I especially thank all my colleagues at the University of Hohenheim, my close friends and my family for being at my side, for their constant and fundamental support, encouragement and exchange of ideas.

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Executive Summary

Advancing economic, social and environmental sustainability in the agri-food sector is increasingly pursued by various actors along global value chains. One option to address sustainability concerns is to use voluntary sustainability standards and certifications/labels as market-based governance tools for self-regulation. Recently, the demand for particular climate standards and labels has increased, however little is known about their potential and challenges. Individual aspects of such voluntary sustainability certifications have been investigated, such as the effectiveness and impact of certifications or the purchasing decisions of consumers. However, a holistic and interdisciplinary approach by considering the complete value chain is rare and, thus challenges are overlooked and proposed solutions remain limited in scope. Moreover, LCA-based certifications addressing climate change mitigation present a new field of research.

Against this background, this thesis aims to elicit the challenges and potential of sustainability certification in the agri-food sector. Taking the case of the world's first carbon neutral certified coffee, the complete chain – from standard development to consumer choices – has been examined. This coffee is produced by Coopedota, a Costa Rican cooperative of small-scale farmers, and exported to a family-run specialty coffee roaster, Hochland Kaffee Hunzelmann GmbH, in Germany. In the case under consideration, a newly released and highly prescriptive standard for carbon neutrality, the Publicly Available Specification (PAS) 2060, has been adopted since 2011. PAS 2060 is the first independent international standard for carbon neutrality that provides a common definition and a recognized method that is based on a life cycle assessment (LCA). To achieve carbon neutrality, the respective greenhouse gas (GHG) emissions are compiled, before continuous reduction activities are executed and the residual GHG emissions are offset by purchasing carbon credits. Costa Rica is relevant because it is actively pursuing carbon neutrality at the national level and the case of Coopedota serves as a pioneer in this field.

In this thesis, an interdisciplinary case study approach is used to investigate in a holistic manner the challenges of carbon neutral certification in the agri-food sector. The study is guided by a conceptual framework developed from relevant literature on voluntary sustainability standards. The three specific objectives of the thesis are: (1) identify the success factors that made the carbon neutral certification in Coopedota possible and understanding the major challenges related to the standards implementation; (2) estimate the potential of on-farm carbon

sequestration to compensate for the coffee carbon footprint and reduce carbon offsetting; and (3) estimate the willingness to pay for a carbon neutral label among German consumers of specialty coffee.

This thesis contains three main chapters in addition to a general introduction and discussion. The first chapter addresses existing knowledge gaps regarding the role of social network dynamics, actor characteristics and linkages for successful pioneering in sustainable development, and investigates the challenges of implementing PAS 2060 by Coopedota. Qualitative research methods, such as in-depth interviews, participatory social network and process mapping as well as field observations were applied. The study found the prior achievements of the cooperative (e.g. compliance to ISO norms) and a 'fertile ground' in terms of ongoing climate change mitigation policies, as important factors for the successful implementation of the standard. Further success factors were a strong central and visionary actor and a diverse network of supporting actors from science, business and politics. The main challenges in implementing the carbon neutral certification were the acquirement of reliable farm data and the advertisement and communication of a carbon neutral label.

The second chapter focuses on the problem that biogenic carbon sequestration is rarely considered in LCA-based standards. To estimate the annual potential of biogenic carbon accounting in coffee-agroforestry systems (CAFS) a literature review was conducted and the carbon sequestration based on a carbon inventory at the coffee farms was modeled. The results of a 20-year simulation show that on average, CAFS at Coopedota can compensate the carbon footprint of coffee by approximately 160% annually. Simultaneously, a trade-off between carbon sequestration and productivity at reduced inputs appears, which should be minimized.

In the third chapter a marginal willingness to pay (WTP) of € 1.70 for a carbon neutral label was identified on a 250g package of specialty coffee by a discrete choice experiment among German consumers. Yet this marginal WTP was lower than the marginal WTP among the same consumers for direct trade claims or a Fair Trade certificate. Direct trade claims refer to the situation where direct trade relations exist; however, they are not certified and only declared by the retailer, as in the case of the family-run coffee roaster Hochland Kaffee Hunzelmann GmbH. Moreover, a positive synergistic effect was discovered for the combination of the carbon neutral label with direct trade claims. However, a public awareness on the contribution of agriculture to climate change is missing, as is the familiarity of the public with carbon concepts.

Concluding, LCA-based certification for carbon neutrality can be a promising market-based tool for the agri-food sector to mitigate climate change. Such certification holds promise because it addresses recent demands for climate relevant information on agri-food products, while benefitting producers, the environment and consumers alike. Examples of these benefits include a potential increase in resource use efficiency, identification and minimization of GHG emission hot spots and trustworthiness among consumers due to the prescriptive nature of the standards.

Additionally, the interdisciplinary case study approach enabled the identification of multi-faceted challenges and recommendations. One recommendation is that an agricultural perspective needs to be integrated into the standard by, for example, enabling the accounting of biogenic carbon sequestration. Such carbon accounting would prevent criticism of carbon offsetting and foster synergies between climate change mitigation, sustainability, and resilience. Particularly in the case of higher carbon prices, carbon accounting would be economically interesting but further research is needed to provide a robust dataset to enable it. Independent from a potential premium price for the label, access to capital and governmental support programs, especially for smallholders in less developed countries, can foster the implementation of greener technologies and allow stakeholders to benefit from increased efficiencies. The findings of this thesis indicate that coupling a carbon standard with existing sustainability standards, which use similar datasets, could ease the acquirement of reliable farm data on GHG emissions and reduce costs. Moreover, a coupling of standards could ensure additional sustainability practices, beyond the climate aspect, as already associated by consumers. This study also indicates that to establish markets for carbon neutral products, consumers first have to be aware of the extent of the agri-food sector’s contribution to climate change and consumer responsibility in tackling this problem through their purchasing behavior. This thesis further illustrates the importance of innovators in advancing development goals. Taking action on climate change mitigation and shaping a more sustainable agri-food sector requires strong initiatives and visionaries on the ground, as exemplified by the pioneering case of Coopedota.

Zusammenfassung

Entlang globaler Wertschöpfungsketten im Agrar- und Lebensmittelsektor gibt es einen steigenden Bedarf an ökonomischen, sozialen und ökologischen Nachhaltigkeitsaspekten. Eine Möglichkeit, Nachhaltigkeitsprobleme anzugehen, bieten freiwillige Nachhaltigkeitsstandards und -zertifizierungen bzw. Labels, die als marktwirtschaftliche Instrumente zur Selbstregulierung genutzt werden. In den letzten Jahren hat die Nachfrage nach Standards und Zertifizierungen mit Klimabezug wesentlich zugenommen. Dennoch ist bisher wenig hinsichtlich ihrer Potentiale und Schwachstellen bekannt. Einzelne Aspekte solcher freiwilligen Nachhaltigkeitszertifizierungen wurden bereits häufiger untersucht, wie zum Beispiel deren Effektivität und Wirkung oder das Kaufverhalten der Konsumenten. Sehr selten wurden jedoch ganzheitliche und interdisziplinäre Ansätze, welche die gesamte Wertschöpfungskette im Blick haben, betrachtet. Dadurch wurden Herausforderungen übersehen und Lösungsvorschläge blieben in ihrer Nützlichkeit eingeschränkt. Gleichzeitig stellen Zertifizierungen, die sich mit der Eindämmung des Klimawandels beschäftigen, ein neues Forschungsgebiet dar.

Daher ist es das Ziel dieser Arbeit, die Herausforderungen und Potentiale von Nachhaltigkeitszertifizierungen im Agrar- und Lebensmittelsektor zu analysieren. Am Beispiel des weltweit ersten klimaneutral zertifizierten Kaffees, wird - von der Normentwicklung bis zum Verbraucherverhalten - die gesamte globale Wertschöpfungskette betrachtet. Dieser Kaffee wird von der costa-ricanischen Kleinbauernkooperative Coopedota angebaut und verarbeitet. Die Kaffeebohnen werden unter anderem nach Deutschland exportiert und von der Familienrösterei für Qualitätskaffee, Hochland Kaffee Hunzelmann GmbH, geröstet und verkauft. Seit 2011 wird im vorliegenden Fall der neu entwickelte und in hohem Maße präskriptive Standard für Klimaneutralität, der Publicly Available Specification (PAS) 2060, angewandt. PAS 2060 ist der weltweit erste unabhängige Standard für Klimaneutralität, der über eine allgemeingültige Definition und eine anerkannte Methodik nach dem Prinzip der Ökobilanzierung verfügt.

Das Konzept der Klimaneutralität bezieht sich auf den Zustand, in welchem ein Produkt, Prozess oder eine Organisation während einer bestimmten Zeit keine Nettoauswirkung auf den Klimawandel hat. Um Klimaneutralität zu erreichen, werden die jeweiligen Treibhausgasemissionen ermittelt, bevor fortlaufende, emissionsmindernde Tätigkeiten durchgeführt werden und die verbleibenden Treibhausgasemissionen durch den Erwerb von Kohlenstoffzertifikaten ausgeglichen werden. Dem Land Costa Rica kommt hier eine

besondere Bedeutung zu, da es auf nationaler Ebene aktiv die Klimaneutralität anstrebt und die Kaffeekooperative Coopedota dabei eine Vorreiterrolle einnimmt.

Diese Dissertation verfolgt einen interdisziplinären Ansatz in Form einer Fallstudie, um die Herausforderungen einer im Agrar- und Lebensmittelsektor angewandten Klimaneutralitätszertifizierung ganzheitlich zu untersuchen. Der Studie liegt ein eigens entwickelter konzeptioneller Rahmen zugrunde, der sich an relevanter Literatur zu freiwilligen Nachhaltigkeitsstandards orientiert. Die drei Ziele der Dissertation sind: (1) Erfolgsfaktoren zu identifizieren, welche die klimaneutrale Zertifizierung von Coopedota ermöglicht haben und die hauptsächlichen Herausforderungen in Bezug auf die Umsetzung des Standards zu verstehen. (2) Das Potential der Plantagen für Kohlenstofffixierung abzuschätzen, um den CO_2-Fussabdruck des Kaffees auszugleichen. (3) Die Zahlungsbereitschaft für ein klimaneutrales Label unter deutschen Qualitätskaffeekunden zu ermitteln.

Neben der Einleitung und Diskussion besteht die Dissertation aus drei Kapiteln. Das erste Kapitel zielt darauf ab, die bestehenden Wissenslücken in Bezug auf die Rolle sozialer Netzwerkdynamiken und die Rolle der Merkmale und Verbindungen von Akteuren für eine erfolgreiche, entwicklungsrelevante Pionierarbeit zu schließen. Des Weiteren werden die Herausforderungen in der Umsetzung von PAS 2060 durch die Kooperative untersucht. Dafür wurden qualitative Forschungsmethoden, wie Intensivinterviews, partizipative Kartierung von Prozessen und sozialen Netzwerken, sowie Feldbeobachtungen angewandt. Die Studie hat die bereits bestehenden Errungenschaften der Kooperative (z.B. ISO Zertifizierungen) und einen fruchtbaren Boden im Sinne von politischen Klimaschutzprogrammen als wichtige Erfolgsfaktoren identifiziert. Weitere Erfolgsfaktoren waren ein starker, zentraler und visionärer Handlungsträger der Kaffeekooperative, und ein vielseitiges Netzwerk von unterstützenden Akteuren aus Wissenschaft, Wirtschaft und Politik. Die zentralen Herausforderungen in der Durchführung einer klimaneutralen Zertifizierung bestanden in der Beschaffung zuverlässiger Betriebsdaten und der Vermarktung und Kommunikation eines Klimaneutralitätslabels.

Das zweite Kapitel beschäftigt sich mit dem Problem, dass die biogene Fixierung von Kohlenstoff in Standards, die auf Ökobilanzierung basieren, kaum berücksichtigt wird. Um das jährliche Potential der biogenen Kohlenstofffixierung in Kaffee-Agroforst-Systemen zu erfassen, wurden Daten aus der Literatur und aus dem Feld ausgewertet. Auf dieser Grundlage konnte die Kohlenstofffixierung basierend auf einer Kohlenstofferfassung in den Kaffeeplantagen modelliert werden. Die Ergebnisse der Simulationen besagen, dass über einen

Zeitraum von 20 Jahren durchschnittlich etwa 160% des jährlichen CO_2-Fussabdrucks von Kaffee durch die Kaffee-Agroforst-Plantagen von Coopedota ausgeglichen werden könnten. Gleichzeitig stellt sich ein Zielkonflikt zwischen Kohlenstofffixierung und Ertragsfähigkeit bei verringerten Inputs heraus, den es zu minimieren gilt. Im dritten Kapitel wurde eine marginale Zahlungsbereitschaft deutscher Konsumenten von € 1.70 für ein klimaneutrales Label auf einer 250g Packung Qualitätskaffee mit Hilfe eines Discrete-Choice-Experiments ermittelt. Diese lag jedoch unter der marginalen Zahlungsbereitschaft derselben Konsumenten für nicht-zertifizierte direkte Handelsbeziehungen oder ein Fair Trade Label. Zudem wurde in dem Fall einer Kombination des Klimaneutralitätslabels mit einer deklarierten direkten Handelsbeziehung ein positiver synergetischer Effekt auf die Zahlungsbereitschaft gefunden. Allerdings ließ sich auch feststellen, dass das Bewusstsein der Öffentlichkeit für den Beitrag der Landwirtschaft zum Klimawandel, ebenso wie eine Vertrautheit mit den zu Grunde liegenden Klimaschutzkonzepten, sehr gering ist.

Aus der Dissertation ergibt sich, dass eine Klimaneutralitätszertifizierung, die auf Ökobilanzierung basiert, ein vielversprechendes, marktwirtschaftliches Werkzeug sein kann, um den Beitrag des Agrar- und Lebensmittelsektors zum Klimawandel zu reduzieren. Solch eine Zertifizierung ist zukunftsträchtig, da sie zum einen die jüngste Nachfrage nach klimarelevanten Informationen auf Produkten bedient und zum anderen, da Produzenten, die Umwelt und auch Konsumenten davon profitieren können. Beispiele dafür sind eine potentiell erhöhte Effizienz der Ressourcennutzung, die Identifizierung und Minimierung von Emissions-Hot-Spots und eine gesteigerte Glaubwürdigkeit gegenüber Konsumenten durch den präskriptiven Charakter des Standards.

Dank des interdisziplinären Forschungsansatzes in Format einer Fallstudie konnten, zusätzlich zu den Potentialen, auch die vielschichtigen Herausforderungen einer Klimaneutralitätszertifizierung identifiziert werden, aus denen sich Empfehlungen ableiten lassen. Eine dieser Empfehlungen ist es, eine landwirtschaftliche Perspektive in den Standard zu integrieren, z.B. indem biogene Kohlenstofffixierung berücksichtigt wird. Durch die Berücksichtigung der Kohlenstoffspeicherung in den Plantagen würde die Kritik am Emissionshandel vermieden werden und Synergien zwischen der Eindämmung des Klimawandels, Nachhaltigkeit und Resilienz gefördert werden. Eine Anerkennung der biogenen Kohlenstoffspeicherung wäre, besonders im Fall von höheren internationalen Kohlenstoffpreisen, auch wirtschaftlich interessant. Gleichzeitig bedarf es hier weiterer Forschung, um robustere Datensätze zur Verfügung zu stellen. Unabhängig von potentiellen

Premium-Preisen, bedürfen vor allem Kleinbauern in wirtschaftlich schwächeren Ländern einer verstärkten Zuwendung durch Regierungsprogramme, um den Zugang zu grünen Technologien zu gewährleisten und damit von der erhöhten Effizienz zu profitieren.

Ein weiteres Ergebnis der Dissertation zeigt, dass die Kopplung eines Kohlestoffstandards mit bestehenden Nachhaltigkeitsstandards, die ähnliche Datensätze verwenden, die Erhebung verlässlicher Daten über Treibhausgasemissionen erleichtert und die Kosten senken kann. Darüber hinaus könnte eine Kopplung von Standards weitere Nachhaltigkeitspraktiken sicherstellen, die über den Klimaaspekt hinausgehen, wie es bereits von Verbrauchern assoziiert wird. Außerdem deutet die Studie auch darauf hin, dass zur Etablierung von Märkten für klimaneutrale Produkte Verbraucher sich zunächst darüber bewusstwerden müssen, dass der Beitrag des Agrar- und Lebensmittelsektors zum Klimawandel ein erhebliches Problem darstellt, wofür sie sich in ihrem Kaufverhalten verantwortlich zeigen können und sollten. Insgesamt lässt sich festhalten, dass Pionieren eine enorme Bedeutung innerhalb der Entwicklungsarbeit zukommt. Maßnahmen zur Eindämmung des Klimawandels und die gleichzeitige Ausgestaltung eines nachhaltigeren Agrar- und Lebensmittelsektors erfordern daher starke Initiativen und Visionäre, wie das Vorreiterprojekt Coopedota.

List of Abbreviations and Acronyms

4C	Association Common Code for the Coffee Community
AED	La Asociación Empresarial para el Desarrollo (Business association for development) (Costa Rica)
AFOLU	Agriculture, forestry, and other land use
AGC	Aboveground Carbon
ASC	Alternative specific constant
BGC	Belowground Carbon
BN	Banco Nacional (national bank)
BSI	British Standards Institution
CAFS	Coffee Agroforestry Systems
CATIE	Tropical Agricultural Research and Higher Education Center (Costa Rica)
CATSA	Central Azucarera Tempisque, S. A. (Tempisque Sugar Cane Industries) (Costa Rica)
CF	Carbon Footprint
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement (French agricultural research and international cooperation organization)
CN	Carbon Neutrality
CO2	Carbon dioxide
COP	Conference of the Parties
CS	Carbon Sequestration
DCC	Direccion de Cambio Climatico (Climate change devision of the ministry for environment) (Costa Rica)
DCE	Discrete Choice Experiment
DT	Direct Trade
EARTH	Universidad EARTH, *Escuela de Agricultura de la Región Tropical Húmeda*
EPD	Environmental Production Declaration
FT	Fair Trade
FONAFIFO	Fondo de Financiamiento Forestal de Costa Rica (National Fund on Forest Financing)
GAP	Good Agricultural Practices
GDP	Gross domestic product
GHG	Greenhouse gas
GIZ	Gesellschaft für Internationale Zusammenarbeit (German Agency for International Cooperation)
GmbH	Gesellschaft mit beschränkter Haftung (company with limited liability)
ICABR	International Consortium on Applied Bioeconomy Research
ICAFE	Instituto del café de Costa Rica (Coffee Institute of Costa Rica)
ICO	International Coffee Organization
INCAE	Instituto Centroamericano de Administración de Empresas (Latin-American Business School)

INTECO	Instituto de Normas Tecnicas de Costa Rica (Institute of Technical Standards of Costa Rica)
ISO	International Standards Organization
LCA	Life Cycle Assessment
LUC	Land Use Change
MAG	Ministerio de Agricultura y Agropequario (Ministry of Agriculture and Livestock) (Costa Rica)
MICIT	Ministry of Research and Technology (Costa Rica)
MINAE	Ministry of Environment and Energy (Costa Rica)
MINSA	Ministerio de Salud (Ministry of Health) (Costa Rica)
NAMAs	National Appropriate Mitigation Actions
NDCs	Nationally Determined Contributions
NGO	Nongovernmental Organization
PAS	Publicly Available Specification
PCF	Product Carbon Footprint
PES	Payments for Environmental Services
QR-Code	Quick response code
RUE	Resource Use Efficiency
SAN	Sustainable Agriculture Network
SCAA	Specialty Coffee Association of America
SFS	School of Field Studies University Costa Rica
SNA	Social Network Analysis
SOC	Soil Organic Carbon
UCR	Universidad de Costa Rica (University of Costa Rica)
UK	United Kingdom
UN	United Nations
USA	United States of America
USDA	United States Department of Agriculture
UTZ	A program and quality label for the sustainable cultivation of agricultural products
VSS	Voluntary sustainability standard
WTP	Willingness to Pay

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1 Introduction

"We are the first generation that can end poverty, and the last generation that can take steps to avoid the worst impacts of climate change. Future generations will judge us harshly if we fail in upholding our moral and historical responsibilities."

Ban Ki-Moon, 28 May 2015, in Leuven, Belgium.

In the spirit of Ban Ki-Moon's speech, this thesis investigates the case of a Costa Rican coffee cooperative that took such a step forward to combat climate change by implementing the world's first carbon neutral certification on coffee. The aim of the study is to learn from this pioneer case and to examine the challenges and potential of a carbon neutral certification for climate change mitigation and sustainable development along a global agri-food value chain.

The introduction Chapter states the problem that this thesis is addressing before introducing the world's first case of carbon neutral certified coffee in Costa Rica, providing also general information on the study area. Based on the problem identified, and the case-specific open questions, the research rationales and objectives are formulated. Thereafter, an interdisciplinary conceptual framework provides a holistic overview on voluntary sustainability standards, their development, linkages and factors, and then integrates the case of carbon neutral coffee certification into it. Alongside, relevant definitions are provided as they are being touched in the framework. The conceptual framework aims at providing a basis to answer the complex and interlinked research questions in a structured manner and, therefore, indicates how the Chapters 2, 3, and 4 are embedded in the framework. The introduction ends by describing the unique methodological approach used in this thesis and by providing a short outline of the thesis.

1.1 Problem Statement

The 2015 Paris Agreement – for the first time - brings all nations together to address climate change (UNFCCC, 2017). It emphasizes the increasing intensities of natural disasters, which reveal the importance of combating climate change and its consequences for the planet and humanity. Since the adoption of the Kyoto Protocol in 1997, a wide range of programs, initiatives, mechanisms, funds and structures were created to achieve the internationally binding targets on emission reduction to mitigate climate change (Grubb et al., 1999). Heavy emphasis has been placed on the industry, energy, and transportation sector while more recently the agriculture, forestry, and other land use (AFOLU) sector also received increased attention (Dickie et al., 2014). Beside the potential in emission reduction, agriculture's biophysical potential for mitigation is similar to that of the energy and industrial sector and go beyond that of the transportation sector (Wollenberg et al., 2013). Today it becomes more apparent that the AFOLU sector, in particular agriculture, is both a part of the problem and the solution to combat climate change, while at the same time suffering extremely from the consequences of global warming effects (OECD, 2015; Smith et al., 2007; Wollenberg et al., 2013). It was estimated in 2008 that food systems (with their complete value chains) contribute between 19-29% to the global greenhouse gas (GHG) emissions, out of which agriculture alone (including land use change) is responsible for approximately 14-24 % of global anthropogenic emissions (Vermeulen et al., 2012). Carbon or climate standards and certifications are, among many other initiatives, an increasing attempt to reduce GHG emissions generated throughout the agri-food value chains (Notarnicola et al., 2015b; Wollenberg et al., 2013). Carbon labels on products are on the rise, indicating e.g. the amount of GHG emissions an item contributed, the reduction in emissions or the product's carbon neutral status (Finkbeiner, 2009; Schaefer and Blanke, 2014). Carbon standards fall under the category of voluntary sustainability standards (VSS). In the last decade, certification and labels on aspects of sustainability have become increasingly important in global value chains (Tallontire et al., 2011), especially since social and environmental externalities of production are often unregulated or ineffectively regulated by governments (Abbott and Snidal, 2009). In this way, voluntary standards, as a market-based tool, present an opportunity to better govern global value chains and their respective externalities. Throughout this process new standards are developed and implemented (e.g. by pioneers), or former ones are adjusted; activities that are accompanied by a variety of challenges along the complete product value chain. However, research has selectively paid attention on these challenges rather than approaching them holistically to provide solutions that serve all actors and objectives related to the standard. Investigating these multiple challenges and understanding the potential and implications aims at raising issues for improvement in existing approaches, easing the adoption and achieving the global sustainable development goals of combating climate change, and eradicating hunger and poverty.

Against this background, the thesis aims to elicit the multi-facetted challenges and potential of sustainability certification in the agri-food sector by using an interdisciplinary case study approach. Taking the case of the world's first carbon neutral certified coffee, the complete chain – from standard development to consumer choices – will be examined.

1.2 The case of carbon neutral certified coffee in Costa Rica and its relevance

1.2.1 PAS 2060 and carbon neutrality

An example of such a new voluntary carbon standard is the Publicly Available Specification PAS 2060 to demonstrate carbon neutrality (see definition in Box 1). The British Standard Institution developed PAS 2060, with input from governments as well as from public and private organizations. With this, PAS 2060 is the world's first independent standard for carbon neutrality (CN) that provides a common definition and a recognized method (Co2Balance, 2011; Thorn et al., 2011). The detailed procedures in PAS 2060 are described in Chapter 2.

Box 1: Definition of Carbon Neutrality

Carbon neutrality is defined as "the condition in which during a specified period there has been no net increase in the global emission of GHGs to the atmosphere as a result of the GHG emissions associated with the subject during the same period" (BSI, 2014 p. 2).

Put into an equation, carbon neutrality can be expressed as

$$CN = E - R - C$$

Where E is the amount of emissions calculated as the carbon footprint, R refers to reductions in emissions through new technologies or processes and C illustrates the amount of carbon credits purchased to fully compensate the remaining emissions.

1.2.2 Coopedota R.L.

Since 2011, Coopedota, a coffee cooperative in the central highlands of Costa Rica, produces the world's first carbon neutral coffee in compliance with PAS 2060. As Costa Rica announced its ambitious goal to achieve national CN in 2006, Coopedota evolved into the pioneer that demonstrated to the country that becoming carbon neutral is possible.

Coopedota is known for its high quality coffee (exclusively *Coffea Arabica* variety in non-irrigated agroforestry systems), which is produced by more than 800 small-scale farmers. The Valley of Santa Maria de Dota, in the canton Dota, provides a unique climate and high elevations (1,500-2,200 m asl) with coffee cultivated on slopes of up to 60% inclinations (Castro-Tanzi et al., 2012). The area reports average rainfalls of about 2,400 mm per year with mean annual temperatures of 19°C (ICAFE, 2017). On average, the members cultivate three ha of coffee in production systems that can be classified as “commercial polycultures” or “shaded monocultures” (Moguel and Toledo, 1999). These systems are exclusively market-orientated with high levels of agrochemical inputs and limited integration of commercial or legume shade trees. The most common shade trees at Coopedota are the leguminous *Erythrina poeppigiana* trees, different *Musa sp*. varieties, Avocado (*Persea americana*), and various citrus species. Approximately 90% of Coopedota’s coffee is exported as green coffee, mainly to Germany, the USA, and Japan. The remaining 10% is roasted at the cooperative’s roasting facility and sold domestically. A more than 40-yeardirect trade partnership exists between Coopedota and Hochland Kaffee Hunzelmann GmbH, a family run coffee roastery in Stuttgart, Germany. For both actors this trading agreement covers about 70% of their coffee produced and roasted respectively.

During the last few decades, sustainability has become increasingly important to the cooperative and has been included, step-by-step, in their management policies. With this development, good agricultural practices have been introduced alongside the ISO 1401 and ISO 9001 standards, and a group of more than 100 farmers joined the Rainforest Alliance certification and simultaneously the CN certification. Since 2011, part of the cooperatives coffee is certified as carbon neutral.

1.2.3 Coffee in Costa Rica – a suitable example

Coffee is a suitable crop to exemplary study the use of a carbon neutral certification to mitigate climate change due to its economic relevance, its role in the climate change debate, and its history in labeling. Insights into these aspects and the specific role of Costa Rica in the developments of CN approaches are described next.

Coffee is one of the most valuable primary products in world trade (Mussatto et al., 2011). Coffee covers more than 10 million hectares and provides livelihoods to more than 25 million people along its value chain (Donald, 2004; Jha et al., 2014; Rahn et al., 2014). In several developing countries, a major share of the gross domestic product is generated by approximately 4.3 million smallholders producing coffee (Jha et al., 2014). The global demand for coffee has increased by 33% between 2000 and 2012 and is expected to continue rising (ICO, 2014). The economic importance of coffee can be expected to grow, as the process of transitioning from a fossil fuel based economy to a biomass based economy (bioeconomy) increases the demand for byproducts and substances of coffee production (Fernandez-Gomez et al., 2016; Mussatto et al., 2011; Poltronieri and D 'urso, 2016). At the same time, the production area for coffee is shrinking, increasing the pressure on the supply side.

Climate change, mainly climate change adaptation, has become a central issue in the coffee sector (FNC, 2016; ITF, 2010). Bunn et al., (2014) predict a 50 % loss of area suitable for coffee production by 2050 due to its susceptibility to climate change effects like temperature increase, pests, and changing rainfall patterns. Nevertheless, coffee, along its value chain, is also substantially contributing to climate change (Kilian et al., 2013; PCF Pilotprojekt Deutschland, 2008; van Rikxoort et al., 2014). In Costa Rica coffee production is responsible for 9 % of national GHG emissions and for 25% of emissions generated by the agricultural sector (Nieters et al., 2016). As a perennial crop grown in agroforestry systems, the biophysical potential of coffee production systems in Costa Rica to mitigate GHG emissions should be rather promising. Recently, leading agroforestry scientists reported on the contribution of tree cover to the carbon pool on agricultural lands (Zomer et al., 2016). Other studies have mainly raised attention on the potential of soils as carbon sinks under agroforestry management (Gama-Rodrigues et al., 2011; Häger, 2012; Kinoshita et al., 2016; Mutuo et al., 2005; Noponen et al., 2013). Despite these findings, temporary carbon sequestration is not systematically accounted for in carbon budgeting (ITF, 2010; Zomer et al., 2016). How important climate change adaptation and mitigation is to the coffee sector highlights the fact that eight coffee producing countries (responsible for 32% of global coffee production) mentioned the coffee sector in their submitted Nationally Determined Contributions (NDCs) (Solís, 2016). Due to this, the financial support to climate actions in the coffee sector can be expected to increase.

Coffee also has an extensive history of being a favorite research crop to investigate issues of certification and labeling. Coffee is a globally traded product and a variety of voluntary sustainability certifications (organic, Fair Trade, UTZ certified, Rainforest Alliance, 4C Association) are used in coffee production and trade (Grabs et al., 2016). More recently, private certification programs have also been developed (mainly C.A.F.E. Practice from Starbucks and AAA Nespresso). Consumers are used to looking out for labels on coffee packages that indicate certain social and environmental standards, which justify a premium price (Basu and Hicks, 2008; Loureiro and Lotade, 2005; Van Loo et al., 2015). Thus, coffee cannot be neglected in studying relevant issues of the rising demand for carbon labeling in the agri-food sector.

Regarding climate policy, Costa Rica is an interesting case country. Its economy is heavily based on the service sector, including tourism, which accounts for 70% of the country's gross domestic product (GDP) and secondly on agricultural production with around 7% GDP contribution (World Bank et al., 2014). The country is already suffering from the effects of climate change but is also taking a leading role in renewable energies, reforestation, forest conservation and climate policy. For its leading role in climate change mitigation policy, the former president and holder of the noble peace prize, Oscar Árias Sanchez announced in 2006 the ambitious goal to achieve national carbon neutrality by 2021 (Ball et al., 2009). In this low-carbon development strategy Costa Rica is carrying out a number of national appropriate mitigation actions (NAMAs), a program of the United Nations Framework Convention on Climate Change (UNFCCC), where developed countries support other countries in climate change mitigation efforts (World Bank et al., 2014). Inside the NAMA-café, the country started with several pilot projects (Nieters et al., 2015). These projects follow the national norm to demonstrate carbon neutrality, INTE 12-01-06:2011 from INTECO (instituto de normas tecnicas de Costa Rica) is applied. The project runs from 2015-2019, is financially supported by German ministries and related organizations and involves a diversity of local ministries, NGOs and research institutions (Nieters et al., 2015). The carbon neutral certified coffee of Coopedota holds as a motivation and pioneer example for this NAMA pilot project.

1.3 Knowledge gaps, specific research objectives and hypotheses

In the following text, the research objectives and questions of this thesis are presented on the background of the main knowledge gaps.

The state of the art of applying life cycle assessment (LCA) in the agri-food sector has been recently put together by Notarnicola et al., (2015a). It includes issues of methodology, international initiatives, certification and labeling, and presents examples from different sectors e.g. the olive oil and wine sector. It does not cover carbon neutral value chains or the PAS 2060 specification. Further, considering other peer-reviewed publications, cases of agri-food products that have been certified as carbon neutral by PAS 2060 have not been investigated thus far. The objective of this thesis is to examine the unique case of the world's first carbon neutral coffee and its complex challenges and implications along its global value chain from a holistic and interdisciplinary point of view.

Certification and implementation of carbon neutrality and success factors in innovation

Beyond the need to understand how PAS 2060 can be implemented in the agri-food sector and what the challenges are, pioneers and innovations can be considered as important for the implementation of newly developed sustainability standards, such as PAS 2060. In general, pioneers are recognized as particularly important for achieving sustainable development

(Forrest and Wiek, 2014). Based on that, it is necessary to understand the factors that foster successful innovations. It is widely recognized that capable people are a key factor, however, there are knowledge gaps regarding the social network dynamics and the role that different types of actors and different types of linkages play in successful pioneer cases of innovation (Hermans et al., 2013; Johnson and Silveira, 2014; Klagge and Brocke, 2012). With this in mind, the specific research questions for the first topic were formulated. This topic is addressed in Chapter 2.

a. Taking coffee as an example, how can the PAS 2060 CN certification be implemented on an agri-food product and what are the challenges that arise related to agri-food products?

b. How did the idea of carbon neutral coffee at Coopedota emerge?

c. Why was Coopedota successful in implementing the CN certification?

Accounting for on-farm carbon sequestration

Carbon neutrality certification is different from other LCA-based climate specifications such as PAS 2050 (Specification for the assessment of the life cycle greenhouse gas emissions of goods and services), since it additionally includes the step of carbon offsetting. Carbon offsetting is, however, confronted with criticism, stating that it is a practice of "greenwashing", unfulfilling the promises of GHG reduction and development benefits, as well as ethical concerns regarding the possibilities of organizations and industries to purchase carbon offsets instead of making efforts to reduce their own emissions (Bock, 2013; Hyams and Fawcett, 2013). Accounting for on-farm carbon sequestration (CS) could be one attempt in the agri-food sector to reduce the need for carbon offsetting in carbon neutral value chains, particularly in perennial or agroforestry systems. However, accounting for CS is rarely considered in LCA, since it is not compatible with the LCA principles (Cerutti et al., 2015; De Rosa et al., 2017). Very little information on how to account for on-farm mitigation in LCA exists (De Rosa et al., 2017), and there is a need to better understand the mitigation potentials of agricultural or agroforestry systems (Smith et al., 2014). So far little is documented on annual sequestration rates of coffee-agroforestry systems (Kumar and Nair, 2011), while the carbon neutrality certification is on an annual basis. With this in mind, the specific research questions of the second research topic were formulated. This topic is dealt with in Chapter 3.

a. What are the challenges of accounting for on-farm CS in coffee-agroforestry, which have been identified by the literature so far?

b. Investigating the case of carbon neutral coffee at Coopedota, what is the potential of CS in coffee plantations to compensate coffee GHG emissions inside the product's value chain and what are the implications?

c. What are factors at the farm level that should be considered to increase the potential for a complete compensation of coffee emissions? In other words, by which means can the coffee farmers of Coopedota contribute more to effective emission compensation?

Willingness to pay for a carbon neutral labeled coffee

Consumer's willingness to pay (WTP) for different sustainability labels (e.g. Fair Trade, organic, Rainforest Alliance, carbon footprint) was assessed in several studies using choice experiments (Basu and Hicks, 2008; Gassler, 2016; Kim et al., 2016; Lombardi et al., 2017; Rousseau, 2015; Saunders et al., 2010; Tait et al., 2016; Van Loo et al., 2015). Among the studies addressing carbon labels, no or a relatively low willingness to pay was found e.g. compared to a Fair Trade label. However, in Japan and the UK consumer stated that carbon labels have a strong influence on their fruit choices (Tait et al., 2016). So far, no study could be found, that assesses a WTP for a carbon neutral label on agri-food products based on an internationally recognized standard like the PAS 2060, verified by a third-party certification body. To complete the carbon neutral certification also on the retail side, it would be important to assess whether the carbon neutral certified coffee from Costa Rica could potentially gain premium prices in the specialty coffee market in Germany, where coffee prices already reflect the higher quality of the coffee. With this in mind, the specific hypotheses of the third research topic were formulated. This topic is dealt with in Chapter 4.

H1: Hochland customers have an additional WTP for a carbon neutral label indicating that the coffee they purchase has no net-impact on climate change.

H2: The interaction of the carbon neutral and Fair Trade label or a non-certified direct trade claim has an additional effect on the choice decision of coffee consumers. In other words, the simultaneous presence of these labels affects consumer's utility in a synergistic way.

H3: The preference for the attributes constituting coffee alternatives is heterogeneous among Hochland coffee consumers. We further hypothesize that such heterogeneity is partly explained by selected idiosyncratic variables that enter the part-worth specification as the vector w_i .

1.4 Conceptual framework

This section describes the interdisciplinary conceptual framework, which was developed specifically for this thesis based on existing literature. Alongside the framework, important definitions are provided in boxes. The following sections elaborate on the structure and the different components of the framework and indicate how the framework is guiding the thesis' research.

1.4.1 Structure of the conceptual framework

The conceptual framework, displayed in Figure 1, aims at illustrating developments at regional, national, and international levels and how the discussion around sustainability is linked to the development and implementation of new voluntary standards in global agri-food value chains. The conceptual framework further aims at visualizing the interlinkages between actors **[A-E]** and processes/effects **[1-4]** related to the implementation of a new sustainability standard, continuing to use the example of PAS 2060 for carbon neutrality in the global coffee value chain. The structure of the framework is as follows: the underlying structural element is a "relational global value chain" (Gereffi et al., 2005), indicating a direct trade relationship between the retailer and the producer/manufacturer. The left side represents the actions taking place in the producing country, which in the case of coffee is usually a developing country. The right hand side represents the processes taking place in consuming countries, which are mostly developed countries. Actors related to the development and implementation of new standards are illustrated by letters, with A indicating a potential beginning of the framework. Alongside with the actors, several international or regional developments as well as processes of standard implementation and effects of certification are depicted as numbers. The framework is not of a static and linear structure but rather of circular character, since it includes potential adjustments of the standard. Such an adjustment is illustrated here with dashed lines and forms in a second loop, also indicated with a small "**b**". As this thesis uses a case study approach, examples from the PAS 2060 specification for carbon neutrality are integrated into the framework using ***italic*** letters. To cope with the complexity and interdisciplinarity of the topic, the conceptual framework strives at embedding the three Chapters of this thesis, illustrated by the colors **red** (Chapter 2), **green** (Chapter 3) and **blue** (Chapter 4), into a wider context. Further, it presents a frame for the merging discussion in Chapter 5.

Voluntary sustainability certifications are widely studied with very different focuses (Abbott and Snidal, 2009; Mithöfer et al., 2017; Mitiku et al., 2015; Snider et al., 2017; Solér et al., 2017; Tscharntke et al., 2015; Van Loo et al., 2015). The main topics researched are governance through voluntary standards, producer perspective and environmental or sustainability effects, economic benefits and consumer willingness to pay (behavior). Little attention has been placed on the implementation of new standards and certifications, and the factors that influence their development or adjustment. By going through the conceptual framework in the following (stations are marked with **[no./letter]**), these issues will be elaborated on.

1.4.2 Consumer concerns, public discourses and policy trends

The circular structure of the framework suggests that there might be several entry points to the cycle. There might also be simultaneous developments and thus the framework is not necessarily a sequence of processes but also an illustration of time and direction independent linkages. Consumer concern **[A]**, public concerns and discourses as well as international developments and policies, e.g. regarding environmental issues, can be seen as background factors driving decisions and also developments of new standards or initiatives. The “policy issue-attention cycle” is an attempt to illustrate how sustainability concerns and discourses evolve and develop over time under the influence of media, social interaction and science (Mithöfer et al., 2017; Tomich et al., 2004). During the last 20 years, the awareness about environmental degradation caused by agricultural practices as well as social concerns on human rights and equity in agri-food supply chains has been rising. Globalization and rapid development in media availability have contributed to the necessary access to information on consequences of consumer choices. The important role of media to raise public concerns and discourses, particularly in the global North, is well known (Holt and Barkemeyer, 2012; Hughes, 2005). National and international trends and policies may be a response to the public, particularly to consumers, but they might also foster and consolidate these debates through according political actions. Examples for such political actions and trends in the field of climate change are the Kyoto Protocol, the Sustainable Development Goals (e.g. goal no. 13 on climate), and NAMAs, which are widely applied in Costa Rica’s coffee and livestock sectors (Grubb et al., 1999; Nieters et al., 2015; UN, 2017).

Further, it can be assumed that NGOs and public or private pioneers are the most active group of stakeholders pushing sustainable development, such as the development of new voluntary sustainability standards as a mechanism of governance in global value chains (Mithöfer et al., 2017).

1.4.3 Voluntary standards system and their development

Voluntary sustainability standards **[B]** and certificates aim to fill the existing gaps in social and environmental governance (Tscharntke et al., 2015; Vermeulen, 2010) and are depicted as a form of "social regulation" (Raynolds, 2012). They address sustainability trends and enable consumers to make informed choices, especially in global value chains and are developed responding to needs in the market.

There are different types of standards such as specifications, requirements or guidelines, which are mainly differentiated by the degree of prescriptiveness (see definition in Box 1). Standard systems are voluntary measures, which ensure that actors applying them comply with according norms. The standard systems consist of three main components: the type of standard, a certification or verification process and the labeling (Tscharntke et al., 2015), meaning it is important to note that solely complying with a standard does not necessarily indicate an existing certification or label (see definition in Box 2).

Box 2: Definitions in standard systems

Standards are documents that provide "requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose" (ISO, 2017b).

Certification is the "provision by an independent body of written assurance (a certificate) that the product, service or system in question meets specific requirements" (ISO, 2017c).

Accreditation is the formal recognition by an independent body, generally known as an accreditation body that a certification body operates according to international standards (ISO, 2017c).

Labeling refers to the possibility that "labels or other means of communication may be used to differentiate sustainable products at the consumer level" (Tscharntke et al., 2015).

Specification is the most common type of standard, which is a highly prescriptive standard setting out detailed absolute requirements. It is commonly used for product safety purposes or for other applications where a high degree of certainty and assurance is required by its user community (BSI, 2017).

International voluntary standards usually pass a long (on average 3 years) process in which actors from different backgrounds (industry experts, government departments, consumers, research organizations, and others) follow a consensus-based approach (ISO, 2017a).

An accelerated way to standardization is available by creating a PAS, usually taking 9-12 months. A PAS offers a sponsored route in which potentially any organization can commission a standard, ensuring its independence and reliability by a standardized development process (PAS 0), including a public revision. It may well be sector specific and provide product specifications, codes of practices, guidelines and vocabularies or could be used as an assessment benchmark. Due to this rapid yet reliable process of standard development, PAS appropriately represent newly developed standards. As they might be sector specific, yet applicable in various settings, pioneers are needed and well suited to implement a PAS in new sectors. The example of PAS 2060 for carbon neutrality was created by a group of experts, consisting of certification bodies, consultancies, industry, and carbon credit trading experts. The agri-food sector was not heavily involved in the standard development (except for forestry) nor does it seem to be the main sector of application (BSI, 2014).

1.4.4 Pioneers and producers/manufacturers

Such newly developed standards and certifications require one or more pioneers **[D]** for implementation, which comes with relatively specific challenges, depending on the types of sectors, products, and value chain structures (Mithöfer et al. 2017). But also the often observed interaction of voluntary standards and public legislation shape the way producers and the value chains operate and function, thereby affecting the responses of innovators (Berman, 2013).

The agents that implement such standards are usually producers or manufacturers **[C]**, who might have their own concerns towards sustainability (Potts et al., 2014), but more often are motivated by consumer demands or political trends to ensure their competitiveness e.g. in the case of coffee in terms of business strategy or market differentiation (Ponte, 2002).

In larger sectors, such as the coffee and cocoa sector, transnational private companies might take on the role of the implementing agent and thus of the pioneer (Giuliani et al., 2017). However, these initiatives resulted mainly in in-house certifications such as the AAA program of Nespresso. In fewer cases political agents or research centers are performing as the pioneer together with producers who implement a new voluntary standard (see e.g. coffee NAMA-café and INTE 12-01-06: 2011, Hidalgo, 2013; Nieters et al., 2015).

1.4.5 Implementation of new standard

As described by Mithöfer et al., (2017), p. 79, “adherence to, and implementation of, sustainability standards imply a shift from state to market regulation of sustainability concerns as well as a shift from national to global governance of sustainability concerns (Vermeulen, 2010)”. Beside this, the practical implementation **[1]** of a sustainability standard comes along with changes and adjustments of the general management, production and processing techniques and technology, training, market development and monitoring and enforcement of compliance (Potts et al., 2014). Some examples are the banning of certain agrochemicals, implementation of more efficient technologies to reduce GHG emissions, social norms and labor managements, and quality controls in manufacturing practices. The monitoring and reporting can be done by the implementing partner or in forms of field visits by the certification body, which is often a service included in the certification process.

A central issue in implementation is the need for a context specific implementation of sustainability standards (Potts et al., 2014; Wollenberg et al., 2013). Context specific can be attributed to regional issues, the interplay of national legislation and standard requirements, sector characteristics, structure of the value chain (global, intermediaries), but also to type of producer characteristics (smallholders, cooperatives, companies) (Abbott and Snidal, 2009; Giuliani et al., 2017; Mithöfer et al., 2017; Potts et al., 2014; Tallontire et al., 2011).

The implementation of a new standard also comes along with new costs. Beyond the costs for certification, there can be a number of additional costs such as expenses for monitoring and reporting, for adjustments in management and technology, for consultancy, and potentially for marketing (Manning et al., 2012; Potts et al., 2014). In the case of PAS 2060, additional costs also arise from the purchase of certified carbon credits for the offsetting of emissions.

1.4.6 Effects of certification on sustainability

Such adoptions or changes of practices are meant to lead to improvements in environmental and/or social performances **[2]**, which add value to the product being certified. There are mixed results in the literature on socio-economic effects of sustainability certification (Beuchelt and Zeller, 2011; Tscharntke et al., 2015). Generally, the effectiveness and impact of various sustainability standards in the agri-food sector has been the subject of a number of research studies, however, these have faced difficulties in rigorously comparing different standards and establishing causal relationships (Mitiku et al., 2015; Tscharntke et al., 2015). In their analysis on the evolvement of sustainability standards, Mithöfer et al., (2017) state that sustainability certifications only provide “partial solutions for ecosystem service and social problems” (p. 82). According to the authors, certifications often show a higher impact on improving documentation and management than they do on actual production practices.

1.4.7 Role of Retailers

Retailers **[E]** increasingly care about sustainability and in recent years particularly about climate friendly attitudes. In the UK, large supermarket chains (e.g. Tesco) have started providing information on product carbon footprints (Schaefer and Blanke, 2014). In Germany, large supermarket chains, but also smaller retailers, have become carbon neutral on an organization level, or even sell carbon neutral products (Aldi Süd, Omira, Naturata chocolate). Transnational coffee buyers (e.g. Nespresso, Starbucks) have created their own in-house sustainability certification (Giuliani et al., 2017). These developments in the market indicate that pressure to provide sustainable or climate friendly agri-food products and to prove it exist, even for smaller companies or e.g. roasters. This also presents an important marketing strategy to any type of retailer (Onozaka et al., 2015). However, to become a carbon neutral commodity (e.g. coffee) and to sell it with a label requires collaboration along the complete value chain. This might be easier in the case of shorter global value chains and would impact the marketing conditions of labeled products.

1.4.8 Economic benefits and consumer behavior

Certification labels on agri-food products have gained vast importance and are perceived as having a strong influence on consumer behavior and choices **[A]**. Although the certifications itself, as well as the necessary changes to achieve the certification, come at additional costs, the benefits to producers, to the socio-ecological environment (see Section 1.4.6) and consumers, are supposed to prevail **[3]**.

On the producer side, where a differentiated product enables access to specialized markets, these positive economic effects are not yet proven, and research results from the coffee sector are very mixed; positive effects on smallholder welfare and food security were found (Chiputwa et al., 2015; Chiputwa and Qaim, 2016; Haggar et al., 2017; Jena and Grote, 2016; Ruben and Fort, 2012), in contrast to less promising studies (Beuchelt and Zeller, 2011; Jena et al., 2012; Johannessen and Wilhite, 2010). The basic theory builds on the concept of premium prices for certified coffee, which are paid by the buyer and reach the producer. However, except for Fair Trade where the premium is defined to be US$ 0.20/pound of green coffee, premiums of voluntary sustainability certifications are variable and defined by the buyer (Snider et al., 2017). Further, the impact of a premium depends also on the differential, which is another component of the final sales price in coffee and results from the coffee quality or the countries reputation in coffee quality. In the case of Costa Rica, the price differential ranges from US$ 0.10 to

0.50/pound of green coffee (Snider et al., 2017), and might clearly exceed the potential premium price reaching the producer. This is particularly so because only a share of certified production is finally sold as certified and at premium prices and premiums might have to be shared among several stakeholders along the value chain (Mithöfer et al., 2017; Rahn et al., 2014; Snider et al., 2017).

On the consumer side, which is usually located in developed countries, the certification increases the product quality and the new attribute and value of the product increases consumer utility. The main benefits of certification and labeling to consumers lie in undertaking informed purchasing choices, thereby influencing the environmental and ethical way of food production and trade. However, consumers today are often confused and overstrained by the variety of labels and might have lost trust in the effectiveness and impact of labels due to scandals and unproven claims (Abbott and Snidal, 2009; Hamrick and Gallant, 2017; Sirieix et al., 2013). Thereby, consumers' willingness to pay (WTP) and demand for certain labels can vary strongly based on country, societal status, education, gender, age, and the product being looked at (Gadema and Oglethorpe, 2011; Guenther et al., 2012; Tait and Saunders, 2011; Van Loo et al., 2015).

1.4.9 Revisions of standards

Voluntary standards, particularly PAS standards, are continuously subject to changes and adjustments in the requirements they state **[Second loop]**. These revisions might be driven by upcoming consumer concerns, or may be undertaken in order to improve and update the standard. They occur based on the latest technical advances and research findings. The second loop (dashed lines) in the conceptual framework illustrates a potential field of revising the LCA-based PAS 2060 for carbon neutrality (see definitions in Box 3).

Box 3: Definitions in carbon accounting

Life Cycle Assessment is the "compilation and evaluation of inputs, outputs and potential environmental impacts of a product system throughout its life cycle" (BSI, 2011).

Carbon Footprint refers to the "absolute sum of all emissions and removals of greenhouse gases caused directly and indirectly by a subject either over a defined period or in relation to a specified unit of product or instance of service and calculated in accordance with a recognized methodology" (BSI, 2014).

Carbon offsetting "mechanism for claiming a reduction in GHG emissions associated with a process or product through the removal of, or preventing the release of, GHG emissions in a process unrelated to the life cycle of the product being assessed. An example is the purchase of Certified Emission Reductions generated by Clean Development Mechanism projects under the Kyoto Protocol" (BSI, 2011, p. 5).

Biogenic carbon refers to carbon that is contained in biomass (BSI, 2011, p. 2).

Carbon sequestration or removals "typically occur when CO_2 is absorbed by biogenic materials during photosynthesis" (BSI, 2011, p. 5). In other words, it can be defined as a "process by which trees and plants absorb carbon dioxide, release the oxygen, and store the carbon" (EPA, 2017).

The public and consumers **[A]** are concerned about the appropriateness of practices to offset carbon footprints (Hyams and Fawcett, 2013). This criticism, mainly towards aspects of "greenwashing" and limited actual effectiveness of offsetting practices (meaning, does offsetting actually results in a reduction of GHG?), but also towards a moral justification (is it morally acceptable to pay others for taking over the duty of emission reduction instead of making the efforts in GHG reductions by one self?) could potentially be addressed by revising the standard accordingly **[b]**. One proposition could be to involve the accounting of on-farm CS in the carbon balance. Despite a considerable potential of perennial crops to sequester carbon (see e.g. Paustian et al., 2016; Pretty and Ball, 2001), it is generally omitted in LCA, and due to remaining uncertainties the accounting of biogenic CS does not conform to existing LCA principles (Bessou et al., 2013).

In PAS 2050, the standard on how product carbon footprinting should be carried out, the subject of CS accounting is handled as follows: "Carbon incorporated in plants or trees with a life of 20 years or more (e.g. fruit trees) that are not products themselves but are part of a product system should be treated in the same way as soil carbon, unless the plants and trees are resulting from a direct land use change occurring within the previous 20 years" (PAS 2050 p. 9). Regarding the treatment of soils "it is acknowledged that scientific understanding is improving regarding the impact of different techniques in agricultural systems. For this reason, provision is made for future supplementary requirement or revision to the PAS 2050 requirements that could facilitate the inclusion of emissions and removals arising from changes in soil carbon." (PAS 2050 p. 12).

Accounting for on-farm CS would involve a carbon inventory and monitoring in the implementation phase **[1b]**. Despite the additional costs that would be incurred, this practice could result in an additional ecological improvement and provide synergies between climate change mitigation and adaptation if agroforestry systems and tree integration are incentivized **[2b]**. However, the literature also shows that there might be a trade-off **[4b]** between productivity and conservation approaches such as CS (Haggar et al., 2017; Mithöfer et al., 2017; Solér et al., 2017).

Finally, such a revision of the standard and a potential extra recognition by a modified label might increase consumer's utility and trust.

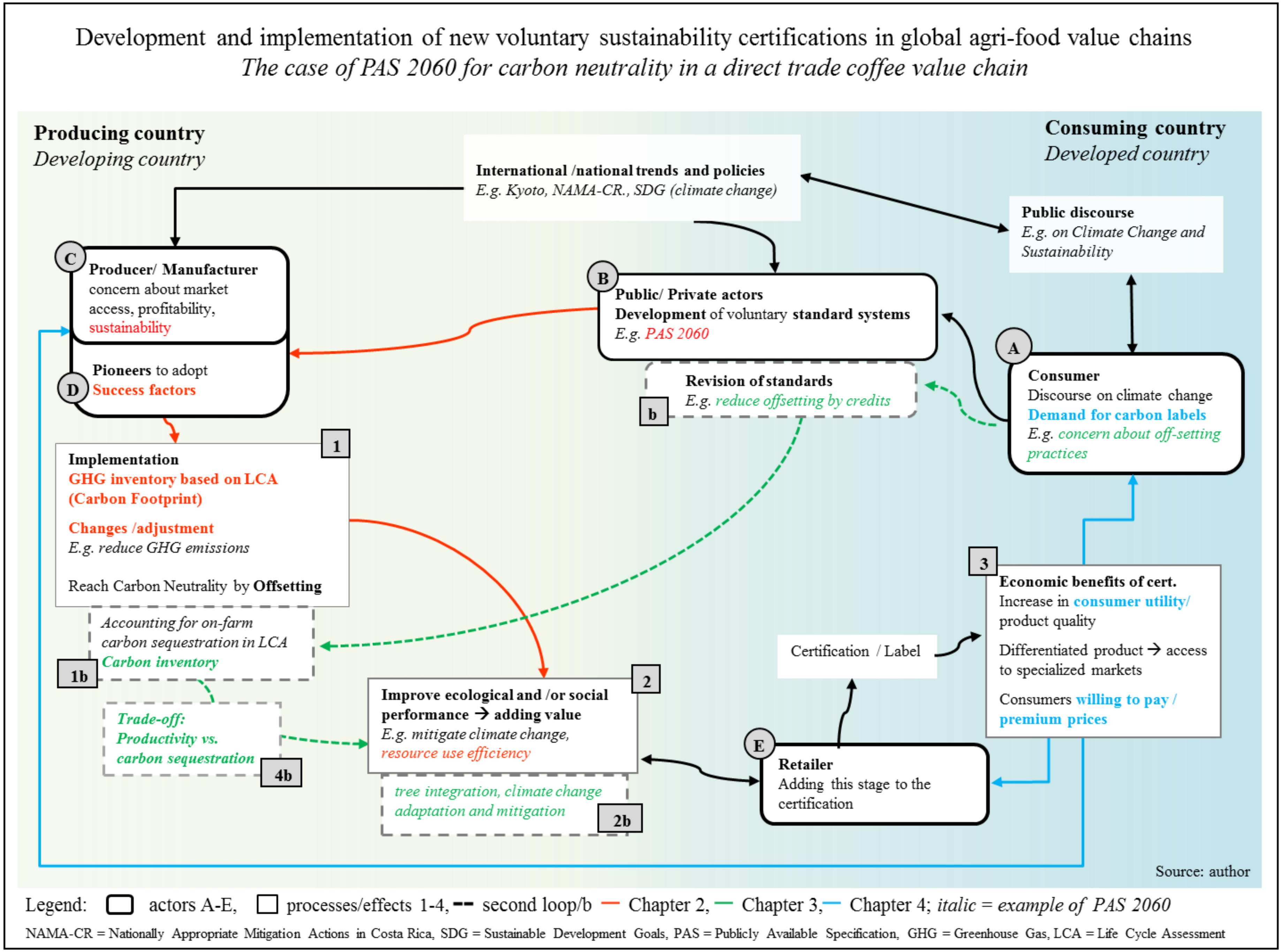

Figure 1: Conceptual Framework

1.5 Methodological approach

To gain a holistic understanding of carbon neutral certification and its role in the future, an interdisciplinary research approach was chosen, to integrate the different dimensions that certification touches upon. This implied also the use of a diverse set of methodologies from different disciplines such as governance, social networks, socio-economics, environmental economics, and ecology.

There is a variety of definitions and concepts regarding interdisciplinary research and the transitions to multidisciplinartity, crossdisciplinarity or transdisciplinarity are fluent (Aboelela et al., 2007; Strang, 2009; Toomey et al., 2015). Nevertheless, it has generally become more clear that in order to answer modern, global, and complex questions, integration and linking of different disciplines from social and natural sciences is necessary (Aboelela et al., 2007; Farrell, 2011; Sillitoe, 2004). The integration of different perspectives and research approaches can then be differentiated based on the level of collaboration and communication (Aboelela et al., 2007). Yet, in most cases, interdisciplinary research or collaboration in research is carried out by bringing together experts from different disciplines to talk about a common topic (Strang, 2009). The uniqueness of this thesis approach lies rather in using an interdisciplinary research approach that is guided by one holistic conceptual framework and is performed by one person who has interacted and collaborated with experts from the different disciplines. The challenge here is to look at the case of carbon neutral certified coffee in a holistic manner and to dive into the different perspectives of the disciplines touched upon, and to integrate them into an overarching perspective in order to discuss the main results of this thesis. This approach may lead to conclusions that may go beyond a mere adding up of different perspectives.

This thesis utilizes a case study approach (Yin, 2009) to carry out the interdisciplinary research in the set frame, the benefit being that this approach offers a variety of other advantages such as a more comprehensive and in-depth analysis of factors and conditions (see more details in Yin, 2009 and Section 4 in Chapter 2). The fieldwork was carried out between October 2014 and May 2015. The last four months were spent at the coffee cooperative Coopedota. The participation in the everyday life at Coopedota facilitated the use of direct observations as a research tool and enabled a deep understanding of relationships, structures, and processes inside and outside the organization. Further data collection to analyze the WTP for carbon neutral coffee took place between October and November 2016 with consumers of specialty coffee in Stuttgart, Germany (see details on data collection in the respective Chapters).

A set of methods was applied and is described in detail in the respective Chapters. Here, methods used are listed and their application is indicated by relating the methods to the conceptual framework, using the respective letters or numbers in brackets:

- Literature search **[B, D, 1, 3, A]**
- Mixed methods approach **[C, D, 1, 2, b]**; combination of qualitative and quantitative research methods in the field of socio-economics
- The Net-Map tool and social network analysis **[C, D, 1]**
- Carbon inventory **[1b]**
- Biophysical carbon accounting model **[1b, 2b, 4b]**
- Discrete choice experiment and WTP **[3, A]** in the field of environmental economics and consumer behavior.

In addition to this range of methodologies, the research looked into the following thematic fields:

- development of voluntary sustainability standards and certification (Mithöfer et al., 2017; Schaefer and Blanke, 2014; Tallontire et al., 2011; Tscharntke et al., 2015),
- innovations and pioneers in agricultural development (Hermans et al., 2013; Jänicke, 2005; Spielman et al., 2011),
- LCA in the agri-food sector (Notarnicola et al., 2015b),
- climate change mitigation in agriculture (policies) (Wollenberg et al., 2013) and offsetting mechanisms (carbon trading) (Gold Standards, Plan Vivo, Clean Development Mechanisms),
- CS in agroforestry (Kumar and Nair, 2011),
- carbon accounting mechanisms (Brandão et al., 2013),
- consumer sustainability behavior (Guenther et al., 2012; Tait and Saunders, 2011; Vermeulen, 2010)
- and the “coffee world” in- and outside of Costa Rica (Bacon, 2008; ICO, 2014; Jiménez, 2013).

Due to the faced complexity, the focus of this thesis lies on integrating the different methods and knowledge systems and relating them to the relevant issues related to the case under investigation. With this in mind, and limiting it to the scope of the thesis, it is impossible to avoid a potential heterogeneous distribution of attention to certain issues.

1.6 Outline of the thesis

The further structure of the thesis is as follows: Chapter 2 investigates the case of implementing a carbon neutrality certification in an agri-food commodity (coffee) in Costa Rica and the challenges faced during the process. Further, it particularly looks at the underlying dynamics that made the cooperative a pioneer and the success factors that enabled the implementation of the certification. Chapter 3 examines the potential of CS in CAFS based on the available literature and a carbon inventory in the coffee farms. It analyzes the challenges in accounting for biogenic CS with regard to LCA-based standards and the potential to lower the need for external carbon offsetting. Chapter 4 analyzes the willingness to pay of German consumers for specialty coffee regarding the introduction of a carbon neutral label. In doing so, it investigates consumer behavior and purchasing decisions regarding different sustainability labels and claims (carbon neutral, Fair Trade, direct trade claims). Lastly, Chapter 5 illustrates what the main research findings add to the literature and comprises a discussion of the results guided by the conceptual framework of the thesis. Further, data limitations are discussed and the Chapter ends with a final conclusion for future research and policy.

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2 The world's first carbon neutral coffee: Lessons on certification and innovation from a pioneer case in Costa Rica

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This chapter was published in the Journal of Cleaner Production and is available online since March 23, 2018: https://doi.org/10.1016/j.jclepro.2018.03.226

2.1 Introduction

Recent years have seen a growing demand for climate certifications, such as carbon neutrality (CN). The state of being carbon neutral has been defined by the British Standards Institution as a "condition in which during a specified period there has been no net increase in the global emission of GHGs to the atmosphere as a result of the GHG emissions associated with the subject during the same period" (British Standard Institute (BSI), 2014 p. 2). While carbon neutrality is a promising approach, there have been improper claims to carbon neutrality in the past, which were not based on recognized standards. This has created mistrust, especially among consumers (Co2Balance, 2011). Such skepticism can still be observed. Moreover, consumers often expect climate-friendly products to be generally sustainable, which might not necessarily be the case (Swarr, 2009). In the future, the role of climate certification in the agricultural sector may increase, as food systems are responsible for 19-29 % of anthropogenic greenhouse gas (GHG) emissions (Vermeulen et al., 2012). Agriculture contributes to climate change mainly by converting forest to agricultural land and by direct methane and nitrous oxide emissions derived from cattle production and the application and production of nitrogen fertilizers (Bellarby et al., 2008).

To explore the potential of climate neutrality certifications for food products, this paper presents a case study of Coopedota, the first cooperative worldwide that certified its coffee as carbon neural based on a widely recognized international standard. Coffee lends itself well to such a case study because it is a very nitrogen-intensive crop and is responsible for 9% of Costa Rica's national GHG emissions (national inventory 2010 as cited in Nieters et al., 2015). At the same time, coffee suffers from the effects of climate change. Bunn et al. (2014) predict that half of the area suitable for coffee production worldwide will be lost by 2050 due to climate change.

Coffee production in Costa Rica is dedicated to *Coffea Arabica*, which is particularly affected by climate change.

Coffee is also an interesting example for a case study because it is one of the most extensively traded food products worldwide. At the same time, coffee is an important livelihood base of smallholder farmers in the producer countries. The global coffee demand has increased by 33% between 2000 and 2012 (ICO, 2014), and it is expected to continue to rise. This is mainly due to emerging coffee markets, e.g., in Algeria, Australia, Russia, and South Korea, but also due to an increasing consumption in coffee exporting countries (ICO, 2014). Furthermore, coffee has a high potential to support the global movement towards a bioeconomy[1]. Coffee is one of the most valuable primary products in world trade, but processing of coffee leads to substantial amounts of residues, mainly coffee silver skin and spent coffee grounds (Mussatto et al., 2011), but also pulp, husk, and sugars. These residues contain substrates of high value, which can be extracted and used in the pharmaceutical and food industry (Esquivel and Jiménez, 2012; Fernandez-Gomez et al., 2016; Mussatto et al., 2011). Even without using this potential, climate certification of coffee still contributes to the bioeconomy because it leads to increased resource use efficiency (RUE) while reducing emissions along the coffee value chain.

While there are many international efforts to meet climate mitigation demands in the agricultural sector (Lewandrowski and Hohenstein, 2013), the case of Coopedota is unique because this cooperative produces the world's first carbon neutral coffee, certified by the most advanced certification available to date: the publicly available specification (PAS) 2060 for CN. PAS 2060 is the only independent specification that can be applied to certify CN of products or services. Coopedota is also the first company outside of the EU that has achieved certification according to PAS 2060. This pioneer character makes the cooperative a good example of successful innovations for climate protection.

Pioneers and innovations are recognized as particularly important for achieving sustainable development (Forrest and Wiek, 2014). Different factors have been identified to foster innovations in the literature, such as leadership and entrepreneurship, networking, institutional and financial support and political and technological infrastructure (Biggs et al., 2010; Ceschin, 2013; Feola and Nunes, 2014; Grabs et al., 2016; Luqmani et al., 2016). Strandberg quoted in Lipsett et al. (2001) summarized the success factors into three categories: (i) money, (ii) capable

[1]Bioeconomy can be defined as 'the sustainable and innovative use of renewable resources to provide food, feed and industrial products with enhanced properties. Besides economic growth the bioeconomy aims for food security, climate protection and conservation of scarce natural resources'. (Bioeconomy council of the German Government, 2017).

people and (iii) encouragement and support (e.g. by institutions). The importance of capable people (the human asset factor) is widely recognized (Biggs et al., 2010), particularly with regard to the innovativeness of businesses and companies (Ceschin, 2013; Luqmani et al., 2016). Nevertheless, only few studies have tried to understand success factors of green innovations from a social network perspective in particular, there are knowledge gaps regarding the network dynamics and the role that different types of actors and different types of linkages play in successful pioneer cases of innovation (Hermans et al., 2013; Johnson and Silveira, 2014; Klagge and Brocke, 2012). The present case study addresses this knowledge gap.

PAS 2060 accepts three internationally recognized standards to quantify the GHG emissions of products and services. Among them PAS 2050, a specification for the assessment of the life cycle GHG emissions of goods and services. This case study is also of interest because, so far, only a few cases have been studied that used the LCA-based specification PAS 2050 to assess the carbon footprint (CF) of agricultural products. Iribarren et al. (2010) studied canned mussels. Kilian et al. (2013) examined Costa Rican Coffee that is exported to Europe and O'Brien et al. (2014) investigated dairy farms in Ireland. Cases of agri-food products that have been certified as carbon neutral by PAS 2060 have not been investigated, so far. Therefore, the case of the world's first PAS 2060 carbon neutral certified coffee offers the opportunity to generate new insights that are also relevant for potential future applications of PAS 2060, and comparable carbon neutrality certification schemes to agri-food products.

To learn from the experiences of Coopedota and make them available to potential followers, it is important to study the challenges that occurred during the certification process. At the same time, it is important to study the case from an innovation perspective and to examine especially the role of the human factor for successful innovations. Against this background, the following research questions are addressed:

Taking coffee as an example, how can the PAS 2060 CN certification be implemented on an agri-food product and what are the challenges that arise related to agri-food products?

- How did the idea of carbon neutral coffee at Coopedota emerge?
- Why was Coopedota successful in implementing the CN certification?

By addressing these questions, this paper contributes to the limited literature on PAS 2050 based cases of carbon neutral certifications of agricultural products and on SNA approaches to study success factors of pioneer projects. Due to the single case study character of this paper, the possibilities to generalize the findings regarding success factors of pioneers and regarding the implementation of carbon neutral certifications in the agri-food sector can only be sketched out. Nevertheless, the in-depth analysis of a pioneer case of carbon neutrality certification in agriculture provides valuable insights and can also serve as a basis for comparison with future studies in this field.

2.2 The Publicly Available Specification (PAS) 2060

Climate-related information on products and services are on the rise (Finkbeiner, 2009; Schaefer and Blanke, 2014). Several agricultural certification frameworks have created new standards or add-ons of existing standards (e.g., climate module of Rainforest Alliance) to cover the climate aspect. However, carbon neutral certifications are criticized for offsetting practices and, as mentioned above, for false claims to carbon neutrality. The benefits of compensating GHG emissions by carbon credits are questioned due to corruption cases and the fact that these credits are earned by temporal carbon removal, e.g., reforestation projects instead of reducing fossil fuels (Bock, 2013).

PAS 2060 was developed by the independent British Standards Institution (BSI) and finalized in April 2010 and is internationally recognized as a standardized method (Co2Balance, 2011; Thorn et al., 2011). It is applicable to activities, products, services, buildings, projects, towns, cities, and events. There are four steps involved in the certification process: quantifying, reducing, offsetting, and declaration. The steps are explained in the following paragraphs.

1) The first step is to *quantify* GHG emissions[2], usually using an LCA-based framework such as PAS 2050 to assess the CF of a subject. PAS 2050 is based on existing LCA methods (ISO 14040 and 14044) and thereby provides a standardized methodology (Notarnicola et al., 2015). LCAs compile and evaluate the environmental impact of a product system throughout its life cycle and, therefore, using a cradle-to-grave approach, which considers all sections of a value chain up to the disposal stage. However, in carbon footprinting (CF), which applies an LCA that focuses on GHG emissions, a cradle-to-gate approach is preferred, which considers emissions along the value chain until the point of selling. The cradle-to-gate approach is less complex and in turn improves the accuracy of the CF, especially since it is often difficult to estimate what happens to a product during consumption and disposal (Thorn et al., 2011).

[2]As GHGs, seven gases are considered in PAS 2060: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), nitrogen trifluoride (NF_3) (BSI, 2014).

In PAS 2060, the following emission categories are considered: 100% of Scope 1 emissions (direct emissions) and Scope 2 emissions (energy indirect emissions). Scope 3 emissions (other indirect emissions, such as outsourced operations and waste disposal), which tend to be neglected by other carbon neutral approaches, have to be considered if they contribute more than 1% to the total footprint.

2) At the *reduction* stage, a CF management plan has to be elaborated and realistic carbon reduction strategies have to be presented and verified.

3) In step 3, *offsetting*, the remaining emissions after a reduction period need to be compensated by high-quality, certified carbon credits.

4) The fourth step includes two *declarations;* (i) the commitment to CN and (ii) the achievement of CN. In these declarations, PAS 2060 emphasizes that CN cannot be declared when only offsetting is used to compensate for GHG emissions. Thus, in PAS 2060, carbon reduction strategies are central to the specification and, therefore, the certification is valid only for a maximum period of 12 months (BSI, 2014) and has to be renewed thereafter.

The application of PAS 2060 is a very promising approach because the specification uses consistent internationally recognized methodologies and sets out clear rules and principles related to the declaration of carbon neutrality (BSI, 2014). Third party certification bodies can validate the declarations and their accordance to PAS 2060 and, therefore, independently certify the subject. However, it could be criticized that third party verification is not an obligation and self-verification remains possible.

2.3 Innovation systems and Social Network Analysis (SNA)

This paper uses the concept of the innovation system and the tool of Social Network Analysis (SNA) to analyze the case of Coopedota. Innovation systems have been studied at national, regional, and sectoral levels. The agricultural innovation system is an example of a sectoral approach. Knowledge and learning are usually considered key to pioneers who promote innovations (Hall et al., 2003; Spielman et al., 2010). The importance of networks has also been acknowledged in innovation systems research. However, the analysis of network structures and the roles of actors in networks has remained rather “fuzzy” (Stuck et al., 2015) or descriptive (Hermans et al., 2013). Early applications also lacked a clear methodology and quantitative measurements (Grabher, 2006). In the last years, a few studies have used SNA in innovation systems research to address this shortcoming (Hermans et al., 2013; Klagge and Brocke, 2012;

Stuck et al., 2015). The study by Hermans et al. (2013) is of more quantitative nature and among the few studies where SNA was applied to study pioneer cases. In their case, it analyzes the agricultural innovation networks in the Northern Frisian Woodlands (Netherlands), where dairy farmers formed regional environmental farmer cooperatives to protect their unique landscape.

Another observation in the literature on pioneer cases is that innovation is often a combined result of the historically determined characteristics of a specific state, region, sector or company on the one hand and trends in international, national or regional policies on the other hand (e.g., Hermans et al., 2013; Johnson and Silveira, 2014; Klagge and Brocke, 2012). Drawing on this insight, this paper uses a timeline approach to cover those factors that foster innovations. In addition, the Process Net-Map tool (Schiffer and Hauck, 2010) is used to visualize the network of actors involved in the innovation and identify the network structure, the types of linkages between the actors and the importance of the actors for the successful implementation of the CN certification.

2.4 Methodology

For the following reasons, a single case study design was used for the analysis of Coopedota (Yin, 2009): a) The research questions addressed in this study are ‘how” and “why” questions. The goal was to identify the characteristics of an organizational process in a holistic perspective. b) The focus of the research is placed on the contemporary pioneer situation of Coopedota. In such a case, a single case study approach is suitable because it allows for an in-depth analysis to understand the case-specific factors and conditions of success (Yin, 2009). c) It is important to collect comprehensive knowledge on this case and analyze it before the case can be compared with other pioneer cases of climate certification.

As further detailed below, a combination of qualitative research methods was used for data collection, including in-depth expert interviews, semi-structured interviews, focus group discussions, the Process Net-Map tool and direct personal observations.

2.4.1 The case of Coopedota

Production of high quality coffee plays a central role in Costa Rica’s history and also in the country’s identity. The coffee cooperative Coopedota is located in the canton Dota in the Los Santos region, where coffee of the highest quality is produced, due to the unique climate and the high elevation (1500-2200 m asl) of the region. The villagers of Santa Maria de Dota planted the first coffee bushes in 1867 (Coopedota R.L., 2014). In 1960 the cooperative

Coopedota was founded. Since then, the number of members increased from 96 to approximately 800 associate farmers. On average, the members cultivate three ha of coffee on mountainous land. They grow exclusively *Coffea arabica* in non-irrigated agroforestry systems. Approximately 90% of Coopedota's coffee is exported as green coffee, mainly to Germany, the USA and Japan. The remaining 10% are roasted at the cooperative's roasting facility and sold on the national market.

2.4.2 Data collection

The field research for this study was carried out between October 2014 and May 2015. The last four months were spent at the coffee cooperative Coopedota. The participation in the everyday life at Coopedota facilitated the use of direct observations as a research tool and enabled a deep understanding of relationships, structures and processes of the organization. The first author attended the cooperative's general assembly, which provided unique insights on how decisions are made and what issues are important to the members. Data collection also involved in-depth interviews with 30 experts a visit to the NAMA[3]-café experimental farm Hacienda Aquiares, and semi-structured interviews with 100 coffee farmers of Coopedota (Table 1). These interviews gave insights into how the PAS 2060 is applied by the cooperative. The interviews also provided information on historical developments, the vision and the current policies and research efforts regarding carbon neutral coffee and CN in Costa Rica.

To ensure high quality of the obtained information, all interviews were conducted by the authors personally. Moreover, the research benefitted from expert advice by researchers from the University of Costa Rica. Quality assurance also included member checks (discussing the research findings with interviewees), triangulation and peer-debriefing with experts (Bitsch, 2005). The results were also presented at the annual conference of the International Consortium on Applied Bioeconomy Research (ICABR) in Ravello (Italy) to attain peer feed-back.

[3] Nationally appropriate mitigation actions

Table 1: List of interviewees

Position (no. of Int.)	Institution	Role in the certification process	Method
General manager (1)	Coopedota R.L.	Strongly involved in the CN certification	Several interviews
CN Project manager (1)	Coopedota R.L.	Former responsible initiator of CN certification.	Expert interview, Process Net-Map
CN Working Group (2)	Coopedota R.L.	In charge of the certification programs and data administration.	Expert interviews
Senior staff (3)	Coopedota R.L.	Involved in certification monitoring and administration	Several interviews, Process Net-Map
Current and former board members (15)	Coopedota R.L.	Involved in the CN certification process. The participants were at the same time coffee farmers or members of coffee farming families.	Focus group discussions, Process Net-Maps
Coffee producers (100)	Coopedota R.L.	Coffee farmers in the canton Dota/Tarrazu. 50 participants of the CN certification and 50 non-participants were asked about their knowledge on the CN certification and their opinion.	Semi-structured interviews
Mayor (1)	Local Government Santa Maria de Dota	Involved in CN projects	Expert interview
Senior staff (3)	GIZ(1)	Involved in the CN project. Further, representing an implementing partner in the NAMA(2)-café program.	Expert interviews
Forest engineer (1)	INTECO(3)	Supporting the verification of NAMA-café projects as an expert contracted by the National Institute for Technical Norms.	Expert interview
Researchers (6)	CATIE-CIRAD(4), INCAE(5), SFS(6), UCR(7)	Advising the government on the national carbon neutrality strategy. Research on CN in coffee, certification, national strategy and sustainable development.	Expert interviews, Visit of NAMA-café experimental station Hacienda Aquiares.
Ministry staff (3)	MAG(8)	Responsible ministry for NAMA-café, implementing CN country strategy involved in CN at Coopedota.	Expert interviews
Coordinator (1)	Fundecooperación	Representing one of the implementing partners in the NAMA-café.	Expert interview
Director (1) and regional coordinator (1)	ICAFE(9)	Representing one of the implementing partners in NAMA-café.	Expert interviews
Senior staff (1)	CoopeTarrazu R.L.	Person in charge of NAMA-café at the neighboring coffee cooperative CoopeTarrazú R.L.	Expert interview
Senior staff (1)	BSI(10)	Experience with standards and certification (carbon footprints of agri-food products).	Expert interview
Senior staff (1)	FONAFIFO(11)	Program of PES (payments for ecosystems services), shade trees in coffee.	Expert interview
Coffee Entrepreneurs (5)	Micro-Mills (private processing facilities) in central Costa Rica	As private businesses they face challenges regarding certifications that are different from the challenges faced by a cooperative.	Expert interviews

(1) GIZ: German Agency for International Cooperation, (2) NAMA: Nationally appropriate mitigation actions, program adopted by the Costa Rican Government as a strategy to reach national CN by 2021, In the agricultural sector focus has been laid on coffee and livestock, (3) INTECO: National Institute of Technical Norms, (4) CATIE: Tropical Agricultural Research and Higher Education Centre – CIRAD: The French agricultural research and international cooperation organization., (5) INCAE: Latin-American Business School, (6) SFS: The school for field studies, Sustainable Development Studies - Costa Rica, (7) UCR: Universidad de Costa Rica, (8) MAG: Ministry of Agriculture and Livestock, Costa Rica, (9) ICAFE: Coffee Institute of Costa Rica, (10) BSI: British Standards Institute, (11) FONAFIFO: National Fund on Forest Financing.

2.4.3 Group discussions and the Process Net-Map tool

To address the research questions how the idea of carbon neutral coffee at Coopedota emerged and why the certification was successfully implemented, it is important to understand the relevant developments inside and outside the cooperative as well as the roles and relationships of actors that influenced these developments. A SNA is a useful tool to examine the network of actors by displaying the network structure and the position of the actors in the network. In this study, the Net-Map tool, a relatively new participatory SNA approach developed by (Schiffer, 2007), was used. The Net-Map tool is a participatory mapping research method that is based on group interviews. The tool helps to visualize social networks from a participant's perspective and elicits information on the actors' goals. The tool also provides information about the linkages and power relations between actors.

Due to the use of visualization techniques, Net-Map has the advantage of providing in relatively short time in-depth information about complex relations between different types of actors. With minor extensions, the tool can be used to map processes (Raabe et al., 2010). While conventional network analysis focuses on static networks, the Process Net-Map makes it possible to visualize the development of a certain process by displaying the actors involved and showing their type of interactions over time. Additionally, the Net-Map tool involves a scoring of the actors in terms of their power or influence on a specific outcome. The details of applying this method are explained below. The participants commonly agree on an influence score, which then represents the shared subjective perception of the participants regarding the influence or power of that actor. In conventional SNA, it is assumed that one can derive the influence or power of actors by calculating three SNA indicators, which are described as "centrality measures" (Freeman, 1978) 4. These are "betweenness" as a measure of control over other actors' communication, "closeness" as a measure of independence to communicate directly with other actors, and "degree" as a measure of direct connections to other actors in the network. Since these indices do not consider social dependencies between actors that are not captured by the SNA, they may well be confusing or misleading (Freeman, 1978). To address this challenge, this study combined the subjective ranking of importance (as described above) with the conventional power indices derived from SNA. Since the participants discuss and explain their choices when constructing the Net-Map, this tool enables researchers to

[4] This conceptual clarification on centrality in social networks includes detailed information on how these centrality measures are calculated.

understand the rationales behind their scores and come up with plausible explanations in the case that the SNA results differ from the scores assigned by participants.

In conventional SNA, information flow is often the only linkage type between actors that is considered. The Net-Map tool aims at displaying multiple and more differentiated types of linkages, such as linkages that arise due to the provision of funding, formal command structures or provision of services (Aberman et al., 2010).

The Process Net-Map tool is well suited to study success factors in innovation since it offers the possibility to focus on project-related networks and on the role of each actor with regard to a specific outcome, which in this case was the achievement the CN certification. The visualization plays an important role for enabling a rigorous analysis of the case involving several experts or stakeholders at the same time.

The Net-Map tool was applied in three in-depth group discussions were carried out with three to six key informants. These key informants were selected based on their former or actual positions in cooperative boards. Due to this membership, they took part in the creation of a vision for carbon neutral coffee and in the implementation process of the CN certification PAS 2060. As regular cooperative members, all of the participants were also coffee farmers. Key experts, such as the general manager of the cooperative, were interviewed individually, but they were excluded from the group discussions since the other participants might have faced problems when discussing the influence scores of key actors in their presence. Furthermore, normal board members might have held back their memories or opinions in the presence of influential key actors. The three group discussions lasted for about three hours each. They were conducted towards the end of the period in which the expert interviews were conducted, so that suitable informants could be identified and adequate knowledge on CN activities and institutions in Costa Rica had already been acquired. As one strategy of triangulation for quality assurance, personal interviews were held with three experts that were key actors in the network but did not participate in the discussion groups, to validate the results from the discussion groups and to potentially add information. Special attention was paid to cross-check the role of distinguished actors and their linkages.

The application of the Process Net-Map tool encompassed two phases: (1) visualizing the social network and (2) rating the importance of each actor.[5]

[5] More details, including pictures of the use of the method, are provided at this website: https://netmap.wordpress.com/about/.

Phase 1, the creation of the Net-Map started with an introduction round of participants, who explained their background and their involvement in the certification process. This information can be used to assess the value of the data obtained and the perspective this information is derived from. Next, the facilitator asked the respondents two initial questions to start the mapping process, to visualize the timeline of Coopedota's pathway to CN and to identify the actors involved: (1) How did the idea of carbon neutral coffee arise at Coopedota, and how was the certification then achieved? (2) Which actors (persons or institutions) were involved in achieving the CN certification?

Following these questions, the participants discussed and identified the **actors** and specified their involvement in the evolution of carbon neutral coffee at Coopedota. The names of the actors were written on small colored sticky notes (the colors represented different kinds of actors), which were tagged on a big paper sheet. The actors were numbered and explanatory notes were made at the edge of the paper sheet. The discussion was also audiotaped. Linkages between the actors were discussed and drawn on the paper, again using different colors to represent different types of linkages.

The authors identified **six types of linkages** between actors (see Figure 3): funding (money flows), advice (contribution of knowledge), collaboration (interaction regarding the project), help with LCA (active involvement), enforce (enforcement of activities by law) and approve (official approval by the general assembly). The authors decided to keep the linkage "help with LCA" as an independent linkage type, because the service indicated by this linkage was considered more comprehensive than the advice or general collaboration linkages. In the case of "help with LCA" linkages, the actors provided low-cost (or even free) staff, carried out data collection or supported the assessment of the CF based on the required guidelines provided by PAS 2060.

In Phase 2, the ranking of the actors' importance, the objective was to discuss and rate each actor on a scale from 0-6 regarding his or her importance for ultimately achieving the CN certification. For this purpose, participants were asked to build so called "influence towers" using checkers game pieces. The number of pieces represented the score and they were stacked on each other to form the "towers". An important aspect of this step is the discussion of the reasons behind the score that an actor was assigned. This discussion revealed interesting insights and made a differentiated assessment of human-related success factors possible.

The analysis and comparison of the three Net-Maps showed that it was possible to aggregate them, because they did not contradict each other but rather shed light on different aspects of the certification process. Figure 2 presents the combined Net-Map, which includes the information provided by the three individual Net-Maps. For visualization and for the SNA of the aggregated Process Net-Map, the software package VisuaLyzer 2.0 was used.

2.5 Results

To answer the research question of how PAS 2060 can be implemented in an agri-food context, the first section of this chapter presents details on the application of PAS 2060 in Coopedota. The challenges arising in the process are also explained. In the second section, a timeline is constructed, which illustrates how the idea of carbon neutral coffee emerged and how the certification process unfolded. Finally, the combined Net-Map will be presented and the results of the discussion groups will be reported. On this basis, the success factors will be identified that allowed Coopedota to become a pioneer of CN certification in the agri-food sector.

2.5.1 Application of PAS 2060 at Coopedota

Coopedota was first able to have certified its coffee in accordance with PAS 2060 in the cultivation season of 2010/2011. Table 2 displays the amount of coffee that has been certified under this scheme since then. Table 2 also specifies the CF, expressed in t Co_2eq per functional unit (here kg green coffee), and the amount of GHG emissions that had to be offset by carbon credits. It is important to note that unlike in other schemes, the certification in PAS 2060 does not refer to a certain number of farmers or hectares of land, but to a certain amount of raw material that the cooperative decides to include in the certification scheme, in this case kg of green coffee since it was chosen as the functional unit in the LCA. In view of the certification and offsetting costs, the cooperative initially decided to certify an amount that was equivalent to approximately 50% (920,000 kg of green coffee for exportation and 23,000 kg of green coffee for national retail). In subsequent years, the cooperative decided to half the amount of coffee for exportation to 460,000 kg of green coffee. The main reason to reduce the amount of green coffee was that after the first round of certification, it became obvious that the collection of reliable farm data from a comparatively large number of producers presents a major challenge. Therefore, Coopedota took advantage of a farmers' group inside the cooperative that had already adopted the Rainforest Alliance certification of their coffee and that produce approximately the amount of coffee that ended up being the amount certified as carbon neutral. Due to this groups' experience in farm data collection, this group was able to provide reliable information on coffee management to the cooperative. The group consists of 112 farmers. Together, they cultivate an area of approximately 350 ha of coffee. With an average production of 30 fanegas per hectare (a “fanega” corresponds to 46 kg of green coffee), the farmers produce approximately 10,500 fanegas (amounting to 483,000 kg of green coffee, which corresponds to approximately 25% of total production). As noted above, the cooperative decided to certify 460,000 kg of green coffee for exportation and 23,000 kg of green coffee as roasted coffee for national retail and to keep these amounts constant over the years (Table 2). Due to fluctuations in coffee yield, the group of 112 farmers mentioned above might produce more than the amount required for the certification in one year and less than required in the next year. In the latter case, the cooperative has to include additional farmers in the certification scheme and collect farm management data from those farmers.

The fact that the amount of coffee certified stays the same implies that the CF fluctuates over the years because the yields (output per hectare) are not constant whereas the amounts of inputs that the farmers apply per hectare remain fairly constant. For example, the harvest of 2013/2014 was extraordinarily high, which resulted in a comparably low level of emissions per kg of green coffee. This example also illustrates that it is essential to increase resource use efficiency and productivity in agriculture to be able to reduce the CF of agricultural products.

Table 2: Amount of certified coffee and its remaining emissions

Year		**2010/11**	**11/12**	**12/13**	**13/14**	**14/15**
Amount of coffee certified (kg green coffee)	Green Coffee[(1)]	920,000	460,000	460,000	460,000	460,000
	Roasted coffee	23,000	23,000	23,000	23,000	23,000
Emissions ($t\ CO_2eq$)	Green Coffee	1,800	917	1,443	508	859
	Roasted coffee	69	62	90	48	81
Carbon Footprint ($kg\ CO_2eq\ kg^{-1}$ green coffee)	Green Coffee (cradle-to-gate)	**1.96**	**1.99**	**3.14**	**1.10**	**1.87**
	Roasted coffee (cradle-to-grave)	**3.00**	**2.70**	**3.92**	**2.10**	**3.15**
Total emissions to be offset [(2)] ($t\ CO_2eq$)	Green & roasted coffee	1,869	979	1,533	556	940

Source: adopted from Coopedota, (personal communication, April 2015).
[(1)] Green coffee for export and roasted coffee sold nationally.
[(2)] Remaining emissions, which have to be compensated by carbon credits.

Coopedota divided their certified coffee into export coffee (green coffee) and nationally sold coffee (roasted coffee) (see Table 3). The cooperative used a cradle-to-gate approach for green coffee, considering emissions along the value chain until the port in Limon (Costa Rica), arguing that any further emissions are the responsibility of roasters and consumers abroad. For the roasted coffee, however, a cradle-to-grave approach was applied, which includes the emissions arising from the product's consumption and disposal in Costa Rica. Accordingly, the CF of roasted coffee is substantially higher than that of green coffee, as shown in Table 2. For the roasted coffee, Coopedota provided the emission data occurring during roasting (at the cooperative's own roaster facility) and for transportation. The GHG emissions generated at the stage of consumption and disposal were estimated based on national patterns of coffee preparation and waste management.

Table 3: Emissions considered along the value chain (harvest 2010/2011)

	Farm	Mill	Transport	Roasting	Consumption	Residues
Exportation [(1)] (green coffee)	**94%**	4%	2%	Taken over by roaster and consumer		
Carbon Footprint: (kg CO_2eq kg^{-1} green coffee)	1.84	0.07	0.04		--	
National market [(2)] (roasted coffee)	62%	1%	5%	15%	8%	9%
Carbon Footprint: (kg CO_2eq kg^{-1} green coffee)	1.86	0.03	0.15	0.45	0.25	0.26

Source: Adopted from Coopedota R.L., 2011. (For more detail see Appendix 1 and 2)
[(1)] For exported coffee LCA was conducted using the cradle-to-gate approach.
[(2)] For nationally sold coffee LCA was conducted using the cradle-to-grave approach.

In the case of Coopedota, the highest share of GHG emissions along the coffee value chain is generated at the farm level (Table 3). The guidelines of PAS 2050 state that land use change (LUC) is being accounted for if it occurred during the last 20 years (BSI, 2011, p. 11). Since coffee farms at Coopedota have existed for over 50 years, emissions from LUC did not have to be considered in the assessment of the CF. Emissions from (LUC) are known as one of the main sources of agricultural GHG emissions (Bellarby et al., 2008). In case of Coopedota, this emission hot spot is generated not by LUC but by the use of fertilizers that contain nitrogen, phosphorus and potassium (NPK fertilizers). They contributed 1.57 kg CO_2eq kg^{-1} green coffee to the CF of 1.84. GHG emissions are caused both in the production of fertilizers and by the release of N_2O after its application on the soil. Liming, another soil management measure, contributed emissions of 0.27 kg CO_2eq kg^{-1} green coffee. Consequently, it is important to conduct soil analyses to allow for a site-specific application of fertilizers, and to reduce N_2O fluxes, e.g., by applying slow release nitrogen fertilizers. Coopedota is currently testing such techniques.

As shown in Table 3, the emissions arising at the mill and from transportation are relatively low. Surprisingly, in the case of exported coffee, emissions at the milling stage are mainly generated during the transportation of jute sacks from Bangladesh (0.04 kg CO_2eq kg^{-1} green coffee), while only a minor share of emissions is due to drying (0.03 kg CO_2e kg^{-1} green coffee, see Appendix 2). In the case of Coopedota, the relatively low emissions generated by the drying ovens are the result of strong efforts (since 1998, see Table 4) to reduce emissions and save costs. Further, since the pulp waste, which is also produced at the milling stage, is now being composted and not fermented any longer, it does not account for further emissions.

Table 4: Sustainability achievements of Coopedota between 1998 and 2010

Subject	**1998**	**2010**
Wood consumption *(more efficient automatic ovens and using coffee husk as the main fuel)*	8000m^3 / harvest	500m^3 / harvest
Energy consumption *(more efficient automatic ovens)*	7.5kWh / 45kg coffee	3.3kWh / 45kg coffee
Water consumption in the mill *(Recycling of used water)*	1m^3 / 45kg coffee	0.2m^3 / 45kg coffee
Waste water released into river *(treatment and meadow irrigation system)*	100%	0%
Pulp	Fermented	Composted
Nitrogen Fertilizer	incl. pure nitrogen	No pure nitrogen

Source: Adapted from Coopedota R.L., 2011. See more details also in (Jiménez et al., 2013).

The production and transportation of aluminum packages at the roasting stage (Table 3) accounts for approximately 12% of total emissions, whereas the roasting itself is responsible for only 3%. Thus, aluminum packages cause the second largest share of emissions (0.36 kg CO_2eq kg^{-1} green coffee) after NPK fertilizers in the case of roasted coffee, where cradle-to-grave applied.

Emissions at the consumption stage are often hypothetical and, depending on the preparation method used, can vary considerably. According to Coopedota's estimate, they account for 8% of total emissions (Table 3). This estimate is based on the assessment that 50% of Coopedota's nationally sold coffee is prepared in coffee shops, using industrial electric coffee machines, while the other 50% are prepared domestically, using electric coffee makers (74%) or simple filter techniques on electric stoves (20.8%) or gas stoves (5.2%). Emissions arising at the disposal state are in the same range as emissions arising during the consumption stage. Emissions are in particular generated by depositing coffee grounds to landfills, instead of composting them.

2.5.2 Coopedota's pathway to carbon neutrality

Figure 1 shows a timeline of the process that led to certification at Coopedota. To facilitate the understanding of how the idea of carbon neutrality emerged at Coopedota, the timeline shows not only events at the cooperative's level but also at the national and international levels.

2.5.2.1 Timeline of developments

Developments and actions of Coopedota were motivated by national and international policies and trends (Figure 2). The path towards carbon neutral coffee started about 20 years ago. One of the initial factors was the call of Costa Rica's Ministry of Health (MINSA) in 1998 to avoid wastewater entry into rivers, which enhanced sustainable policies at Coopedota. At the same time, the cooperative's manager introduced a cost saving policy and acquired new automatic and energy efficient drying ovens. National interest in active climate policy emerged in 2000 and culminated in 2006, when the then president Óscar Arias Sánchez, announced that Costa Rica should achieve national carbon neutrality by 2021. Achieving this goal would make Costa Rica the first country in the world to become carbon neutral. In parallel to the increasing interest in climate protection, there has also been an increasing international demand for sustainable coffee production. As a response, Coopedota engaged in various certifications related to sustainability, including Rainforest Alliance, Coffee Practice of Starbucks, ISO 9001 and 14001 and Fair Trade. Next to national policies, Coopedota's own experience and achievements, especially with the ISO and the Rainforest Alliance certification, resulted in Coopedota's idea to certify their coffee as carbon neutral. Being a pioneer case of carbon neutrality in coffee, the cooperative also aimed to demonstrate that it is, in principle, possible to make the Costa Rican coffee sector carbon neutral. Coopedota aimed for a high quality and internationally recognized CN certification. An in-depth comparison of available standards led to the insight that PAS 2060 is particularly suitable, because this standard is independent in nature as it was collectively designed by leaders from governments, businesses and NGOs. Carbon Clear, a carbon management consultancy and third party verifier, was selected to support the CF analysis due to its high reputation for being trustworthy. The decision to become carbon neutral led to the assessment of GHG emissions and of the implementation of renewable energy projects from 2009 onwards (ethanol production from sugar-rich waste water, installing of a biodigester that runs on waste water, biomass gasification of dried pulp and husk). During that time the National Institute of Technical Norms (INTECO) worked on a national standard to demonstrate CN, which was finalized in 2011. However, this standard came too late for Coopedota. In fact, Coopedota's pioneering efforts may have encouraged national policy-makers to act on their ambitious goals regarding carbon neutrality. As an indication, representatives of the cooperative joined the 18th Conference of the Parities (COP 18) to the UN Framework Convention on Climate Change in Doha, Qatar in 2012. At this event, 20,000 cups of the world's first carbon neutral coffee from Coopedota were served. This event not only illustrates the awareness of the cooperative regarding international climate policy developments, it shows that the cooperative even played an active role at that level.

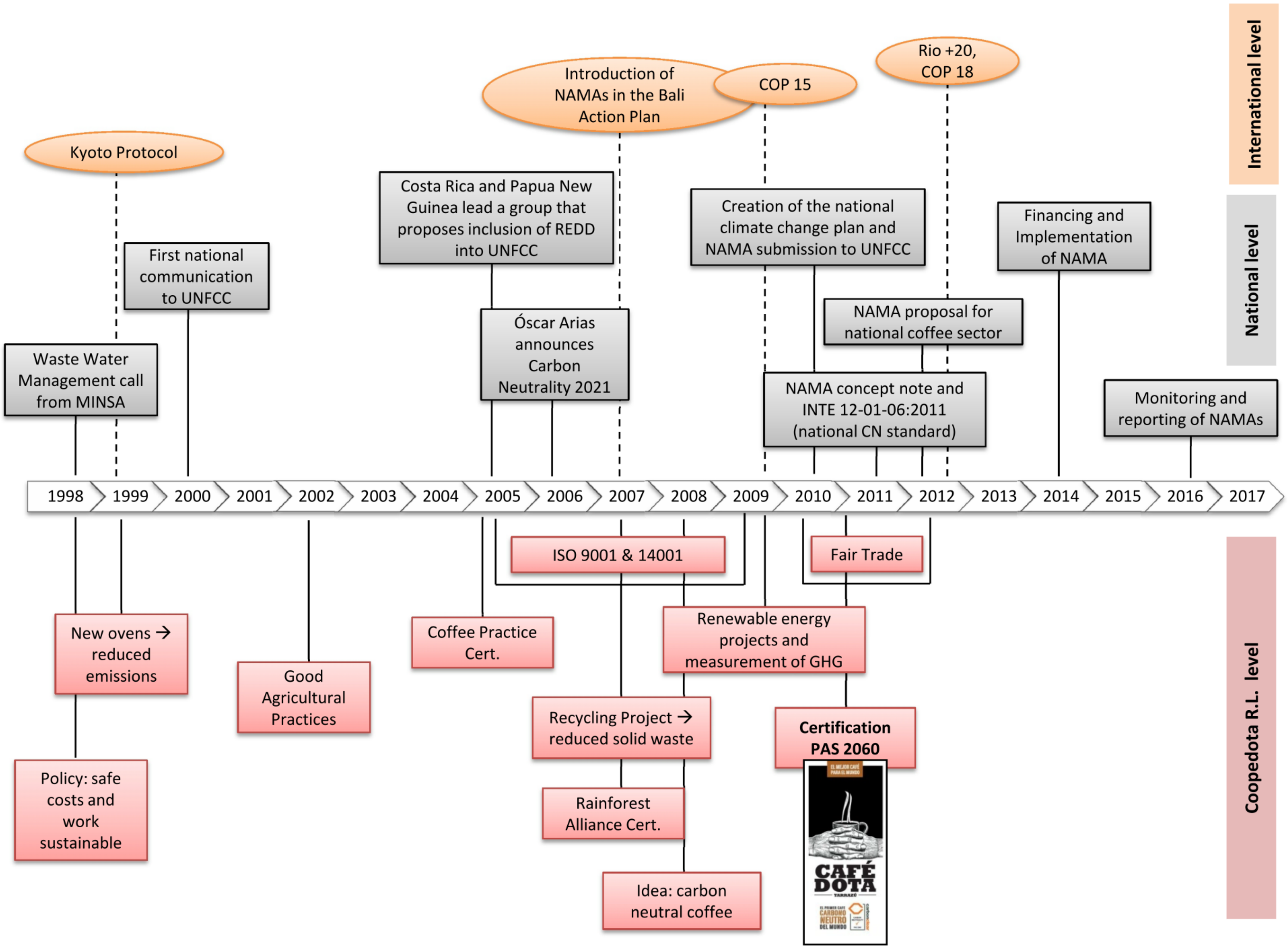


Figure 2: Timeline of Coopedota's path to Carbon Neutrality.

2.5.2.2 The Process Net-Map of Coopedota's way to carbon neutrality.

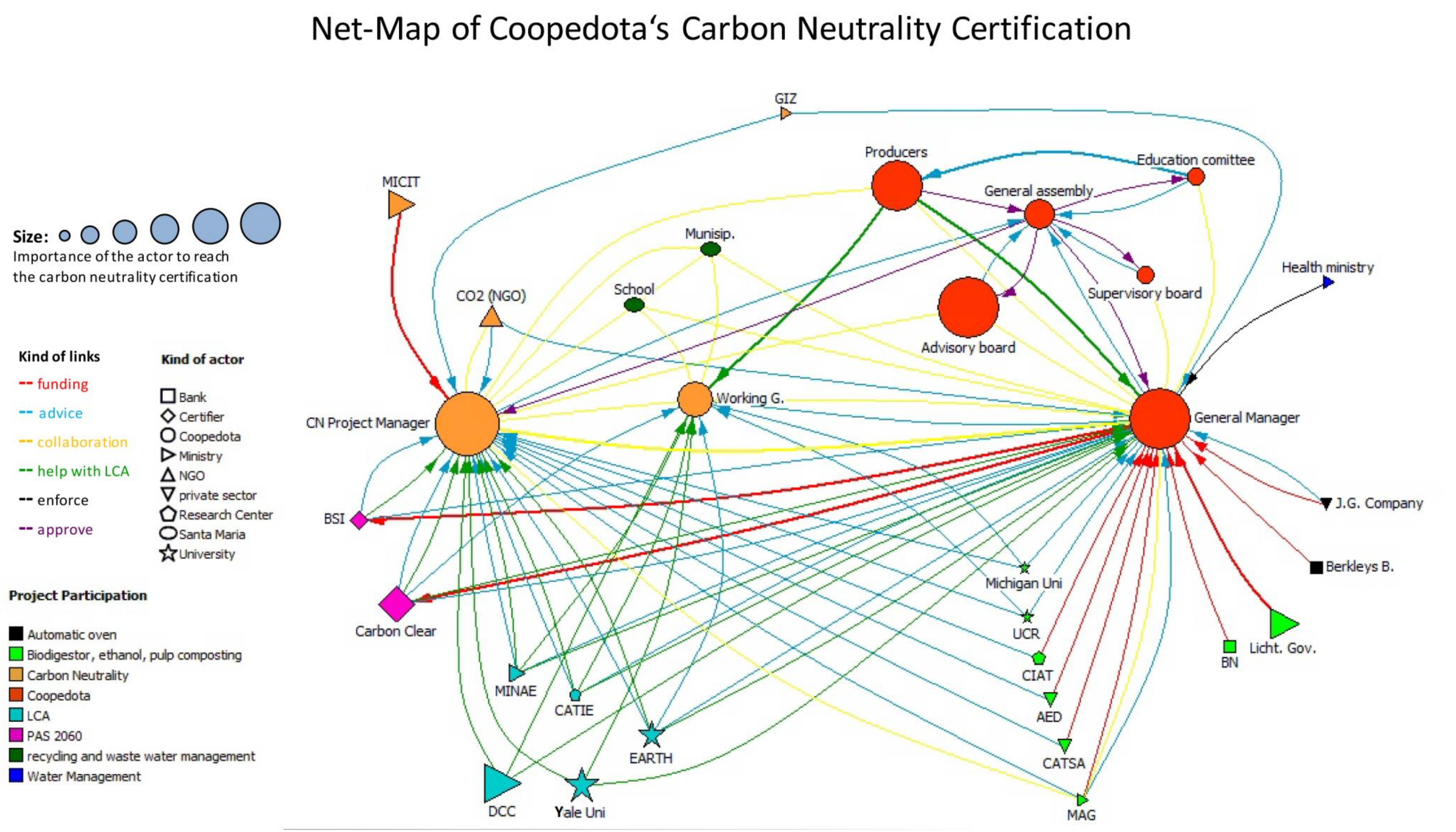
Figure 3 presents the aggregated Process Net-Map, which identifies the actors involved in achieving the PAS 2060 certification. Following an explanation of the map, this section presents an analysis of the network, based on a qualitative and a quantitative analysis.

Actors:

As shown in Figure 3, the cooperative's general manager and the CN project manager have a prominent position in the network, as they are well linked with most of the other actors, but also among each other. Different bodies inside the cooperative, particularly the advisory board and the working group on CN, played an important role in achieving the certification. In general, the network displays a high diversity of actors from different sectors, which illustrates the complexity of expert knowledge and assistance required to achieve the certification as a pioneer. Many actors can be categorized in two project groups: (i) Institutions that assisted in calculating the CF (LCA group, displayed in turquoise color); (ii) institutions involved in the different emission reduction projects, such as composting coffee pulp, installing a biodigester and producing ethanol from sugar rich waste water (displayed in light green color).

Linkages:

In terms of linkages between actors, only few direct funding connections between actors were identified during the group interviews. However, many linkages were identified that involve advice, help or collaboration. Interestingly, most external advice was accompanied by funding or the provision of experts, in particular to assist with the LCA required for the certification. Therefore, the same pair of actors was often linked by two different types of linkages. For example, groups in charge of the biodigester, ethanol and pulp composting (marked in light green) gave advice to the central actors and additionally provided financing for the implementation. Likewise, the LCA group provided advice and sent their staff to actively help with the LCA. This combination of linkages, are here referred to as "double linkages".



Abbreviations:

- **General Manager** -> of Coopedota R.L.
- **CN Project Manager** → Coordinator of Carbon Neutrality Certification
- **Working G.** → Working Group for the Carbon Neutrality Project
- **Producers** → coffee farmers who participate in the Carbon Neutrality Project
- **Munisip.** → Municipality of Santa Maria de Dota including mayor of S. D.
- **School** → in Santa Maria de Dota
- **Health Ministry** → MINISA
- **J.G. Company** → John Gordon Company
- **Barclays B.** → Barclays Bank, UK.
- **BN** → Banco Nacional (CR)
- **Licht. Gov.** → Government of Lichtenstein
- **MAG** → Ministry of Agriculture (CR)
- **CATSA** → Sugarcane Organisation (CR)
- **AED** → Organisation for rural development (CR)
- **CIAT** → Research Center for Tropical Agriculture
- **UCR** → University of Costa Rica
- **Michigan Uni** → Michigan State University
- **EARTH** → Earth University (CR)
- **CATIE** → Research Center on Tropical Agriculture (CR)
- **MINAE** → Ministry of Environment and Energy (CR)
- **Yale Uni** → Yale University
- **DCC** → Climate Change Office of MINAE ministry (CR)
- **Carbon Clear** → Certifier in USA
- **BSI** → British Standards Institute (UK)
- **MICIT** → Ministry of Research and Technology (CR)
- **CO2** → NGO working on Climate Change and Carbon Neutrality (CR)
- **GIZ** → German Society for International Cooperation (GE)

Figure 3: Aggregated Process Net-Map of achieving the CN certification at Coopedota.

Numerical analysis of the social network (SNA)

The general observations reported above are supported by the numerical analysis of the Net-Map. Two network indicators were calculated: density and degree centrality. The results are displayed in Table 5.

Table 5: Network properties

Property	**Value**
Density[(1)]	0.20
Degree Centrality[(2)]	86%

(1) Ratio of all existing links to all possible links. A density of 1 describes a perfectly interlinked network.
(2) How centralized is the network? A degree centrality of 100% is achieved when one actor is linked to all other actors in the network.

The low density of the network indicates a rather poorly interlinked network. One reason for this observation might be the nature of the network as a project-related one, which implies limited boundaries. Therefore, the Net-Map does not display linkages that the same actors may have regarding other projects. As can be seen in the Net-Map, only two actors, the general manager and the CN project manager, are well interlinked, which results in a centralized network that consequently displays a high degree centrality.

Table 6 presents centrality characteristics of the network's actors based on three conventional SNA indices: degree, normalized closeness and normalized betweeness. The table also shows how the focus group participants scored the influence of the different actors. Table 6 identifies the Cooperative's manager and the CN project manager (degree value of 34 and 26, respectively) as the most strongly linked actors within the network. There are two other well-linked actors, the working group and the general assembly (degree value of 13 and 11, respectively). The remaining actors are, however, rather poorly linked. The degree values are consistent with the values of normalized closeness, which supports the observation that not many actors have direct connections with each other. Instead, all are connected to the two central actors of the network. The normalized betweenness values illustrate that these two central actors hold broker positions. This might be the case because they were the active networkers looking for necessary advice and support. Thus, they were building a bridge between actors.

Table 6: Characteristics and importance of the different actors

Actors[(1)]	Degree[(2)]	Normalized Closeness[(3)]	Normalized Betweenness[(4)]	Importance score (0-6)[(5)]
General Manager	34	97%	60%	5
CN Project Manager	26	81%	27%	6
Working Group	13	64%	4%	3
General assembly	11	56%	1%	2
Producers	6	55%	0%	4
Carbon Clear	4	54%	0%	3
MAG	4	54%	0%	0
Advisory Board	4	53%	0%	5
Education committee	4	53%	0%	1
School	4	53%	0%	0
Municipality	4	53%	0%	0
BSI	3	53%	0%	1
Supervisory Board	3	53%	0%	1
CATIE	3	53%	0%	0
EARTH University	3	53%	0%	2
Michigan Univ.	3	53%	0%	0
UCR	3	52%	0%	0
MINAE	3	52%	0%	1
CO2	3	52%	0%	1
DCC	3	52%	0%	3
Yale Univ.	3	52%	0%	3
CIAT	2	52%	0%	0
AED	2	52%	0%	0
CATSA	2	52%	0%	0
GIZ	2	52%	0%	0
BN	1	50%	0%	0
J.G. Company	1	50%	0%	0
Barclays Bank	1	50%	0%	0
MICIT	1	50%	0%	2
Lichtenstein Gov.	1	50%	0%	2
Health Ministry	1	45%	0%	0

(1) See Figure 2 for full form of abbreviated actors
(2) Number of links an actor has with other actors in the network
(3) Connectedness of an actor. 100% means to have connections with all other actors.
(4) The % of actors that have to go through a certain actor, to get into contact with other actors.
(5) Discussion group respondents subjectively ranked the actor's importance (0-6) to achieve CN certification.

Importance of actors to reach CN:

Since the importance score of actors assigned by the focus group participants is not always consistent with the SNA centrality measures, it is important to examine the rationale behind the scoring, which was expressed by the participants during the Net-Map session. This rationale is explained in Table 7.

Table 7: Rationale behind the importance score of the actors

Actor/importance	Explanation
General manager of Coopedota & Manager of CN project: Importance: 5/6& 6/6	The *general manager* possesses a very central and strong position inside the cooperative and as such can steer the cooperative's bodies and members. Further, as a visionary, he is especially interested in pioneer projects. His good command of English enables him to build networks at the national and international level. A high importance was assigned to the *CN project manager* too, who, at that time, was responsible for sustainability issues at Coopedota. Here again, individual characteristics were important. This person graduated at the EARTH University in Costa Rica. Further, she also worked for the NGO "CO2", which is active in climate issues and projects. Therefore, she had access to information on national and international climate policies and was able to create an external network related to climate change. She was a key driver on Coopedota's way to CN due to her talent to successfully apply for funds and due to her strong personal interest and commitment. Her good command of English was also helpful. Even though the manager of the CN project was the person in charge, every actor had to go through the general manager, as well. The CN project manager was responsible for planning and application of projects, whereas the general manager was handling any official activity and funding.
Advisory Board: Importance: 5/6	The *Advisory Board* was rated as very important because the general assembly mostly followed the decisions of this board. Moreover, the board was able to influence the decisions of the general manager.
Producers: Importance: 4/6	Surprisingly, most of the *coffee farmers* were not aware of the CN certification, including farmers who provided data for the certification. They had never heard about it, confused it with other certifications or did not know what it stands for. The reasons might be the complexity of the topic and a certain general confusion about the various certifications pursued by the cooperative. Still, the producers were seen as an important actor because they deliver the necessary farm data, which has to be

	reliable. The participants were well aware of how important farmers' compliance is for the success of the certification.
Working Group (WG): Importance: 3/6	The *Working Group* was created as the responsible body for all activities inside the CN project. The Working Group consisted of two persons: one was responsible for data keeping and communication with CarbonClear and the other one for collecting data and managing the group of certified producers. The Working Group was mainly operating under the supervision of the CN manager.
DCC, Yale University, CarbonClear, EARTH: Importance: 3/6, 3/6, 3/6, 2/6	These actors were rated as essential, because they actively supported the LCA measurement and calculation and contributed important expert knowledge. In this activity, strong collaboration between the different actors was taking place, which also might be due to their own interest in the project. For ministry staff, it was helpful to participate because they wanted to implement similar projects. For the universities, Coopedota was an interesting field to apply scientific knowledge in a pioneer project, and for CarbonClear it was the first time verifying PAS 2060 for an agricultural product. Thus, the project provided a learning opportunity for all of these actors.
Funding (MICIT & Lichtenstein Gov.): **Importance**: 2/6, 2/6	The Ministry of Research and Technology (*MICIT*) supported the CN project manager by funding an internship at the BSI (UK). This created a unique opportunity to learn first-hand about climate certification in general and PAS 2060 in particular. Another important donor was the *Government of Lichtenstein*, which supported the cooperative financially in the CN project.
General Assembly: Importance: 2/6	The *General Assembly* was one of the few actors for whom the focus groups participant initially had different opinions regarding the influence score. One opinion was that, officially, the General Assembly has the power to cancel any project and, therefore, their support was essential. A contradicting opinion was that, in practice, the General Assembly usually follows the suggestions of the cooperative's Advisory Board and the general manager. Thus, did not actively contribute to reach CN certification. After intensive discussions, the participants agreed with the second opinion, which resulted in the comparatively low rating of 2/6.
MINAE: Importance: 1/6	The focus group members rated the influence of the Ministry of Environment and Energy (*MINAE*) as rather low. However, according to the personal interview with the CN project manager, it seems that the support of MINAE for the CN project was of higher importance than the participants suggested. The CN project manager felt that it was important for all processes to have the Ministry on board. Apparently, this was not obvious to the members of the focus groups. The collaboration of the

	ministry may also have opened doors at the national and international level for collaboration and support.
John Gordon Company and Barclays Bank: Importance: 0/6	The cooperative acquired new drying ovens, which were manufactured by the *John Gordon Company*, located in the UK. This collaboration further enabled Coopedota to get a loan from *Barclays Bank* (UK). The focus group members did probably not recognize the importance of these actors because they did not consider them to be a direct part of the CN project. However, the participants recognized the role that these ovens played to reduce the energy use for drying coffee and, thus, for reducing GHG emissions. Investing in these ovens was, indeed, the starting point of a development that finally led to the idea to certify a part of Coopedota's coffee as carbon neutral.

In conclusion, the Net-Map identified strong individual actors, with commitment and visions, as essential for the successful CN certification. The findings also indicate a high awareness of participants regarding importance of obtaining reliable data from farmers in the certification process. Surprisingly, however, the farmers themselves had little or no knowledge about the existence of the CN certification, probably because not all farmers were involved in the scheme and those involve provided the data primarily for the Rainforest Alliance certification. The Net-Map interviews also showed that funding was usually combined with advice, resulting in "double linkages" in the Net-Map diagram. This result may be due to the fact that Coopedota preferred support for improved processes, increased efficiency and capacity building over pure financial support. Finally, since Coopedota's coffee was the first agricultural product that was certified in accordance with PAS 2060, the case provided a learning opportunity not only for the cooperative but also for BSI, CarbonClear, universities and ministries. The shared interest to use the pioneer case of Coopedota as a learning platform created a strong collaboration between the different actors.

2.6 Discussion

Based on the objectives of the case study, this section will identify the challenges of CN certifications and discuss success factors in innovations.

2.6.1 Challenges of carbon neutral certifications: Lessons from Coopedota

From the case study, six different challenges can be derived, which are discussed in the following. They are highly relevant for other organizations that are interested in applying CN certification.

1) Farm data

The findings of the study show that the data provided by the farmers play a key role for a successful certification, since the trustworthiness of farm data is essential. Farm data are the basis of CF calculations at the production stage. In the case of coffee, the emissions from farm production account for the highest share of emissions along the value chain, which is also the case for most other agricultural products (Notarnicola et al., 2015). The problem of data availability and quality is well known by the literature, particularly the lack of complete and reliable data regarding the production of farm inputs and the dispersion of their compounds into the air after application. Since these are secondary data the focus was placed on LCA databases such as Ecoinvent v.3 (Notarnicola et al., 2015; Salomone et al., 2015). Less attention has been paid to the availability and quality of primary data at the farm level. This may be the case because most LCA studies on agri-food products have been conducted in developed countries where farm management activities are well documented. In developing countries, farm management data are rather difficult to obtain, especially if production takes place on a relatively large number of small family farms, who do not usually keep records. Coopedota was able to solve this problem by working with a group of farmers who were already certified under Rainforest Alliance. Therefore, they were already used to the process of data collection. The strategy to combine CN certification with other types of certification may also be a valuable strategy for other organizations, especially since this approach also reduces transaction costs. Some certification schemes offer climate certification as an “add-on”, which is another strategy to resolve the data problem. The climate module, developed by the Sustainable Agriculture Network (SAN) under which Rainforest Alliance Certification is operating, is an example. It may also be useful to enhance collaboration between different certification schemes by enabling them to use the same data pool.

2) Emission reduction versus offsetting

The PAS 2060 includes the step of offsetting emissions which remain after reduction efforts so as to achieve climate neutrality. While there is a large body of literature that deals with emission reduction in agricultural products, the issue of offsetting has received more limited attention, so far. Carbon offsetting is often rather confronted with mistrust and is being related to "greenwashing" (Bunning et al., 2013). The reasons for this negative image include (i) a confusing set of related terms, such as zero-carbon, carbon neutral, carbon-free and climate-neutral; (ii) lack of transparency on how carbon reductions were achieved and where the carbon credits came from; and (iii) a lack of comparability due to missing standardized methodologies and differences in functional units, as further discussed below (Bunning et al., 2013). PAS 2060 aims to address these problems and create trust by requiring carbon management plans and emission reduction so as to avoid simple offsetting. By accounting for past carbon reductions, this certification also creates incentives for organizations that have already made substantial progress in emission reductions, as in the case of Cooepdota. Hence, the PAS 2060 certification is not only attractive for firms that still have high emissions and, therefore a high reduction potential, but also for those that have already reduced emissions. Still, from a certain point onwards, further emission reductions will become increasingly expensive and, therefore, the long-term economic feasibility of the PAS 2060 approach needs to be studied, as further explained in the next section.

3) Economic feasibility

CN certification involves (i) costs arising from the reduction of emissions and (ii) costs associated with the data collection (CF analysis), fees for the certification and offsetting. The reduction of emissions may, however, also lead to reduced costs, e.g., reduced costs for energy and fertilizers. On the benefit side, an organization that certifies its products as carbon neutral may achieve a premium price in the market and benefit from a positive image. In the case of Coopedota, the major economic benefit was the reduction of energy expenses, especially by using energy efficient drying ovens. Coopedota also benefitted from their former implementation of other standards and certification (ISO 9001, 14001 and Rainforest Alliance). Further a wide network of supporting organizations helped to reduce the transaction costs arising from the CF analysis. Since coffee is a perennial crop, one could take on-site carbon sequestration into account, which would reduce the costs for offsetting. However, due to lack of reliable data, this potential benefit has not been realized, so far (see Point 6 below). Coopedota mostly sells its green coffee to their long-term customers, companies in high-income countries that are specialized in roasting and marketing of high-quality coffee. These business partners value the image of Coopedota as being environmentally friendly and communicate this image to their customers, even though they have, so far, not specifically marketed Coopedota's coffee as carbon neutral. For long-term economic feasibility, it might, however, be important to sell coffee that is certified under PAS 2060 with a climate label to the end-consumer so as to achieve a price premium.

4) *Comparability (functional units, system boundaries, standardized approaches)*

As indicated above, it has remained difficult to compare different labels containing information on GHG emissions of agri-food products for carbon neutrality (Schaefer and Blanke, 2014). One problem is the calculation of the carbon footprint, because the *functional unit* can differ. In the case of coffee, one can calculate GHG emissions per kg green coffee, as in this paper or by Kilian et al. (2013). An alternative is calculating emissions per cup of coffee, as in case of a Tchibo project ((PCF Pilotprojekt Deutschland, 2009). Emissions have also been calculated per hectare or coffee bush (Andrade et al., 2014). A comparison of these approaches shows that CFs differ mainly at the farm and the consumption level. The footprint calculated for Tchibo's coffee corresponds to 4.0 kg CO_2eq kg^{-1} green coffee. Coopedota calculated a value of 1.9 kg CO_2eq kg^{-1} green coffee and Kilian came up with a value of 1.50 kg CO_2eq kg^{-1} green coffee for coffee produced in Costa Rica. One reason for the higher value of Tchibo's coffee could be the fact that it is produced in Kenya, where productivity and input levels might have a different relationship than in Costa Rica.

Another problem regarding the comparability is the difference in *system boundaries*, since either cradle-to-gate or cradle-to-grave approaches might be used. In the case of Coopedota, both approaches were used, which might be confusing. In general, the cradle-to-gate approach is preferred in CF calculations since the emissions at the consumer level are very variable and it is unclear who is responsible for them (Environmental Product Declaration (EPD), 2013; O'Brien et al., 2014; Schaefer and Blanke, 2014). However, to be able to sell coffee as carbon neutral to consumers in Europe, at least the emissions for shipping, roasting, distribution and packaging should be included and made mandatory for labelling. In the assessment of Coopedota, consumption emissions (emissions occurring during the preparation of coffee) were 0.25 kg CO_2eq kg^{-1} green coffee, corresponding to 8% of total emissions (see Table 3). The study by Kilian et al. (2013) concluded that consumption was responsible for about 60% of total emissions (2.15 kg CO_2eq kg^{-1} green coffee). In Tchibo's case, emissions of 2.17 kg CO_2eq kg^{-1} green coffee were calculated in the best estimation scenario. In a min-max scenario, emissions ranged from 1.19 - 7.30 kg CO_2eq kg^{-1} green coffee. The reasons for these differences are assumptions on how the coffee is prepared (automatic coffee machine, filter coffee machine, simple filter systems) and which energy source is used to heat the water. These findings show that the CF varies very widely at the consumption level, which indicates that there is a very high potential for emission reduction by consumers.

The above considerations show that comparability between different carbon labels and certification schemes remains a major challenge. One has to acknowledge, however, that valuable efforts have been made to address this challenge, e.g., by BSI or ISO in creating *standardized specifications*, such as PAS 2050, ISO 14067 and by developing guidelines for specific sectors, known as Product Category Rules (EPD, 2013).

5) Communication and marketability

The challenge of communicating different carbon labels has been highlighted in the literature (Schaefer and Blanke, 2014). Unlike other climate labels, carbon neutral labels do not indicate the amount of GHG emissions that is associated with a specific product nor do they provide information on emission reduction or offsetting. Moreover, as mentioned before, there is mistrust in the public with regard to offsetting. These factors complicate the marketability of carbon neutral products and their potential to gain premium prices. Although the topic is complex, it is important to ensure transparency and provide sufficient information to consumers in order to gain their trust in high-quality standards for carbon neutrality. Government agencies and civil society organizations may also play a role in informing and sensitizing consumers about carbon emissions that are associated with the consumption of different food products.

6) Carbon sequestration

Although PAS 2060 is probably the most updated approach for CN certification, on-site carbon sequestration is not accounted for, with the exception of land use change. The reason is that carbon sequestration by perennial crops is generally omitted in LCA (Bessou et al., 2013). There is, however, a considerable potential for carbon sequestration by perennial crops, especially if they are managed with attention to this goal (see, e.g., Pretty and Ball (2001) and Paustian et al. (2016). For reasons of scope this problem is not discussed in more detail.

2.6.2 Success factors as implications for innovation projects

The case study presented in this paper also provides important lessons regarding the factors that enable organizations to promote innovative strategies of making their agricultural products more climate-friendly. The case study confirms findings from the innovation literature which indicate that policies and societal trends are important success factors (Hermans et al., 2013; Johnson and Silveira, 2014; Klagge and Brocke, 2012). Political and societal frame conditions create a fertile ground for innovation, but without the right people and their social outreach and inspiration, innovation efforts may still fail. This finding is consistent with the theory that ideas are dynamic and develop over time (Jakku and Thorburn, 2010; Pahl-wostl et al., 2007).

In addition to these success factors, the Process Net-Map made it possible to identify a number of additional factors, which influenced Coopedota's success.

1) *Central actors, network functions and individual commitment*

The actors involved in Coopedota's certification process form a rather centralized network. This finding is in line with the studies by Hermans et al. (2013) and Klagge and Brocke (2012), who also found that centralized networks are often more successful in innovation and pioneer projects. However, Hermans et al. (2013) also found that networks that rely on one or two strong actors are often not robust and, therefore, the resilience of innovations can be threatened. Further, they conclude that "In order for an innovation to spread beyond the immediate participants and also have an impact on other levels of the innovation system, three network functions[6] have to be performed by the actors in the network". These functions also "can be performed by one and the same person, although the capacity to perform two or more network functions is a very rare trait." (p. 127). They found this to be very rarely the case. Nevertheless, the Net-Map results suggest that in the case of Coopedota, the central actors performed these network functions. The general manager and the CN project manager were both active in knowledge creation and learning. They understood how to lobby for their ideas and gain the support of ministries. They clearly had visions and the spirit of entrepreneurship and they held broker positions, especially in case of the CN project manager. The findings suggest that the two central actors that performed all three network functions was a key factor to achieve PAS

[6] Hermans et al. (2013), p. 119 identified the following three network functions: (1) Learning and knowledge co-creation: Knowledge co-creation refers to the importance of knowledge creation in collaborative settings as a process of social learning, which means that ideas are generated, exchanged, but also change over time. (2) Upscaling and institutional entrepreneurship. Upscaling refers to the vertical or hierarchical links between the different levels of the innovation system. We think of this process as similar to the role of the 'power promotor': the process of upscaling deals with the necessity to gain support of an actor higher up in the hierarchy. In the case of innovation networks these are often the administrative authorities. Upscaling is done by institutional entrepreneurs in the innovation network as they perform a political function within the network: lobbying and translating the results of an innovation in political terms.
(3) Outscaling and innovation brokerage. Outscaling is a horizontal process that concerns how knowledge travels between different types of organisations. From an innovation systems perspective this process encompasses more than just the transfer and diffusion of technology. In innovation networks that are composed of more than one sector, brokers are necessary to connect the different types of organisations and to understand and translate the discourses, rules and practices of various types of organisations. These actors are well versed in different types of institutional logic and can facilitate communication between different types of actors, whether they have a stake in the process or not.

2060. This implies that it is important to carefully select suitable and well connected personalities for project management positions, particularly in centralized networks.

2) Diverse set of actors

The network consists of many types of actors who belong to different sectors, including scientific organizations, the private sector, NGOs, and ministries. This diversity was not only essential to source a wide range of knowledge and expertise, but also to ensure funding, to lobby and to create new ideas. The importance of a diverse set of actors has been also recognized in innovation literature (e.g. Van Bueren, Klijn, and Koppenjan 2003; Johnson and Silveira 2014).

3) Double linkages

SNA is usually applied to analyze network structures and network characteristics of its actors, but it is less suited to analyze the nature of linkages that actors have with each other. The case study shows that the analysis of different types of linkages can add important insights. Using the Net-Map approach, the authors found that "double linkages" (see Section 2.5.2. linkages) were a striking characteristic of the network. The interviews confirmed that these "double linkages" created an added value, which suggests that combined services can be seen as a central success factor for innovation. Future research will be needed to confirm this finding.

4) Support of ministries

Even though the cooperative members were not well aware of it, the interviews with the central actors suggest that the support of the Ministry for Environment and Energy (MINAE) was essential. Even though this ministry was not directly involved in the project, it was rather important for Coopedota to engage in lobbying, networking and gaining the support of other ministries. The finding is supported by the innovation literature, which has also recognized the importance that governmental actors have for innovation pioneers. This role is usually attributed to ministerial staff and their function in administration and power (Hermans et al., 2013; Klagge and Brocke, 2012).

5) Creation of new positions or working groups

This case study is in line with the findings of Klagge and Brocke (2012), who observed that creating special positions or working groups is helpful in innovation projects. As compared to the other success factors, this is a rather common practice in project and innovation activities.

2.7 Conclusions

Overall, one can conclude from this case study that PAS 2060 has a considerable potential to promote climate protection in agricultural production, because efforts have been made to strengthen the trustworthiness, comparability and transparency of this approach towards climate certification. The case study also shows that the carbon footprint calculations required for PAS 2060 are a valuable tool to identify emission hot spots regarding GHG emissions along (agricultural) value chains and to create awareness about these hot spots. In the case of Coopedota, reduction of emissions was not the biggest challenge, because the cooperative had already engaged in this activity. The biggest challenge was to figure out how to apply PAS 2060 in the agri-food sector for the first time. Future projects that aim to certify agri-food products with PAS 2060 can probably benefit from the experience of the certifier CarbonClear on how to apply the certification. Depending on the type of product, there might be still differences (e.g., in case of non-perennial crops or different processing requirements) that need to be addressed. Geographical and biophysical circumstances might be different. In view of the challenge of data availability, new location-specific challenges may arise if other organizations apply PAS 2060.

Next to these general conclusions, a number of specific conclusions can be derived from the case study, as well. One conclusion refers to the importance of *good quality farm data* on type of input used and the amount applied. This can be seen as a common challenge, especially in developing countries, where farmers might be illiterate. Coopedota successfully addressed this challenge by including those farmers in the PAS 2060 certification who were already certified under the Rainforest Alliance. These farmers were familiar with the documentation of farm management activities. Another conclusion refers to the importance of the *functional unit* that needs to be specified for calculating the CF (e.g., kg of green coffee). Likewise, the *system boundaries* (cradle-to-gate or cradle-to-grave) need to be specified in order to identify emission hot spots along a value chain. CF studies are essential to detect *emission hot spots*, to assess their variability and dynamics and to identify suitable (economic and technical) areas of emission reduction. The identification of emission reduction strategies is essential to set up the required *carbon management plan*. Pure offsetting is not an option in PAS 2060, which enhances the credibility of this standard. However, *carbon accounting* (that is acknowledging on-site carbon sequestration) is not an option yet, even though this would be particularly important in coffee. Recognizing biogenic carbon sequestration in climate certification might encourage farmers to adopt agroforestry systems, which could significantly contribute to a sustainable integrated mitigation and adaptation approach. Taking carbon sequestration into account may also reduce mistrust towards carbon neutral claims, which continues to challenge the marketability of products that are labelled carbon neutral.

Another conclusion refers to the progress that Coopedota had already made regarding emission reductions prior to engaging in PAS 2060. Examples include applying Good Agricultural Practices (GAP) and ISO 9001 and 14001. These *prior achievements* turned out to be essential to finally certify Coopedota's coffee as carbon neutral. Since such standards are widely applied, other businesses which consider the application of PAS 2060 should analyze whether they have already gained experience, which would facilitate the application of this standard. As a first step, it might be useful to implement other environmental standards or sustainability labels before aiming at carbon neutrality. In general, the question is, whether it is better to have a range of specific labels with different focus areas, or whether it is advisable to combine different certification schemes with the aim to create new holistic labels (sustainability labels) that cover all these aspects at once.

The case study also allows for conclusions regarding the role of pioneers in the field of climate change mitigation in the agri-food sector. Analyzing Coopedota's case from an innovation systems perspective, this study illustrates the importance of a *fertile ground* in terms of conducive political and societal *frame conditions*.

The Net-Map results confirmed a number of success factors that have been identified in the literature on innovation networks. These include the positive role of a diverse set of actors and strong central actors as well as the need to create new positions and ensure the support of ministries. Coopedota's case underlined the crucial role that central actors can play when they perform more than one of the three *"necessary network functions"* at the same time (see 6.2). In this case study the central actors were performing all three network functions, which is a capacity that can be rarely found (Hermans et al., 2013). Nevertheless, the reliance on few central actors may also threaten the robustness and resilience of an innovation system if such strong actors leave the organization.

This case study also identified a success factor, which has not been detected in the literature on social networks and innovation systems so far: the role of "*double linkages"*. These were defined here as a combination of different links between actors, for example funding combined with advisory services or advice combined with the on-site support by experts. These "double linkages" created an added value to the services received by the actors, and, thus, were found to be an important success factor. Identifying this factor was only possible by using the innovative *Process Net-Map tool*, which does not only provide valuable insights into the importance of different actors and the power relations between them, but also into the different types of linkages and their role in the network.

To facilitate a wider adoption of carbon neutral certifications, additional research would be helpful, including economic feasibility studies and simulations for different types of economic actors and financial situations. It would also be important to analyze the application of certification in other regions, for different types of processing coffee, and ultimately for different crops, which may involve different types of challenges. Still, it is perhaps the most encouraging aspect of Coopedota's case that it was a cooperative of smallholder coffee farmers in the mountains of Costa Rica that was able — through its own vision, initiative and effort — to certify the world's first carbon neutral coffee.

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3 Accounting for on-farm carbon sequestration in carbon neutral certified coffee

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3.1 Introduction

Climate Change is one of the most threatening and challenging problem facing mankind today. Agriculture contributes approximately 10-12% of global anthropogenic greenhouse gas (GHG) emissions, mainly due to emissions of CH_4 and N_2O, and an additional 9-11% by land-use change activities such as deforestation (Smith et al., 2014). In recent years, it has gained common understanding that the agricultural sector needs to abate GHG emissions (Wollenberg et al., 2013), increasing the pressure and expectations on farmers even more.

The rise of climate certifications and carbon labeling onagri-food products (Finkbeiner, 2009; Schaefer and Blanke, 2014) due to a strong demand by consumers (Gadema and Oglethorpe, 2011), illustrates a similar picture. Examples are carbon neutral certified agri-food products, complying with the Publically Available Standard (PAS) 2060 for carbon neutrality. PAS 2060 is based on single-impact life cycle assessment (LCA) and the carbon footprint (CF). For PAS 2060 a GHG inventory of the products' value chain has to be undertaken and emissions that cannot be further reduced have to be compensated by internationally certified carbon credits (BSI, 2014). "Carbon neutral" in PAS 2060 is defined as a 'condition in which during a specified period there has been no net increase in the global emission of GHGs to the atmosphere as a result of the GHG emissions associated with the subject during the same period' (BSI, 2014 p. 2). Emissions from land use change (LUC) have to be accounted for if the LUC occurred during the last 20 years (BSI, 2011 p. 11). Although PAS 2060 is probably the most updated approach for certifications on carbon neutrality, on-farm CS, other than LUC, is not accounted for. The reason is that CS by perennial crops is generally omitted in LCA (Bessou et al., 2013), since there is a high degree of uncertainties which is not compatible with LCA guidelines, and carbon accounting lacks recognized and standardized methodologies (De Rosa et al., 2017). There is, however, a considerable potential for CS by perennial crops, especially if they are managed with attention to climate change mitigation (see, e.g., Paustian et al., 2016; Pretty and Ball, 2001). Since considerable mistrust exists towards offsetting practices (Co2Balance, 2011) the recognition of on-farm CS could potentially rebuild trust, and create an incentive for sustainable management practices. Further it could potentially result in financial savings and investment into new technologies.

Coffee is one of the most traded products worldwide (Esquivel and Jiménez, 2012) and occupies more than 11 million ha (Waller et al., 2007). Coffee production systems vary from full sun (dominant in Brazil) to traditional polyculture systems with large shade trees, e.g. in Central America such as Guatemala or Nicaragua (Moguel and Toledo, 1999). In Mesoamerica coffee is usually grown in agroforestry production systems; however, in Costa Rica a more "technified system" (i.e., high yielding varieties, limited shade tree integration and diversity, high agrochemical inputs and more), aiming at high productivity is common (van Rikxoort et al., 2014). In general, AFS and CAFS (coffee agroforestry systems) have been acknowledged for their important contributions to climate change mitigation and their potential to sequester carbon. IPCC estimates the CS in improved AFS with 0.3 t C ha^{-1} $yr^{-1}$and in case of converting to AFS 3.1 t C ha^{-1} yr^{-1} (Watson et al., 2000). On the one hand carbon is sequestered through accumulation in above ground carbon (AGC) and on the other hand the integration of trees and their production of litter biomass enhance the content of soil organic carbon (SOC) in the system (Nair et al., 2009).

Aside from LCA-based certifications, accounting for CS is usually done on a project basis e.g. land-use change or reforestation projects, with durations of around 20 years. Most of the internationally available certified carbon credits are generated by such projects (e.g. Joint Implementation and Clean Development Mechanism), as well as renewable energy projects. In reforestation or afforestation projects, it is the land-use change that leads to increases in CS, which then will reach a new equilibrium after approximately 20 years. Accounting for temporary CS in such static modeling approaches offers the opportunity to address issues of permanence, saturation and additionality, which are characteristics to be considered in temporary carbon sequestration. Permanence is the longevity of carbon stocks, since they are considered as reversible (Smith et al., 2014). Saturation refers to the fact that carbon stocks in living biomass (soil and vegetation) cannot increase indefinitely but reach new equilibriums (Smith et al., 2014). Environmental additionality refers to the environmental integrity of the claimed amount by which greenhouse gas emissions are reduced due to a project relative to its baseline (IPCC, 2014). In agriculture and agroforestry, the situation is different. These systems have often been established more than 20 years ago, or they might be permanently changing (rotation agriculture). Since there might be no LUC to be considered, it might be difficult to observe CS rates. However, CS might compete with yields. High yields are the focus of agricultural activities, and should not decrease due to their importance for food security and household income.

There is also a need to better understand the mitigation potentials of agricultural or agroforestry systems (Smith et al., 2014). So far, data on carbon stocks in the different carbon pools (shade trees, crops, litter, roots, soil organic carbon) are scarce, and little is known on their annual sequestration rates (Kumar and Nair, 2011). Furthermore, there is very little scientific experience with certifications on carbon neutrality for agricultural products and very little information on how to account for on-farm mitigation in LCA (De Rosa et al., 2017).

Only few studies related detailed data on coffee emissions and CS (Andrade et al., 2014; Noponen et al., 2013a; van Rikxoort et al., 2014) to each other. While van Rikxoort et al. (2014) compared different intensities of coffee production systems regarding coffee CF and carbon stocks, Noponen et al. (2013a) analyzed the compensation of emissions by CS and their economic implications. Andrade et al. (2014) assessed the CF of three different coffee production systems in Colombia, including GHG emissions along the value chain and on-farm CS. However, none of these studies present annual carbon balances but rather project based evaluations, including a baseline and a certain time period of the project. In the LCA society there are attempts to overcome the problem of static models model, and replace them with time-dependent accounting of carbon fluxes, which also manage to fulfill LCA principles. De Rosa et al. (2017) have developed a simplified and flexible model for forest carbon fluxes that accounts for carbon balances using a time frame unit of 1 year. In line with these developments in carbon accounting the following study addresses the necessity for a dynamic model to account for CS in PAS 2060 certified coffee. It, therefore, aims at assessing carbon data of CAFS and discusses how to obtain them. Using data from Coopedota's case of carbon neutral certified coffee allows for a unique analysis of the on-farm CS potential to compensate the emissions of the coffee. By this, the potential integration of on-farm CS accounting into climate certifications will be discussed. This paper focuses on the following research questions:

1. What are the challenges of accounting for on-farm carbon sequestration in coffee-agroforestry that have been identified by the literature so far?
2. Investigating the case of carbon neutral coffee at Coopedota, what is the potential of carbon sequestration in the coffee plantations to compensate coffee GHG emissions inside the product's value chain and what are the implications?

3. What are factors at the farm level that should be considered to increase the potential for a complete compensation of coffee emissions? In other words, by which means can the coffee farmers of Coopedota contribute more to effective emission compensation?

3.2 Materials and Methods

As shown above, temporal carbon accounting along a product's own value chain is a new and little-researched area. A lack of standardized methodological procedures and rules also challenges the carbon accounting in this study. On this background, the following sections are focusing on a complete description of the methodological steps undertaken in this study. After depicting the literature review the research area and sampling design will be presented. Emphasis will then be put on describing the carbon inventory and finally the carbon accounting model with its associated assumptions.

3.2.1 Literature review

The structured literature review included the search in journal databases, professional research websites such as research gate, google scholar, Mendeley, but also library catalogues of Universities and research institutions (particularly the research institute CATIE).

During the search for suitable articles and data a wide range of search terms was used, as the issue of carbon accounting is relatively new and has been investigated using different terminology. Some examples are: carbon accounting vs. temporal carbon sequestration vs. carbon fixation vs. C_{O2} sequestration/ fixation, biogenic carbon sequestration, on-site offsetting, in-setting, carbon credits, carbon neutral, coffee vs. agro-food vs. agroforestry, CF compensations.

Selection criteria for the literature sources were its relevance to the research topic, geography and Coffee-Erythrina agroforestry systems. Peer review was an important selection criterion, however in cases of high relevance and in high geographical accordance other research papers and dissertations were included, under the condition of sound methodology. Further the age of the research material was a selection criterion regarding the topic of identified challenges, and less important for carbon sequestration potential in CAFS.

Finally, to reach comparability, presented data in research articles were translated if necessary, e.g. to make sure under above ground carbon any below ground carbon is excluded, or looking at planting densities to reach comparability on area scales.

3.2.2 Study site and sampling design

The study was conducted with members of the coffee cooperative Coopedota in the Los Santos region, Costa Rica. The central hub of Coopedota is located in Santa Maria de Dota (9°39’N, 83°58’W), a small village, surrounded by coffee fields at altitudes of 1,500-2,200 m amsl. The area reports average rainfalls of about 2,400 mm per year and mean annual temperatures of 19°C (ICAFE, 2017). There are two distinct seasons; a dry season (December – April), and a wet season (May – November). This study was conducted between December 2014 and March 2015, which falls within the harvest time of coffee. The landscape of the Los Santos region is mountainous with coffee cultivated on steep slopes of up to 60% (Castro-Tanzi et al., 2012). According to the soil map of Costa Rica’s Ministry of Agriculture the main soil types of the region are Entisols and Inceptisols but also Alfisols, Andisols, and Ultisols are occasionally found (Chinchilla et al., 2011b, 2011c; Oviedo Alpízar, 2011). In general, erosion is one of the major constraints in the study area. About 60% of the area is moderately affected and 18% severely affected by erosion (Chinchilla et al., 2011a). Eight transects were selected for measurements, which are located around the valley of Santa Maria de Dota (Figure 4).

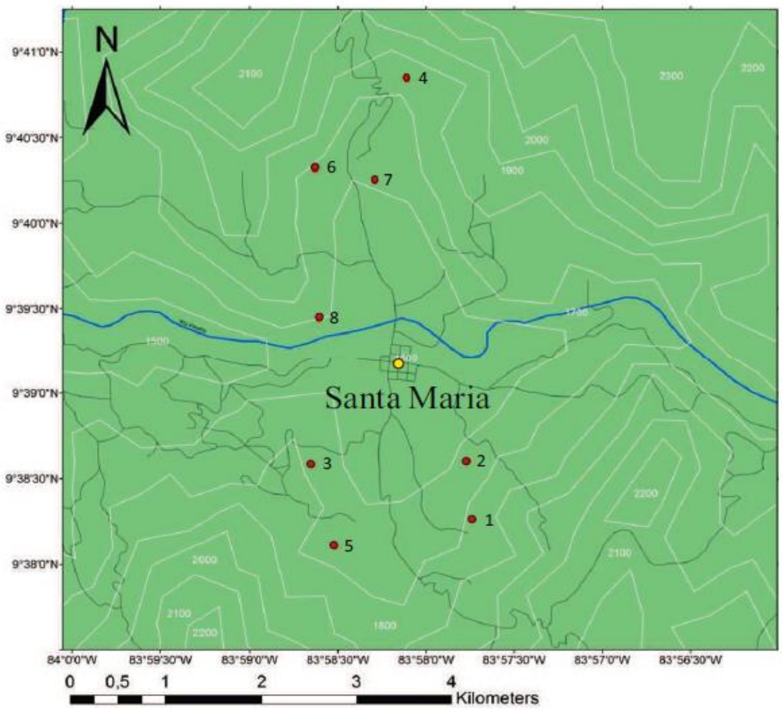


Figure 4: Location of the eight monitored farms in the Valley of Santa Maria de Dota (ArcGIS).

Coopedota has more than 800 coffee farmers, from which 112 coffee growers are carbon neutral certified. Eight farmers were selected for this study, based on the location of their coffee fields at a comparable altitude range (1640 to 1830 m amsl). Among these fields, eight representative transects, with a size of 10 x 20 m, were selected, paying attention on similar values of inclinations (25.4° to 41.7°).Slopes, measured using a clinometer (SUUNTO), pointed, however, into different directions (Table 8). To exclude border effects, space was left to the roads or neighboring fields. Graphs of each transect, including information on plant species, plant location and tree crown extension, were created with SigmaPlot 12.0 to visualize differences among coffee fields. Transect number F6 dropped out of the study after evaluating the results, since it presented an exceptional (subsistence) case and was not representative for Coopedota's coffee farms.

Table 8: Characteristics of the of selected farms

Farm	Compass	Slope in degree	Altitude in m amsl
F1		35.5	1830
F2		34.9	1708
F3		41.7	1727
F4		33.2	1775
F5		36.8	1694
F6#		35.1	1724
F7		27.3	1641
F8		25.4	1655

Finally, this farm dropped out due to its subsistence character, which is not a common practice in the area.

3.2.3 Household survey

Overall, 100 households, among them the ones providing the seven farms,were randomly chosen from the members' list of Coopedota, 50 participating in the carbon neutral certification and 50 conventional households. For the household survey a semi-structured questionnaire wasdeveloped. The questionnaire was designed in a way that paid attention on coffee prodution (management, productivity, costs and revenues), the economic situation of the family, socio-demographic characteristics and the carbon neutrality certificaiton.

3.2.4 Carbon inventory

From the transect graphs four dominant carbon components were identified: (i) *Erythrina poeppigiana*, a legume shade tree, (ii) *Persea americana* (avocado), (iii) *Musa sp*., representing several banana species and (iv) *Coffea arabica*.

Allometric equations were used to estimatecarbon stocks inside the transects based on total above ground biomass (AGB) and below ground biomass (BGB).In general, these equations usediameter at breast height (dbh),in the case of coffee diameter at 15 cm (d15)and tree height (h) as input parameters. Several allometric equations were thoroughly evaluated to avoid over- or underestimation as suggested by (Youkhana and Idol, 2011). Table 9 presents the finally selected equations used in this study.

3.2.4.1 Shade trees: Erythrina poeppigiana and Persea americana

For Erythrina allometric Eq. (2) of (Noponen, 2012) was selected. Appendix 3 indicates that this equation has a reasonable performance compared to others, and additionaly considers the tree pruning, which was an important feature in the *Erythrina* – Coffee systems in Dota.

In the case of avocado trees, no specific allometric equation was found. Therefore, this study followed the example of (Somarriba et al., 2013) and used Eq. (3) which is representative for fruit trees.

Tree height (h) was estimated by using an inclinometer (NIKON Forester 550). The diameters at breast height (dbh in cm) of all trees in the transects were measured at a height of 1.3 m on the side facing the slope (Hairiah et al., 2011). For forking trees, the diameters of all forked stems were measured and a diameter equivalent (de) was calculated (Hairiah et al., 2011):

$$\mathbf{de} = \sqrt[2]{\sum(\boldsymbol{dbhforked})^2} \qquad (1)$$

3.2.4.2 Coffea arabica

Coffee management varies around the world, putting emphasis on the local parameterization of allometric equations. A variety of allometric equations specifically for *C. arabica* in Central America is presented by (Segura et al., 2006), with the advice using a simple model that excludes the height parameter (h), since it can be affected by different pruning habits. Therefore, the best-fit model (R^2= 0.93) excluding height was used in this study Eq. (4).

Between 12 and 18 coffee stands were selected randomly, depending on how heterogeneous the transect seemed. Diameters at 15 cm (d15 in cm) above the ground on the side facing the slope and plant height (h in m) were measured.

Table 9: Allometric equations and carbon factors used to estimate carbon stocks.

Eq. no.	Target	Allometric equations	Carbon factor	Source
(2)	*Erythrina poeppigiana*	$\ln AGB = 5.993 + 1.799 * \ln(dbh) + 0.105 * h$	0.5	(Noponen, 2012)
(3)	*Persea americana* (Avocado)	$\text{Log}_{10} AGB = -1.11 + 2.64 * \text{Log}_{10}(dbh)$	0.5	(Somarriba et al., 2013)
(4)	*Coffea arabica*	$\text{Log}_{10} AGB = -1.181 + 1.991 * \text{Log}_{10}(d_{15})$	0.47	(Segura et al., 2006)
(5)	*Musa sp.*	$AGB = 0.0303 * dbh^{2.1345}$	0.4	(Hairiah et al., 2011)
(6)	BGB	$BGB = e^{-1.0587 + 0.8863 * \ln(AGB)}$	0.5	(Cairns et al., 1997)

AGB (Above Ground Biomass), BGB (Below Ground Biomass), dbh (diameter at breast height), d15 (diameter at 15 cm from ground), h (plant height in m)

3.2.4.3 Musa sp.

For *Musa* sp. the widely used allometric equation Eq. (5) of Arifin, (2001) was applied (cited in (Hairiah et al., 2011; Henry et al., 2009; Schmitt-Harsh et al., 2012; Zake et al., 2015). For estimating the above ground biomass of *Musa* sp., the dbh (in cm) was measured for all pseudostems per corm.

The above ground biomass of all shade trees and *Musa* sp. were summed up per transect and converted into Mg ha^{-1}. For coffee the plant density from the transect graphs were used to convert the average coffee AGB into Mg ha^{-1}.

3.2.4.4 BGB

BGB was estimated using Eq. (6) in Table 9 developed for tropical forests by (Cairns et al., 1997). It is based on the relationship of AGB and BGB and has been used in several coffee agroforestry studies (Andrade et al., 2014; Häger, 2012; Schmitt-Harsh et al., 2012; Zake et al., 2015).

3.2.4.5 Carbon factors *(see also Table 9)*

Coefficients, to convert biomass into carbon, range from 0.4 to 0.5 (Fonseca et al., 2012). The most widely accepted and used is 0.5 (Fonseca et al., 2012; Henry et al., 2009; Jain and Ansari, 2013; Nair, 2012; Schmitt-Harsh et al., 2012; van Rikxoort et al., 2014), which was used for trees and BGB. Coffee plants have a higher percentage of leaves, which are less lignified. The analyzed carbon concentration of the leaves was at 45%. Hence, the default value 0.47 by IPCC, (2006), was used. For *Musa* sp., 0.4 was used to convert AGB into carbon, which is the average of the carbon concentration of the leaves and pseudostem (Abdullah et al., 2013).

3.2.4.6 SOC

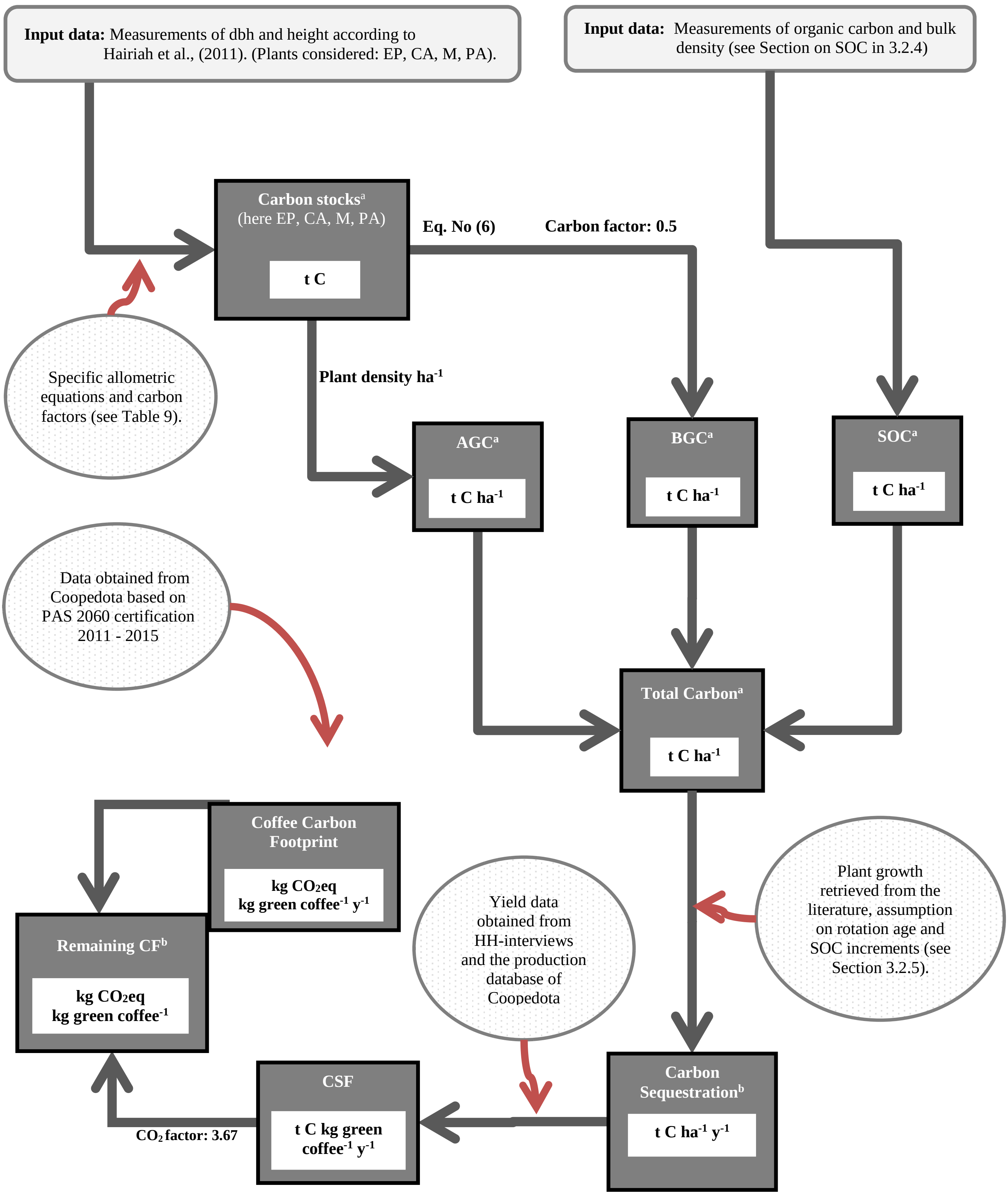
Disturbed soil samples were taken from three locations within transect F2, F4, F7, and F8at soil depths of 0-5 cm, 5-10 cm, 10-20 cm and 20-40 cm. Samples were thoroughly mixed to represent the variation in each plot. SOC content was determined using the Walkley-Black chromic acid wet oxidation method (Walkley and Black, 1934). Five undisturbed soil samples were taken from three spots within each transect at soil depths of 0-20 cm, and 20-40 cm to determine the bulk density. Samples were oven dried at 105°C and the bulk density was calculated following the formula:

$$\boldsymbol{\rho}_{s} = \boldsymbol{M}_{t} / \boldsymbol{V}_{o} \qquad \textbf{(7)}$$

Where ρ_s is the bulk density in g/cm^3, M_t the dry weight, and V_o the volume of the cylindrical core. The average of the three locations was used to represent each plot's soil organic carbon content and bulk density. SOC was calculated by multiplying the carbon content with the bulk density at the specific depth. The average SOC of the four investigated transects was used as an approximation for the other transects F1, F3, and F5.

3.2.5 Carbon accounting model

To address the data availability in this study and the little-researched approach to estimate annual carbon balances, an on-site carbon accounting model was developed. The structure of the model including information on data input and underlying equations is presented in Figure 5. All computations were done using Microsoft Excel 2010. The computing of simulations usually goes along with a set of assumptions and decisions how to extrapolate the measured data. All assumptions were made based on information from literature or knowledge obtained in the field survey, and are described in the following. The simulation was done backwards



Legend: AGC (Aboveground carbon), BGC (Belowground carbon), SOC (Soil organic carbon), TC (total carbon), CSF (carbon sequestration footprint, CF (carbon footprint), EP (*Erythrina poeppigiana* –shade tree), CA (*Coffea arabica*), M (*Musa sp.*), PA (*Persea americana* –Avocado), dbh (diameter at breast height), HH (Household), PAS 2060 (standard for carbon neutrality).
a: measured data in 2015, **b:** simulated data 2011-2028.

Figure 5: The on- site carbon accounting model: carbon pools, factors and input data

for a period of five years (until 2010) to cover the time of the carbon neutral certification, which provides data on the coffee CF from 2011 onwards. Simulation has been done to the future for a period of 13 years (till 2028) to cover a total period of about 20 years (2010-2028). A minimum of 20 years is also used by the IPCC for CS accounting.

3.2.5.1 Shade trees

CS of shade trees was modeled based on *E. poeppigiana* only, as the monitored transects (i) contained only few avocado trees; (ii) there is little information on the growth pattern and CS of avocados; and (iii) *Musa* sp. are of minor importance for CS due to their low carbon content and short lifetime.

Literature on tree growth and dbh increments for tree specific groups were screened and compared with age related *E. poeppigiana* data in Costa Rica and other relevant sites. Based on this in-depth comparison, the growth of *E. poeppigiana was* finally simulate following the dbh increments for medium size and shade intolerant trees (Adame et al., 2014) measured for the pioneer tree *Cecropia* (Co) by Clark and Clark (1999) in a tropical forest in Costa Rica. These dbh increments are given for the different dbh size groups and applied as such in the simulation. The simulated data are in line with the reported maximum age of *E. poeppigiana* trees in Coopedota.

The tree height was put as constant over the simulation time to account for pruning activities in the field. Simulation was done for each tree in the plot and the values were summed up and extrapolated to hectare basis.

3.2.5.2 Coffea arabica

For coffee, dbh increments were calculated based on age-dependent data from the literature of *E. poeppigiana* – CAFS in Costa Rica (see Appendix 4). A power trend line was fitted to the data points, resulting in the following equation:

$$\boldsymbol{y = 1.8857x^{-0.713}} \quad (8)$$

where y is the dbh increment of coffee in cm year^{-1}, and x is the coffee bush age. R^2 was 0.7352. Using Eq. 8 coffee bush age of the monitored plants was determined as well as the dbh increment at these certain ages. For backward simulations, it was assumed that old bushes were replaced at a reasonable age in former years and differing among farms (between 25 and 51 of age). The corresponding information was obtained from the household survey. A comparison with transect values of measured maximum aged or second largest aged bushes was used to proof these assumptions. In Coopedota, coffee fields are selectively renovated, which means, single old or infested plants are replaced by new seedlings. This has an effect on the carbon pool development of coffee plants. Therefore, from 2015 onwards coffee renovation in the simulation was limited to 5% (meaning renovating not more than 5% of the coffee plants on a hectare every year). In other words, from 2015 onwards coffee bush renovation was fixed in the simulation at an age of 25 years, based on the cooperative's technical recommendations. Simulation was done for each measured bush separately and finally summed up. It then was multiplied by factors based on measured coffee bush density in the plot to reach hectare related values.

3.2.5.3 BGB

Below ground carbon was calculated using the formula of (Cairns et al., 1997; see Table 9) for coffee and *E. poeppigiana* separately and finally summed up.

3.2.5.4 SOC

On the one hand, little is known about the developments of soil organic carbon over time and especially about the formation of stable carbon pools in the soil. On the other hand, soil organic carbon formation depends on several environmental factors such as soil type, soil aggregates, farm management, microorganisms' activity, input quality and levels, and climatic factors, which complicates its simulation. *E. poeppigiana* are known as high input shade trees with litter input of 8-14 $tha^{-1}y^{-1}$ (Beer, 1988). Data on SOC levels and developments in coffee – *E. poeppigiana* agroforestry systems in Costa Rica are scarce. However, in a study on cacao – *E. poeppigiana* agroforestry systems in Costa Rica SOC increments of 2.08 t C ha^{-1} yr^{-1} were measured (Beer et al., 1990) and in a study on alley cropping of maize and beans with *E. poeppigiana* in Costa Rica SOC increased by 1.78 t C ha^{-1} yr^{-1} (Oelbermann et al., 2006). Since these values might overestimate the developments in the soil, UNFCCC suggests applying a maximum of 0.8 t C ha^{-1} yr^{-1}in Clean Development Mechanism projects (UNFCCC, 2011). Therefore, this sequestration rate was used for all farms of this study.

3.2.5.5 Coffee carbon footprint and coffee yields

The CF data from Coopedota in t CO_2eq kg^{-1}green coffee for both exported coffee (farm to ship) and domestically traded coffee (farm to disposal) were used as general emissions. From this value, the CS of each transect was subtracted to get the remaining emissions. Positive values represent remaining emissions that further need to be outbalanced by carbon credits, whereas negative values describe remaining CS after outbalancing the coffees emissions.

Since the CF is based on the functional unit of kg green coffee, information on coffee yields is essential to associate CS with GHG emissions. Coffee yields per hectare of the investigated farms for the years 2010 -2015 were obtained from the cooperative's delivery lists and the farm household surveys. To simulate the years 2016 – 2028, the average yields of each farm over the documented period (2010-2015) were applied.

3.3 Results

Following the research questions of this study, the first section will present the results of a literature review on the major challenges in on-farm carbon accounting. The awareness over existing obstacles in carbon accounting provides an important basis for the simulation results from the here developed carbon accounting model. Thus, the second result section will illustrate the potential of carbon sequestration to compensate the CF at Coopedota. Finally, looking into the farm specific performances, the third section will provide further insights into on-farm carbon accounting and identify factors influencing the emission compensation potential.

3.3.1 Results from the literature review

To participate in climate change mitigation, Wollenberg et al. (2013) identified three possibilities: (i) reduce direct emissions (e.g. reduce fertilizer inputs), (ii) remove greenhouse gases from the atmosphere by CS (e.g. in vegetation and soils), (iii) prevent new emissions by protecting existing carbon stocks (carbon maintenance, such as in standing forests). Agriculture plays a role in all the three options to participate in climate change mitigation. Climate friendly agriculture, particularly CS in vegetation and soils, is therefore an important opportunity to contribute to climate change mitigation. Nevertheless, the formation and capture of biogenic carbon in agricultural systems is a complex procedure, and is influenced by many abiotic, biotic and anthropogenic factors. Research on agroforestry systems has increasingly addressed the quantification of carbon stocks and their development over time in the last decade (Kumar and Nair, 2011). However, to account for biogenic CS in LCA-based carbon neutral certifications a wide range of challenges remain. Table 10 presents and explains the major fields of challenges identified by the systematic literature review. These challenges can be categorized in four groups: natural (A), theoretical/ideological (B, C), methodological (D, E) and knowledge/research challenges (F, G, H). Dynamic and divers production systems are basic challenges for accountability and comparability that need to be considered in the creation of any robust accounting system. Especially, since it is a central issue in theoretical and ideological debates on the climate impact of biogenic carbon sequestration (B) and the suitability of different modeling approaches (C). Major challenges also exist in the field of methodologies. The lack of standardized methodologies and basic carbon databases (D) and an uncareful use of definitions (E) further complicate the comparability of generated data in the literature.

Another methodological issue is the handling of future fates of the carbon and the time horizons that should be considered (F). Challenges are not only found in the methodologies applied, there is also still considerable fundamental research and knowledge missing to develop suitable methodologies for carbon accounting. One of the most promising carbon sinks are agricultural soils, particularly the long-term stable carbon pools in the soils (Gulde et al., 2008). However, little is known on how to increase this carbon pool and measurements are difficult and costly (H). Finally, considerable research is looking at carbon balances of renewable energies. However, some of the challenges might not exclusively belong to one of the categories as e.g. the product end-of-life can be also considered a theoretical challenge as it is also related to whether apply generic or dynamic modeling approaches.

Table 10: Main existing challenges for a robust accounting of on-farm carbon sequestration

Challenges		**Characterization**	**Sources**
A.	Dynamic and diverse systems	Systems change over time, and there is a wide range of different systems with various combinations of plants, or intensive (high input) to extensive (organic) management systems.	(Brandão et al., 2013; Wollenberg et al., 2013)
B.	Theoretical concept: biogenic carbon vs. fossil carbon	There is an ongoing debate on whether biogenic carbon over a long-term period contributes to climate change mitigation at all, or whether the focus should lie on the prevention of releasing fossil carbon.	(Brandão et al., 2013; Pearse and Böhm, 2015)
C.	Generic versus dynamic approaches	Generic approaches assume an average sequestration value, whereas dynamic approaches measure sequestration rates, which lead to a limited time frame of sequestration processes.	(Brandão et al., 2013; Goglio et al., 2015; Smith et al., 2014)
D.	Data availability and comparability	Databases are insufficient or missing (e.g. for tree functional groups, age related tree growth, carbon factors). Further, the units of the data are not standardized (e.g. stocks, rates, per are, per tree, volume) and not all components (litter, below ground carbon, SOC) are necessarily included (see also Section on Definition and carbon dara next page).	(Adame et al., 2014; Cairns et al., 1997; Clark and Clark, 1999; Kariuki et al., 2006; Segura et al., 2006)
E.	Definitions	A lack in differentiation and the uncareful use of definitions have led to errors in data presentation and misunderstandings (e.g. carbon stocks vs. carbon sequestration, see Section on Definition and carbon data next page).	(Nair, 2011)
F.	Product end-of-life	The system boundaries of carbon product's life cycle (wood, compost, residues) are not well defined and it remains unclear *what should be considered in carbon accounting*. The timing of carbon storage or release is different for (i) substitution processes (e.g. burning fire wood instead of fossil fuels, organic fertilizer instead of inorganic), or for (ii) future use (e.g. wood in construction, burning, organic fertilizer, or left in the fields to contribute to SOC).	(Brandão et al., 2013)
G.	Lack of fundamental research	Tree growth patterns, carbon factors and allometric equations are not available for many plant species in specific areas. Further, the development of biomass growth models is insufficient.	(Defrenet et al., 2016)
H.	Soil organic carbon relevant but complex	SOC has the highest potential in carbon stocks and long term storage, but is also the most complex and least understood component in agricultural systems.	(Goglio et al., 2015; Hergoualc'h et al., 2012)

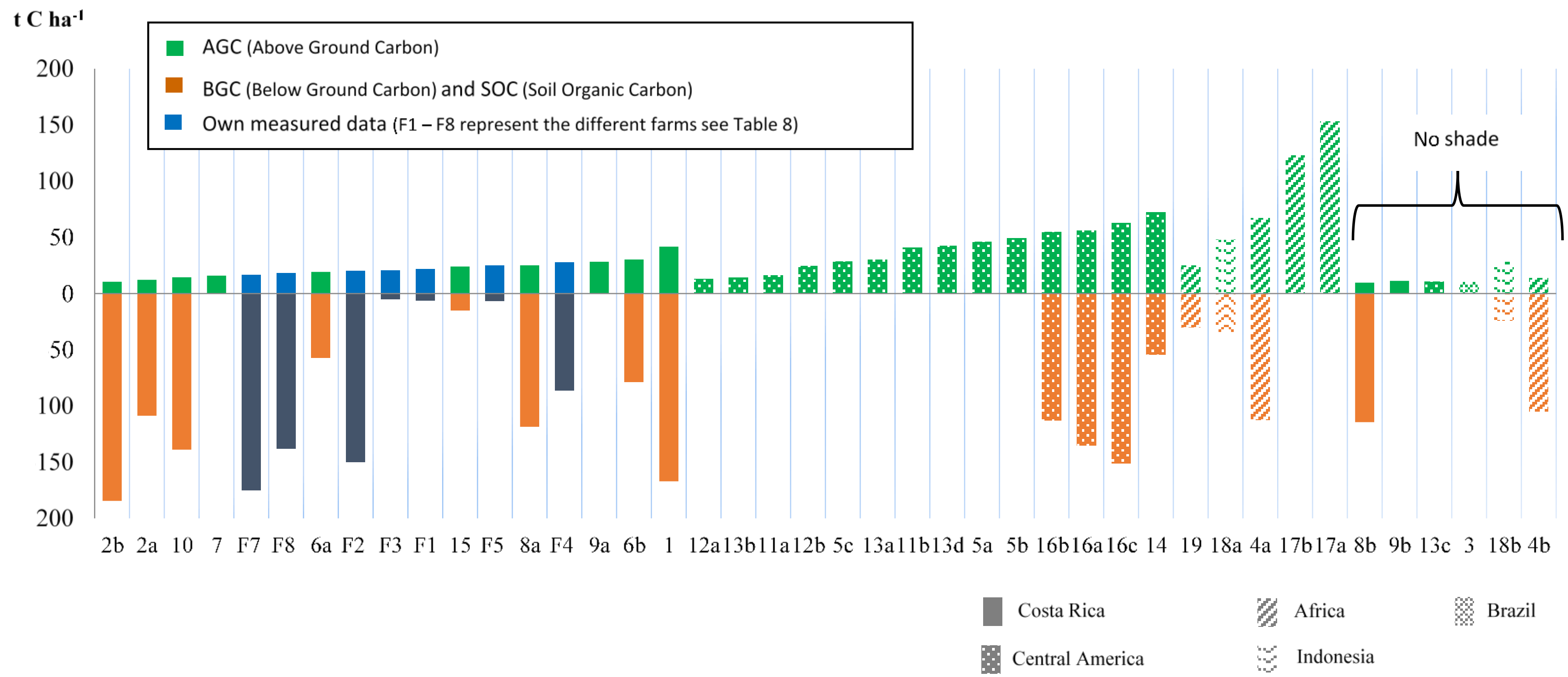
3.3.1.1 *Definitions and carbon data*

This study used carbon data from the literature for its model generation and systematically compared the carbon results with data of relevant research. For this reason, this section provides a closer look on the challenge of data availability and comparability (D) and definitions (E).

One of the challenges in carbon accounting is the uncareful use of definitions, particularly the sometimes missing differentiation between carbon stocks and carbon sequestration or fixation. Carbon stocks reveal the amount of carbon at a certain point in time and measured in a defined area (usually expressed as t C ha^{-1}), while carbon sequestration is defined as the annual change in carbon stocks in a defined area (usually expressed as t C $ha^{-1}yr^{-1}$). In LCA-based carbon accounting, CS rates are required due to the rule of additionality (Brandão et al., 2013), whereas most of the available data are available as carbon stocks, in other words the available carbon data lack of increments in time. Clear differentiation between carbon stocks and CS is thereby of ultimate importance to engage in carbon accounting. This issue has been often neglected in research (Nair, 2011), resulting in misleading conclusions and misunderstandings. These misleading data presentations become even more problematic in the debate on whether to limit carbon accounting to the rule of additionality (as it is done in LCA-based carbon accounting), or to also consider the issue of carbon maintenance or carbon carrying capacity (Ajani et al., 2013) as also applied in REDD+ projects). Therefore, this study considers a clear differentiation between carbon stocks and CS as an important basis, also regarding the interpretation of the study results.

Besides a lack in robust carbon data, particularly of CS data, no standardized methodological approach exists (Brandão et al., 2013; Goglio et al., 2015). Figure 6 illustrates the diversity of CAFS and the dominant role of SOC reported by different studies. Most of the publications in the figure investigated carbon stocks of coffee grown under various shade covers. Only few studies looked at unshaded monocultures or analyzed differences between shaded and unshaded systems. In Costa Rica, the majority of coffee production systems can be classified as “commercial polyculture” or “shaded monoculture” (Moguel and Toledo, 1999), describing market oriented coffee-agroforestry systems with limited and specialized shading and high levels of inputs. This might be the reason why above ground carbon stocks in Costa Rican CAFS are relatively low. Unshaded monocultures have a generally lower above ground carbon component, whereas in Ethiopia, very high values are reported. However, it is not only the systems that are diverse, but also the methodologies used that are heterogeneous. Many studies measure or estimate only AGC, others measure AGC and BGC, but not SOC. Further, a closer look into the studies presented in Figure 6 shows that a diverse set of allometric equations is used to estimate carbon stocks of different trees and bushes. Additionally, carbon stocks per hectare depend strongly on tree density and the age of the systems. Another problem regarding comparability is that studies include or exclude different carbon pools from the quantification (dead wood, litter, BGC, SOC). Very strong differences between studies were found regarding the soil depth considered in the studies (ranging from 20 cm to 4 m). Further, different sampling techniques might contribute to the diversity of the presented data set.

The challenges in data acquisition become also obvious when collecting age related carbon stock data e.g. on *E. poeppigiana* and *C. arabica*. Despite the advantageous situation in Costa Rica regarding research on coffee-agroforestry and carbon sequestration, Figure 7 demonstrates the challenges in data heterogeneity due to system differences, abiotic factors and differences in methodologies applied.



1 Costa Rica -(Alpízar et al., 1985)

2 Costa Rica - (Ávila et al., 2001)
a) coffee - eucalyptus
b) coffee – *E. poeppigiana*

3 Brazil-(Coltri et al., 2015)

4 Togo - (Dossa et al., 2008)
a) shaded
b) unshaded

5 Nicaragua - (Goodall et al., 2015)
a) 2003
b) 2008
c) 2012

6 Costa Rica - (Häger, 2012)
a) conventional
b) organic

7 Costa Rica- (Harmand et al., 2007)

8 Costa Rica- (Hergoualc'h et al., 2012)
a) shaded
b) unshaded

9 Costa Rica- (Miguel Magaña et al., 2004)
a) coffee - eucalyptus
b) unshaded

10 Costa Rica- (Noponen, 2012)

11 Nicaragua - (Rahn et al., 2014)
a) commercial polyculture
b) traditional polyculture

12 El Salvador - (Richards and Méndez, 2014)
a) 2001
b) 2010

13 C. America - (van Rikxoort et al., 2014)
a) commercial polyculture
b) shaded monoculture
c) unshaded monoculture
d) traditional polyculture

14 Guatemala - (Schmitt-Harsh et al., 2012)

15 Costa Rica - (Siles et al., 2010)

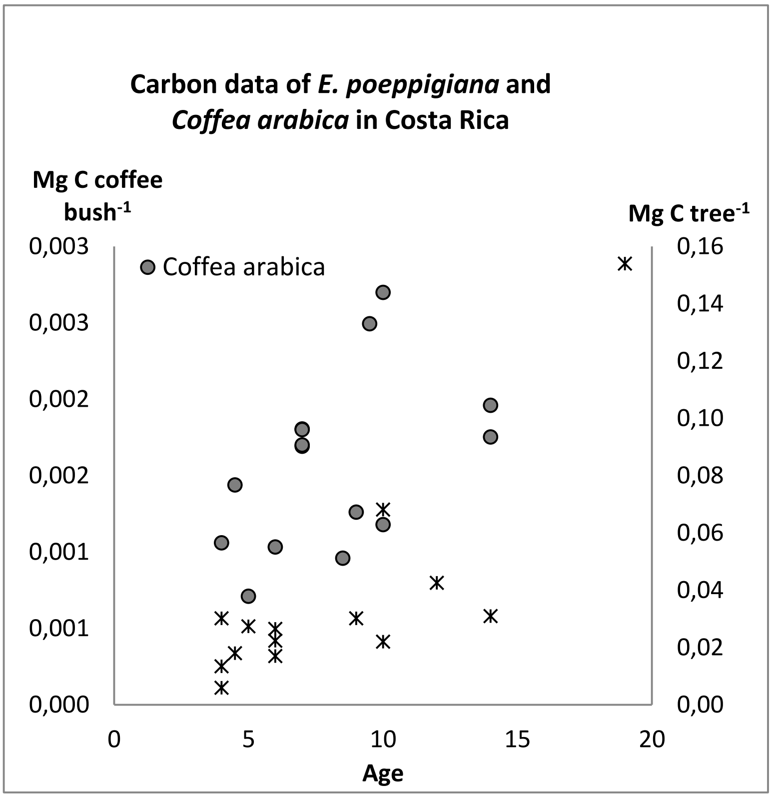
16 Mexico - (Soto-Pinto et al., 2010)
a) polyculture conventional
b) polyculture organic
c) *Inga sp.* shade

17 Ethiopia - (Tadesse et al., 2014)
a) smallholder
b) state owned

18 Indonesia - (Noordwijk et al., 2002)
a) shaded
b) unshaded

19 Uganda - (Zake et al., 2015)

Figure 1: Comparison carbon stock data available from the literature and own carbon measurements.



Sources:

Erythrina poeppigiana: (age in years)

(Miguel Magaña et al., 2004)	(4)
(Beer et al., 1990)	(5 and 10)
(Glover and Beer, 1986)	(14)
(Alpízar et al., 1985)	(4.5)
(....2007)	(9)
(....2003)	(4)
(Masera et al., 2003)	(6 and 12)
(Oelbermann et al., 2005)	(4,10, and 19)
(Noponen, 2012)	(6)
(Haggar et al., 2011)	(6)

Coffee arabica (age in years):

(Miguel Magaña et al., 2004)	(4 and 14)
(Ávila et al., 2001)	(9.5)
(Siles et al., 2010)	(7)
(Siles et al., 2010)	(7)
(Hergoualc'h et al., 2012)	(7,8.5,9 and 10)
(Harmand et al., 2007)	(7 and 14)
(Alpízar et al., 1985)	(4.5 and 5)
(Coltri et al., 2015)	(10)
(Noponen, 2012)	(6)

Figure 6: Summary of available data from the literature on age related carbon stocks in *E. poeppigiana* and *C. arabica*

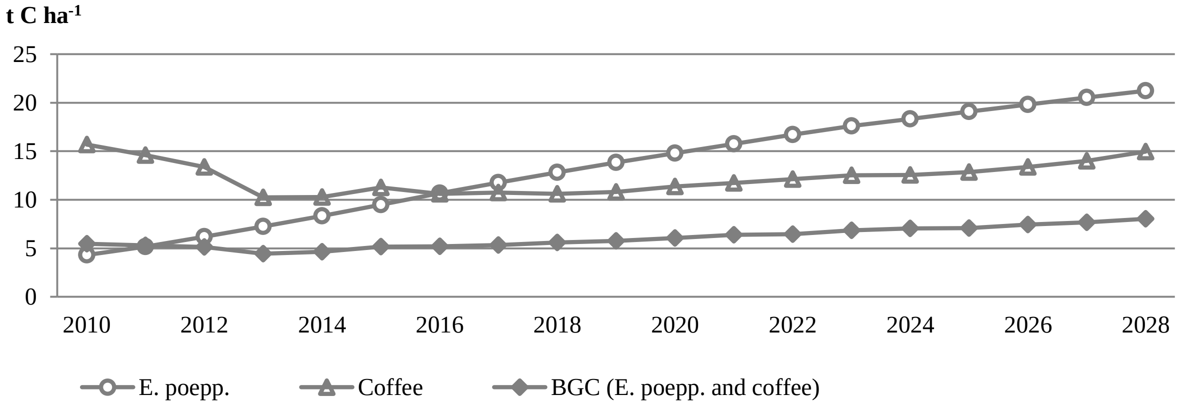
3.3.2 The potential of carbon sequestration at Coopedota to avoid offsetting

The first result section identified a wide range of multi-faceted and inter-sectoral challenges to integrate carbon accounting into LCA-based carbon standards. On this background the modeling results will be presented in the following with particular focus on a clear differentiation between carbon stocks and carbon sequestration. A disaggregated presentation of the results aims also at contributing to a growing carbon database.

3.3.2.1 Modeling results

This section presents simulation results of the on-farm carbon accounting model from 2011 to 2028. The results will be first disaggregated into the different carbon pools to offer insights on the different roles of shade trees, coffee plants, BGC and SOC in carbon sequestration but also to allow a better comparability with similar studies. Afterwards the overall potential of CAFS to compensate Coopedota's CF will be presented.

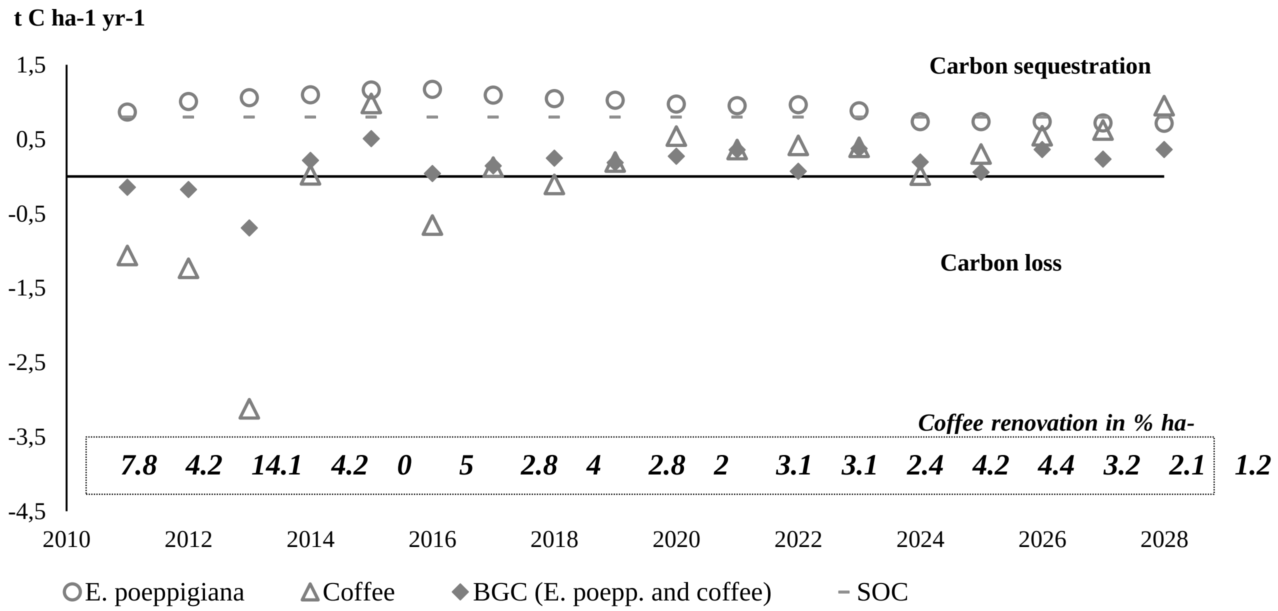
Four different carbon pools are distinguished in this study: carbon captured in shade trees, coffee bushes, BGC (roots) and SOC. The *E. poeppigiana* shade trees cumulated the highest amount of carbon over the simulation period, with carbon stocks ranging from 4 t C ha^{-1} in 2010 to 22 t C ha^{-1} in 2028 (Figure 8). Carbon stocks of coffee bushes are decreasing during the first years but in 2028 almost reach the initial amount. BGC slightly increases during the simulation period as it is related to the developments of total AGC. SOC stocks reached 170 t C ha^{-1} in 2028 (see Section 3.3.1) and by this presenting a far higher level compared to the other pools.



Average carbon stocks of shade trees (*E. poeppigiana*), Coffee and BGC of both plants, (n=7).

Figure 7: Simulated development of carbon pools across investigated farms.

Figure 9 illustrates the annual changes in carbon stocks, in other terms the CS rates of the different carbon pools. Positive values represent a sequestration of carbon from the atmosphere, whereas negative values mark a release of carbon back to the atmosphere. The CS rates of SOC remain constant over the simulation period since changes in SOC have been set at 0.8 t C ha^{-1} yr^{-1} based on IPCC (UNFCCC, 2011) and due to high levels of biomass input into the system, originating from the pruning of shade trees. Shade trees show exclusively positive sequestration rates, since none of the trees have reached the age of logging, however, towards the end of the simulation period, the rates are decreasing in magnitude. The CS rate of coffee bushes fluctuates strongly. The renovation intensity presented in Figure 9 is higher in years when coffee CS rates are lower, in many cases even negative. A correlation analysis showed that there is a strong negative correlation between the coffee CS rates and the renovation intensities (-0.94) as well as with BGC sequestration and the coffee renovation intensities (-0.91).



Positive numbers illustrate sequestration and negative numbers carbon losses to the atmosphere. Numbers in italic show the average coffee renovation rate.

Figure 8: Development of carbon sequestration rates of each carbon pool.

The average CS rates of the different carbon pools and their standard deviation is presented in Table 11. All carbon pools resulted in a positive CS, particularly the shade trees and the SOC. Except for the coffee pool, which on average shows a slightly negative CS and a comparably high standard deviation. Overall CS of the investigated CAFS is positive, however the standard deviations demonstrates the high variations in the data.

Table 11: Average carbon sequestration rates over all years (2010-2028) and all farms

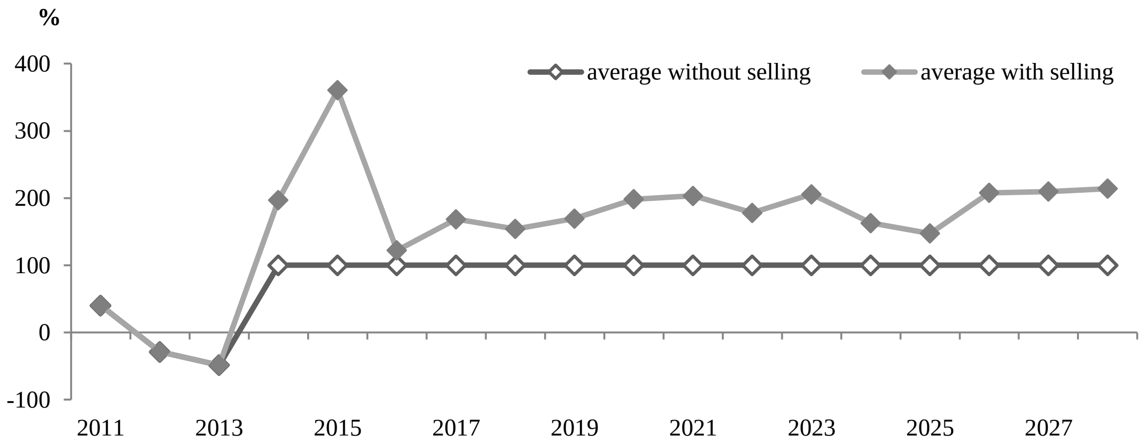
Carbon pools	t C ha^{-1} yr^{-1}	t CO_2eq ha^{-1} yr^{-1}
AGC *E. poeppigiana*	0.81 ± 0.57	2.97 ± 2.09
AGC Coffee	-0.04 ± 1.91	-0.15 ± 7.00
BGC (Coffee and *E. poepp.*)	0.14 ± 0.59	0.51 ± 2.16
SOC	0.8	2.93
Total C without SOC	0.91 ± 2.64	3.34 ± 9.68
Total C	1.71 ± 2.64	6.27 ± 9.68

AGC = above ground carbon, BGC = below ground carbon, SOC = soil organic carbon, N = 7

Overall, the SOC pool showed the far highest values in carbon stocks, whereas regarding carbon sequestration the shade trees performed similarly to the SOC. Shade trees might even sequestering more carbon, considering the root carbon of these trees (BGC), however disregarding a potential logging effect. For the coffee carbon pool the standard deviations are the highest, and annual renovations of plantations is highly correlated with its carbon sequestration rate.

3.3.2.2 *Offsetting through on-farm carbon sequestration*

Based on the field observations obtained in this study, the majority of production systems existing at Coopedota, are represented by the seven farms. This justifies that the average CS of all farms can be related to the coffee CF of Coopedota's farmers group (about 112 farmers), which participate in the carbon neutrality certification. Since the PAS 2060 limits the carbon neutrality certification to 12 months, project-like approaches with longer time periods are unsuitable, rather a "comprehensive" accounting approach, that considers net annual carbon changes, can be applied (Murray et al., 2007). Two scenarios are possible: (i) CS rates can only be accounted for compensating existing emissions; any additional CS will not be considered. (ii) Additional CS can be sold as carbon credits, to generate more income. In Figure 10 insufficient CS, and even additional carbon losses, can be observed during the first years of simulation. These were the years without any limitation regarding coffee plant renovation. After limiting coffee renovation to a maximum of 5% in 2015, CS exceeded the coffee CF. In many years, the emission compensation rate reached almost 200%. In the year 2015 the data were collected and thus, do not include any coffee renovation. In this case it compensated 360% of the coffee carbon footprint. Overall, CAFS managed to fully compensate the coffee emissions after limiting the coffee renovation to 5%.



The unfilled symbols illustrate the scenario where the cooperative can only account for on-site sequestration but cannot sell remaining sequestration as carbon credits. The filled symbols represent the case in which the cooperative can sell carbon credits.

Figure 9: Compensation of emissions (average over all farms, 2011 - 2028).

3.3.3 Farm specific results

In order to come closer to the nature of on-farm carbon accounting and its potential, we were looking into the farm specific performances and aimed at a first identification of possible factors to increase the potential for CF compensation.

Coffee - agroforestry farms at Coopedota differed in their composition. Pure *Musa* sp. shading was found (F2) as well as, mixed shading of *Musa* sp. and *E. peoppigiana* (F4 and F5), diverse shading with a variety of tree species, mainly avocado, anona, citrus species and *E. poeppigiana* (F7) and pure *E. poeppigiana* shading, either with big but light canopies of trees (F3 and F8) or heavily pruned (F1) (see Figure 11 and Appendix 5 and 6). These types of CAFS are common in Costa Rica (Castro-Tanzi et al., 2012; Defrenet et al., 2016; Häger, 2012; Hergoualc'h et al., 2007; Muschler, 2001; Noponen et al., 2013b; Polzot, 2004) and are representative for coffee production systems at Coopedota, according to the household survey data and personal field observations.

The selected coffee farms also differed regarding biophysical parameters: planting density of shade trees and coffee bushes, plant age, stem diameter, yields, agrochemical inputs and carbon stocks (Table 12). Carbon stocks were highest in SOC (78.9 – 170.3 t C ha^{-1}, mean: 131.5 t C ha^{-1}), followed by *E. poeppigiana* shade trees (mean: 11.3 t C ha^{-1}) and coffee bushes (mean: 9.5 t C ha^{-1}). Most of the carbon attributed to the SOC pool, was found in depths of 0-20 cm. Carbon stocks from *Musa* sp. and *Persea americana* remained minor, since the later was found only in F7 and the former is not a woody species. Total carbon stocks measured in 2015 was lowest in F4 and highest in F7, with a mean total carbon stock of 156 t C ha^{-1} over all farms.

The distribution of carbon among carbon pools changes when the carbon is related to plant units instead of hectares. Per plant unit *E. poeppigiana* shade trees showed much higher carbon stocks (0.003 – 0.11 t C tree^{-1}, mean: 0.029 t C tree^{-1}) than coffee bushes (0.000011 – 0.0066 t C bush^{-1}, mean: 0.002 t C bush^{-1}). Proportionally, the same is true for BGC of each species, since it is estimated in relation to AGB. Here, below-ground carbon stocks of *E. poepp*. (0.001 – 0.02 t C tree^{-1}, mean: 0.006 t C tree^{-1}) exceed the once of BGC coffee (0.000006 – 0.0018 t C bush^{-1}, mean: 0.001 t C bush^{-1}). The relatively high carbon stocks of shade trees indicate the potential of increasing shade tree density to increase carbon stocks in the farms.

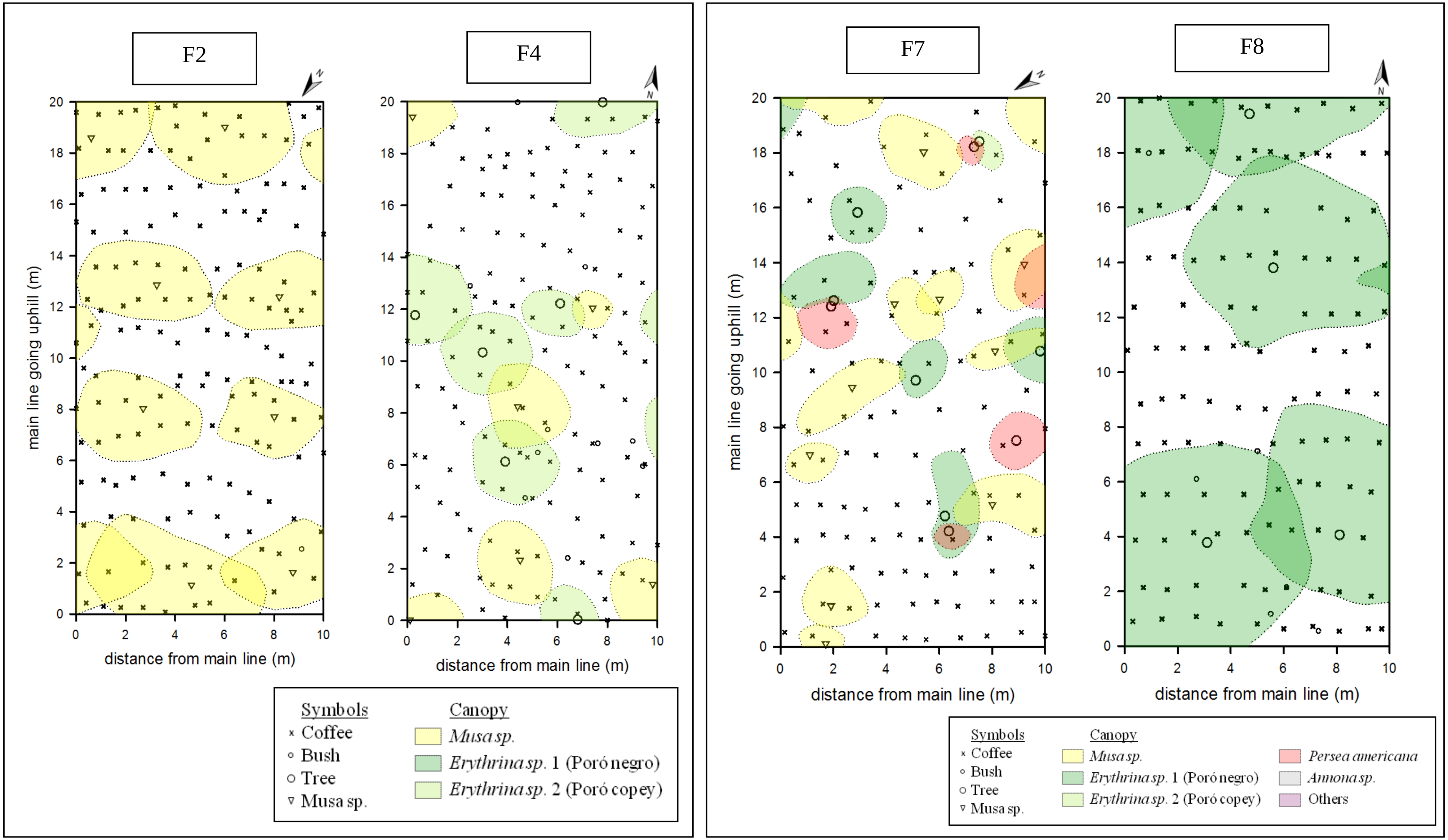


Figure 10: Visualization of coffee farm F2, F4, F7 and F8

Table 12: Biophysical characteristics of transects in 2015**.**

		F1	F2	F3	F4	F5	F7	F8
Shade trees *E. poeppigiana*	Height	4.5		6.5	4.9	6.3	5.1	8.3
	(m)	(±0.5)		(±1.7)	(±0.7)	(±1.1)	(±1.1)	(±1.3)
	dbh	26.1		24.6	28.9	17.8	18.6	25.9
	(cm)	(±2.8)		(±12.5)	(±3.6)	(±3.0)	(±2.7)	(±5.1)
	Age	14.6		15.8	16.0	12.0	12.1	14.7
	(years)	(±1.2)		(±5.7)	(±1.9)	(±0.7)	(±0.7)	(±2.4)
	Density (trees ha^{-1})	150		400	300	650	300	200
Coffee plants	D_{15}	9.4	5.6	5.5	8.2	5.8	8.6	6.7
	(cm)	(±4.2)	(±4.0)	(±1.9)	(±4.4)	(±2.5)	(±2.0)	(±3.3)
	Age	22.6	10.3	6.9	18.2	7.9	15.3	11.1
	(years)	(±15.5)	(±13.8)	(±4.4)	(±13.6)	(±7.1)	(±6.1)	(±7.1)
	Density (bushes ha^{-1})	5,500	8,400	4,400	6,000	8,400	4,000	6,000
	Yields#	1,800	1,754	811	1,171	2,112	2,519	1,328
	(kg green coffee ha^{-1})	(±565)	(±937)	(±200)	(±870)	(±640)	(±967)	(±460)
Inputs (kg ha^{-1})	N	267	359	207	284	252	267	375
	P	74	75	52	41	59	74	90
	K	223	359	187	162	239	223	349
Carbon stocks (t C ha^{-1})	*Musa sp.*		8.46		1.29	3.12	1.20	
	Avocado						0.69	
	E. poepp.	4.36		16.36	11.01	11.69	5.17	8.43
	Coffee	17.49	11.89	4.48	15.49	10.06	9.41	9.97
	BGC	6.00	6.41	4.80	7.33	6.29	4.68	4.86
	SOC 0 -20	91.04*	86.80	91.04*	56.67	91.04*	124.04	96.67
	SOC 20-40	40.43*	56.78	40.43*	22.19	40.43*	46.28	36.47
	Total Carbon	**159.32**	**170.34**	**157.11**	**113.98**	**162.63**	**191.47**	**156.40**

dbh = diameter at breast height, D_{15}=Diameter at 15 cm of trunk, # = average yield between 2010 and 2015, *=average value obtained from measured transects (F2, F4, F7, F8).

In all investigated farms total carbon stocks ranged from 106 t C $ha^{-1}$to 214 t C ha^{-1} and were increasing (Figure 12). F7 contains the highest carbon stocks throughout most of the simulation period, only in the last 5 years F5 reached the same level. The lowest stocks are in F4, which has clearly lower SOC levels than F7 (see Table 12).

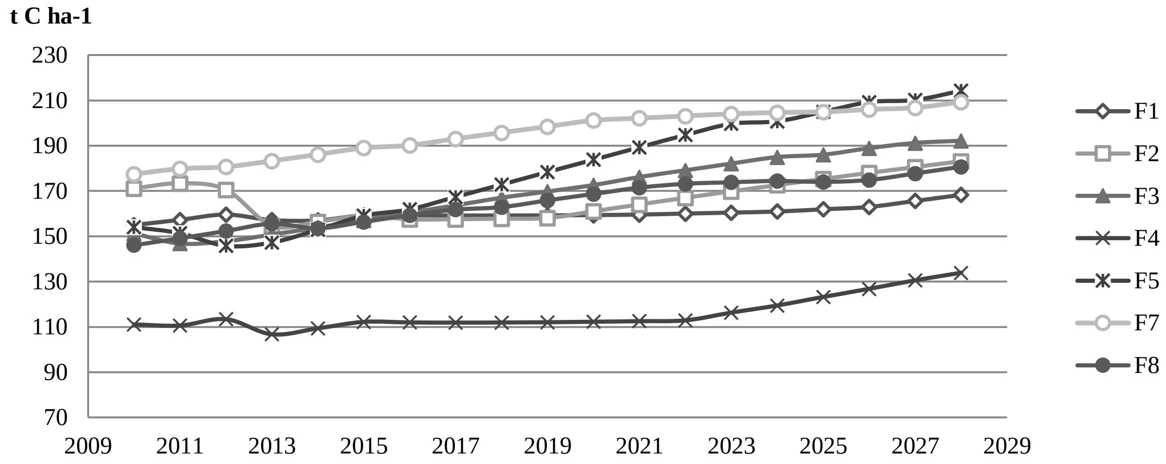


Figure 11: Total carbon stock development in the farms.

Figure 13 illustrates the variation of CS rates during the simulation period. Across all farms the medians of the boxplots, and even the 25% quartile, show exclusively positive values, indicating that carbon stocks increased annually. In terms of carbon sequestration F7 has positive values, meaning this farm was constantly sequestering carbon and never experienced carbon losses to the atmosphere. Nevertheless, its median is lower than most of the other farms (F2, F3, F5, F8). A clearly higher median as well as the highest CS rates were found in F5, with more than 5 t C ha^{-1} yr^{-1}.

Looking at Table 12 it is noticeable that F5 contains a relatively high number of shade trees and coffee plants which are also of smaller age. F7 also has young shade trees but only half the amount of shade trees and coffee plants compared to F5. The minimum CS rates, and thus strong carbon losses, (-16t C ha^{-1} yr^{-1} in 2013, when coffee renovation was 44%) are observed in farm F2. The lowest median is found in F1, where shade tree density was little, and relatively old coffee bushes dominated.

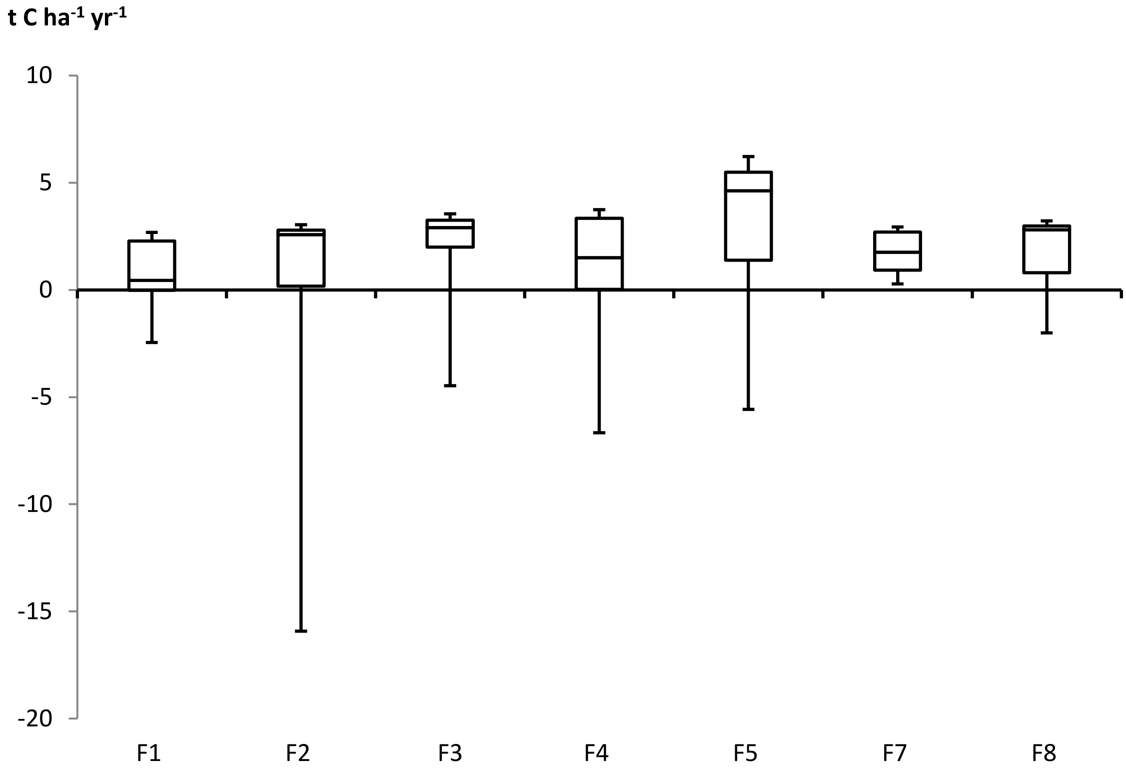
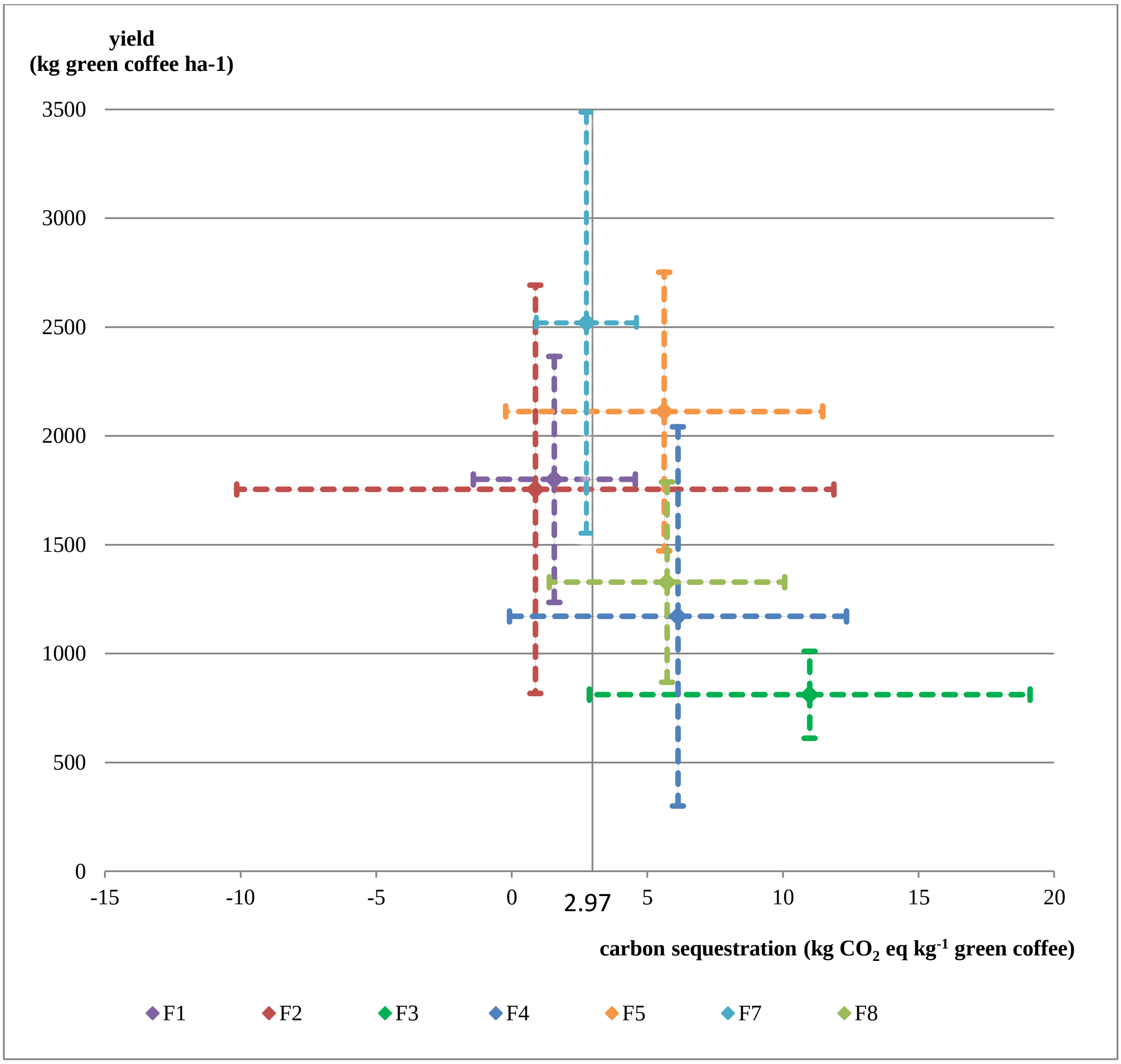


Figure 12: Carbon sequestration rates and their variation from 2011 – 2028 in the different farms

To compensate the CF the carbon sequestration has to be related to the amount of kg coffee produced. To get a better understanding of the relationships between CS and productivity, Figure 14 relates the average CS (in kg CO_2eq kg^{-1} green coffee yr^{-1}) to the yields in each farm. By this it supports the understanding of which farm performs closer to the described optimal balance. The dashed line illustrates the CS necessary to compensate the CF average of 2.97 kg CO_2eq kg^{-1} of green coffee yr^{-1} (data obtained from Coopedota). So far the coffee CF has been compensated by buying international carbon credits. Most of the farms, on average, can compensate the coffee's CF with their on-farm CS (F3, F4, F5, F7, F8). Farm F3 performs best in terms of compensation, since it has high CS rates, and at the same time low yields. However, farms that want to be profitable need much higher yields than F3. Therefore, F5 and F7 represent better production situations. For example, F5 illustrates a good compromise of producing sufficient coffee under high CS rates. F5 has an average yield of more than 2000 kg ha^{-1} yr^{-1} and on average more than 5 kg CO_2eq sequestered kg^{-1} green coffee yr^{-1}.



Carbon sequestration in kg CO2eq kg^{-1} green coffee yr^{-1} (average values and SD, simulation period from). Positive values indicate carbon sequestration, negative values carbon emissions. The dashed line at - 2.97 represents the minimum CS rate to compensate the cooperative's coffee carbon footprint.

Figure 13: Relationship of farm yields and on-site carbon sequestration between 2011 and 2028.

Table 13 compares the average emission compensation rates, which is the percentage of emissions that could be compensated by on-farm CS, of the different transects. In the time period 2011 – 2028 F3, F4, F5 and F8 would have been able to compensate completely the coffee emissions by their on-farm CS. The emission compensation rate was highest in F3 with 375% and reaching about 200% in F4, F5 and F8. In F7 the on-farm CS could almost fully compensate the emissions, 91%, while in F1 and F2 only about 50% of emissions could have been compensated. Over all transects the mean of the emission compensation rate reached 164% and by this clearly exceeded 100%. Since the limitation of coffee plant renovation to 5% ha^{-1} from 2015 onwards has shown to be effective to increase the annual CS, Table 13 presents the emission compensation rate for that time period (2016 – 2028). In contrast to the complete time frame F2 could now compensate 130% of the emissions, in F4 and F8 the emission compensation rate slightly dropped (175% and 174% respectively), while in F5 and F3 it slightly increased (248% and 410% respectively). Transects F7 and F1 would still not be able to fully compensate the emissions, their compensation rate even dropped to 77% and 47% respectively. Overall the mean emission compensation rate is 180% and is 16 percentage points higher compared to the complete time period.

Table 13: Average emission compensation rate in all transects before and after limiting coffee renovation

		F1	F2	F3	F4	F5	F7	F8	mean
2011 – 2028	CS kg^{-1}	1.57 (± 2.99)	0.87 (± 11.01)	10.98 (± 8.12)	6.13 (± 6.21)	5.62 (± 5.85)	2.75 (± 1.85)	5.72 (± 4.34)	4.81 (± 3.45)
	ECR (%)	56 (± 94)	46 (± 305)	375 (± 283)	209 (± 204)	189 (± 205)	91 (± 54)	185 (± 149)	**164** (± 93)
2016 – 2028*	CS kg^{-1}	1.41 (± 1.93)	3.86 (± 3.23)	12.20 (± 3.67)	5.21 (± 5.56)	7.37 (± 2.86)	2.28 (± 1.42)	5.17 (± 3.26)	5.36 (± 3.61)
	ECR (%)	47 (± 65)	130 (± 109)	410 (± 124)	175 (± 187)	248 (± 96)	77 (± 48)	174 (± 110)	180 (± 45)

*From 2016 onwards the coffee renovation was limited to max. 5% ha^{-1}; CS: carbon sequestration in kg CO_2eq kg^{-1} green coffee; ECR: Emission compensation rate in %; The coffee **carbon footprint** was taken from Coopedota as carbon footprint along the complete coffee value chain until the stage of disposal, with an average of **2.97** kg CO_2eq kg^{-1} green coffee (see Table 2).

3.4 Discussion and Recommendation

The first objective of this research was to identify the reported challenges and potentials of on-farm CS accounting in CAFS. On the one hand literature results on challenges and potentials of on-farm CS accounting in CAFS were presented. In the following, these findings will be discussed in a global context and with attention to the role of biogenic carbon. On the other hand, carbon stocks have been measured in CAFS in Costa Rica to finally create a carbon accounting model and simulate the CS potential of such systems in the case of Coopedota and to understand some important factors at the farm level. In this section selected issues in the development of the model will be critically discussed and its results will be compared to data from the literature to proof plausibility. Then the potential of on-farm carbon accounting in the case of Coopedota will be evaluated before discussing the farm specific results and drawing implications from them.

3.4.1 Challenges versus potential of carbon accounting

3.4.1.1 A global perspective

From the literature review, it became obvious how diverse and challenging agricultural carbon accounting is. The challenges range from low data availability (e.g. data on tree growth rates), over difficulties in measurements (e.g. SOC), to diverse accounting approaches (generic vs. dynamic, different time horizons, different baselines). Additionally, natural challenges of system diversity as well as inconsistencies in methodology complicate the development of models and indicators. Uniform presentation of data (e.g. same units) is required in order to increase comparability between studies and make generalizations possible. There is a need to develop approaches on how to extrapolate CS and how to include the risk of carbon release. All these numerous challenges support the argumentation against considering biogenic carbon and thus temporal CS to mitigate climate change. However, the following paragraph will address the importance of temporal CS as a climate change mitigation strategy.

Relating the carbon stocks of this study to the global level of carbon stocks in different biomes, the measured CAFS contained 95 – 203 t C $ha^{-1}$and have advantages compared to croplands containing only around 82 t C ha^{-1}. CAFS are rather comparable to tropical savannas containing about 146 t C ha^{-1} and which have a similar allocation of carbon into AGC pools and SOC pools (see Appendix 7). Nevertheless, tropical forests containing approximately 243 t C ha^{-1} still form a higher carbon sink opportunity than CAFS (Watson et al., 2000). This comparison illustrates, on the one hand, the potential of CAFS, and the importance to maintain them instead of establishing cropland. On the other hand, no tropical forest should be cleared to establish new coffee plantations, as suggested by the literature (Ambinakudige, 2006; Gaveau et al., 2009).

Research in this field has identified further relevant arguments that emphasize the importance of biogenic carbon in climate change mitigation: Conservation and thus avoided emissions (Bellarby et al., 2008), replacement of fossil fuels (Levasseur et al., 2010) and multi-beneficial environmental effects (Montagnini and Nair, 2004). Therefore, additionally to the prevailing importance of reducing emissions from fossil fuels, there is a need to motivate high biogenic carbon levels and thus a need to quantify biogenic carbon potentials to the best accuracy. Smith et al. (2007) have estimated the global potential for mitigation in agriculture based on biogenic carbon at the level of energy and industrial sector and even higher than the potential of the transportation sector. So, overall, despite numerous challenges, CAFS have a relevant potential in CS.

3.4.2 Model development and plausibility of results

3.4.2.1 Carbon stocks and coffee age estimation

After 20 years of simulation *E. poeppigiana*'s carbon stocks ranged from 8.4 – 37.1 t C ha^{-1}, depending on tree planting densities and age. This is similar to the results of Oelbermann et al. (2004) who measured carbon stocks of 12, 20, and 40 t C ha^{-1} at age 19, 12 and 24 years. Beer et al. (1990) found 9.3 t C ha^{-1}at age 10 and Gama-Rodrigues, et al. (2011) reported 17.4 t C ha^{-1} in Brazil (based on Fontes, 2006). Since carbon stocks per area depend on planting density, a comparison of carbon stocks in individual plants at a certain age would be more relevant. However, many studies assess tree experiments, which are recently planted and therefore generate data of mainly young plant age. Regarding coffee, the carbon stocks measured in this study also corresponded with data from the literature (see Figure 6). Therefore, data from literature were also used to estimate coffee plant age and growth rates, as the basis of simulating CS.

Defrenet et al. (2016) have recently studied in depth the relationship of coffee age and growth ring width in Costa Rica with a maximum plant age of 44 years. They proved that growth ring width and distance of rings to the center are good indicators of coffee age. This means, the commonly measured dbh can also serve as an indicator of age. Comparing the dbh measured in this study and the resulting coffee age estimates with the values measured by Defrenet et al. (2016), the diameters at age 25 are similar (10.2 cm versus 11 cm respectively). However, the diameter increments at younger age were overestimated in this study, and underestimated at older age respectively. For the overall CS this overestimation effect was balanced out at the age of 25, which happened to be the age of coffee renovation in this study. This implies that the simulation in this study should take more time in the first years of coffee plant development to recover the growth rates of older plants by new bushes. It would then speed up as bushes become older.

3.4.2.2 Coffee renovation intensity and carbon sequestration potential

The amount of total carbon is, mainly determined by the amount of SOC which, in this study, resulted in a mean stock of 132 t C ha^{-1} in 2015, whereas AGC and BGC reached only 44 t C ha^{-1} in 2028. In this study SOC sequestration rates, however, have been put at a constant. So, farm specific CS and variations in CS are then determined by shade trees (density and age) and the composition of the coffee plantations (i.e. coffee bush planting density, renovation rates, and coffee bush age). Carbon stocks of coffee bushes are decreasing during the first years, due to their intensive renovation.

In Coopedota, coffee fields are selectively renovated, which means, single old or infested plants are replaced by new seedlings. This has an effect on the carbon pool development of coffee plants. Therefore, from 2015 onwards coffee renovation in the simulation was limited to 5% (renovating not more than 5% of the coffee plants on a hectare every year meaning a selective coffee plant logging at age 25, which is recommended by Coopedota). This has led to a slow increase in coffee carbon stocks. The same holds true for the BGC pool, as it is related to AGC of coffee. A strong correlation between coffee plant renovation and CS in coffee plants as well as in BGC indicates that even smaller amounts of plantation renovation might affect the CS rates. Thus, the decision to limit selective renovation to a maximum of 5% per hectare has proven to be efficient in terms of CS rates. Other studies have not looked into the effect of renovation intensities in perennial crops, often because they assessed longer time steps (instead of annual time steps). Instead they have looked at replacing shade trees or tree plantations after longer time periods (see e.g. Masera et al., 2003). The findings of this study illustrate the overlooked importance of plantation management and the risk of losing bushes due to pest infestations or climatic events, especially regarding its impact on CS rates of coffee plants. It seems to be the most limiting factor in whether the CF can be completely compensated or not.

Overall the CS rates simulated in this study (Table 12) are within the range of other research, however, comparably low. Mendez et al. (2011) listed several studies on coffee agroforestry (age 3-40 years) with CS rates (all excluding SOC) of 0.45 - 11.2 t C ha^{-1} yr^{-1} and an average of 3 t C ha^{-1} yr^{-1}. Andrade et al. (2014) reported higher rates (shade trees 13.8 ± 6.91, coffee 2.6 ± 1.9, BGC 3.3 ± 1.57 all in t CO_2eq ha^{-1} yr^{-1}). The study from Colombia is one of few studies that show the high standard deviation in CS as observed in this study too. SOC sequestration in agroforestry was reviewed by Noponen et al. (2013b) and they showed similar CS rates ranging from 0.3 - 4.16 t C ha^{-1} yr^{-1}. Regarding BGC Polzot (2004) found very similar sequestration rates for BGC in coffee of 0.15 t C ha^{-1} yr^{-1} compared to the findings of this study (-0.0113 ± 0.29 t C ha^{-1} yr^{-1}). These comparisons illustrate that this study rather underestimates the CS potential of coffee agroforestry. However, IPCC quantified the agroforestry potential of CS at 0.3 t C ha^{-1} yr^{-1} for improved management and 3.1 t C ha^{-1} yr^{-1} in cases of adopting AFS, meaning in cases which include LUC (Watson et al., 2000). Therefore, it can be assumed that CS rates in this study are realistic, although the standard deviation is high.

3.4.3 The potential for compensating coffee emissions at Coopedota

A central question in this study was related to the potential of temporary CS in CAFS in Costa Rica to compensate the CF of coffee on an annual basis. Since little is known about these potential for carbon neutral products, this study aimed at providing a first idea of the magnitude of possible compensation and present issues that have to be kept in mind in such a procedure. This section will, therefore, shortly discuss this emission compensation potential and draw some implications from the findings of this study.

3.4.3.1 Emission compensation by on-farm carbon accounting and the role of coffee productivity

After limiting coffee renovation to a maximum of 5% in 2015, CS exceeded the coffee CF (see Section 3.3.2 and 3.4.2). In 2015, the highest emission compensation rate (360%) was observed. One reason might be the relatively low CF in a year of high yields at a usual rate of agro-chemical inputs (see Chapter 2). Another reason might be that in 2015, the carbon stocks were measured and thus there is no renovation considered in this particular year. Overall, the modeling results indicated that on average about 160% ± 93 of the coffee CF could be offset by on-farm carbon sequestration. It reveals a high potential for integrating temporary CS into the LCA-based carbon balance of carbon neutral coffee from Costa Rica. Nevertheless, it has also to be considered that shade tree logging was not considered, data variation is strong and sequestration rates might drop in the long-run due to effects of saturation. In other words, the production system might reach equilibrium (Six et al., 2002) and carbon sequestration will not continue endlessly. If the carbon accounting would also consider the maintenance of carbon stocks, other factors become more important. In the case of accounting for stability and amount of carbon stocks the most important factor would be the amount of SOC due to its higher levels compared to AGC (see chapter 3.2.1). In particular, attention should be given to the long-term carbon fixation in the stable carbon pool (Gulde et al., 2008). For high SOC contents, shade trees with their BGC and their litter inputs remain an important factor. Additionally, erosion prevention measures as well as soil management (mulching, compost applications), and farm inclinations will have major effects on SOC levels, as it has been reported by the literature (Lorenz and Lal, 2014). In contrast to the manifold challenges, the offsetting potential of coffee plantations in Costa Rica is of an unneglectable size, even more so if maintenance of carbon is also considered in the accounting. Ajani et al. (2013) present a land sector ranking system that includes carbon carrying capacity attributes (stock density and stability) to differentiate ecosystems and provide policy makers with important and suitable information regarding biogenic carbon in climate change. However, how to include carbon maintenance or carbon carrying capacity into LCA-based carbon standards, however, would be a question for further research.

A deeper look into the offsetting mechanism shows that a high CS rate is not the only factor that distinguishes whether a coffee's CF can be sufficiently offset. Since the functional unit of coffee's CF is determined as kg CO_2eq kg^{-1} green coffee, the CS (in kg CO_2eq ha^{-1} yr^{-1}) has to be related to the coffee yields (kg green coffee ha^{-1}) to express the remaining emissions (in kg CO_2eq kg^{-1} green coffee) and to calculate the emission compensation rate. This illustrates a strong trade-off between higher coffee yields and the emission compensation rate. The amount of coffee produced on a hectare becomes further important as the main business of farmers is coffee production, and thus, yields should be maintained at high levels. The aim is, to find the optimal balance, where high yields are generated with minimum amounts of GHG emissions (e.g. minimum agro-chemical inputs) and a maximum CS rate.

3.4.3.2 Implications for the cooperative

This study illustrates the existing potential of on-farm CS to completely compensate the cooperatives emissions in the carbon neutrality certification. In this case, the cooperative would not have to continue obtaining international carbon credits, but potentially would have to finance carbon monitoring in farms to account for on-farm CS. The cooperative certifies at the moment 483,000 kg of green coffee (about 25% of their total production), total emissions amount to approximately 1,000 t CO_2eq yr^{-1}. Assuming the lowest price for a ton of CO_2, which approximately 1 USD (Hamrick and Gallant, 2017), the total cost for credits result in approximately 1000 USD yr^{-1}. If carbon credits are available or bought at such low prices, which is widely criticized, reference (Hamrick and Gallant, 2017), it suggests that savings would not necessarily motivate the cooperative to account for CS in the plantations, especially since it might have to bear investment into additional monitoring costs. Only in the case that the cooperative could sell remaining CS (after compensating own emissions) as carbon credits, savings might increase. Beside the economic incentives, accounting for on-farm CS and by this supporting the integration of trees into the coffee plantations would motivate sustainability in the farms. There might also be an effect of a higher reputation in case offsetting is avoided and emission compensation takes rather place inside the same value-chain. It can be seen as a win-win situation, where a climate change mitigation strategy also addresses the issue of adaptation and thus contribute to a more sustainable, resilient and carbon neutral agri-food value chain. For the cooperative long-term solutions and resilient systems could benefit its development.

Further, if well communicated, a higher transparency and true claims could lead to a higher recognition of the carbon neutrality label. Resulting premium prices for the labeled coffee or savings in the certification could then be reinvested into increasing carbon stocks in the farms or to increase the volume of coffee certified.

So, what does the cooperative need to promote in order to ensure full compensation of coffee GHG emissions? Is the most important factor the CS rate in the field, the yields ha^{-1} or the amount of GHG emissions ha^{-1}? To better understand these relationships, a matrix of all possible combinations was designed (see Figure 15) using minimum and maximum scenarios based on the data of this study. By calculating the remaining CF (after compensation), it was observed that in the scenarios were CS was high, the coffee CF was completely compensated (dark grey cells showing negative values), independent of high or low yields and high or low emissions. The most undesired scenarios (white cells) occurred when low CS occurred in

	C (carbon seq.) (kg CO_2eq ha^{-1} yr^{-1})	**Y** (yield) (kg ha^{-1} yr^{-1})	**E** (emissions) (kg Co_2eq ha^{-1} yr^{-1})
Min	**c** = -22020	**y** = 800	**e** = 2400
Max	**C** = 22020	**Y** = 2500	**E** = 7500

Matrix of possible combinations			
	ECY	EcY	Ecy
	eCY		ecY
	eCy	ECy	ecy

Compensation as remaining CF (kg CO_2eq kg^{-1} green coffee) = **(E/Y) - (C/Y)**				Dark grey = C White and Light grey = c White = Y Light grey = y
	-5,81 (ECY)	11,81 (EcY)	36,90 (Ecy)	
	-7,85 (eCY)		9,77 (ecY)	
	-24,53 (eCy)	-18,15 (ECy)	30,53 (ecy)	

Negative values reveal that the CF could be fully compensated.

Figure 14: Evaluation of factor importance on carbon footprint compensation.

relation with low yields, independent of high or low emissions. This means high CS rates are the most important factor, followed by high yields whereas the magnitude of emissions was less influential. The role of CS rates that have high influence on the successful offsetting of emissions is even more crucial as they come along with high variability. Therefore, not only high CS rates should be incentivized but also continuous and stable carbon development is of importance. As the magnitude of yields is also highly important a suitable balance between CS and productivity is determining the offsetting potential.

3.4.4 Implications for the coffee farms

From relating the characteristics of each farm (see Table 12) to its CS rate, additional factors were observed that determined the performance of farms:

(i) The number and age of **shade trees**, namely more and younger trees, increased the CS, especially since BGC is a function of AGC and increases simultaneously. Further, its litter contributes to the contents of SOC. Farm evaluations have shown that trees can help to buffer the effect of coffee renovation. F2 could not compensate the effect of strong coffee renovation due to missing shade trees. Further *E. poeppigiana* trees were comparably young in F5 and F7 while their carbon sequestration was comparably high (see Section 3.3). *E. poeppigiana* had the highest sequestration rates and can continuously sequester carbon for more than 50 years. As a pioneer plant it has a strong growth which is reduced when it is growing older (Adame et al., 2014). The important contribution of shade trees to biogenic CS in CAFS is well known and documented (Kumar and Nair, 2011). However, the effect of potential logging at some point in time has not been considered in this study. As soon as logging of shade trees would occur in the future, such variations would have to be expected in the *E. poeppigiana* pool too. Further, then it would depend on how the wood is used and how fast or when the carbon is released back to the atmosphere (end-of-life) (Brandão et al., 2013). This might be difficult to trace.

(ii) Higher **planting densities**, both of shade trees and coffee, increased CS ha^{-1} (densities: in F5 *E. poeppigiana* 650 plants ha^{-1} and coffee 8 400 bushes ha^{-1}; in F1 *E. poeppigiana* 650 plants ha^{-1} and coffee 8400 bushes ha^{-1}). Defrenet et al. (2016) have not observed competition problems in an *Erythrina* – Coffee system of lower density (*E. poeppigiana* 7.4 plants ha^{-1} and coffee 5 580 bushes ha^{-1}shade), since through regular coppicing the roots occupied different soil depths. Nevertheless, potential negative effects from competition between coffee plants or coffee and shade trees and the then higher risk of pests and diseases have to be considered, however, remain still unclear.

This study identified well performing farms in terms of dealing with the trade-off between carbon sequestration and productivity (F5 and F7, see Figure 14). However, it can be argued that the magnitude of coffee yields is less suited to indicate the economic situation of a farm. It might depend on the costs and amount of agricultural inputs if the gross margin of a farm is higher compared to another farm. In the case of F5 and F7 the data on fertilizer inputs indicate that there is no clear difference between the two in terms of costs. The lowest performance in terms of CF compensation was found in F1 and F2, where high yields seemed to be achieved at the expenses of CS. To fully understand, what the optimal combinations and performances are, CS rates should be plotted against the GHG emissions of each specific farm instead of the average emissions from the cooperative, as it is the case here.

3.5 Conclusion

In carbon accounting many challenges can be still observed: data availability, data acquisition methods, data presentation and accounting approaches. For a first step, it would be most important to standardize methods used in measurements, calculation procedures (e.g. allometric equations) and data presentation (units). This would facilitate the comparison of data among the manifold studies and would support the creation of databases. High quality databases covering a divers set of plants and climates would be the basis to make on-farm carbon accounting coincide with the principles of LCA and, thus, facilitate its consideration in PAS 2060. Today, carbon balances are becoming a frequent tool to assess the environmental friendliness of products and services. Biogenic carbon should be accounted for in such carbon balances to improve the information and to value the environmental role of maintaining carbon stocks in agricultural production systems. Besides the lack of data on carbon stocks and in particular on carbon stock changes over time, no standardized methodological approach exists so far to account for carbon changes in agricultural LCA (Goglio et al., 2015). This complicates any improvement for substantially needed carbon databases and models and illustrates the need for pioneering, and case related studies.

Despite all these challenges, the on-farm carbon accounting model, established in this study, generated realistic outcomes. With an average CS rate of 1.7 t C ha^{-1} yr^{-1}, the CAFS could fully compensate the coffee GHG emissions; however, the standard deviation of CS rates is high. This study has also identified important factors to increase the potential for complete emission compensation. Thereby, high CS rates were identified to be the most important factor. High yields turned out as the second most important factor to achieve complete compensation of GHG emissions, while the magnitude of the CF was less relevant. That indicates the importance to overcome the trade-off between CS and productivity. To achieve high on-farm CS rates, renovation of coffee plantations needs to be limited to a maximum of 5%, resulting in a maximum coffee age of 25 years, as recommended by the cooperative. The relevance of renovation intensities in perennial corps and the level of farm productivity have been rarely studied so far. Further, high densities of young shade tree (if possible) were important, due to their high potential in CS (0.81 t C ha^{-1} yr^{-1} in *Erythrina poeppigiana*). Although the effect of shade tree logging has not been part of this study, their importance lies also in a relevant contribution to the BGC pool and their substantial litter input which builds up SOC levels.

Nevertheless, the pure consideration of CS (rule of additionality) can be questioned. Due to saturation effects, where agricultural production systems reach new equilibriums, CS rates cannot increase unlimited. Farming at highest attainable carbon levels (their carbon carrying capacity), might represent a more long-lasting approach to climate change mitigation and environmental sustainability. Further, it might be easier to simultaneously increase carbon stocks and yields than to increase CS and yields, which is of relevance to support food security and household income. Thus, programs designed for climate change mitigation should motivate for high yields at high carbon levels and should offer benefits that are also accessible for small-scale farmer.

3.6 References

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4 Willingness to pay for a carbon neutral label among German consumers of specialty coffee

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4.1 Introduction

In 2008, food systems contributed 19 – 29% to the global anthropogenic greenhouse gas (GHG) emissions (Vermeulen et al., 2012). The private sector and consumers can address their contributions to climate change using climate labels. On the one hand, companies benefit from an improved image that gives them a competitive advantage compared to non-certified actors, while a reduction of product carbon footprints may imply direct energy savings, which in turn might save costs (Cohen and Vandenbergh, 2012). However, at the consumer end, the willingness to pay (WTP) for carbon labels on agri-food products remains unclear, particularly for "carbon neutral" (CN) labels that, however, are increasingly applied and demanded. The world's first coffee that was certified as CN is being produced by Coopedota, a Costa Rican coffee cooperative and exported to a German family roaster. This study uses the unique case of Coopedota to investigate the WTP for a CN label among German coffee consumers to reduce the existing knowledge gap. In addition, this study assesses the synergistic effect of using multiple labels on coffee, in this case a CN label in combination with a Fair Trade label or direct trade claims. By doing so, this study makes an important contribution to the literature, since we have not come across any publication on synergistic effects in the WTP of consumers for multiple labels on coffee.

In general, carbon labels display the carbon footprint (CF) of a product, or the CF reductions achieved. A CF illustrates a product's impact on climate change and has become an important indicator for environmental sustainability. "Carbon Footprinting" is based on a life cycle assessment (LCA) that focuses on GHG emissions along a product's value chain. Although LCA has been applied to agricultural and food products for more than 20 years, only recently standardized methodologies and frameworks (e.g., Environmental Product Declarations, Publically Available Specification (PAS) 2050, GHG Protocol) have been developed. The standardized methodologies address the particular challenges encountered in agri-food life cycles in a comparable way. Such challenges are diverse due to dynamic production systems or inexact emission measurements and are distinct from industrial products, for which LCA has been developed originally (Notarnicola et al., 2015).

More recently, LCA-based carbon neutral labels were introduced, which declare no net-impact of a product on climate change. For instance, Coopedota, a coffee cooperative in Costa Rica, is producing the world's first coffee certified as CN since 2011. The cooperative applied the internationally recognized norm PAS 2060 for carbon neutrality, which was developed by the independent British Standards Institution (BSI) in 2009. PAS 2060 is the only independent specification to demonstrate carbon neutrality of products or services and aims at improving the transparency of CN claims (CarbonClear, 2011).

Assessing the WTP for a carbon neutral label based on the pioneer case of specialty coffee from Coopedota is interesting for the following three reasons: (i) coffee is one of the most traded products in the world and, as such, is an important export and import commodity for many countries (Lashermes et al., 2008). The demand for coffee is expected to further rise due to emerging coffee markets (e.g. in Algeria, Australia, Russia) and an increase in coffee consumption within coffee producing countries (ICO, 2014). (ii) The contribution of coffee to climate change is non-negligible as it is a nitrogen intensive plant with a long and complex value chain, which at the end-consumer stage requires an energy intensive preparation of the beverage[1]. In Costa Rica for instance, the coffee sector is responsible for 25% of the domestic agricultural GHG emissions (Nieters et al., 2015). (iii) Coffee is a highly differentiated product that lends itself to carrying labels (often several at once) that may convey e.g. fair trading conditions or organic agriculture. Thus, coffee consumers are already used to paying premium prices for additional (sustainability) characteristics.

The German coffee roaster Hochland Kaffee Hunzelmann GmbH (herein after referred to as 'Hochland') is a family business located in Stuttgart. It is well known for its high quality coffee (specialty coffee[2]) and imports about 70 % of Coopedota's coffee beans, yet does not sell the coffee with a carbon neutral label; this would imply further certification steps by the roaster to use the label at the point of sale in Germany. By labeling products as CN, consumers would be given the option to reflect on their purchasing decision and to influence their personal CF. The questions then arise as to what the value adding potential of climate labels, particularly carbon

[1] Kilian et al. (2013) illustrate the potential emission hot spot at the consumption stage, particularly when using automatic coffee machines.

[2] According to SCAA (Specialty Coffee Association of America) "specialty coffee" is defined as a coffee that scores ≥ 80 points on the 100-points coffee quality scale (tested by certified coffee tasters or licensed Q-Graders based on the official cupping protocol) (SCAA, 2017).

neutral labels, in the agri-food sector are, and whether consumers are willing to pay a premium price for carbon neutral agri-food products. To answer these questions, we conducted a choice experiment with Hochland coffee consumers between October and November 2016. The choice data obtained from 80 respondents was analyzed with random parameter logit models to test the following alternative hypotheses:

H1: Hochland customers have an additional WTP for a carbon neutral label indicating that the coffee they purchase has no net-impact on climate change.

H2: The interaction of the carbon neutral and Fair Trade label or a non-certified direct trade claim has an additional effect on the choice decision of coffee consumers. In other words, the simultaneous presence of these labels affects consumer's utility in a synergistic way.

H3: The preference for the attributes constituting coffee alternatives (as described in the discrete choice experiment) is heterogeneous among Hochland coffee consumers. We further hypothesize that such heterogeneity is partly explained by selected idiosyncratic variables that enter the part-worth specification as the vector w_i (see Section 4.4.3).

4.2 Insights from the literature

Carbon labels aim to cover the climate part of the ecological aspect enclosed in sustainability certification. Studies on the CF of coffee illustrate that consumption can cause a major part of GHG emissions along the coffee value chain. According to Kilian et al., (2013) the CF at the stage of consumption in Germany is 2.15 kg CO_{2eq} kg^{-1} green coffee and thereby responsible for 45% of the coffee's total CF. In a pilot case study, Tchibo GmbH, a leading coffee roaster in Germany, has analyzed the product carbon footprint of its Privat Kaffee Rarity Machare in accordance with ISO 14040/14044. By assessing the minimum, maximum and best-fit scenarios, emission hot spots and their variability were illustrated. Besides a hot spot of GHG emissions at the raw material production stage, mainly due to chemical inputs (33 – 66%, best fit 56%), GHG emissions at the consumption stage showed a potentially high contribution to the overall product carbon footprint (20 – 59%, best fit 30%) (PCF Pilotprojekt Deutschland, 2008). The CF at the stage of consumption is relatively high because GHG emissions are related to a functional unit, in this case the amount of green coffee (in kg) or a cup of coffee. A substantial amount of energy, especially when using automatic coffee machines, is consumed to prepare one cup of coffee that consists of 6 – 7 g of coffee powder and 125 ml of water. Hence, consumers play an essential role in reducing the CF of coffee and should take action to improve their personal carbon footprint.

In theory, carbon labeling enables informed consumer choices with respect to climate change implications of products. However, the establishment of a carbon-labeling market requires globally standardized methodologies for the calculation of product's emissions and a credible third-party certification system (Cohen and Vandenbergh, 2012). According to Gadema and Oglethorpe, (2011), consumers state a relatively strong demand for carbon labels in general (although there is a high degree of confusion in interpreting and understanding the labels). This result seems corroborated by Vanclay et al., (2011), who observed an increase in sales of products with a lower carbon footprint. In contrast Grunert et al., (2014) find that sustainability labels (e.g., carbon footprint, Animal Welfare and Fair Trade, among others) play a minor role in consumers' food choices that may nevertheless contribute to consumers' utility. Their results also show that the Rainforest Alliance label (which includes a large number of social and environmental criteria) was rated of a higher utility to consumers than the carbon footprint label, which displays the amount of carbon emissions caused by a product. Röös and Tjärnemo, (2011) further state that, among other aspects, a perceived "overpricing" could be one reason for low sales of carbon labeled products.

The mixed results regarding consumer's demand for sustainability and carbon labels, as elaborated above, might be partially related to a diversity of different carbon labels available and confusion, particularly on the term carbon neutral. Schaefer and Blanke, (2014) highlight the opportunities and challenges of carbon labeling for horticultural products. Moreover, they list a large variety of carbon labels and provide a possible classification. Examples of CO_2-Footprint labels are: (i) color codes - which indicate, if a product has a high, average, or low carbon footprint, (ii) carbon reduction labels, which assure that the carbon footprint of a product has been reduced and (iii) carbon neutral labels, indicating that the product's emissions have been balanced out by buying carbon credits (offsetting). However, the term carbon neutral is often misunderstood. First, because there exists a wide range of similar terms; carbon free, zero carbon, carbon negative, carbon positive (Bunning et al., 2013), lacking clarity on what the differences among them is. Second, because the term carbon neutral is often used incorrectly or without a clear definition. Lombardi et al., (2017), for example, assessed the consumer's attitude towards climate neutral milk. In fact, this study contains no clear definition to what they refer with the term climate neutral. Considering the choice cards that have been used in the discrete choice experiment (DCE), the term "climate neutral" is used as a synonym for "carbon reduced" milk (Lombardi et al., 2017). Since carbon labels target climate change and globally traded products, and to avoid confusion, certifications should be based on international and standardized guidelines and should be third-party verified (Cohen and Vandenbergh, 2012).

PAS 2060 is an example of such a specification. In PAS 2060, carbon neutral is defined as a "condition in which during a specified period there has been no net increase in the global emission of greenhouse gases to the atmosphere as a result of the greenhouse gas emissions associated with the subject during the same period" (BSI, 2014, p. 2).

So far, we could not find a study that assesses the WTP for a carbon neutral label on agri-food products based on an international third-party standard like the PAS 2060. Several studies conducted choice experiments to assess the WTP for different sustainability labels on agri-food products, including carbon labels (e.g. Lombardi et al., 2017; Tait et al., 2016; Van Loo et al., 2015). Among the studies that specifically address carbon labels, Van Loo et al., (2015) conducted a choice experiment to determine the WTP for different sustainability labels on coffee, including Fair Trade, Rainforest Alliance, USDA Organic and the Carbon Trust emission reduction label, indicating that the producer reduced the carbon footprint of its product. Their results show no WTP for the carbon reduction label, however, consumers were willing to pay a premium price for Fair Trade or organic labeled coffee. In Japan and the UK Tait et al., (2016) investigated the WTP for fruits with reduced carbon emissions in comparison to other attributes like price, water efficiency, waste/packaging and vitamins. The authors found a carbon label to be a significant attribute influencing fruit choices in these countries, showing the highest WTP values compared to the other attributes. An explanation to those contradictory results could be that there is a considerable country effect (Grunert et al., 2014). It might also be that consumers do not have enough background knowledge to benchmark a carbon footprint without any further information. Focus groups conducted by Upham et al., (2011) suggest that it is better to use labels disclosing the amount of carbon reduction rather than labels that present an absolute value of carbon emissions.

Notwithstanding the considerable number of studies that have dealt with consumer's WTP for carbon labels on agri-food products, very little is known in relation to the effect of different combinations of labels. Particularly on coffee, it is common practice to use multiple labels at once. Many studies have referred to this phenomenon (Henseleit, 2011; Tait et al., 2015; Van Loo et al., 2015), however, to the best of our knowledge, we could not identify a study that used a discrete choice experiment to assess the synergistic effect of consumer's WTP for multiple labeling (including a carbon label) on coffee.

In conclusion, although there seems to be a demand for sustainability and carbon labels, it remains unclear if, and how this is transferred into increasing consumer's utility. One factor might be related to a prevailing confusion due to a diversity in carbon labels and uncertainties in terminology. There might be a WTP for carbon neutral coffee, but it is expected to be rather low, particularly if prices of specialty coffee are already higher due to higher quality. The novelty of this study is that it examines the WTP for a clearly defined carbon neutral label in compliance with PAS 2060, moreover particularly on high quality (specialty) coffee in Germany, and additionally assessing the synergistic effect of multiple labeling including a carbon label.

4.3 The case

Coopedota, a coffee cooperative located in the central highlands of Costa Rica, is known for its high quality coffee (exclusively *Coffea Arabica* variety), which is produced by more than 800 small-scale farmers. During the last few decades, sustainability has become increasingly important to the cooperative and has been included, step-by-step, in their management policies. With this development good agricultural practices have been introduced, alongside with the standards ISO 1401 and ISO 9001, and a group of more than 100 farmers joined the Rainforest Alliance certification. In 2011, the cooperative's efforts towards sustainability culminated in part of their coffee being certified as carbon neutral for the first time. Until now, the cooperative produces the world's first carbon neutral coffee, certified with an international and independent high quality standard, the PAS 2060. Unlike other certifications for carbon neutrality, the LCA-based PAS 2060 includes not only the offsetting of GHG emissions by carbon credits but also an obligatory reduction of annual carbon emissions. Limiting the declaration of carbon neutrality to 12 months presents a measure to control for continuous emission reductions (BSI, 2014).

In LCA it is important to define the system boundaries that frame the analysis, either using cradle-to-gate or cradle-to-grave. Cradle-to-gate relates to assessing all GHG emissions from raw material production (coffee cherries) until the product leaves the manufacturing facility. In the case of Coopedota the "gate" is the port where the coffee is sold (e.g. to German importers). Cradle-to-grave additionally includes GHG emissions until the disposal stage. In the case of Coopedota, 90% of its green coffee is being exported, mainly to Germany, and 10% of its production is sold as roasted coffee in national stores and cafeterias. To serve both retailers, 460,000 kg green coffee for export are certified, applying cradle-to-gate boundaries and 23,000 kg green coffee for national retail, applying cradle-to-grave as system boundaries. Selling coffee labeled as carbon neutral in Germany, however, would require expanding the system boundaries for exported coffee from a cradle-to-gate to a cradle-to-grave assessment and to add the stages of transportation, storing, roasting, consumption and disposal that take place in Germany.

Hochland, as mentioned above, imports 70% of its specialty coffee from Coopedota, is considering selling their coffee with a carbon neutral label in Germany. To achieve the carbon neutral label, they would need to certify the remaining stages along the coffee value chain, which take place on their watch (oversea transport, roasting, storage and retail, consumption and disposal). However, to raise awareness on consumer-based emissions and allow consumers to take responsibility, premium prices for a carbon neutral label should be introduced. Additionally, premium prices could support the economic availability of labeling and provide the farmers with better prices.

The case of Coopedota and Hochland offers a unique opportunity to investigate carbon neutral labeling of high-quality agri-food products and the associated WTP by a group of consumers (Hochland consumers) in Germany, who already pay higher prices for specialty coffee.

4.4 Materials and methods

The WTP for carbon neutral specialty coffee was estimated by using a mixed logit model. The data for this model estimation was generated by a DCE. To identify the coffee attributes that were finally included in the choice experiments, three focus group discussions with clients of Hochland were carried out, which is a common procedure. The required survey among consumers of specialty coffee was executed in the two coffee bars of Hochland, located in the city center of Stuttgart. Semi-structured expert interviews with representatives of the roasting company Hochland were performed to obtain the required background information.

4.4.1 Focus group discussions

The three focus group discussions were embedded in a guided tour at the roasting plant of Hochland, and lasted approximately 20 to 30 minutes each. The aim of these interviews was to identify the relevant attributes to be included in the DCE. To figure out the most important attributes, participants were asked to name coffee attributes that influence their purchasing decisions. Subsequently, the researcher encouraged a discussion based on other coffee characteristics, in case they were not mentioned by the participants, yet were considered important in other studies, such as organic agriculture, other common sustainability labels and packaging. At the end of the discussion, the participants were asked to agree on a ranking for the five most important characteristics in their purchasing decision. Through this procedure, the focus group discussions offered direct insight on consumer's attitudes towards carbon neutral coffee.

4.4.2 Discrete choice experiment

The attributes for the choice experiment (see Table 14) were identified using the results from the focus group discussions and following recommendations from the literature[3]. Coffee flavor, which the focus group participants also identified as relevant for their purchasing decisions, was omitted as an attribute from the DCE due to its subjective nature.

In every choice set two choice alternatives were defined as 250g coffee packages, one of which carried the carbon neutrality label (certified in compliance with the PAS 2060 standard), while the other was labeled as "not carbon neutral". Respondents could also opt out the choice of either coffee package by choosing a third alternative labeled as "none". As such, two alternative specific constants (ASCs) were specified for each coffee package, with both their zero values set to define the opt-out alternative as the reference.

Table 14: Choice alternative attributes, corresponding design levels and other variable definitions

Definition	*Attribute levels*	*Coding*	*Variable name*
Coffee attributes (variables appearing in choice sets)			
Carbon neutrality certified coffee	Alternative specific constant		*CN*
Coffee without carbon neutrality certification	Alternative specific constant		*n-CN*
Direct trade with farmers (not certified/trust based)	no, yes	dummy	*DT*
Fair Trade certification label	no, yes	dummy	*FT*
Price of coffee (EUR)	3.90, 5.40, 6.90	metric	*PRICE*
Idiosyncratic variables (used to explain preference heterogeneity)			
Age < 30 years (considered to be ages typical of individuals with a relatively low disposable income)		dummy	*YOUNG*
Female respondent		dummy	*FEMALE*

Both coffee packages were additionally described by attributes that defined the retail price and the trade conditions with the coffee growers. The latter was coded with two dummies that indicated either a non-certified "direct trade" (relying on the customers' trust) or an independent label certifying Fair Trade. Both dummies indicate ordinal levels of the same variable, "trade conditions", and thus "non-certified direct trade" and Fair Trade could never be simultaneously true.

[3]For literature on which criteria to consider when identifying relevant attributes, we consulted Backhaus et al. (2016), Bateman (2002) and Telser (2002).

Three levels of the price attribute, 3.90 €/250 g; 5.40 €/250 g; 6.90 €/250 g, were chosen in accordance to actual retail prices from Hochland, which is known for selling “specialty coffee” at correspondingly higher prices. Therefore, the values in the defined price range are high, relative to the average German retail price of € 2.53 for a 250g coffee package in 2016 (Statista, 2017).

4.4.3 Survey design and data collection

Twelve choice sets (see. Figure 16 for an example choice card) were generated with an efficient design for a random parameters logit model with panel data structure using Ngene software (Chaloner and Verdinelli, 1995). The required parameter priors were obtained from estimating a conditional logit model on data resulting from a DCE pilot study with 16 participants. The

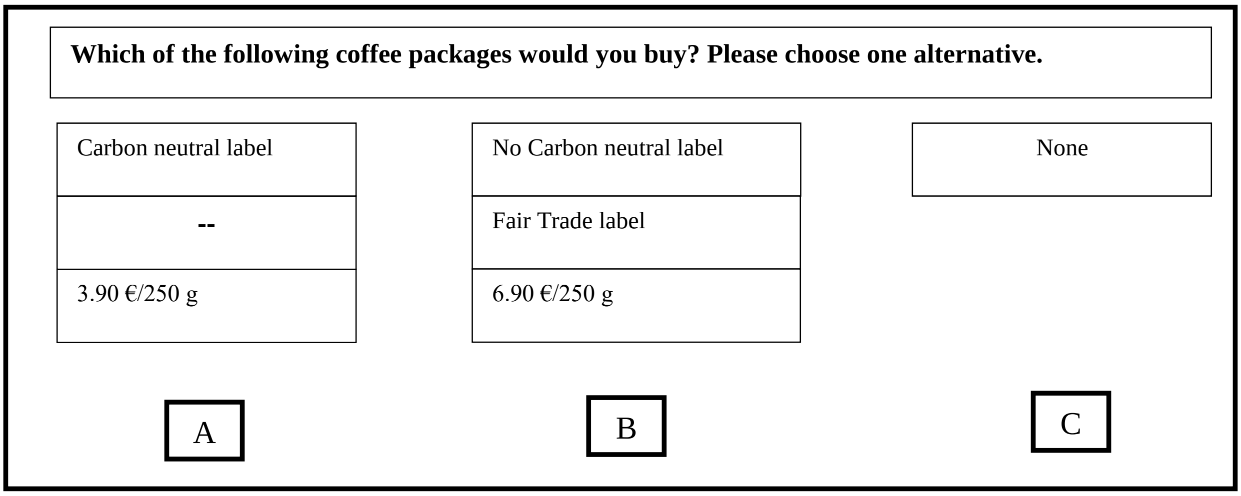

Figure 15: Example of a choice card

pilot study was conducted in a coffee bar of Hochland in the city center of Stuttgart, Germany. Additional constraints were introduced for the generation of the design to avoid unrealistic combinations, e.g. lowest price in combination with independent Fair Trade and carbon neutral labels.

A total of 192 coffee consumers were approached which were seated in two different Hochland coffee bars, 84 thereof agreeing to participate in the DCE, which results in a response rate of 43.8%. Nevertheless, four questionnaires had to be discarded, as they had not been fully completed. A sample of 80 interviewees (resulting in 960 choice observations) thus provided the data for the choice analyses, which specifically address the preference of actual and potential Hochland customers. The experiment took place between October and November 2016, during weekdays and weekends, at random times within the coffee bar’s opening hours, to avoid a selection bias. Participants were chosen by a random sequence generated with

Microsoft Excel. The consumption of at least one cup of coffee per week was a precondition for participation. As an incentive, each participant was given a small package of coffee and the possibility to win a 20 € coupon. At the beginning of the experiment, each participant was given an overview on the hypothetical coffee purchase, the different attributes and corresponding definitions (see Appendix 8). Subsequently, the participants were confronted with the twelve choice sets, each one consisting of an opt-out option and two hypothetical 250g coffee packages that differed in their attribute level combinations.

4.4.4 Discrete choice modeling and willingness to pay estimation

From the researcher's perspective, the utility that an individual i derives from a coffee alternative j ($U_{ij}, j = 1, \ldots, J$) can be expressed as

$$U_{ij} = V_{ij}(X_j) + \varepsilon_{ij} = \beta' X_j + \varepsilon_{ij} \,, \qquad (1)$$

where X_j is a vector of observed variables that relate to the coffee alternative and are weighted by parameters β to account for their relative contribution to the individual's utility (i.e. part-worth utilities). U_{ij} is decomposed into a systematic (explainable) component (V) and a stochastic (unexplainable) component (ε) that represents unobservable influences over the respondent's choice. A utility maximizing coffee consumer will choose an alternative h with utility superior to that of any other alternative j; the probability of such choice can be expressed as the standard logit model, provided that ε_{ij} is independent and identically distributed (IID), following an extreme value distribution type I (Train, 2009).

The mixed logit model is a general form of the standard logit model that allows for taste variation in the utility function with parameters β_i. The (unconditional) choice probability P_{ih} is the expected value of the standard logit probability over all the possible values of β_i, weighted by the continuous mixing distribution $f(\beta)$. In this study, we assume a normal distribution for all attribute parameters β. As such, the choice probability is given by

$$P_{ih} = \int \frac{e^{\beta' X_h}}{\sum_{j=1}^{J} e^{\beta' X_j}} \phi(\beta|\theta) d\beta, \qquad (2)$$

where θ collectively denotes the moments of the normal density, which are the parameters to be estimated. The random parameters are specified as follows

$$\beta_i = \beta + \delta' w_i + \sigma v_i, \;\; v_i \sim N(0,1) \,, \qquad (3)$$

Where β is the fixed population mean, w_i are (observed) idiosyncratic characteristics that induce heterogeneity around the mean, v_i is the individual (unobserved) specific heterogeneity and σ is the standard deviation of β_i around β. Some random coefficients only present unobserved heterogeneity (homogeneous parameter means), in which cases the vector δ is set to zero. The introduction of additional stochastic elements through β_i in the utility function, which in this study were allowed to correlate across alternatives and choice situations, partially relaxes the restrictive IID assumption (Hensher et al., 2005; Hensher and Greene, 2003).

Due to the labeled nature of this study's DCE, we included two alternative specific constants (ASCs) in our models: the first (CN) captured the mean preference for a 250 g coffee bag that is certified for carbon neutrality, while the second (n-CN) captured the mean preference for a 250 g coffee bag without such certification. Similarly, we specified part-worth for the DT and FT dummies (see Table 14) that are specific to each alternative. Accordingly, we defined DT_CN and FT_CN for the carbon neutrality certified coffee and DT_n-CN and FT_n-CN for the coffee without carbon neutrality specification. Thereby, the parameters specific to the carbon neutrality certified coffee capture possible synergistic effects (i.e., the addition or deduction of utility due to a simultaneous presence of two attributes, be it either CN and DT or CN and FT)[4], which can be inferred by contrasting them to their corresponding alternative-specific parameter counterparts in the n-CN alternative.

All parameters and ASCs were allowed to be heterogeneous among the coffee consumers, except for the price coefficient (PRICE) in the willingness to pay (WTP) models. The WTP point estimate for an attribute k can be calculated as

$$WTP_k = -\frac{\beta_k}{\beta_c}, \qquad (4)$$

where β_k is the estimated coefficient of the attribute of interest and β_c is the price coefficient. Similarly, the WTP standard deviations can be estimated as σ_k/β_c. Forcing a homogeneous part-worth on the price coefficient is a common strategy to overcome the challenge of obtaining WTP estimates as the ratio of two random part-worths (e.g., the moments of the WTP ratio distribution are undefined).

[4] Recall that FT and DT can be seen as two ranks of the same ordinal variable, which nevertheless by design could never simultaneously describe one coffee alternative.

4.5 Results

4.5.1 Qualitative results from the focus group discussions

The focus group discussions were carried out to determine the most important coffee attributes influencing the purchasing decision of Hochland customers. All groups mentioned attributes such as flavor, price, caffeine content, stomach-tolerance, packaging (preferred bigger size of packages to reduce waste) and Fair Trade relations as the most important factors influencing their purchasing behavior. However, the environmental aspects related to the production and consumption of coffee, especially those concerning its carbon footprint, had to be introduced by the moderator in every focus group discussion. The participants did not seem to be aware of the environmental impacts of coffee production and felt that “coffee is a natural product” and thus believe that no carbon emissions could be attributed to its production and consumption. After providing information about the carbon footprint of coffee and the case of carbon neutral coffee of Coopedota, the participants expressed their interest in carbon neutrality and mentioned that it could possibly influence their purchasing decision. Further, especially younger respondents stated that they did not know about the environmental problems along the coffee value chain; however, they stated that this issue would play a minor or even no role at all in their purchasing decision.

4.5.2 Descriptive statistics of the DCE participants

Table 15 presents the socio-demographic characteristics of the respondents compared to the German population. The sample of this study is biased, if compared to overall Germany, towards higher education levels, with 71% of respondents holding an *Abitur* (the German equivalent of the A-level, allowing the entrance into University), instead of 30%. Furthermore, the attainment of higher academic degrees in our sample is 50 percentage points higher than that of Germany as a whole. From the sample of 80 DCE participants 55% were female and exhibited an age distribution similar to that of the German population. In addition to representing gender and age, our sample exhibits a distribution of coffee drinking habits that is similar to that of the coffee consuming population in Germany.

4.5.3 Mixed logit results and WTP

We fitted mixed logit models to the 960 choice observations that resulted from the DCE using NLOGIT 5 / LIMDEP 10 econometric software (see Table 16). Thereby, we elicited respondents’ preference (and preference heterogeneity) for the presented coffee attributes and subsequently obtained corresponding WTP point estimates. We further examined the data for sources of taste heterogeneity by interacting the parameter means with socio-demographic variables, which were selected following a stepwise-backward elimination. The random parameter terms were assumed to be normally distributed and allowed to correlate in all models.

Table 16 presents three models that were selected in accordance to the Akaike information criterion (AIC). The estimated coefficient means and the corresponding standard deviations in all models reveal a significant preference for all tested non-monetary coffee attributes. As expected, the coefficient for the price attribute presented a negative sign in all models.

Table 15: Socio-demographic characteristics of the sample

Characteristics		Sample share (%, n= 80)	Share in German population(%)
Gender	Female	55	51[a]
	Male	45	49[a]
Age	<30	25	30[a]
	30 – 49	29	27[a]
	50 – 65	33	22[a]
	65 +	13	21[a]
Education	Realschulabschluss*	29	23[b]
	Abitur*	71	30[b]
	Vocational training	35	49[b]
	University degree	65	15[b]
Coffee drinking habits	At least 1 cup a week	14	
	1-2 cups / day	30	31[c]
	3-5 cups / day	53	48[c]
	6 and more cups a day	4	7[c]

*Hauptschulabschluss or Realschulabschluss require at least 9-10 years of school education. Abitur (the German equivalent of the A-level) is the highest German school degree after 12-13 years, which is required to enter University.
[a](Statistisches Bundesamt, 2015) data from 2014, [b] (Statistisches Bundesamt, 2011) Estimations for 2015, [c] (Statista, 2008)

In the first model (M1), the full parameter vector was set to be random. A significantly positive estimate for n-CN indicates that Hochland coffee consumers experience utility from acquiring a 250g coffee package, disregarding the absence of a certificate for carbon neutrality. Moreover, the comparatively higher estimate for CN indicates a utility increase in the presence of a carbon neutral label. The difference between CN and n-CN corresponds to the change in utility attributed to the carbon neutral label. The utilities of each coffee alternative (CN and n-CN) were described by alternative specific coefficients (dummies) of "trade conditions"; namely DT_CN and DT_n-CN for "non-certified direct trade" with and without the presence of a carbon neutral label, and FT_CN and FT_n-CN for the Fair Trade label with and without the presence of a carbon neutral label. Thereby, we inspected for possible synergistic effects (see hypotheses in Section 4.1, and Section 4.4.3): a significant difference between DT_CN and DT_n-CN suggests that there is a positive synergistic effect between the carbon neutral label and a "non-certified direct trade" claim. In other words, the utility that respondents perceived from choosing a coffee that is both directly sourced from the growers (without certification) and certified as carbon neutral was higher than the sum of the independent part-worths for "non-certified direct trade" and carbon neutrality. Nevertheless, such synergistic effect could not be determined for the Fair Trade label, as FT_CN = FT_n-CN could not be rejected. In this regard, M1 guided the utility specifications for M2 and M3, which accordingly only present the interaction between carbon neutrality and "non-certified direct trade". for coffees that are not certified as carbon neutral, a Fair Trade certified coffee is preferred over a (non-certified) directly sourced coffee, meaning $(\beta_{\mathrm{NCO2}} + \beta_{\mathrm{FT}}) > (\beta_{\mathrm{NCO2}} + \beta_{\mathrm{DT}})$. This inequality nevertheless does not hold for coffees that are certified as carbon neutral, meaning $(\beta_{\mathrm{CO2}} + \beta_{\mathrm{FT}}) = (\beta_{\mathrm{CO2}} + \beta_{\mathrm{DT}})$ could not be rejected.

Our analyses proceeded with M2, a model that only differs from M1 in that a homogeneous part-worth was assigned to the price attribute. The WTP point estimates were then obtained according to Equation 4 (see Section 4.4.3). On the other hand, the average WTP for a carbon neutral label can be obtained as the difference between the two alternative coffee packages, $WTP_{(CN\ label)} = WTP_{(CN)} - WTP_{(n-CN)}$ = € 1.77. Table 17 provides a summary of Hochland costumers' average WTP, estimated for 250g coffee packages resulting from different attribute combinations. We found higher WTP for a Fair Trade label than for direct trade claims and even lower WTP for a carbon neutral label. The highest WTP was found for the combinations of a carbon neutral certificate and a Fair Trade label or direct trade claims. There was little difference in WTP between these two combinations (FT + CN and DT + CN).

Table 16: Mixed logit coefficients for an all-parameters-random model and for two fixed-cost models with corresponding willingness to pay (WTP) estimates.

		M1: All-parameters-random		*M2: Fixed-cost*				*M3: Fixed-cost (explained heterogeneity in mean)*			
Variable		*Coefficient* [a]	*(SE)*	*Coefficient* [a]	*(SE)*	*WTP (€)* [a) d)]	*(SE)*	*Coefficient* [a]	*(SE)*	*WTP (€)* [a) d)]	*(SE)*
CN	*Mean* (β)	10.27**	(1.17)	8.37**	(0.83)	4.38**	(0.12)	8.73**	(0.86)	4.54**	(0.19)
	SD (σ)	12.86**	(2.49)	1.34**	(0.37)	0.70**	(0.21)	2.33**	(0.43)	1.21**	(0.26)
n-CN	*Mean* (β)	7.43**	(1.30)	4.98**	(0.89)	2.61**	(0.31)	6.81**	(0.87)	3.54**	(0.23)
	SD (σ)	15.08**	(3.01)	3.51**	(0.50)	1.84**	(0.33)	3.36**	(0.51)	1.75**	(0.32)
DT_CN	*Mean* (β)	7.05**	(0.91)	7.93**	(0.89)	4.16**	(0.32)	9.73**	(1.16)	5.06**	(0.42)
	SD (σ)	4.21**	(0.85)	5.02**	(0.55)	2.63**	(0.40)	6.66**	(0.59)	3.46**	(0.48)
DT_n-CN	*Mean* (β)	4.46**	(0.81)	6.14**	(0.96)	3.22**	(0.43)	7.28**	(1.04)	3.78**	(0.43)
	SD (σ)	5.94**	(0.92)	5.20**	(0.49)	2.72**	(0.39)	5.55**	(0.61)	2.89**	(0.44)
FT_CN	*Mean* (β)	6.89**	(1.28)	8.21**	(0.82)	4.30**	(0.28)	8.81**	(1.07)	4.58**	(0.40)
	SD (σ)	4.42**	(1.15)	4.19**	(0.42)	2.20**	(0.32)	4.97**	(0.41)	2.58**	(0.35)
FT_n-CN	*Mean* (β)	6.86**	(0.86)	$FT\_n-CN \equiv FT\_CN$				$FT\_n-CN \equiv FT\_CN$			
	SD (σ)	6.29**	(0.87)								
PRICE	*Mean* (β)	−1.87**	(0.26)	−1.91**	(0.21)	−1.0		−1.92**	(0.21)	−1.0	
	SD (σ)	2.65**	(2.65)	Fixed parameter				Fixed parameter			
Heterogeneity in random parameter mean (δ): covariate × attribute											
YOUNG[e] (w_i): CN		-		-				−1.17*	(0.40)	−0.61*	(0.22)
FEMALE (w_i): n-CN		-		-				−2.14**	(0.62)	−1.11**	(0.31)
Log-Likelihood (LL)		−519.76779		−575.87057				−564.74623			
Parameters (*K*)		35		21				23			
AIC/*N*		1.156		1.243				1.224			
Adjusted [McFadden] R^2 [c]		0.3929 [0.4040]		0.3324 [0.3397]				0.3446 [0.3524]			
LRT [b) c)] (*df*) χ^2		(33) 704.64607**		(19) 592.44051**				(21) 614.68919**			

Refer to Table 1 for variable definitions. *N*=960 observations. [a] Significance levels: * $p < 0.05$, ** $p < 0.001$. [b] Likelihood ratio test. [c] Based on LL = −872.09082 of a restricted model with two intercepts only, i.e., choice probabilities set at each alternative's sample shares. Source: own calculation. [d] Willingness to pay point estimates (in EUR) were obtained as the ratio of the (random) coefficients to the fixed price coefficient. [e] The dummy YOUNG is true for individuals of age < 30 years.

Finally, we estimated M3 to explain preference heterogeneity with regards to a carbon neutrality certification, by interacting the ASCs of both coffee alternatives with the dummies FEMALE and YOUNG, which respectively indicate gender and respondents with less than 30 years of age (see Table 14). FEMALE was interacted with n-CN, while the YOUNG was interacted with CN. Table 16 shows how the preferences (and the corresponding WT) of individuals with the characteristics FEMALE and YOUNG deviate from the mean preference for CN and n-CN of those individuals who do not present such characteristics. In view of this, one can calculate the mean WTP of females for n-CN a*s,* $WTP_{Female\ (n-CN)} = -(\beta_{n-CN} + \delta_{Female})/\beta_c =$ € 2.43, which is € 1.11 less than that of the average male. Furthermore, according to the estimates in M3, the mean $WTP_{(CN\ label)}$ of young respondents (below the age of 30 years) is € 3.90. This is € 0.61 less for a carbon neutral label than that of the average individual of age 30 years and above.

Table 17: WTP estimates (in €) for coffee packages with different labels

Coffee package description		WTP Model 2
Coffee 250g, Arabica (100%), medium roast	**(no CN)**	2.61
	… with **CN**	4.38
	… with **DT (no CN)**	5.83
	…with **FT (no CN)**	6.91
	… with **CN and DT**	8.54
	… with **CN and FT**	8.68

CN = carbon neutral label, DT = direct trade claims, FT = Fair Trade certification, Akaike information criteria (AIC).
Source: own calculation

In relation to our hypotheses, the following results were found:

We could reject the null hypothesis associated to *H1*: Hochland customers are willing to pay a higher price for a carbon neutral label.

Moreover, we could not falsify the null hypothesis associated to *H2* with regard to a synergistic effect in case of simultaneous presence of a carbon neutral and a Fair Trade label (CN and FT). In contrast, the interaction with the direct trade claims (CN and DT) even resulted in a positive synergistic effect, meaning that in this case we could falsify the null hypothesis associated to *H2*.

As anticipated, we could keep *H3*: the preference for the proposed coffee attributes is heterogeneous among Hochland customers.

4.6 Discussion

A carbon neutral label certifies that all emissions, associated with the life cycle of the coffee were offset and the product has no net-impact on climate change. As anticipated, we found a marginal WTP for such a carbon neutral label, which resulted in € 1.77 (Model 2) among consumers of specialty coffee in Germany.

Similar results were found in an auction study on WTP for wine with different sustainability labels, where undergraduates in Naples were willing to pay 30% more for a wine with a carbon neutral label than for the conventional wine (Vecchio, 2013). Similar results were found in a study on WTP among young adults for different characteristics of wine in Austria (Gassler, 2016). Gassler found increased WTP for wine labeled as carbon neutral of approximately 60%. These references suggest that our results are plausible. A premium of € 1.77 (68%) for the carbon neutral label, as the difference of the alternative specific constants estimated in this study, might slightly overestimate actual WTP of Hochland customers for a carbon neutral certification, but lies within a realistic range.

In Table 17 the estimated total WTP derived from model M2 are listed for 250g coffee packages (100% Arabica beans) with different hypothetical labels and claims, where values ranged from € 4.38 (250g package with a CN label) to € 8.68 (package with direct trade claims and a CN label). To verify the plausibility of our result we compared the estimated WTP with market prices for high quality 250g coffee (specialty coffee with 100% Arabica beans), which ranged between € 5.50 – 8.50 (see Appendix 9). The majority of these come with direct trade claims, Fair Trade certification, organic certification or a combination of them. This comparison suggests that the WTP estimates of this study are plausible and reveal the real market prices for high quality coffee with sustainability certifications.

Overestimations of the WTP are common in such studies, due to the fact that a DCE is a stated-preference-method (see Hess and Rose, 2009, p. 26). A bias is often caused by socially desirable answers (Fisher and Katz, 2000), which might have contributed to the overestimation of WTP also in our study. It must be further considered, that the results reflect the price people are willing to pay and not compulsorily the real price in the market. However, consumers show low knowledge on prices (Schneider et al., 2009, pp. 219). Further, the sample in this study is biased in the direction of a high education level and therefore - probably – a relatively high level of income. By targeting urban consumers of specialty coffee, this was expected.

In the model M2 we found higher marginal WTP for a Fair Trade label (€ 4.30) than with direct trade claims (€ 3.22) and a carbon neutral label (€ 1.77). Another study in Italy similarly found lower WTP for carbon related characteristics on agri-food products than for other sustainability labels. Vecchio and Annunziata, (2015) conducted experimental auctions with chocolate bars at the University of Naples. They report higher WTP for bars with a Fair Trade than Rainforest Alliance label, and a lower WTP for chocolate bars with carbon footprint information. The higher preference for trade condition claims (i.e., Fair Trade or non-certified direct trade) relative to that for a carbon neutral label may be explained in the rather novel and abstract nature of the latter. These characteristics contrasts with the familiarity of German coffee consumers to fair trade claims and labels, and the issues these labels address (such as child labor and underpayment of producers). These are established not only in the retail market for coffee, but also in that for many other import goods that are derived from labor-intensive primary agricultural products, such as cocoa and sugar cane. In fact, the participants of our three focus group discussions were all unfamiliar with the carbon footprint of coffee production and consumption, whereas they were acquainted with the greenhouse gas emissions (GHG) from burning fossil fuels. Differences in WTP depend on whether and what information the participant was provided with, since consumers might be less familiar with carbon labels (Sirieix et al., 2013) and it might remain unclear what the labels mean (Gadema and Oglethorpe, 2011; Hartikainen et al., 2014). Although prior to the DCE exercise, the participants were informed about the GHG contribution of coffee throughout its life cycle, such information may have been insufficient to alter their (stated) purchasing behavior. It may still have fallen short of achieving a deeper understanding of the related meanings and concepts. In a pilot study on consumer perception about sustainability labels in the UK, Sirieix et al., (2013) conclude that the reasons for a missing familiarity are not only insufficient knowledge or information but also a missing familiarity with underlying concepts such as carbon. The need for familiarity with concepts applies also in this study, where it might not be sufficient to receive the information on what carbon neutrality is, but rather a deeper understanding of the meaning and concepts can alter buyers' behavior (Pieniak et al., 2010; Salzmann et al., 2006). Other studies suggest it is important to record the personal attitude of respondents towards climate change. Kragt et al., (2016) find that individuals who do negate human-induced climate change exists have a negative relationship with WTP for climate attributes.

Regarding the multiple use of labels our results were surprising. Admittedly, the second hypothesis was postulated with the expectation of a negative synergistic effect. The simultaneous presence of a carbon neutral label and claims of direct trade or a Fair Trade certificate were expected to result in a marginal utility smaller than the sum of the corresponding independent effects. Neither of them did. We could not find any effect with respect to the combination of a carbon neutral label with a Fair Trade label, but we found even positive synergistic effect when a carbon neutral label was added to direct trade claims. So far, to the best of our knowledge, there are no studies looking at the interaction of a carbon neutral label on coffee (or comparable carbon footprint certifications) with other sustainability labels. Henseleit, (2011) looked at chocolate with organic and Fair Trade labels. She found that the interaction of these two labels does not necessarily result in a higher WTP. Nevertheless, around 40% of the respondents would pay more (on average € 0.50) for a chocolate where both labels are present. As far as coffee goes, 80% of organic coffee in Germany is additionally Fair Trade certified (Braun, 2015). This might indicate a certain familiarity of consumers with the multiple use of labels on coffee and the acknowledgement of such a combination (e.g. environmental and trade labels). On the other hand, our results suggest (see Table 17), adding a carbon neutral label to a coffee that was directly sourced from the growers (DT claims), such as the coffee of Hochland, it would reach a WTP close to that of a Fair Trade certified coffee (with or without a carbon neutral label). A possible explanation for this result is that the trust coffee consumers bestow on a label that certifies one claim is spilled over to the product's other claims that lack a third-party certification; in our case, the certified carbon neutral label possibly conferred trust to the non-certified direct trade claims.

Furthermore, we could partly explain the heterogeneity in the preference for a carbon neutrality certification with socio-demographic variables: females report a decrease in utility when the carbon neutral label is absent. On the other hand, relatively young Hochland customers (i.e., below the age of 30 years) showed a lower preference for a carbon neutral label than the customers with ages 30 years and above, a result that is consistent with the general attitude of the youngest focus group (with average age of 30 years). This result may be explained by the relatively low purchasing power of individuals at the beginning of their productive lives. These according differences in preferences of age and gender are consistent with observations from other studies (Grunert et al., 2014; Ubilava et al., 2010; Vecchio, 2013; Vecchio and Annunziata, 2015).

4.7 Conclusion

Consumers of specialty coffee in Stuttgart, Germany, are willing to pay a premium price for a carbon neutral label. This WTP is clearly lower than for a Fair Trade certificate or a non-certified direct trade claim. One reason seems to be consumers' unfamiliarity with a carbon neutral label and with the underlying concepts of carbon emissions in the agri-food sector and of carbon offsetting schemes. Another finding of this study was a positive synergistic effect when a carbon neutral label was simultaneously present on the coffee package with a direct trade claim. This means, consumers were willing to pay more for a combination of these labels than they would be for the sum of the single labels. A possible explanation is that the credibility towards direct trade claims might increase when it is combined with a third-party certified carbon neutral label. Further, German consumers might prefer a combination of fair trade related attributes with other sustainability labels since they are used to such a combination of labels on coffee products; the majority of organic coffee in Germany is simultaneously certified Fair Trade. In this case, the combination of direct trade claims with a carbon neutral label seems to be equally preferred as the combination of a Fair Trade certificate and a carbon neutral label.

From this, we can deduce that our results may hint at an incipient demand for carbon neutral labels (or similar carbon footprint certificates) on specialty coffee, particularly from older females. Moreover, our results may serve as a directive for German coffee roasters who directly source their coffee from the growers: certifying their production for carbon neutrality may compensate for the lack of a third-party Fair Trade certification. Nevertheless, as a precondition, consumers should be sensitized on the impact of agri-food products to climate change and public knowledge on carbon and offsetting concepts is required to increase the impact and demand for carbon neutral labels.

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5 Discussion

Sustainability standards are usually multidimensional and complex due to a participatory development process (Potts et al., 2014). They can be applied on a high number of different products, processes or organizations. These diverse application possibilities can, however, result in trade-offs (Mithöfer et al., 2017). Recently, the demand for climate standards and labels has increased, however, little is known about their particular potential and challenges (Schaefer and Blanke, 2014). Further, individual aspects of voluntary sustainability certifications (among them climate standards), have received the attention of scholars, such as the effectiveness and impact of certifications or the purchasing decisions of consumers. However, taking a holistic and interdisciplinary approach by considering the complete value chain is rare and, thus, challenges are overlooked and proposed solutions are limited in scope.

Addressing these knowledge gaps, the thesis used an interdisciplinary case study approach to elicit the multi-facetted challenges and potential of sustainability certification in the agri-food sector. Taking the case of the world's first carbon neutral certified coffee, the complete chain – from standard development to consumer choices – was examined.

In the remainder of this final chapter of the thesis, a summary of the main results and their contributions to the existing literature is presented and the methodological and data limitations are discussed. The outcomes of the different Chapters will be analyzed and discussed using the conceptual framework. An integration of the ultimate outcomes will finally lead to overarching implications derived from the case study.

5.1.1 Contribution of major results to the literature

In Chapter 2 we examined the pathway of the world's first CN certification in coffee at Coopedota – from idea to implementation – to determine the success factors underlying this pioneering process. Further, we had a closer look into the implementation of PAS 2060 in coffee to identify major challenges and lessons learned. We used qualitative methods (expert interviews, Process Net-Mapping in group discussions and field observations) to facilitate discussion and gain a deeper understanding of potentially hidden success factors.

To the best of our knowledge, this is the first study that investigates the implementation of PAS 2060 for CN in the case of an agri-food product. The book of Notarnicola et al., 2015 offers a holistic overview on international methodologies and implementations of LCAs in the agri-food sector. It also provides a deep understanding of the advantages and challenges still prevalent today related to the use of LCA in the agri-food sector. Explanations and experience with methodologies, certification and labeling for carbon neutral products are still little to non-existent. The present study is also one of few studies that have looked at success factors in green innovations from a social network perspective. In particular, there are knowledge gaps regarding the network dynamics and the role that different types of actors and different types of linkages play in successful pioneer cases of innovation (Hermans et al., 2013; Johnson and Silveira, 2014; Klagge and Brocke, 2012).

The results indicated that the carbon footprint analysis created awareness on emission hot spots along the coffee value chain and is suitable as a tool, which supports the evaluation of efficiency in terms of GHG emissions. One major challenge applied to the subject of good quality data, particularly in retrieving reliable data from the farm level provided by coffee producers. Smallholder farmers are often not used to bookkeeping and face difficulties or show little motivation to contribute. Restricting the carbon neutral certification to farmers, which already participate in the Rainforest Alliance Program, turned out to be a successful solution, since these farmers were already used to providing farm management data to the Cooperative. It was also found that PAS 2060 places a central importance on emission reduction, instead of solely offsetting, nevertheless, local reforestation or agroforestry and its resulting on-site carbon sequestration is not accounted for. This is contrary to the national NAMA-projects and carbon neutral activities in Costa Rica. Further, the communication and marketing of a carbon neutral label remains another challenge, which has also been documented by other studies on carbon labels (Schaefer and Blanke, 2014; Van Loo et al., 2015).

In terms of success factors, the results showed that the most important success factors include a combination of (i) prior achievements in Coopedota’s sustainability policy (ISO 9001, 14001), which were incentivized by a fertile ground (national and international trends and debates) and (ii) strong, visionary actors that performed the necessary network functions. These necessary network functions were described by (Hermans et al., 2013) and can be summarized as the ability of actors to create knowledge, lobby for their ideas and hold broker positions in a diverse network. Nevertheless, a highly centralized network may jeopardize the sustainability of the innovation project.

In Chapter 3 we investigated the potential of accounting for on-farm carbon sequestration in coffee-agroforestry systems in Costa Rica in order to compensate GHG emissions along the coffee value chain. In this study a dynamic carbon sequestration model, named the on-site carbon accounting model, was developed based on a detailed carbon inventory of selected farms. This model uses information on above ground and below ground carbon stocks and carbon increments to estimate annual carbon sequestration rates in coffee farms, and relates them to the carbon footprint of the coffee product. Thus, estimations of annual emission-compensation-rates were calculated within a time horizon of 20 years based on data from the coffee cooperative Coopedota in Costa Rica.

Only few studies have related detailed data on product emissions (e.g. rigorous coffee CF) and CS in coffee to one another (Andrade et al., 2014; Noponen et al., 2013; van Rikxoort et al., 2014). None of them presented annual developments of compensation rates by using a dynamic model. More common are stationary or generic models that are project based evaluations (e.g. the implementation of an agroforestry system model), including a baseline and the computation of a project's impact after a certain time period (Ravindranath and Ostwald, 2010). Further, many studies undertake their investigation on experimental sites, which are planted and thus of a limited age (Coltri et al., 2015; Haggar et al., 2011; Hergoualc'h et al., 2012; Oelbermann et al., 2004). In contrast, this study visualizes a real-life situation (in a field trial) and considers annual changes in emission-compensation-rates, allowing for a deeper understanding of the factors influencing the performance of carbon sequestration projects.

The carbon sequestration rates and their high variability found in this study correspond to findings from literature on CAFS in Central America. Another result of this study is that the on-farm carbon sequestration rate would completely compensate the carbon footprint of coffee. On average up to 164% of the carbon footprint could be annually compensated over a period of 20 years.

As an important factor to increase on-farm CS rates, annual renovation of coffee plantations should be limited. A reasonable area for annual renovation was found to be at maximum 5% of a hectare, resulting in a maximum coffee plant age of 25 years. Furthermore, important for high CS rates are high shade tree densities (if possible) in the coffee plantations, due to their high CS potential, their importance in BGC, and the considerable litter input that increase the SOC.

Factors that determine the potential of whether a complete compensation of the coffee CF can be achieved or not were found to be (from most influential to least influential): (i) carbon sequestration rate ha^{-1}, (ii) coffee yields ha^{-1} and (iii) carbon footprint of the coffee product.

These results indicate that it is essential to create synergies between productivity and climate change mitigation and adaptation, and to find an optimal balance between sufficient carbon sequestration and maintaining high yields at reduced inputs. The interplay of these factors finally determines the sustainability performance of the system.

In conclusion, accounting for carbon sequestration would avoid the “greenwashing” image of offsetting practices; it would reduce offsetting costs and incentivize tree incorporation into plantations, which would support environmental sustainability as well as sustainable livelihoods through farm diversification.

In Chapter 4 we analyzed the willingness to pay for a carbon neutral label among German consumers. We thereby focused on consumers of specialty coffee, since they already pay higher prices for their coffee and might be less inclined to pay for an additional carbon neutral label. A mixed-logit model was estimated based on a discrete choice experiment. Little is known on consumer’s preferences and attitudes towards carbon neutral labels in the agri-food sector (few studies in Italy and Austria by (Gassler, 2016; Vecchio, 2013; Vecchio and Annunziata, 2015).Very little is also known on synergistic effects when climate labels coexist with other labels (Henseleit, 2011) on a package. Although studies have reported an increasing market demand for climate labels, the evidence from choice experiments suggests that the willingness to pay for such labels is smaller than for other well-known sustainability labels such as Fair Trade and Organic (Van Loo et al., 2015; Vecchio, 2013; Vecchio and Annunziata, 2015). Determining factors are gender, age, and attitude towards climate change. As a response to the results from our focus group discussions, which indicate a lack of understanding on carbon concepts and the contribution of agriculture to climate change, we provided basic information on the investigated labels to the participants. The results of this chapter support the evidence of dedicating higher utility for consumers to a Fair Trade label than a carbon neutral label. Nevertheless, a marginal willingness to pay of € 1 – 1.77 for a carbon neutral label was estimated. Similar to other studies, we found that females and older people were willing to pay more for a carbon neutral label compared to the average consumer. Contrary to the findings of (Henseleit, 2011) our results indicate a positive synergistic effect, the combination of DT claims and a CN label seems to be preferred by German consumers even over combining a CN label with a Fair Trade certification. A possible explanation is that German consumers are used to such a combination of labels on coffee products since the majority of organic coffee is simultaneously certified Fair Trade. Further, the credibility of DT claims might increase when it is combined with a third-party certified CN label. Nevertheless, as consumers stated in the focus group discussions: *“coffee is a natural product, where is there a problem with greenhouse* *gas emissions"* there is a need to sensitize consumers on the impact of agri-food products to climate change and create public knowledge on carbon and offsetting concepts. This refers particularly to an increased understanding by the public on the problem of GHG emissions generated by agricultural products.

5.1.2 Limitations of the study and future research

This study uses an interdisciplinary and case study approach and looks at several aspects of voluntary sustainability standards from development of standards to changes in consumer behavior and a possible revision in the field of accounting for biogenic carbon. As novel as an interdisciplinary and holistic approach might be, it comes with limitations. This section will discuss the overall limitations of the study before eliciting specific limitations of Chapters 2 - 4 and finally outlines recommendations for future research.

A single case study approach provides a number of advantages; particularly it offers unique insights into underlying factors and dynamics that can hardly be observed in larger, representative studies (Yin, 2009). Nevertheless, its representativeness has limitations and generalizations can be made only with restrictions, as results might be context specific. In the case of carbon neutral coffee from Costa Rica, results might be country specific, sector specific, or certification specific. A discussion on the wider implications of the case study has to keep these context specific constellations in mind and indicate their relevance in other potential contexts. Still, to gain initial understandings and learn lessons from the pioneer case of carbon neutral coffee a case study approach is very suitable, since it provides the necessary insights to efficiently design future research on this topic. As a next step it is recommendable to compare the case of carbon neutral coffee with climate friendly products from other sectors, to investigate the influence of value chain structure (global vs. local, direct vs. intermediates) and to conduct research on country specific factors and the role of legal and institutional frameworks (also recommended in Chapter 2). Further, the certification for carbon neutrality as a tool to mitigate climate change in the agri-food sector could be evaluated in comparison to other available certification or mitigation mechanisms.

Interdisciplinary approaches in research are increasingly demanded and executed due to their advantages in approaching growingly complex issues and problems (Strang, 2009). Addressing the multi-faceted topic of voluntary sustainability certification, particularly in the case of carbon neutrality certification in the agri-food sector, with an interdisciplinary research approach is promising, as it can provide insights into the manifold aspects of certification, climate change mitigation and global value chain governance. An interdisciplinary approach offers the opportunity to integrate these aspects and obtain a wider or even holistic picture of carbon neutrality in the agri-food sector. Compared to most interdisciplinary studies, where several experts from different disciplines join together, this thesis is unique; it was carried out by a single person, who undertook the interdisciplinary research, backed up with expertise from the respective disciplines. This approach has advantages and disadvantages in contrast to common interdisciplinary research, which will be outlined in the following:

Common interdisciplinary research is costly and can face substantial challenges in coordination, communication and agreement procedures and might, therefore, also be more time-consuming (Aboelela et al., 2007; Foran et al., 2014; Strang, 2009). Although common interdisciplinary research usually works under a common research objective and framework, the results might be a compromise, which includes a bit of each perspective, rather than an overarching result with an integrated, holistic perspective. An interdisciplinary approach executed by a single one person has a stronger integrative character and it might be able to look into niche issues that fall between two different disciplines or to capture the various aspects of a dilemma or conflicting interests (Wagner et al., 2011). Despite these potential advantages of interdisciplinary research approaches, there is also the possibility that it misses some aspects or argumentations that would otherwise be pushed by the respective experts.

A limitation of the thesis is that an economic cost-benefit analysis of the carbon neutrality certification was not conducted, which, however, is a fundamental aspect for adoption and implementation (especially a limitation in Chapter 2). Despite this limitation, the thesis touches on profitability aspects across the conceptual framework. It, thereby, became obvious that a detailed cost-benefit analysis should not only consider mere economic aspects but additionally issues of reputation and comparative advantages compared to non-adopters as well as addressing future trends (see more explanation on these aspects in Section 5.1.3).

In Chapter 3, due to time and labor restrictions, the number of investigated farms is small and their representative nature is limited. A larger sample size would increase the explanatory value of the carbon accounting model. The carbon accounting model would further benefit from a larger sample size in soil measurements and the consideration of pH values. In general, the soil compound is rather underrepresented in the carbon inventory. Beside time restrictions, measurements on soil organic carbon are still under development and especially the long-term carbon storage in soil lacks scientific knowledge. As a next step, the carbon accounting model could be used to simulate certain field situations such as different methods of coffee renovation, logging of shade trees or different carbon footprints. Further, it would be of high interest to collect data on the farm specific carbon footprints in order to relate them to the farm specific carbon sequestration and to evaluate the overall farm performance. These data could also enable the analysis of a beneficial balance between carbon footprint, productivity and carbon sequestration.

In Chapter 4 this thesis investigated the WTP of German consumers of specialty coffee. This is a niche market; the consumer group is not very representative of the overall consumers in developed countries. Nevertheless, approaching educated and wealthier consumers of urban areas was expected to obtain results from a potential consumer group of a carbon neutral certification that is considered rather complex for understanding. Future studies are necessary to look at other consumer groups and other countries, since consumer behavior and WTP for sustainability labels is country and context specific (Grunert et al., 2014). It would also be important to include respondent's attitude towards climate change and sustainability (Kragt et al., 2016). Finally, consumer WTP for a carbon neutral label could be investigated in comparison with other labels and regarding combinations of labels (synergistic effects).

Although some of the samples are rather small (e.g. Chapter 3, the number of farms investigated), and a niche consumer group is addressed (e.g. Chapter 4, looking at consumers of specialty coffee), the findings of this study are relevant in a wider context and provide unique insights and lessons into the field of voluntary standards for climate change mitigation in the agri-food sector.

5.1.3 Potential of carbon neutrality certification for climate change mitigation in the agri-food sector

The objective of this thesis was to examine the potential and challenges of using certification to mitigate climate change by investigating the pioneer case of carbon neutral certified coffee in Costa Rica. The conceptual framework, which was introduced in the first Chapter, targets at providing guidance for an overarching analysis of voluntary sustainability certifications across disciplines and value chain boundaries. The conceptual framework aims particularly at identifying core challenges, bottlenecks and potential, which lead, through an overarching integration, to multi-facetted and comprehensive recommendations. The outcomes of the different Chapters will be analyzed and discussed using the conceptual framework presented in the introduction and indicated by the respective **[letters/no.]**. An integration of the ultimate outcomes will finally lead to overarching implications that the case under consideration has in a wider context. It will also enable the formulation of overarching policy recommendations.

The PAS 2060 for carbon neutrality is an example of a recently developed standard that addresses the aspect of climate change mitigation as a part of the discourse on sustainability. It has been applied for the first time on an agri-food product, namely coffee, in 2011 by the Costa Rican coffee cooperative Coopedota.

PAS 2060 for carbon neutrality is based on an LCA to measure the CF of a product, process or organization. Different standards are available and acknowledged to conduct the LCA and assess the CF; PAS 2050, GHG protocol, ISO 14046. The measurement of a CF is a relatively common tool and has been executed for a range of agri-food products. The resulting footprint can be indicated on the final product as climate information or label (Notarnicola et al., 2015). The difference in PAS 2060 is the annual carbon management plan that is required, which organizes and emphasizes emission reductions. Another particularity of PAS 2060 compared to a mere CF measurement is the step of offsetting to reach carbon neutrality by purchasing certified carbon credits from the international carbon market. In other words, a carbon neutral label compared to other climate labels (see e.g. Schaefer and Blanke, 2014) additionally requires emission reduction and carbon offsetting. This is beneficial to the consumer, since "carbon neutral" means that all associated emissions are reduced or compensated and, thus, there is no need to compare products regarding their carbon footprint. Such a comparison is challenging, since consumers face difficulties in benchmarking the information (Schaefer and Blanke, 2014) and in many cases it is anyway not comparable, as production might differ based on crop, country, resources, varieties and other factors. In contrast, communication can be more difficult; consumers need to be familiar with the concept of carbon neutrality, while most consumers are already familiar with the concept of carbon footprints. Further, it is more difficult to access information on emission reduction activities of a carbon neutral certified product, which, however, might be of interest to consumers. As offsetting is criticized, a carbon neutral label should be associated with a high degree of trust regarding substantial efforts in emission reduction, which is the case in PAS 2060. Compared to the climate module of SAN, the PAS 2060 is not composed of several guidelines and suggestions on a voluntary basis, but as a highly prescriptive specification, it rather provides actual numbers and requires detailed and strict procedures of monitoring, aiming at the highest possible credibility. These aspects are important to gain consumer's trust and to move towards approaches that stay relevant in the long run.

For the analysis and discussion of the outcomes of the thesis it is essential to keep these basic differences between common climate labels (displaying the CF or a reduction of the CF) and a carbon neutral label in accordance to PAS 2060 (including offsetting) in mind.

5.1.3.1 *Standard development*

In addition to an “increasing market demand for ‘climate relevant’ information along supply chains and towards consumers” (Finkbeiner, 2009, p. 92) **[A]**, global trends, policies and developments led to the launching of the PAS 2060 for carbon neutrality. These trends indicate the importance of carbon labels and climate related information on products today and in the future. The main aim of a standard is theoretically to close a gap in legal regulations left by weak states (Djelic and Sahlin-Andersson, 2006) and thus provide alternative governance options or a kind of “self- or social regulation” (Raynolds, 2012). This is particularly the case for a carbon neutral certification, since it is recent and little has been done in international policy to govern climate change mitigation in the agricultural sector (Wollenberg et al., 2013). Sustainability standards **[B]** are usually multidimensional and complex due to a participatory development process (Potts et al., 2014). They can be applied on a high number of different products, processes or organizations. These diverse application possibilities can, however, result in trade-offs (Mithöfer et al., 2017). As it was the first application of PAS 2060 on an agri-food product, new challenges in the implementation, especially high quality farm data provision, were encountered and questions were raised regarding the accounting for biogenic carbon, which was different from the use of PAS 2060 in e.g. an industry setting. Technical support by BSI in combination with external expertise was fundamental to enable the implementation of PAS 2060 in coffee. These findings can be explained by considering the context in which the specification was developed: no experts from the agri-food sector involved (BSI, 2014), target groups are rather industry and carbon trading companies, western perspective as it was developed in the UK (see also Manning et al., 2012; Vellema and Van Wijk, 2015). It can be concluded that PAS 2060 lacks an agri-food perspective and might require revisions. A revision could be e.g. the integration of on-farm carbon accounting into the standard, the consideration of the different structures of global agri-food value chains (Mithöfer et al., 2017), addressing the specific needs of development countries (Henson and Humphrey, 2010), the integration of a smallholder’s perspective or the tackle of sector/commodity specific challenges. A revision should further include clear guidelines on how to communicate a carbon neutral label to agri-food consumers, so that a carbon neutrality certification can be used as a marketing tool (Manning et al., 2012), which generates permium prices. Especially since premium prices might not be a necessity in an industry setting. These findings suggest that it is advisable to consider the context in which a standard was developed in order to evaluate its quality, under which circumstances its application is beneficial, and whether adjustments or revisions would be necessary.

Considering a revision **[b]** of the standard and including an agri-food perspective could e.g. contain the following issues: how to deal with biogenic carbon, natural disasters, and pests in carbon balancing? Where are the system boundaries? Can biogenic carbon in living fences be considered? Another solution to the missing agricultural perspective could be, to combine the standard with other sustainability standards from the agricultural sector, e.g. with the Rainforest Alliance certification, as successfully executed by the coffee cooperative Coopedota. (see recommendation 1b in Section 5.2)

Looking at a potential revision of the carbon neutrality standard, accounting for biogenic carbon sequestration inside the farms would fulfill the requirement to take up consumer concerns and their intrinsic associations with a carbon label, and it would further integrate the agri-food perspective into the standard (see recommendation 1a in Section 5.2). As there was a high potential to compensate the CF by biogenic carbon sequestration, there is a need for the LCA society to further develop their rules on how to account for biogenic carbon storages, as it is not yet compatible with the LCA principles of high precision. Apart from that, internationally traded carbon credits often result from tree plantations where the same process of carbon sequestration is acknowledged. This discrepancy should be addressed and the acknowledgement of carbon sequestration should be handled comparably, especially to avoid further mistrust and criticism by the public.

5.1.3.2 The role of pioneers in development

This study confirmed in Chapter 2 that international trends and policies are not only driving the emergence and development of new voluntary sustainability standards but are also a factor for a successful pioneer **[C]** and the implementation of the new standard. A wide range of literature has been dedicated to understand the role of pioneers for development. It has been recognized that pioneers are important as a thriving factor to progress on the ground, to prove practicability of new technologies, systems, and standards but also to provide lessons learned (Grabs et al., 2016; Lundvall, 2007). The case of Coopedota in Costa Rica is seen proof that carbon neutral coffee production is possible. Furthermore, such a pioneer project can foster a new and particular identity of the executing actor or organization, which might in turn motivate sustainable and long-term involvement in this subject. Coopedota has gained a wide and diverse social network through its pioneering activity, which can be of value in the future. In order to promote the multiple benefits of pioneer work to sustainable development and the society, it is essential to provide knowledge and experience on success factors in green innovation. In Chapter 2 the importance of governmental or ministry support to pioneers became apparent, since it enabled lobbying and endorsement higher up in the hierarchy. Another success factor was the interplay of local developments and regulations with the standard that provided a "fertile ground" for the implementation of a carbon neutral certification. These conditions might be less favorable in many developing countries, where green loans are not available and environmental regulations are less strict. Consequently, the potential of a carbon neutral certification to be successfully implemented also depends on the local legal framework and governmental support programs (see recommendation 2 in Section 5.2). Another substantial success factor laid in the prior achievements of the cooperative namely the experiences and data available from the ISO 14001 certification for environmental management of an organization. Such prior achievements are crucial considerations and might provide the first step towards a carbon neutral certification, particularly for organizational units such as the administrative body of a processing facility.

5.1.3.3 Producer perspective

At the producer, manufacturer side **[D]**, concerns and awareness on the contribution of agriculture, and their up- and downstream value chain, to climate change has risen. Some of this concern might be consumer driven; other concern is influenced by national policies and trends, as well as producers' own worries, as was the case in Costa Rica. Producers are motivated to adopt sustainability standards because it offers alternative marketing channels, potential premium prices and might strengthen their competitiveness (Blackman and Rivera, 2011). The case of Coopedota shows that new sustainability standards do not entail these benefits without a consumer group that is aware of the new standard and willing to pay higher prices for accordingly labeled products. However, the case of Coopedota also shows that increased efficiency and a competitive advantage compared to non-certified actors, following the demand for sustainable products, are of equal importance. The pressure on competitiveness might also come from the private sector as leading companies, e.g. Nespresso and Starbucks have developed their in-house standards[11] for sustainable and high quality coffee. Whether it is advisable for small-scale producers to take up the challenge with leading companies in the coffee business by adopting sustainability standards can be questioned, because standards are generally addressing producers that have a high supply capacity (Mithöfer et al., 2017). In doing

[11] AAA Sustainable Quality™ Program: "Nespresso's vision is to further reduce the company's carbon footprint by 10%. In addition, we seek to strengthen coffee farm resilience to climate change and help reverse the degradation of natural ecosystems through an extensive agroforestry program in the AAA regions. We aim to become 100% carbon efficient in our operations by compensating our residual operational carbon footprint through the same agroforestry program. This mechanism consists in planting trees within the Nespresso value chain so that the benefits delivered by the trees on top of carbon sequestration (for instance, soil regeneration, water availability…) can create shared value for the farmers and Nespresso value chain partners." (Nespresso, 2017)

so, most standards might miss the small-scale perspective and needs. Nevertheless, the trend moves towards carbon efficient production practices and organizations.

The challenges for small and medium-scale producers lie particularly in their limitations with regard to investment capital and social capital to foster the implementation **[1]** of a sustainability standard (Potts et al., 2014; Rahn et al., 2014; Smith et al., 2007). In the case of carbon neutral coffee, reducing GHG emissions can be achieved through changes in production practices, the introduction of new technologies or a restructuring of the organization. These changes can be costly, but bare the potential to increase efficiency and save expenses, such as the new ovens at Coopedota, and the CN working group to manage the certification. However, especially new or energy saving technologies require investments and loans, which might not be available. Another challenge for the certification was the annual collection of reliable farm data e.g. on agricultural inputs and transportation used, particularly because emissions at the farm level are likely to be hot spots along the value chain. The availability and reliability of farm data has been recognized as a major obstacle in agri-food certification (Bessou et al., 2013) and is expected to be even more challenging in developing countries with lower literacy rates. Costa Rica, with a long tradition in social democracy, is rather an exception in this regard, as it has one of the highest literacy rates (97.8 %[12]) among developing countries (83.3%). The combination of different sustainability certifications, with similar data requirements, has proved to be a solution in the case of Coopedota (PAS 2060 and Rainforest Alliance). Further, support and training on bookkeeping could help improving the data quality and availability. (see recommendations 2, 3a, 3b in Section 5.2)

5.1.3.4 Sustainability implications

Sustainability certifications are typically looked at regarding their effectiveness and impact **[2]**. Environmental improvements in the case of carbon neutrality are related to a reduction of a product's or an organization's impact on climate change. On the one hand, actual reductions in the carbon footprint are achieved and on the other hand carbon offsetting is used. The study found that reducing the CF motivates resource use efficiency (RUE) since e.g. the CF of coffee is smaller when a high productivity is reached with little inputs. However, it can be challenging to produce at high RUE due to increased risks and limited knowledge or technologies. Farmer training, soil analyses and extension services can help to increase RUE in production. Furthermore, research on new technologies, efficient and adapted varieties and climate friendly

[12] Literacy rates of adults ages 15 and older, data are taken from the last available sources between the years 2005 and 2015 (UNDP, 2016).

production techniques e.g. the use of slow-release nitrogen fertilizer, can support farmers in decreasing the carbon footprints at farm level. Nevertheless, the incentives to produce at the most efficient level might not be as strong as in the case of new regulations and abolishment of inefficient technologies, which relates back to the important role of the interplay between local regulations and the standard applied. Over time, another critical aspect is the increase of marginal costs for emission reductions, which might bias the implementation of a carbon neutrality standard by actors that are richer or that have relatively high emission levels and thus larger potential for long-term annual reductions. Although PAS 2060 is dedicated solely to mitigating climate change, respondents of this thesis seemed to associate a carbon neutral product with a contribution to overall sustainability. Different possibilities exist to take up these consumer perspectives. Combining the carbon neutrality certification with other sustainability standards, e.g. in the case of coffee the Rainforest Alliance certification, could include other environmental aspects of management practices and the social dimension of agricultural production. (see recommendations 1b, 3b, 4a in Section 5.2)

An option to increase the sustainability effect of PAS 2060 is the accounting for carbon sequestration at the farms **[second loop]**. From the environmental and agricultural perspective, accounting for on-farm carbon sequestration could incentivize tree integration and in doing so support sustainable and resilient production systems that would also address synergies of climate mitigation and adaptation (Kumar and Nair, 2011). As investigated in Chapter 3, coffee agroforestry systems in Central America have a high potential to fully compensate coffee's carbon footprint and could thus avoid purchasing carbon credits for offsetting. From an economic point of view on the one hand, this would save expenses, although it is not substantial, as long as prices for carbon credits remain low. On the other hand, additional costs arise due to required carbon inventories and monitoring. Moreover, a potential trade-off between tree diversity and density and coffee productivity exists (see Chapter 3), which needs to be managed at the optimum. To integrate biogenic carbon accounting into an LCA-based standard such as the PAS 2060, the scientific community is required to provide the necessary methodologies and databases that meet common LCA principles. Research is also needed to improve and speed up carbon inventories and monitoring techniques and to provide information and recommendations regarding optimal balances between productivity, quantities of agricultural inputs and carbon sequestration. (see recommendation 1.1, 4b, 4c in Section 5.2)

5.1.3.5 Retailer perspective

The role of retailers **[E]** in certification is rather indistinct. In the studied case, the retailers were not taking part in the certification since for the export coffee a cradle-to-gate approach (from the farm to the port in Costa Rica) was used as the system boundary. However, this already indicates the importance of communication between actors along the value chain, in order to label the final product and sell it at a premium price. In many cases, it is the roaster or retailer (major buyers) that demands certified coffee and urges the producers to adopt a certain standard (Giuliani et al., 2017). PAS 2060 regulates the issue of certification by the obligation that “the quantified carbon footprint shall cover at least 95% of the emissions from the subject” (BSI, 2014, p. 23). In doing so, the use of a carbon neutral label is, however, not clearly limited to a cradle-to-grave system boundary, or at least requiring the inclusion of all emissions before the stage of consumption in order to sell the product at a premium price. Nevertheless, in the case of coffee, the stages of roasting, packaging and retail should be included in the carbon footprint offset, before labeling the commodity as carbon neutral. In this case consumers can show responsibility through their purchasing decision (Kogg and Mont, 2012) and shared value is created. In other cases, retailers might have a separate or independent approaches to make their business, or part of it carbon neutral. For example, the family-run roastery Hochland certified its aluminum packages as carbon neutral through myclimate. Such efforts and achievements should be acknowledged and integration into the overall certification should be possible. (see recommendations 5 in Section 5.2)

5.1.3.6 Consumer perspective

Despite a growing consumer demand **[3, A]** for low-carbon agri-food products, specific market niches for carbon neutral products do not yet exist and premium prices as such are not obtained. One reason is that carbon neutral labels are fairly new. Another reason is the complexity of the topic and the unfamiliarity of consumers with the label and its underlying concepts (Sirieix et al., 2013). Therefore, communication of such labels or certifications is still very difficult, and the public needs to be informed and educated about climate labeling. Overall it is important to include the responsibility of the consumer as an actor to change the system through informed purchasing decisions. Especially standards and certifications indicate the responsibilities of consumer countries in GHG emission reductions and enable consumer choices (Bastianoni et al., 2004; Munksgaard and Pedersen, 2001). In global trade consumers are usually located in developed countries and producers in developing countries, which makes a consumer responsibility perspective very relevant. By their purchasing decisions, consumers should in fact prefer producers that engage in climate change mitigation, rather than expecting them to be self-motivated to reduce emissions (Bastianoni et al., 2004); however, incentives and options are limited. Furthermore, this thesis and other CF analysis of coffee show that, depending on the type of coffee preparation, the consumption step itself can represent the emission hot spot along the complete value chain (Kilian et al., 2013). Nevertheless, the share of information on emissions included from consumption and disposal of a carbon neutral label is limited and induces little motivation for consumers to reduce these emissions. However, high quality/transparency of certifications and trust in a label is essential to support consumer choices. Consumer utility can increase, particularly when consumers can lower their personal carbon footprint (in case of cradle-to-grave) and support companies who take over responsibility to mitigate climate change. Notwithstanding a growing demand for climate friendly products, also in the agri-food sector, the awareness of the contribution of this sector to climate change is not well understood. A consumer response from Chapter 4 describes the underlying misconception: *"coffee is a natural product; how can it cause GHG emissions?"* In contrast to cars, industry, and airplanes, it remains unknown how agriculture contributes to climate change. That means, if consumers do not see a problem with agri-food products in relation to climate change, their willingness to purchase carbon neutral products might be limited since it will not provide the feeling that their choice makes a difference! Even consumers with an increased awareness on that problem assume that it is relatively easy to certify coffee as carbon neutral since they anticipate that carbon sequestration in the farms is being accounted for. (see recommendation 1b, 5 in Section 5.2)

5.2 Recommendations and conclusion

From the general discussion of the thesis results, several recommendations can be drawn that address one or more elements of the conceptual framework. In this final section, the main recommendations will be listed and elaborated on.

Recommendations might depend on growing systems and the types of consumers being addressed. For private smallholders (family businesses) the situation is typically very different than for smallholders organized in a cooperative, and again different than for large-scale growers and private companies. Policy recommendations made in this section are mainly derived from the case of small-scale coffee producers organized in cooperatives and family roasters in Europe.

1. Future development of PAS 2060 for carbon neutrality

a. Revision of the standard e.g. by accounting for biogenic carbon sequestration

To open up PAS 2060 to a wider field of application outside of the industry and carbon-trading sector, an agri-food perspective should be integrated. A revision of the standard could include the accounting for on-farm biogenic carbon. In Chapter 3 the high potential of coffee agroforestry systems to offset the coffee carbon footprint pointed out and indicated the beneficial effects of incentivizing carbon sequestration in the farms such as increased sustainability and improved adaptation to climate change. Further accounting for biogenic carbon would take up consumer concerns and their intrinsic associations regarding a carbon neutral label and offsetting practices, and it would further integrate the agri-food perspective into the standard. In case international carbon prices would rise, accounting for biogenic carbon could provide economic benefits to the farmers and offer independence from international carbon markets. Accounting for biogenic carbon sequestration would, however, require the LCA community to agree on a methodology that is compatible with the LCA principles of precision. Further, particular advice on how to communicate the label as it is e.g. provided in by SAN for their staff and businesses using the climate module (SAN, 2011), could harmonize and facilitate communication and enable consumers to become familiar with carbon neutral concepts.

b. Combination with other standards

Facilitating the combination of PAS 2060 with other standards could provide a set of solutions for existing challenges. A combination of several standards that use similar datasets could improve the cost-benefit ratio for producers and/or retailers and especially ease the provision of high quality farm data, as shown in Chapter 2. The acknowledgement of prior achievements (e.g. ISO 14001) or existing certifications of different stages along the value chain (e.g. certification of roasters or manufacturing facilities) would make PAS 2060 more attractive and applicable in the agri-food sector. Further, a combination with existing standards that focus more on social or environmental aspects of production could provide achievements in overall sustainability, as it is demanded and associated by consumers. Depending on the combination of certifications or standards chosen, multiple labels might increase the WTP of consumers (see synergistic effects in Chapter 4). Finally, a combination of labels could present a win-win for both labels affected.

2. Governmental support

This thesis highlighted the importance of the interplay between a standard and local or national regulations. In many countries or regions, governments can support the adoption of voluntary sustainability standards by implementing strict environmental regulations that address similar issues. In addition to stricter environmental regulations, it might be necessary to launch support programs for cleaner or more efficient technologies and energies, and to provide loans to smallholders to enable them to invest in clean and efficient technologies.

3. Capacity building and extension service

a. Bookkeeping

In most developing countries, where the primary production of agri-food products takes place, farmers are illiterate or not very educated and might thus be unfamiliar with keeping records of their farming activities, e.g. on quantities and dates of fertilizer applications. Specific training or monitoring systems (e.g. taking pictures, or using QR-codes tracking systems) would help improve the availability of farm management data, which is basic and essential to voluntary sustainability certifications such as carbon neutrality certifications. The training or monitoring systems can be provided by cooperatives, public extension services, or as a service of the standard developer or certifier. In other cases, it could also be provided by retailers as it is being done by Nespresso (Nespresso, 2017).

b. Increasing efficiency

Further trainings, services and advice could be tailored to reduce the carbon footprint of the agri-food product. Challenges and potential to increase efficiency can differ between products, which makes sector specific consultancy more targeted. Independent advice e.g. on efficient fertilization and farm management, in cooperation with governmental support programs (e.g. for soil analysis free of charge) and with research institutions (e.g. to provide recent knowledge on appropriate technologies) is necessary to reduce the carbon footprint at the farm level.

4. Contributions that could be made by the scientific community

a. Climate friendly production techniques

A considerable amount of research has been conducted on climate friendly production techniques in which agroforestry systems play a central role (Kumar and Nair, 2011; Rahn et al., 2014; van Rikxoort et al., 2014). However, there is continuous need to provide production technologies to farmers that reduce GHG emissions at the farm level, such as climate friendly but efficient fertilizers (e.g. slow release nitrogen fertilizer) or liming practices.

b. Carbon inventory and monitoring

Carbon inventories and monitoring are both time-consuming and costly, and databases to speed up the process of carbon inventories are still insufficient, as shown in Chapter 3. Research could considerably contribute to facilitate carbon accounting on-farm by providing LCA practitioners with tree specific (or for tree functional groups) and geo-referenced data on carbon increments and growth rates, as well as wood density and carbon in roots (De Rosa et al., 2017; Nair et al., 2009). Further, satellite images and remote sensing technologies could be further developed to enable their use in monitoring carbon dynamics on farms.

c. Trade-off between productivity and carbon sequestration

If on-farm carbon sequestration would be accounted for in a carbon neutrality certification, research could substantially contribute to improve farm performance in terms of mitigating climate change while being profitable, by investigating the optimal balance between productivity, agro-chemical inputs and carbon sequestration on the farms. Such a model could potentially be used for consultancy purposes with farmers, but it could also provide information on increasing food-security by using fruit trees on the farms, or to increase biodiversity.

Generally, it can be questioned if standards, looking at measurable carbon sequestration rates are the way forward, as agricultural production systems will reach a new equilibrium (saturation) and thus a limit in carbon sequestration (Noponen et al., 2013; Smith et al., 2014). To successfully proceed in climate change mitigation, not only carbon removal from the atmosphere and thus carbon sequestration is important, but also carbon stock maintenance is required. Carbon stock maintenance would also be generally beneficial for agricultural production systems, since producing at high carbon levels in soils and above ground should foster productivity and sustainability. Thus, programs designed for climate change mitigation should encourage high yields at high carbon levels and should offer benefits that are also accessible to small-scale farmers.

5. Communication and public awareness

Despite rising consumer demand for climate friendly products and carbon labels on agri-food commodities (Van Loo et al., 2015) major challenges prevail. Due to its complexity and its recent appearance, the public is unfamiliar with the concept of carbon neutrality. A diverse set of standards and approaches towards climate friendly products and the related differences in communication contribute to confusion on the consumer side. Additionally, consumers are unaware and unclear about the contribution of agricultural practices to climate change. A public dialogue on carbon concepts and carbon neutrality needs to be enhanced and awareness on emissions from the agri-food sector should be increased. PAS 2060 has the potential to facilitate this knowledge creation, by using its prescriptiveness and trustworthiness to educate the public on GHG emissions. A clear and standardized communication strategy could, thereby, clear up the confusion. As a harmonized standard, PAS 2060 can take the lead and set common rules for standards and communication, and familiarize the public with carbon neutrality. For this purpose, digital tools can be used to support the knowledge creation among consumers, e.g. apps that provide information for various labels or providing QR-codes to inform consumers transparently.

In conclusion the thesis illustrates the various potential of a carbon neutral certification. As a marketing tool or economic instrument it is promising however various challenges have to be addressed, such as the missing agri-food perspective, the problems related to the accounting for biogenic carbon, the acquisition of reliable farm data and the missing awareness of consumers on the contribution of the agricultural sector to climate change. Overall, the thesis shows the necessity of approaching complex issues with interdisciplinary and holistic approaches to evaluate for whom, under which circumstances and in which frameworks new approaches or standards work and what potential challenges arise. In this regard, the conceptual framework has proved as a valid and supporting guidance in the overarching analysis. The thesis further indicates how important pioneers are for development and how much can be learned from practical examples. Only by taking the lead and putting concepts into practice, mistakes can be made, lessons learned and improvements achieved. Taking actions on climate change mitigation and shaping a more sustainable agri-food sector requires strong initiatives and visionaries on the ground, such as the pioneer case of Coopedota.

5.3 References

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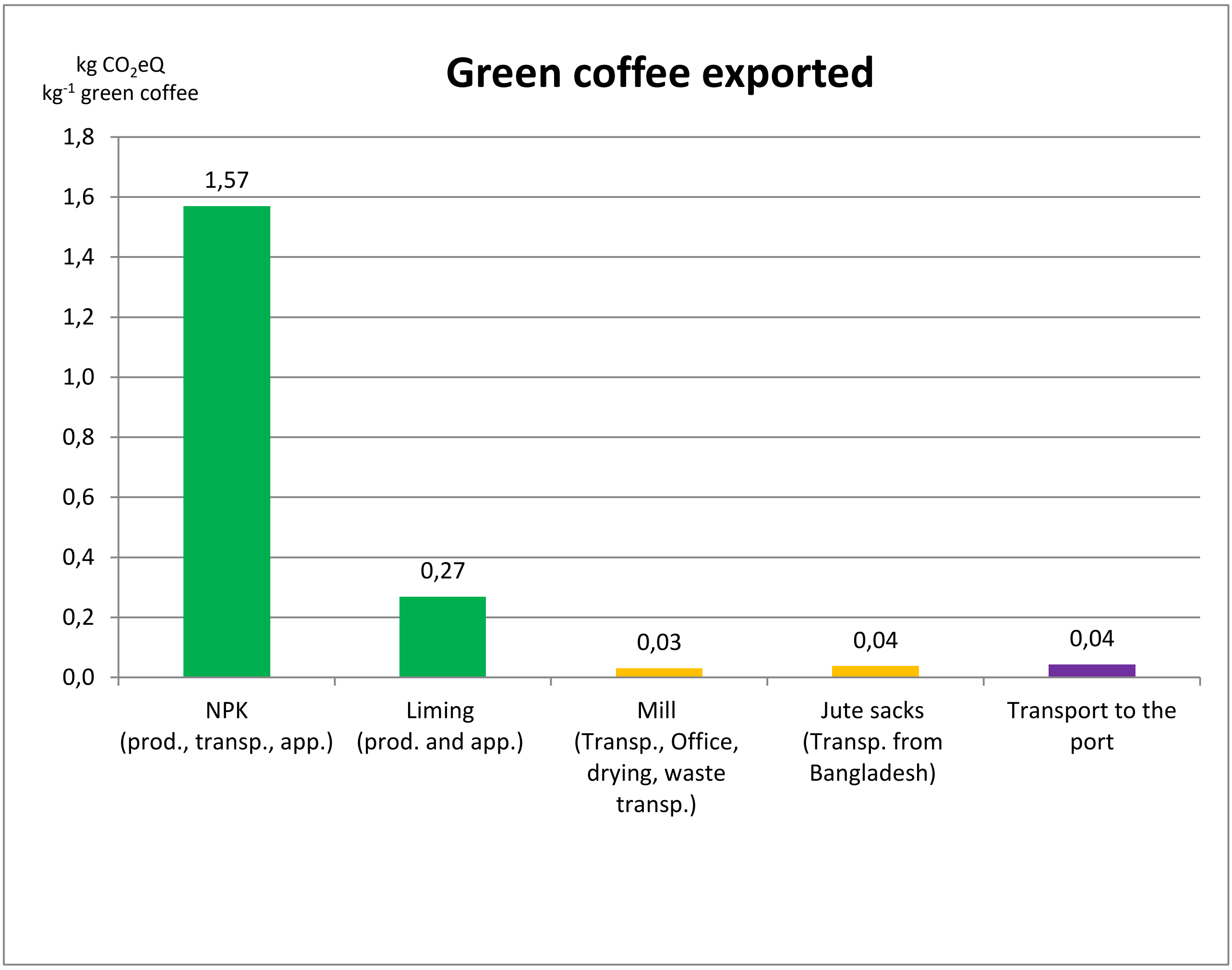
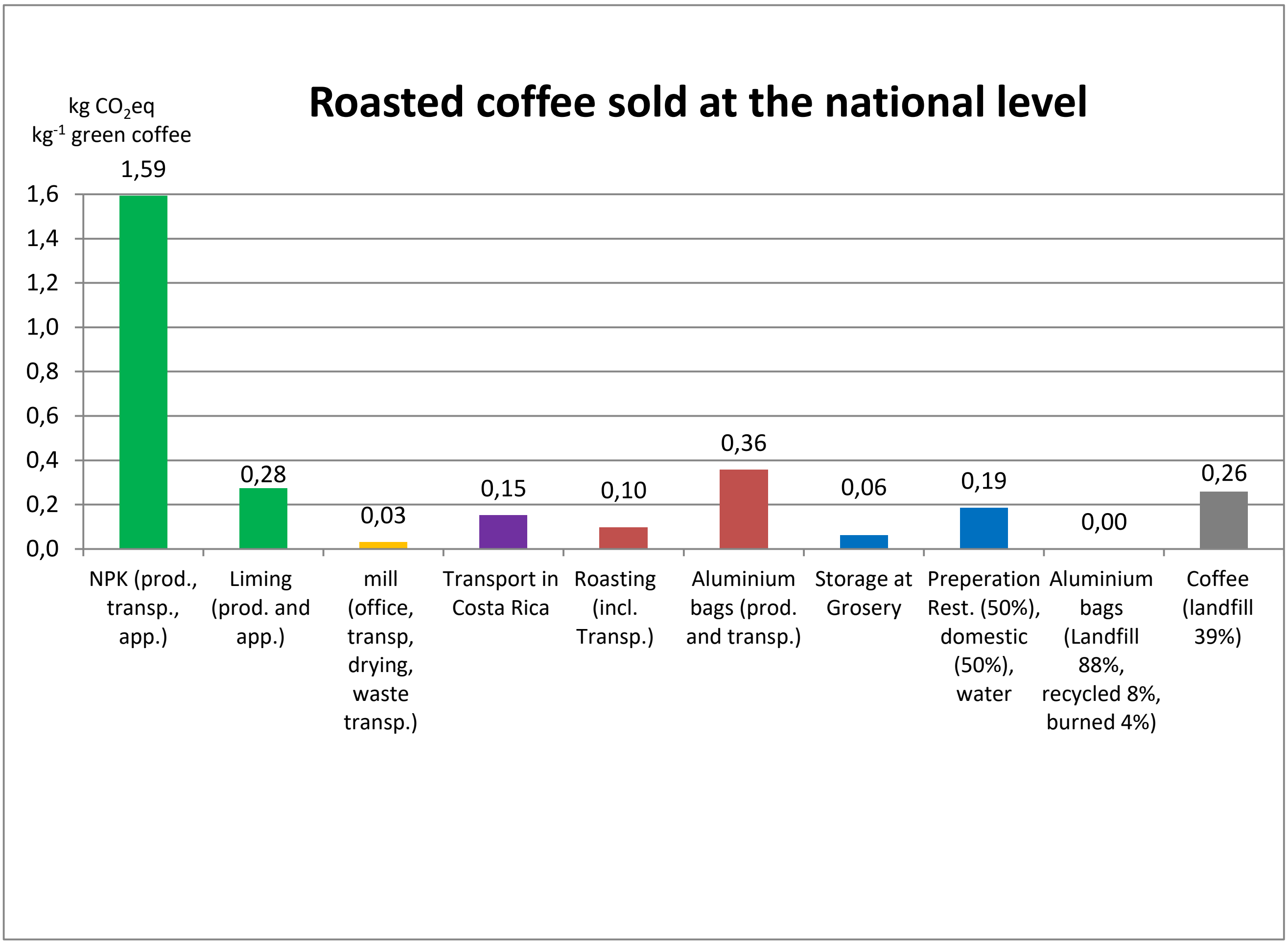
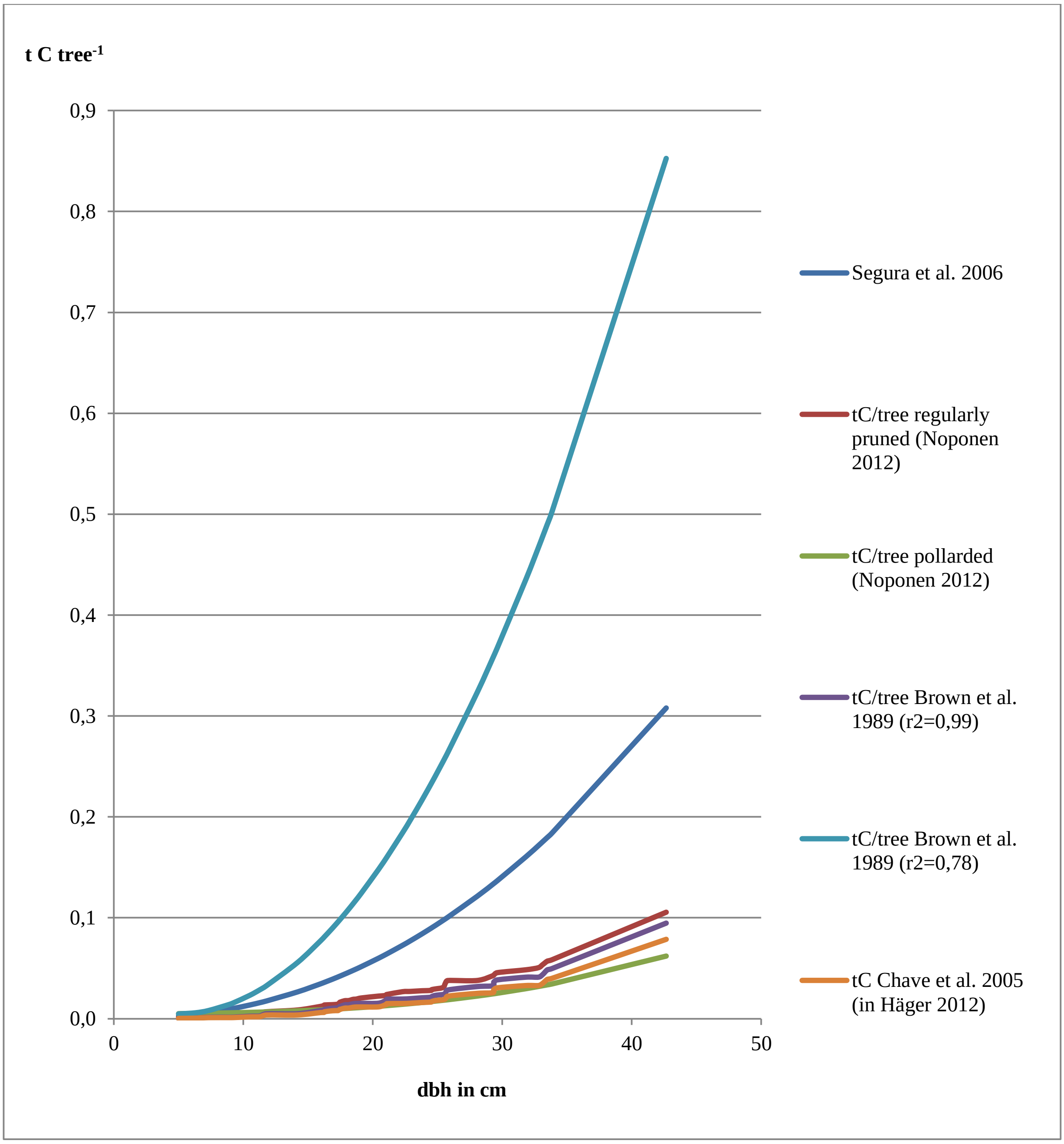
6 Appendices



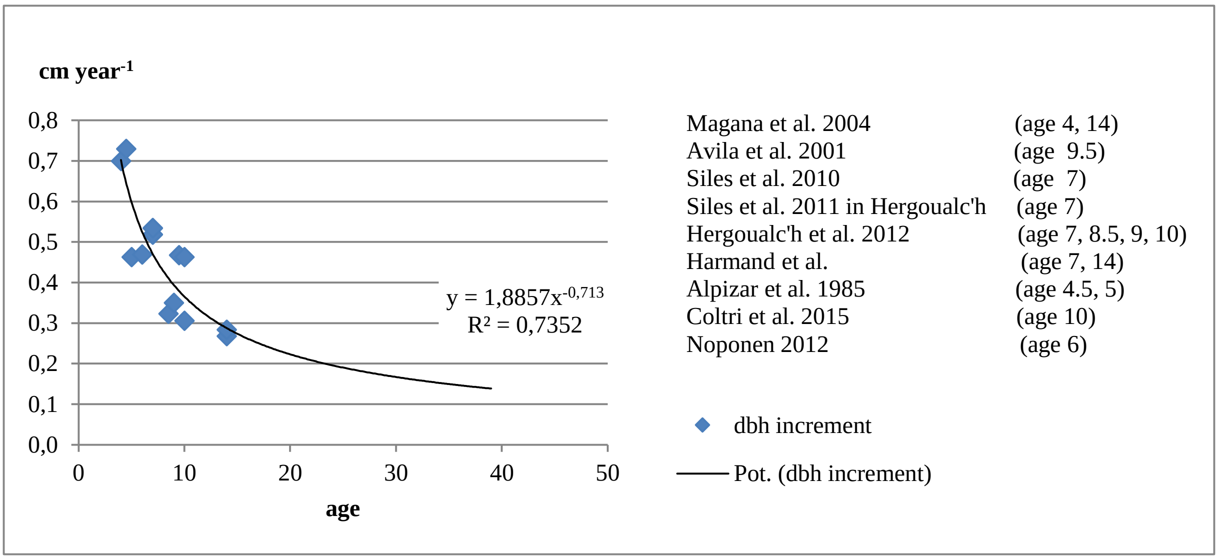
Appendix 1: GHG emissions included in Coopedota's certification of green coffee for export.



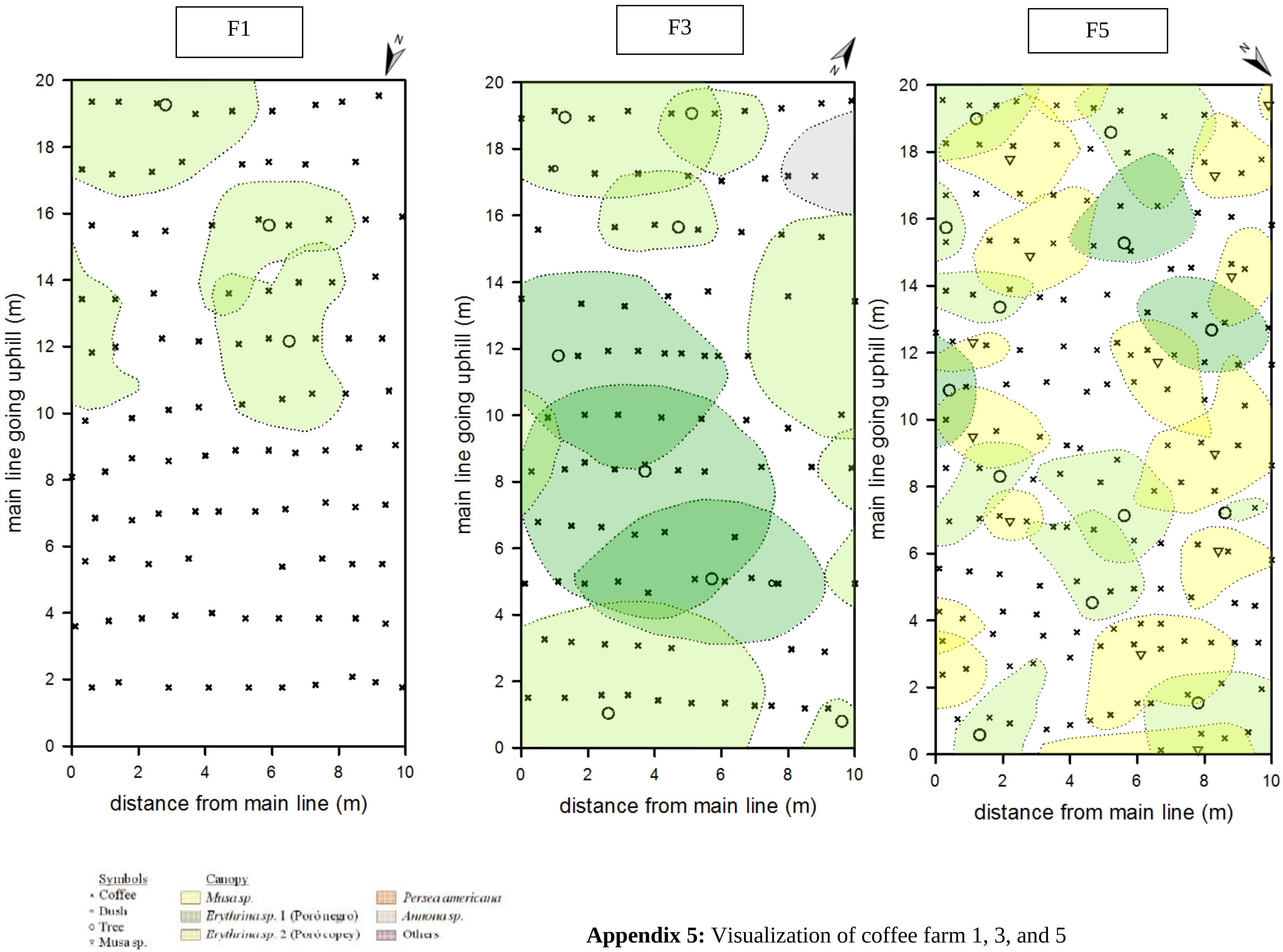
Appendix 2: GHG emissions included in Coopedota's certification of domestically sold coffee



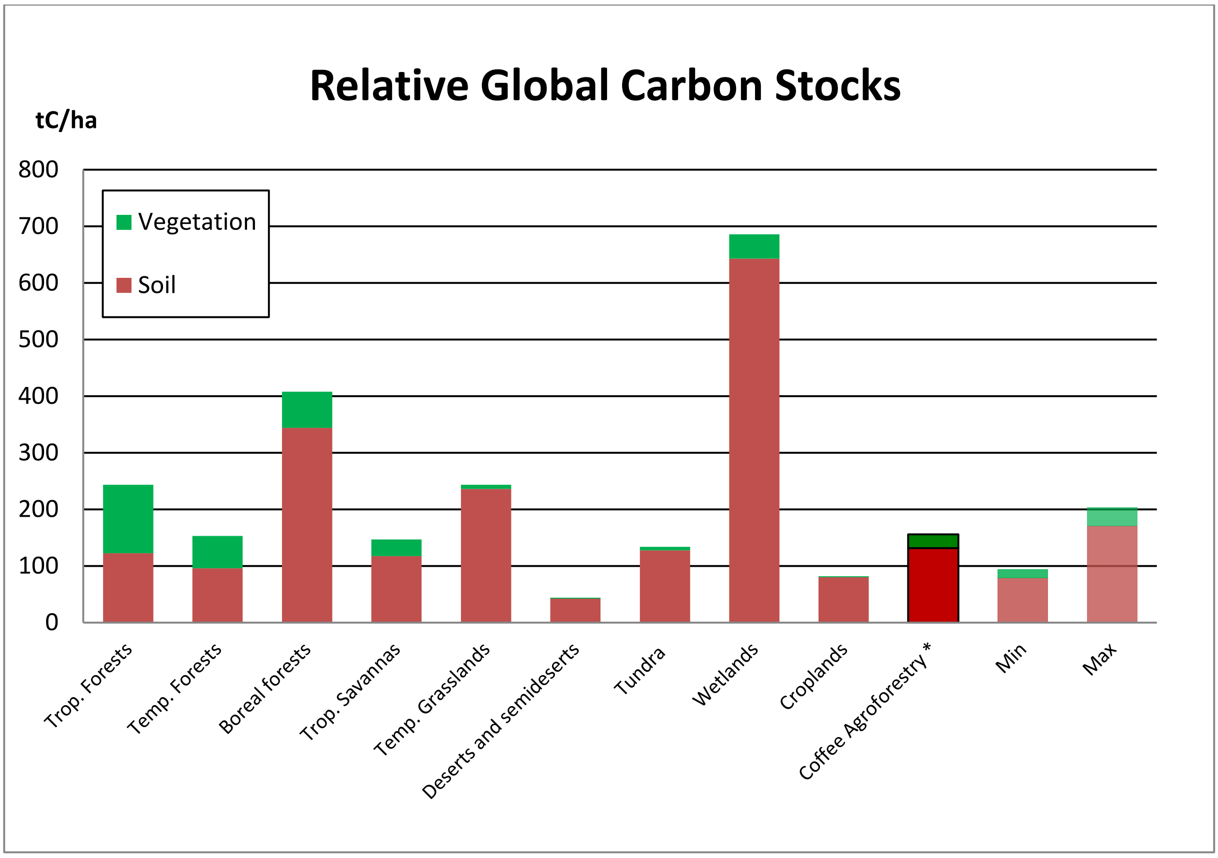
Appendix 3: Comparison of available allometric equations for *Erythrina poeppigiana*



Appendix 4: Increments of diameter at breast height in coffee (in *Erythrina-Coffee* systems. Regression obtained from literature data.



Appendix 5: Visualization of coffee farm 1, 3, and 5



Source: Watson, 2000; * Measured carbon stocks in Costa Rica, including min-max values

Appendix 6: Carbon stock of global biomes compared to carbon stocks in CAFS

Appendix 7: Information on product attributes

Assumptions:

- Every option on the choice card represents a 250g package of “Specialty Coffee” with 100 % Arabica beans
- There is no flavor difference between the two coffee options

Carbon Neutrality

Picture: http://www.co2logic.com	Not only in industry, but also in agricultural food production, greenhouse gas (GHG) emissions are set free, which are responsible for climate change. In Costa Rica, e.g. coffee production contributes to 9 % of the total national GHG emissions.[13]. Most of them develop due to (i) the high-energy input related to coffee consumption (45 %) (ii) in coffee production because of the Nitrogen, which is used as fertilizer (20 %) (iii) in coffee manufacturing, as this leads to the pollution of the water (8%). Compared to locally produced products, there is an additional output of GHG emissions due to export/transport.[14] Carbon neutral in the following context means that GHG produced in one place are compensated for in another place, so in total no GHG are emitted into the atmosphere. Thus, a carbon neutral product does not contribute to global warming. This is possible due to improved techniques on the one hand and offsetting on the other hand. Offsetting means that emissions, which could not be reduced, are balanced by compensation payments (Carbon Certificates), e.g. by investing in projects promoting climate protection in developing countries. In the context of the experiment, Carbon Neutral means that the product is certified in compliance with the international and independent standard PAS 2060.

Independent Fair Trade Label

[13] National inventory 2010 (Nieters et al., 2015)
[14] Appendix 1 and 2

Picture: http://www.fairtrade.net/	Cooperatives and farmers are certified by an independent third-party organization. Criteria for certification are amongst others: • Prohibition of child labor / forced labor • Assured and fair minimum prices • Social premium for joint projects (e.g. for health care, education) • Direct trade without intermediaries • Pre-financing of the harvest and long trading relationships • Ecological standards, e.g. prohibition of Genetically Modified Seeds and hazardous pesticides / enhancement of organic agriculture by granting a premium[15].

Direct Trade Relations

	There are direct trade relations between roaster and producer without intermediary. Similarly, to the independent Fair Trade label, pre-financing of the harvest is possible. There exist direct trade relations between Hochland Kaffee Hunzelmann GmbH and Coopedota. This ensures high quality as well as fair working conditions and a fair price. Direct trade relations are communicated by the company itself and not by an independent organization.

15 http://www.fairtrade.de/cms/media/pdf/FAIRTRADE-Zertifizierungssystem_im_Detail.pdf https://www.fairtrade-deutschland.de/was-ist-fairtrade/fairtrade-standards.html

Appendix 8: Market prices of Arabica coffee in Germany 2017

Source	Name of coffee	Price € kg^{-1}	Price € $250g^{-1}$	Arabica beans %	Labels
Kaffoo	Kaffee Fleck average	28.00	7.00	100	None
Kaffeeroesterei Rudolph	average coffees from Central America	25.00	6.25	100	some FT & organic
Mokuska	average	34.00	8.50	100	some DT & organic
Maya Kaffeeroesterei	Maya Kachalu	23.96	5.99	100	FT and organic
Mount Hagen	Mount Hagen	21.16	5.29	100	FT and organic
Lebensbaum	Lebensbaum Mexico	25.96	6.49	100	FT and organic
Darboven	Sansibar	23.96	5.99	100	FT
Hochland Kaffee Hunzelmann	Biodoro	28.80	7.20	100	DT & organic

FT = Fair Trade certificate, DT = direct trade claims