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The Potential of Mesoamerican Coffee Production Systems to Mitigate Climate Change

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The research presented here is conducted by Henk van Rikxoort under the coordination of Dr. Peter Läderach and Jos van Hal as a project commissioned by the International Center for Tropical Agriculture (CIAT) part of the Consultative Group on International Agricultural Research (CGIAR).

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The Potential of Mesoamerican Coffee Production Systems to Mitigate Climate Change

Abstract

A carbon footprint is used to define the amount of greenhouse gas (GHG) emissions emitted along supply chains and is the first step towards reducing GHG emissions. Carbon footprint standards have emerged as new market requirements for producers of agri-food products to retailers in developed countries and are likely to become a comparative advantage. In the coffee sector specifically little literature and data on the carbon footprints of different coffee production systems and supply chains exists. Furthermore various actors in the voluntary standard community such as the ISEAL Alliance and the TSPN Network call for a verification of the impact of voluntary standards on climate change mitigation. Therefore GHG data from different coffee production systems and voluntary standards has been compiled and compared regarding on-farm carbon stocks and the carbon footprint.

To quantify the on-farm carbon stocks and carbon footprints a GHG quantification model; the Cool Farm Tool (Hillier et al., 2011) has been used. The Cool Farm Tool uses the Tier II methodology of the Intergovernmental Panel on Climate Change (IPCC, 2006) and is based on empirical GHG quantification models built from hundreds of peer-reviewed studies. Field data has been collected in four countries across Mesoamerica from the coffee production systems that are distinguished by Moguel and Toledo (1999): (1) traditional polycultures, (2) commercial polycultures, (3) shaded monocultures, and (4) unshaded monocultures. The researched production systems also include organic, Rainforest Alliance and UTZ certified farms.

The results show low mean carbon footprints of coffee produced in traditional polycultures (5,4 kg CO_2-e/kg^{-1}) and commercial polycultures (4,9 kg CO_2-e/kg^{-1}) versus high mean carbon footprints at shaded monocultures (7,8 kg CO_2-e/kg^{-1}) and unshaded monocultures (8 kg CO_2-e/kg^{-1}). The same trend is observed concerning on-farm carbon stocks; polycultures (81,2 t CO_2-e/ha^{-1}) versus monocultures (27 t CO_2-e/ha^{-1}). The analysis further demonstrates a lower carbon footprint at organic, Rainforest Alliance and UTZ certified farms although this effect is largely counteracted by lower yields. Based on the results a framework for site-specific mitigation has been developed to assist coffee farmers in defining climate friendly farm practices and accelerate climate change mitigation in Mesoamerican coffee production.

Keywords: Carbon footprint, climate change, *Coffea arabica*, Coffee eco-system conservation, Cool Farm Tool, Mesoamerica, Site-specific mitigation, Voluntary standards

El Potencial del Sistemas de Producción de Café Mesoamericanos para Mitigar Cambio Climático

Resumen

Una huella de carbono esta utilizada para definir la cantidad de los gases de efecto invernadero (GEI) emitido por delante cadenas de suministros y es el primero paso para reducir emisiones de GEI. Las estandarizaciones de la huella de carbono han aparecido como necesidades nuevas del mercado para productores de productos alimenticios a revendedores en países desarrollados y se convertirá en una ventaja comparativa de mercadeo. Específicamente en el sector café hay poca literatura y datos sobre las huellas de carbono de diferentes sistemas de producción de café y cadenas de suministros. Además varios actores en la comunidad de las estandarizaciones voluntarias como el ISEAL Alianza y la red TSPN preguntan por una verificación del impacto de los estándares voluntarias a mitigación del cambio climático. Por ello se compilaron y compararon datos de GEI de diferentes sistemas de producción de café con respecto al carbono almacenado y la huella de carbono.

Para cuantificar el carbono almacenado y las huellas de carbono se utilizaron un modelo que cuantifica emisiones GEI; el Cool Farm Tool (Hillier et al., 2011). El Cool Farm Tool utiliza el Fila II metodología del Grupo Intergubernamental de Expertos sobre el Cambio Climático (IPCC, 2006) y es basado en modelos empíricos que cuantifican emisiones GEI que son construido desde cientos de estudios Se compilaron datos del campo en cuatro países en Mesoamérica de los sistemas de producción de café diferenciados por Moguel y Toledo (1999): (1) policultivos tradicionales, (2) policultivos comerciales, (3) monocultivos con sombra, y (4) monocultivos sin sombra. Los sistemas investigados también incluyen fincas que están certificados orgánicamente, de Rainforest Alianza y UTZ.

Los resultados muestran huellas de carbono en promedio bajos de café producido en policultivos tradicionales (5,4 kg CO2-e/kg-1) y policultivos comerciales (4,9 kg CO2-e/kg-1) y huellas de carbono con promedios altos de monocultivos con sombra (7,8 kg CO2-e/kg-1) y monocultivos sin sombra (8 kg CO2-e/kg-1). Se observan la misma tendencia en cuanto al carbono almacenado; policultivos (81,2 t CO2-e/ha-1) contra monocultivos (27 t CO2-e/ha-1). El análisis por los demás demuestra una huella de carbono más baja en las fincas que están certificado orgánico, Rainforest Alianza y UTZ aunque este efecto es en su mayor parte neutralizado por cosechas más bajas. Basado en los resultados se desarrollarlo un marco teórico para mitigación específico por sitio para asistir productores de café en definir prácticas amigables con el clima en cafetales y acelerar mitigación del cambio climático en producción de café en Mesoamérica.

Palabras claves: Cambio climático, *Coffea arabica*, Conservación del ecosistema de café, Cool Farm Tool, Huella de carbono, Mesoamérica, Mitigación específico por sitio, Normalizaciones voluntarias

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LIST OF ABBREVIATIONS

ABG	Above Ground Biomass
ASABE	American Society of Agricultural and Biological Engineers
BGB	Below Ground Biomass
4C	Common Code for the Coffee Community (4C Association)
C	Carbon
CF	Carbon Fraction
CFT	Cool Farm Tool
CGIAR	Consultative Group on International Agricultural Research
CH_4	Methane
CIAT	International Center for Tropical Agriculture
CLA	Country Land and Business Association
cm^{-1}	Centimeter (one)
CO_2	Carbon Dioxide
CO_2-e	Carbon Dioxide Equivalent
CRS	Catholic Relief Service
CUP	Coffee Under Pressure
D	Diameter
DAPA	Decision and Policy Analysis Program
DBH	Diameter at Breast Height
DNDC	DeNitrification – DeComposition
EPA	Environmental Protection Agency
ESA	Agricultural Development Economics Division
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FSB	Feasibility of Implementation
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIZ	German International Cooperation
GMCR	Green Mountain Coffee Roasters
GPS	Global Positioning System
ha^{-1}	Hectare (one)
IPCC	Intergovernmental Panel on Climate Change

kg^{-1}	Kilogram (one)
kWh	Kilowatt Hour
l	Liter
LCA	Life Cycle Assessment
LUC	Land Use Change
MIT	Mitigation
N	Nitrogen
NH_3	Ammonia
N_2O	Nitrous Oxide
PAI	Periodic Annual Diameter Increment
PCF	Product Carbon Footprint
PRC	Correct Practices
RASTA	Rapid Soil and Terrain Assessment
R:SR	Root:Shoot Ratio
SAN	Sustainable Agricultural Network
SFL	Sustainable Food Laboratory
SOM	Soil Organic Matter
spp.	Species
t	Metric Tonne
TCI	Investment Centre Division
TCS	Policy and Programme Development Support Division
TSPN	Trade Standards Practitioners Network
UNFCCC	United Nations Framework Convention on Climate Change
UTZ	¨Utz Kapeh¨ *(¨Good Coffee¨)* (Maya language)
WD	Wood Density
WWF	World Wildlife Fund
yr^{-1}	Year (one)

COMMISSIONER

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This research has been conducted as a project under the Decision and Policy Analysis (DAPA) Program. The DAPA Program focuses on providing several policy-relevant research outputs for areas where significant demand exists in Latin America. This research contributes to the DAPA Program focus area; Climate change and building resilience into agricultural systems.

The DAPA Program conducts research on the effects of climate change on the coffee supply chains of Green Mountain Coffee Roasters (GMCR) in Mesoamerica. This collaboration project, called Coffee Under Pressure (CUP) is strongly focused on climate change adaptation. Both CIAT and GMCR have an interest in exploring besides adaptation as well the opportunities for climate change mitigation. This research has departed from that interest and sets out to contribute to improved decision making regarding climate change mitigation both within the CUP project and on a broader policy level in the Mesoamerica region.

For further information please go to:

CGIAR:	http://www.cgiar.org/
CIAT:	http://www.ciat.cgiar.org/
DAPA:	http://dapa.ciat.cgiar.org/
GMCR:	http://www.greenmountaincoffee.com/

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1 INTRODUCTION

According the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2007) global temperatures increased by 0.74 °C during the 20th century. Most scientists agree that this warming in recent decades has been caused by human activities such as the burning of fossil fuel and deforestation, which have increased the amount of greenhouse gases in the atmosphere (Oreskes, 2004). Future climate model projections (IPCC, 2007) indicate that global temperatures are likely to rise a further 1.1 to 6.4 °C during the 21th century depending on different emission scenarios. Lu and Jian (2007) argue that a further increase in global temperature will cause sea levels to rise and will change the amount and patterns of precipitation, including the expansion of subtropical deserts. Responses to global warming as proposed in the signed and ratified Kyoto Protocol (UNFCCC, 2009) includes the mitigation of the amount of greenhouse gases emitted into the atmosphere.

Especially in subtropical land regions such as Mesoamerica rising temperatures will negatively affect food production and increase pest outbreaks (IPCC, 2007). In this region crops like coffee form the backbone of thousands of families´ livelihoods and contribute significantly to national agricultural Gross Domestic Products (GDP's).

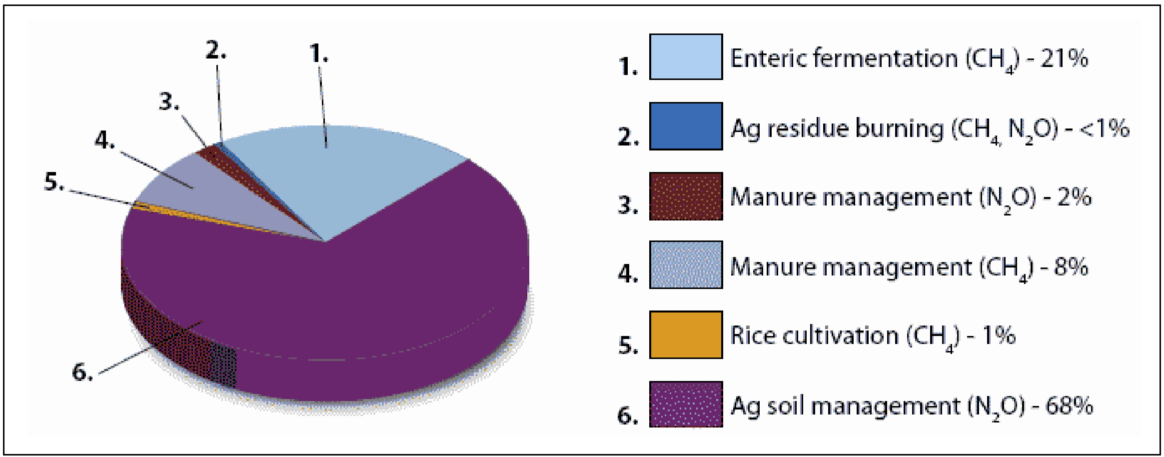

Figure 1: Agricultural GHG emissions.
The pie chart presents the different agricultural GHG emissions by source (mean from 2001 to 2005).
Source: Environmental Protection Agency (EPA), 2007 Inventory report.

But agriculture is besides suffering from the effects of climate change also contributing significantly to the climate change effect itself. Agriculture alone is responsible for 14 percent of global GHG emissions, mainly as a result of soil erosion, poor irrigation practices, the uncontrolled use of fertilisers and other agrochemicals, biomass burning and livestock production (EPA, 2007; Figure 1). When deforestation from farmland expansion and tree plantations is included into the calculations, agriculture is estimated to account for 30 percent of total GHG emissions globally (IPCC, 2007).

Specifically in the coffee sector the first signs that the need for climate change mitigation in agricultural supply chains is recognised are visible. Frontrunners among private companies such as Nestlé and Tchibo started with estimating the amount of emitted GHG's in some of their coffee supply chains by means of applying Life Cycle Analysis (LCA) and Product Carbon Footprint (PCF) methodologies (Nestlé, 2002; Tchibo, 2008). On the macro level of the international trade standards, the Trade Standards Practitioners Network (TSPN) dedicated its last annual conference to explore the role that trade standards can play in contributing to climate change mitigation (TSPN, 2010). As well the International Social and Environmental Accreditation and Labelling Alliance (ISEAL Alliance) is currently implementing a program that aims at supporting its members—standard setting organisations—to upscale their efforts to mitigate climate change. Individual voluntary standards active in the coffee sector such as Rainforest Alliance and the Common Code for the Coffee Community (4C Association) are already actively working on designing standards that can encourage and validate climate friendly coffee farming (Rainforest Alliance, 2011; Sangana PPP, 2011).

Due to ongoing work by scientists it is well understood how different agricultural practices are impacting the GHG emission balance. Regarding carbon sequestration is recognised that agroforestry systems store more carbon than unshaded systems (Flynn and Smith, 2010). Concerning the emissions from agriculture it was found that the application of fertilisers is causing N_2O induced CO_2 emissions (Bouwman, 1990; Granli and Bockman, 1994). As well GHG emissions from the production of fertilisers arise which are the result of industrial processes (Kongshaug, 1998). Furthermore the production of pesticides is a major worldwide contributor to GHG emissions (Bellarby et al., 2008). Finally Von Enden and Calvert (2002) found that wet processed coffee can generate and discharge up to 20.000 liters of wastewater per ton coffee cherries processed which emits high quantities of CH_4 into the atmosphere.

1.1 Problem definition

Although the current state of science combined with a strong interest from voluntary standard actors and the coffee private sector for climate change mitigation are encouraging, there still exist knowledge gaps that prevent stakeholders along coffee supply chains to make informed decisions in defining high-impact climate change mitigation strategies. These knowledge gaps concentrate around:

Carbon footprints – Are already applied by various stakeholders in the coffee sector (Nestlé, 2002; Salamone, 2003; Tchibo, 2008) to estimate the impact of specific supply chains on the climate. But the results cannot be compared as the methodologies[1] applied and the emission factors included in the calculations vary widely. Furthermore the existing carbon footprints of coffee supply chains always consist of one case study and therefore fail to bring forward the differences in emissions and carbon sequestration occurring in various coffee farming systems.

Voluntary standards – The ISEAL Alliance argues that although voluntary standard systems have the potential to contribute to mitigation efforts, this potential has not yet been realised[2]. Furthermore the ISEAL Alliance states that the effective and efficient entry point for contribution by voluntary standards to mitigation has to be explored. This argument is further grounded by the members of the TSPN Network that call for research to verify the impact of voluntary standards on climate change mitigation (TSPN, 2010).

Mitigation practices – Although the effect of different agricultural practices on GHG emissions and carbon sequestration is known (Lal, 2005; Bouwman, 1990; Bellarby et al., 2008), the current state of science lacks a comprehensive overview of those climate change mitigation practices that have been proven to be most effective in different coffee production systems specifically.

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[1] ISO 14067 Draft Product Carbon Footprint Standard, WRI Product Life Cycle Accounting and Reporting Standard, UK PAS 2050 Product Carbon Footprint Standard, ISO 14040 Life Cycle Assessment

[2] Trough own participation in a joint GIZ/ISEAL workshop: Supporting ISEAL Members to Scale-Up their Efforts to Mitigate Climate Change.27 and 28 October 2010, GIZ House, Bonn, Germany

Based on the latter key areas that highlight the focus area for further research the following problem definition has been defined:

There exists a lack of knowledge on how different coffee production systems and voluntary standards have an impact on climate change.

1.2 Research formulation

1.2.1 Objective

To quantify the effects of different coffee production systems and voluntary standards on climate change. To develop a framework for effective climate change mitigation on coffee production level.

1.2.2 Questions

Main question

What is the difference in on-farm carbon stocks and the carbon footprint of coffee grown in different production systems?

Sub questions

1. What is the difference between four different coffee production systems distinguished by Moguel and Toledo (1999) regarding on-farm carbon stocks and the carbon footprint?
2. To what extend have organic, Rainforest Alliance and UTZ certification systems an impact on the on-farm carbon stocks and the carbon footprint?
3. How is the yield level of different coffee production systems impacting on climate change?
4. Which agricultural practices are most effective in mitigating the effects of climate change on coffee production level?

2 BACKGROUND

2.1 GHG quantification studies in the coffee sector

2.1.1 Life cycle assessment applied in coffee production

Salamone (2003) used a LCA to—among other environmental effects—quantify the effect of coffee production on GHG emissions. LCA is a methodology used for analysing and assessing the environmental loads and potential environmental impacts of a material, product or service throughout its entire life cycle, from raw materials extraction and processing, through manufacturing, transport, use and final disposal[3]. The author took three stages into account; production, processing/packaging and consumption. The results show that the processing/packaging stage of the researched coffee supply chain contributed the least to GHG emissions with 1.7 percent. Cultivation had much greater GHG impacts, contributing with 12 percent to the total amount of GHG emissions. According to Salamone (2003) more than 80 percent of the GHG emissions in the researched supply chain are attributed to the consumption of the coffee. The study is largely based on a general coffee production system and not taking into account different farming systems and geographical contexts. A yield figure of 190 kg/ha^{-1} is assumed as an average and used throughout the study. As well only one coffee processing method —dry processing—and average fertilisation scenarios have been used by the authors. Consequently the study is not able to attribute levels of GHG emissions to different coffee production systems and bring forward context specific climate change mitigation focus points on farm level.

2.1.2 Nescafé *Classic* life cycle assessment

Nestlé is as well applying a LCA approach to assess the emitted GHG's from farm to fork in various supply chains. These studies are used by Nestlé to work with its stakeholders to define and implement improvements regarding climate change mitigation. The following GHG emission factors have been included in a conducted Nestlé coffee LCA study; production of agricultural raw materials, product manufacturing, packaging, distribution, consumption and end-of-life disposal. The results show that at the Nescafé Classic coffee product approximately 50 percent of the total energy use occurs during the consumption phase. The study also showed that overall, Nescafé Classic uses about half the energy,

[3] ISO 14040: 1997. Environmental management. Life cycle assessment. Principles and framework.

emits about half the GHG's and consumes about two-thirds of the amount of water compared to drip-filter coffee. The data presented (Nestlé, 2002) does not go in-depth regarding the focus area of this research; coffee production level. Furthermore it remains unclear which emission and sequestration factors have been taken into account or left out in the study.

2.1.3 Tchibo product carbon footprint

In 2008 and 2009, Tchibo was active in the German PCF pilot project which was initiated by the World Wildlife Fund (WWF), the Öko-Institut e.V. and the Potsdam Institute for Climate Impact Research. The project set out to calculate the product carbon footprints of various consumer goods. In the project Tchibo calculated the product carbon footprint of a Rainforest Alliance certified coffee product (Tchibo, 2008). All stages of the lifecycle were reviewed, especially with regard to the key sources of CO_2 emissions, known as ¨hot spots¨. The study revealed that the carbon footprint of the coffee product researched is 8.4 kg CO_2-e per kg coffee produced, processed and consumed. The conclusions from the study are:

1. Coffee farming is one of the two GHG emission hot spots, primarily due to the use of agricultural materials such as fertilisers and pesticides.
2. The second major source of CO_2 emissions is coffee preparation. In other words, the consumer's choice of how to prepare the coffee or the machine used for preparation can contribute to reducing the carbon footprint.
3. By comparison, the roasting and packaging of the coffee, and its transport along the value chain, are of minor significance in the overall footprint according Tchibo.

The study conducted by Tchibo provides a detailed outline on what happens in terms of emitted GHG's on coffee production level including a quantification of the different emission factors. This allows for the statement that the use of agrochemicals in contributing most to GHG emissions on coffee production level. Still only one farm has been researched in this study and this happened to be a coffee plantation. How the data from this single plantation relates to the numerous other coffee production systems and especially smallholder farming remains unclear. The emissions of CH_4 occurring during coffee fermentation and the generation and discharge of wastewater has been left out of consideration completely in the assessment. Furthermore the main strength of coffee farming systems to sequester carbon in soils and living biomass has been ignored as well in the research conducted by Tchibo.

2.2 Science on emissions from agricultural practices

2.2.1 Carbon sequestration in biomass

Every coffee production system is able to sequester carbon in biomass whereby the literature supports that agroforestry systems store more carbon than unshaded systems. Although unshaded coffee plantations sequester carbon in coffee plants, shading these systems increases their carbon concentrations. This finding applies throughout the tropics (Lal, 2005; Davidson, 2005; Anim-Kwapong, 2009; Bellarby et al., 2008; Flynn and Smith, 2010). In these studies carbon stocks are often measured in; (1) above ground biomass, defined as shade trees, coffee shrubs and litter and (2) below ground biomass, defined as soil organic carbon and carbon stored in root biomass. A wide variety of studies are available stating figures on carbon sequestered in coffee farms. A selection is presented in Table 1 with a focus on studies with some form of reference to a particular coffee production system or management level and studies that are conducted in the area of interest; Mesoamerica.

Table 1: Carbon sequestration studies in Mesoamerican coffee production.
Partly adapted from: Estudio de Línea Base de Carbono en Cafetales. Castellanos et al. (2010).

Reference and location	**Production system**	**Carbon stock coffee plants t CO_2-e ha^{-1}**	**Carbon stock shade trees t CO_2-e ha^{-1}**	**Annual carbon sequestration t CO_2-e ha^{-1} yr^{-1}**
Aguirre, (2006)	Natural coffee	-	47.6	-
	Traditional polyculture	-	35.6	-
Chiapas, Mexico	Shaded monoculture	-	23.1	-
Mena, (2008) Costa Rica	Coffee shaded with *Cordia* spp.	2.3	22.6	-
Soto-Pinto et al. (2009)	High management	147.2		3.4
	Medium management	115.9		2.7
Chiapas, Mexico	Low management	84.5		2.1
Soto-Pinto et al. (2010) Chiapas, Mexico	Coffee under diversified shade	-	39.4	-
Castellanos et al. (2010) Guatemala	135 shaded coffee farms, Rainforest Alliance certified	7.3	36.1	-

This data regarding carbon sequestration in coffee production systems is all measured using the same unit of measurement (t CO_2-e/ha^{-1}) and the studies are all conducted in Mesoamerica. This allows thus for some form of comparison. Aguirre (2006) shows that natural coffee production systems are sequestering higher amounts of carbon compared to shaded monocultures. This finding is further strengthened by Soto-Pinto et al. (2009) who show that high management systems sequester higher amounts of carbon versus their lower management counterparts. It remains unclear though what exactly defines a high management system and a low management system in terms of agricultural practices. From the current available data one is unable to make statements regarding the effect of voluntary standard systems on carbon sequestration. As well there is a very limited amount of data available for annual carbon sequestration (t CO_2-e ha^{-1} yr^{-1}). Only Soto-Pinto et al. (2009) report figures on annual carbon sequestration in coffee production systems (Table 1). Furthermore in a wide variety in the data reported by the different authors can be observed. This is the consequence of inconsistency in quantification methods and data collection procedures between the studies. As well some studies take only into account above ground biomass where others include below ground biomass as well in the quantifications.

2.2.2 Emissions from fertiliser production and application

From the carbon footprint studies presented in the previous chapter it can be concluded that the main GHG emissions occurring on coffee production level arise from the production and application of fertilizers. The application of fertilisers is causing N_2O induced CO_2 emissions. This refers to the emissions occurring from microbial nitrification processes in soils. The processes of oxidation from ammonium to nitrate and the reduction of nitrate to gaseous forms of nitrogen are the source of N_2O emissions arising from fertiliser application (Bouwman, 1990; Granli and Bockman, 1994). The rate of N_2O emissions depends mostly on the availability of mineral N source, meaning directly related to the rate of fertilisation (Granli and Bockman, 1994). N_2O emissions from soils are the dominant source of atmospheric N_2O, contributing with about 57 percent to the total annual global emissions of this green house gas (IPCC, 1997). Thus proper fertiliser application, taking into account type, timing, and placement, helps to reduce fertiliser usage, and therefore the GHG emissions associated with fertilisers. For example, studies in Costa Rican and Brazilian coffee production systems have indicated that inorganic N fertiliser applications can exceed optimal dosages by up to 200 kg N/ha^{-1}

(Wintgens, 2009). As well the way how fertilisers are applied is influencing the amount of emitted GHG's. This is illustrated by Hultgreen and Leduc (2003) who determined that there is a trend for higher emissions of N_2O when urea was broadcast rather than banded, and when urea was placed mid-row, rather than side-banded. GHG emissions from the production of fertilisers are the result of industrial processes (Kongshaug, 1998). The industrial processes that are necessary for fertiliser production are: ammonia production, phosphoric acid production and nitric acid production. Although the current state of knowledge gives a thorough understanding on how GHG emissions from fertiliser production and application are arising, no literature can be found that compares various agricultural productions systems with different levels of inputs and yields with respect to their emission of GHG's.

2.2.3 Emissions from pesticide production

The GHG emissions related to crop protection in coffee production with pesticides are directly related to the energy required for the production of the active ingredients in these pesticides. The production of pesticides is a major worldwide contributor to GHG emissions (Bellarby et al., 2008). Thus reducing pesticide use also directly reduces GHG emissions. Several literature sources point out that agroforestry systems use naturally less pesticides as the production system itself has an improved pest resistance. One reason pest incidence is less in agroforestry systems is because the balance between insect pests and predators is maintained to a greater extent (Rao et al., 2010). Pest incidence is also influenced by the species of tree used and the type of agroforestry system established. Rao et al. (2010) found that diversified shade tree species, shelterbelts and boundary plantings act as barriers to the spread of insects. Taking into account these studies one can conclude that in unshaded monoculture production systems the use of pesticides will increase since these systems have little of the latter described natural resistance to pests. According to Nyambo et al. (1996) the more frequent use of pesticides in unshaded monocultures has led to a number of problems including; outbreaks of new pests and chemical resistant pests, human and livestock health complications and an increase in the costs related to crop production. Furthermore, the use of pesticides can harm population levels of natural pest predators (Nyambo et al., 1996) and therefore trigger a further increase in the use of pesticides. Quantifying the effect of pesticide use on GHG emissions is straightforward and entails calculating the CO_2 equivalence from the energy that is need for the production of different types of pesticides using default values given by the IPCC. There are no studies which quantify the effect of for example IPM strategies or otherwise pesticide reductions on GHG emissions in different agricultural production systems.

2.2.4 Emissions from primary processing activities

After harvesting coffee cherries undergo the first processing steps. There are two initial processing methods applied that are known as dry processing and wet processing. Available literature for both methods has been reviewed regarding the current state of knowledge on GHG emissions arising from the respective processes:

Dry process - The dry processing method consists of removing (de-pulping) the skin, pulp and hull of the coffee cherry. This is done in processing methods that vary widely depending on the organisational level of the coffee producer and the geographical context. The machinery that can be used ranges from small movable hand operated de-pulping machines to large bulk fed fully automatic operating de-pulping installations that are usually found on larger plantations. De-pulping can be done with and without using water. After de-pulping the coffee is usually spread on patios and sun-dried. Though sun-drying is time intensive and when improperly done can be susceptible to disease, insect loss, and decay from rain, wind, and moisture (Sharma et al., 2009). Artificial mechanical drying has therefore been developed to get around these downsides of sun-drying, however it is expensive and energy intensive and therefore contributing to GHG emissions.

Wet process - The wet processing method starts similar as in the dry process with de-pulping the harvested coffee cherry. During de-pulping petrol, diesel (fossil fuels) and water are used—or not—highly depending on the deployed machinery. The second step consists of the fermentation of the de-pulped coffee cherries. This fermentation process takes up to 36 hours (Von Enden, 2002) and is done by soaking the de-pulped cherries in big tanks. When the fermentation is finalised the fermented beans are washed to remove residues and remaining mucilage layers. After this final washing the beans are dried. Drying in the wet process is done exactly the same as in the dry process using either sun-drying or artificial mechanical drying.

Wet processing is believed to deliver higher quality coffee compared to the dry process since small amounts of off-flavours are generated in this process which gives the coffee a better taste and body (Calvert, 1998). Although from a climate change perspective using the wet process in coffee producing means bad news. From the fermentation process and wastewater generation, the green house gas CH_4 is emitted. The amount of CH_4 emitted is related to the amount of wastewater produced and treatment and differs widely among geographical context and used process. An overview for different countries and processes is presented in Table 2.

Table 2: Coffee wastewater generation quantities in different processes.

Reference	**Location**	**Process**	**Water use (liter)**
Von Enden and Calvert, (2002)	Colombia	Fully washed with environmental processing	1-6
Von Enden and Calvert, (2002)	Kenya	Fully washed, reuse of water	4-6
Grendelman, (2006)	Nicaragua	Fully washed, reuse of water	11
Biomat, (1992)	Nicaragua	Traditional, fully washed	16
Deepa et al. (2002)	India	Traditional, fully washed	14-17
Von Enden and Calvert, (2002)	Vietnam	Traditional, fully washed	20

By Table 2 it is clearly brought forward that with extra attention to wastewater generation, treatment and discharge significant reductions in the water use—and thus in emitted GHG's—can be achieved. The literature supports that traditional fully washed processes use up to four times as much water compared to processes that reuse water or apply environmental treatments.

2.3 GHG quantification models

Numerous GHG quantification tools and models are available on the web with a very wide range of application. Most models do not reach further than quantifying the fossil fuel use from for example; transport activities, households, offices and small businesses. Quantifying emissions from agricultural processes requires different measures. This is a consequence of the complex emission sources such as soil released N_2O from fertiliser application, CH_4 emissions connected to the generation and discharge of wastewater and carbon sequestration in on-farm biomass and soils. Optimally all these emission and sequestration factors are taken into account to make final reported CO_2-e figures from farming systems as accurate as possible. For this purpose a couple of options are available and outlined in the next paragraphs:

2.3.1 CALM Calculator

The CLA CALM Calculator (CLA, 2006) measures emissions of CO_2, CH_4 and N_2O from a land-management and carbon which sequestered in soils and trees. Emission sources included in the CALM Calculator are: energy and fuel use, livestock, cultivation and land-use change, the application of N fertilisers and lime. All the occurring emissions are balanced against carbon sequestration in soils and trees at the respective farming system. The CLA CALM Calculator has been produced by the Country Land and Business Association working in partnership with Savills.

2.3.2 EX-ACT Carbon Balance Tool

The EX-ACT Tool (Bernoux et al., 2010) aims at providing ex-ante estimations of the impact of agriculture and forestry development projects on GHG emissions and carbon sequestration, indicating its effects on the carbon balance. The tool is developed by the FAO in collaboration with three in-house divisions; TCS, TCI and ESA. The FAO argues that EX-ACT will help development project designers to select project activities with higher benefits in climate change mitigation terms. Consequently the EX-ACT Carbon Balance Tool works at project level and quantifies the emission balance with and without project intervention to support decision making.

2.3.3 Cool Farm Tool

The Cool Farm Tool (Hillier et al., 2011) is a GHG calculation model which integrates several globally determined empirical GHG quantification models in one tool. The tool recognises context specific factors that influence GHG emissions such as: geographic and climate variations, soil characteristics and management practices at farm level. The model has a specific farm-scale, decision-support focus. Hillier et al. (2011) argue that there is a considerable scope for the use of the model in global surveys to inform on current practices and potential for climate change mitigation.

2.3.4 DAYCENT Model

The DAYCENT Model (Del Grosso et al., 2001) is a biogeochemical model used in agro-ecosystems to simulate fluxes of carbon and N in the atmosphere, vegetation and soil. The inputs for the model include daily maximum and minimum air temperature and precipitation, surface soil texture class, land cover and land use data. The model outputs include daily N-gas flux (N_2O, NO_x and N_2); daily CO_2 flux from heterotrophic soil respiration; soil organic carbon content and N; net primary productivity; daily water uptake and NO_3 leaching.

2.3.5 DNDC Model

The DNDC (DeNitrification-DeComposition) Model (Li et al., 1994) is a process based model to quantify GHG fluxes from agriculture. The DNDC Model is capable of predicting the soil fluxes of all three terrestrial greenhouse gases: N_2O, CO_2 and CH_4. As well as other important environmental and economic indicators such as crop production, NH_3 volatilisation and NO_3 leaching are quantified by the model. The DNDC model has been widely used internationally, including in the EU nitrogen biogeochemistry projects NOFRETETE and NitroEurope.

2.4 Climate change mitigation and voluntary standards

There currently exists a lively dialogue within the voluntary standard community on how to effectively address climate change mitigation in standards systems. As well the first concrete projects to achieve this are initiated by various stakeholders. An overview of the most illustrating examples that support this argument is presented below:

2.4.1 Trade Standards Practitioners Network (TSPN)

The TSPN Network aims at pro-developmental use of voluntary standards by turning them into catalysts for sustainable development[4]. The last annual conference of the TSPN was held at November 17-18, 2011 and titled; ¨Standards for a Sustainable Agriculture and the Mitigation of Climate Change¨. The aim of the conference was to find answers to the question; *Which criteria must be fulfilled so that standards can contribute to climate change mitigation?* The findings of the conference (TSPN, 2010) contained suggestions for further research including; (1) needed research to verify the impact of voluntary

[4] Trade Standards Practitioners Network (TSPN) See: http://tradestandards.org/en/Index.aspx

standards on climate change mitigation and (2) more GHG emission data from developing countries is desired.

2.4.2 ISEAL Alliance

The ISEAL Alliance is currently implementing together with the German International Cooperation (GIZ) a program that aims at supporting its members—standard setting organisations—to upscale their efforts to mitigate climate change. The program initiators argue that while voluntary standards systems have the potential to accelerate mitigation efforts, this potential has not yet been realised. ISEAL further argues that; ¨There are many pathways, strategies and methodologies that standards systems can use to encourage and support mitigation. The challenge is to find the most effective and efficient entry point for this support¨[5].

2.4.3 Rainforest Alliance and the 4C Association

Rainforest Alliance is collaborating with Anacafé and Efico to develop standards to validate climate friendly farming in coffee production through a methodology which allows the certification of good environmental practices (Rainforest Alliance, 2011). The result of the project—a climate module—that can be added to the existing Sustainable Agricultural Network (SAN) standards used by Rainforest Alliance will promote the adoption of good agricultural practices that reduce GHG emissions and increase carbon sequestration. As well the Common Code for the Coffee Community (4C Association) is working together with The German International Cooperation (GIZ) on designing additional module to the existing 4C standards which takes into account climate change mitigation and especially adaptation (Sangana PPP, 2011).

[5] Trough own participation in a joint GIZ/ISEAL workshop: Supporting ISEAL Members to Scale-Up their Efforts to Mitigate Climate Change.27 and 28 October 2010, GIZ House, Bonn, Germany

2.5 Different coffee production systems

Little literature exists that distinguish different coffee production systems in the Mesoamerica region. The most detailed overview is given by Moguel and Toledo (1999) who classified in great detail five different coffee production systems in Mexico and state that this classification can be extrapolated to Central America as well. Moguel and Toledo argue that coffee production systems can be divided into:

1. Traditional rustic systems
2. Traditional polycultures
3. Commercial polycultures
4. Shaded monocultures
5. Unshaded monocultures

In this classification the traditional rustic system is described as a traditional shaded agroforest or ¨mountain¨ coffee system. Coffee is planted in these systems by local Indian communities in isolated areas who have introduced coffee into the native forest ecosystems. The traditional polycultures are shaded agroforests containing native trees and the coffee grown in these systems is cultivated principally by smallholder farmers. This system is agroforest with the most advanced stage of manipulation of the native forest ecosystem. Coffee is grown alongside numerous useful plant species, forming a sophisticated system of native and introduced species for instance by favouring the growth of or eliminating certain tree species (Moguel and Toledo, 1999). In the commercial polycultures most of the native trees are removed. Instead the shade cover is made up of trees that all have an explicit function; adding nitrogen to the soil and more importantly providing additional cash crops such as citrus fruits and bananas. Shaded monocultures aim at high coffee yields and use a shade cover that is almost exclusively made up of Leguminous trees like Inga species. The use of agrochemical products is high in this system, and the production is market oriented and aiming at high yields. The unshaded monoculture has completely abolished the use of shade trees, and coffee plants are grown in full sun light in this system. This system has completely lost the agroforest character and is converted into a plantation (Moguel and Toledo 1999). This coffee producing system requires high inputs of chemical fertilisers and pesticides, the use of machinery, and an intensive work force throughout the yearly cycle.

3 METHODOLOGY

3.1 Sample design

3.1.1 Population

The population for this study is defined as all coffee production systems distinguished by Moguel and Toledo (1999) that can be found at four coffee cooperatives: (1) Apecafé, (2) Acoderol (3) Prodecoop and (4) a Pronatura Sur partner cooperative. Besides these cooperatives three coffee plantations namely: (1) Finca Alianza, (2) Finca Santa Teresa and (3) Finca Las Chicharras are part of the population. Table 3 gives a overview of these organisations together with the respective countries and municipalities. As a sampling frame (list of all cases in the population) the complete lists of coffee growers belonging to the researched cooperatives have been used. These lists were available through the internal data of the Coffee Under Pressure (CUP) project and as well in Cropster C-sar, a digital information management system for coffee supply chains. A sampling frame for the plantations was unavailable and a selection has been made together with the respective private partners.

Table 3: Overview of cooperatives and plantations sampled in Mesoamerica.

Cooperative / Plantation	Country	Municipality
Apecafé	El Salvador	Jayaque
Acoderol	Guatemala	Olopa
Prodecoop	Nicaragua	San Juan del Río Coco
Pronatura Sur partner	Mexico	Oaxaca
Finca Alianza	Mexico	Cacahoatán
Finca Santa Teresa	Mexico	Angel Albino Corzo
Finca Las Chicharras	Mexico	Chicomuselo

3.1.2 Sample method

Optimally a probability sampling design, such as a model-based or a design-based approach (Brus and De Gruijter, 1997; Dobermann and Oberthur, 1997) would have been applied to draw a sample for this study. But several factors such as: (1) long travel times to field sites, (2) limited availability of field support, (3) time intensive data collection procedures and (4) poor farm accessibility prevented the implementation of a strict probability sampling design. Instead a purposive non-probability sampling approach with proportional quota sampling has been adopted to define a sample from the population.

The difference between a probability and a non-probability sample is that a non-probability sample does not apply a complete random selection. But this does not necessarily mean that non-probability samples are not representative of the population. It does imply though that one cannot depend upon the rationale of probability theory, and therefore other ways must be found to show that the population was adequately sampled. In this study this has been done by applying a proportional quota sample whereby the major characteristics of the population are correctly represented by sampling proportional numbers from each quota.

3.1.3 Stratification

A quota sample is the non-probability version of stratified probability sampling whereby an effort is made to insure a certain distribution of demographic variables (Owen et al., 1992). This is done by defining different quotas (strata's) that are considered in the research design as important to be correctly represented within the sample. In defining the different strata for the sample of this research four of the five coffee production systems as distinguished by Moguel and Toledo (1999) have been applied. The traditional rustic system has been left out of the study as this system can only be found in isolated areas, where Indian or local communities have introduced coffee into native forests. Cooperatives can typically not be found in such forest communities which would have made access for data collection very complex. In order to be able to assess as well the influence of different voluntary standards on carbon stocks and the carbon footprint at some coffee production systems sub-strata have been added. These sub-strata consist of; organic, Rainforest Alliance/UTZ and conventional farming systems.

3.1.4 Sample size

By using the estimates outlined by Moguel and Toledo (1999) of the geographical distribution of the different coffee production systems in Mesoamerica a sample size in each strata has been defined. To decide in the field under which production system a researched coffee plot should be classified, the two main criteria on which Moguel and Toledo (1999) distinguished the coffee production system have been used. These criteria are; (1) vegetational and structural complexity and (2) management level observed in the different coffee production systems. The underlying indicators belonging to those two main criteria have been used to make the two main criteria measurable and discriminate

Table 4: Relation of the different sample strata's drawn to the population.
APE = Apecafé, ACO = Acoderol, PRO = Prodecoop, CH / TE = Finca Santa Teresa / Finca Las Chicharras, Al = Finca Alianza, NAT = Pronatura Sur partner cooperative. S = Sample size, P = Population size, An asterisk (*) indicates a lack of information on the population (in the case of plantations within a respective country).

SYSTEM	STANDARD	PARTNER													COUNTRY
		APE		ACO		PRO		CH / TE		AL		NAT		*Sum:*	
		S	*P*	*S*	*P*	*S*	*P*	*S*	*P*	*S*	*P*	*S*	*P*		
Trad-Poly	*Organic*	8	297			13	25							**21**	El Salvador/Nicaragua
	RA / UTZ									2	*			**2**	Mexico
	Rainforest Allicance											2	*	**2**	Mexico
	Conventional	3	93			1	1							**4**	El Salvador/Nicaragua
Com-Poly	*Organic*			3	27	11	21							**14**	Guatemala/Nicaragua
	Organic / RA											2	*	**2**	Mexico
	Conventional			11	91									**11**	Guatemala
Shad-Mono	*Organic*					2	2							**2**	Nicaragua
	Conventional			4	35			2	*					**6**	Mexico
Unshad-Mono	*RA / UTZ*									2	*			**2**	Mexico
													Sum researched production systems:	**66**	

Table 5: Criteria and indicators to distinguish between production systems.

System	Vegetational and structural complexity				Management level		
	Shade tree density **[trees/ha]**	Co-product density **[trees and plants/ha]**	Canopy height **[m-MAX]**	Coffee plant density **[plants/ha]**	Production level **[kg parchment/ha]**	Fertilisation level	Pesticide level
Trad-Poly	*Very high*	*Medium*	*20-30*	*Very low*	*Very low*	*Very low*	*Very low*
Com-Poly	*High*	*Very high*	*<15*	*Low*	*Low*	*Low*	*Low*
Shad-Mono	*Medium*	-	*<15*	*Medium*	*Medium*	*Medium*	*Medium*
Unshad-Mono	-	-	-	*High*	*High*	*High*	*High*

between production systems in the field. Table 5 shows a complete overview of these criteria and indicators and as well how the four different production systems perform regarding each indicator.

3.1.5 Case selection in the field

In discussion with the cooperative technicians who have extensive knowledge of all the characteristics of the production systems that can be found in their department, targeted visits to producers and their respective coffee plots have been scheduled. These visits for field data collection have been repeated until each different strata at the respective cooperative had been filled to the defined sample size. In using this methodology the core variables—four different Mesoamerican coffee production systems—have been correctly represented within the final sample drawn. Table 4 shows a complete overview of how the sample drawn relates to the population, combined with additional data such as the partner organisations and the respective countries sampled within Mesoamerica.

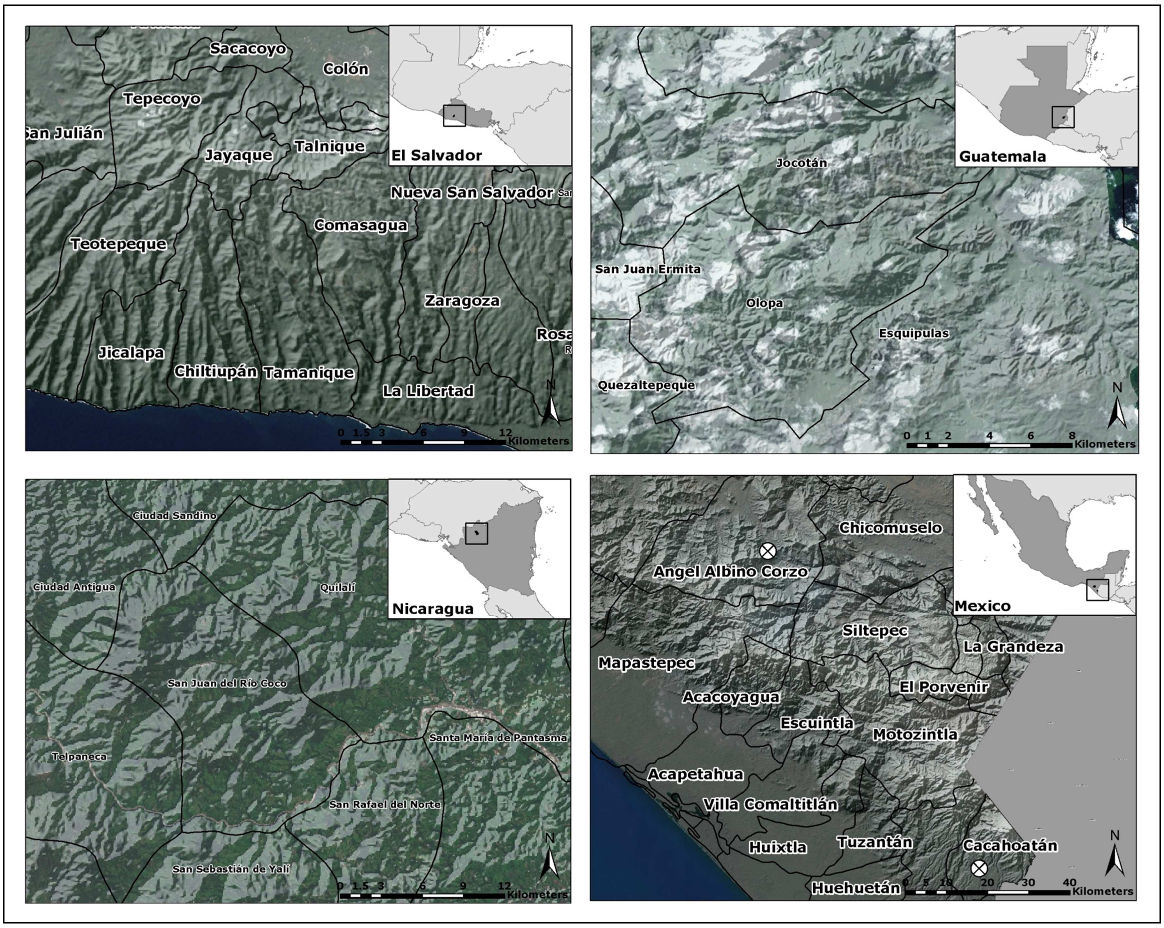


Figure 2: Sample locations in Mesoamerica.
Top left: El Salvador, Top right: Guatemala, Bottom left: Nicaragua, Bottom right: Mexico.

3.1.6 Sample sites

The specific locations of the sample sites can be found in Figure 2. In this figure as well the positions of the different sample sites within Mesoamerica are shown in the smaller inserts.

3.2 Analysis model

As the data collection methodology is largely based on the GHG quantification model that has been chosen for the study, first a justification and outline of this model is presented which is followed by the instrumentation and procedures regarding the actual data collection.

3.2.1 Model selection

In selecting a GHG quantification model that would serve the scope of this study optimally within the given timeframe the following criteria have been maintained:

1. The model must be able to take into account context specific variables such as country, soil and climate
2. The model must be able to quantify not only GHG emissions but as well the carbon stock stored in coffee-eco systems including the annual carbon sequestration.
3. The model must be able to quantify methane emissions that arise from coffee cherry de-pulping and fermentation processes.
4. The model must be able to present results both in [t CO_2-e/ha^{-1}] and [kg CO_2-e/kg^{-1}] to bring to the foreground both the performance of farming systems in terms of land-use efficiency and efficiency per unit product (PCF).
5. The time needed to collect the input data for the model on a large scale in various countries in Mesoamerica must fit into the timeframe of the research project.

Table 6: Performance of GHG quantification models on the maintained criteria.

Model	Selection criteria				
	1	**2**	**3**	**4**	**5**
CALM Calculator		✓	✓		✓
EX-ACT Carbon Balance Tool	✓		✓		✓
Cool Farm Tool	✓	✓	✓	✓	✓
DAYCENT	✓	✓	✓	✓	
DNDC	✓		✓	✓	

When looking back again—with these criteria in mind—to the current GHG calculation models available that are presented in the background chapter is was possible to select the most suitable model (Table 6).The CALM Calculator (CLA, 2006) uses the Tier I IPCC inventory methods (IPCC, 1997; IPCC, 2006) that were designed for GHG accounting on a national level and therefore lack the precision that is desired for this study. The EX-ACT tool (Bernoux et al., 2010) quantifies the carbon stock changes per unit of land [t CO_2-e ha^{-1}] only, and can therefore not present an additional PCF that will make the results of this study much more complete. Both the DAYCENT model (Del Grosso et al., 2006) and the DNDC model (Li et al., 1994) would provide the most accurate quantification results as they make use of detailed accounting methodologies that include process-based soil emission models. For this same reason both models require a high amount of complex input data that typically requires extensive soil sampling and laboratory analysis. Furthermore these models exclude carbon sequestration in biomass altogether, an important aspect that influences the GHG emission balance in coffee-ecosystems significantly and therefore cannot be left out of the study.

3.2.2 Cool Farm Tool

The Cool Farm Tool (Hillier et al., 2011) recognizes context specific factors that influence GHG emissions such as: geographic and climate variations, soil characteristics and management practices at farm level. The model delivers output in [t CO_2-e/ha^{-1}] and [kg CO_2-e/kg^{-1}] so that the performance of production systems both in terms of land-use efficiency and efficiency per unit product (PCF) can be assessed. The Cool Farm Tool includes the factors; carbon sequestration and methane emissions which characterise coffee production and processing specifically. Yet the input data collection that is needed to generate results remains feasible within the timeframe of the study (Table 6). Finally Hillier et al. (2011) argue that there is considerable scope for the use of this model in global surveys to inform on current practices and potential for mitigation—which is exactly what this study seeks to achieve in the Mesoamerica region. For the latter reasons the Cool Farm Tool has been selected as the model that will be used to quantify the GHG emission arising from different coffee production systems throughout this study.

The CFT GHG quantification model calculates the GHG emissions of:

1. Emissions from fuel and electricity use utilizing IPCC default values.
2. Soil carbon sequestration based on an empirical model (a model based on the results of several published studies) built from over 100 global datasets.
3. Carbon sequestration in above and below ground biomass. The allometric equation model developed by Segura et al. (2006) for among others; *Coffea arabica* and a wide variety of shade trees has been used for this purpose.
4. Emissions from pesticide production utilizing IPCC default values.
5. N_2O emissions from fertiliser application based on an empirical model built from an analysis of over 800 global datasets. These datasets refine gross IPCC Tier I estimates of N_2O emission by factoring in the guiding drivers of N_2O emissions such as climate, soil texture, soil carbon and soil pH.

The CFT GHG quantification model uses several empirical sub-models to estimate the overall GHG emissions, namely:

1. Machinery emissions - simplified model derived from (ASABE, 2006).
2. GHG emissions from fertiliser production (Ecoinvent, 2007).
3. Nitrous oxide emissions from fertiliser application (Bouwman et al., 2002).
4. Changes in soil C based on IPCC methodology as in (Ogle et al., 2005).
5. Effect of manure application on soil C based on (Smith et al., 1997).

3.3 Data collection

3.3.1 Procedures

In order to collect the data in the most effective and accurate way certain procedures have been adopted. Throughout the data collection process at each cooperative and farm researched the technician at the respective cooperative played a crucial role. Close assistance of the technician was needed as the farms that needed to be visited were often located in very remote and poorly accessible locations. As well the technician is often one of the persons at the researched cooperatives that provide agricultural extension services. Therefore he has a complete overview of all the topics researched namely farm inputs, outputs, practices, management level and the procedures at cooperative level. It proved that this kind of overview was necessary in selecting cases for data collection, and often to reveal data that sometimes lacked at producer level such as yields and processing details. As well trough his work as an agricultural extension agent he had a well established relationship with farmers which increased the willingness of the latter to participate in the research, share data and time. Data collection at each individual farm started with a semi structured interview with the corresponding farmer. Afterwards the actual coffee plot was visited usually together with the cooperative technician and the farmer. The field visits had two functions:

1. Collecting primary data. To quantify on-farm carbon stocks in above ground and below ground biomass one input variable needed is the tree diameter at breast height. The formula that has been used in defining the amount of trees per species for measurement is as follows:

   (Number of shade tree species/ha) / 5

   This methodology is further illustrated by the example in Table 7.

Table 7: Example of a scheme for measuring shade tree DBH figures.

Shade tree species	**Number / ha**	**Number measured**
Inga punctata	40	8
Cordia alliodora	15	3
Persea americana	8	1

Do define a final diameter at breast height figure at each shade tree species encountered in a particular coffee plot, the mean of all the measurements per species has been used.

In the cases where the variables Soil Organic Matter (SOM) and pH of the soils of the farms were not available at cooperative level, soil samples have been collected at the researched coffee farms and analysed using the Rapid Soil and Terrain Assessment (RASTA) methodology (Cock, 2010).

2. Verifying the collected data in the interviews. The farm visits secondly have been used to verify and refine certain variables that already had been collected in the interview. Most of these variables are based on the perception of farmers. Therefore visiting the actual farm and collecting extra primary data has been used to improve the reliability of the final dataset. To verify the accuracy of the shade tree species and their number per hectare at each farm a counting in a 10 x 10 meter area has been undertaken. By extrapolating the findings to the hectare and comparing these results with the initial data, a final more representative value could be defined. Further verifications consisted of checks regarding coffee tree spacing, mulching status, weeding practices, canopy heights and the presence of different shade strata.

3.3.2 Instrumentation

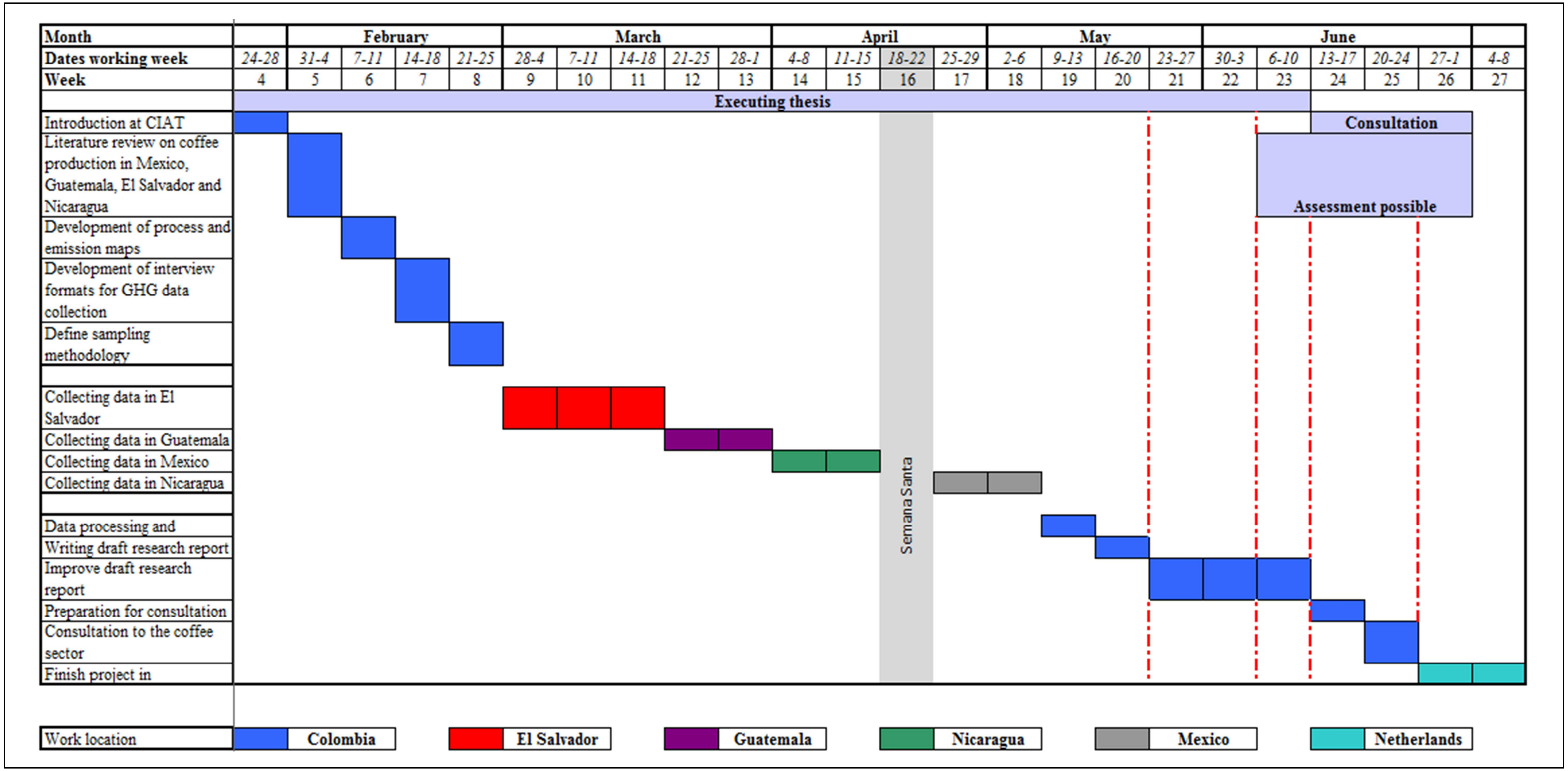
To guide the semi-structured interviews a questionnaire has been developed (see: Annex I and II). Parts of the questionnaire are based on a standard format that is designed by the Sustainable Food Laboratory (SFL) to collect data for the generic CFT tool. Significant modifications have been made to this standard questionnaire format to make it suitable for the specific data collection and context. After the pretesting of the questionnaire new changes have been implemented in order to make data collection more efficient and improve the quality of the data collected. These changes mostly relate to the strategy and wording in questioning. The final questionnaire format uses the sections; general data, crop management, sequestration and field energy use/primary processing. These different sections allow for a structured and logical order in collecting the field data.

To define the geographical locations of the visited coffee sites a GARMIN handheld GPS system has been used to define latitude, longitude and altitude. A tape line has been used to define shade tree and coffee plant diameters at breast height. At sites where soil sample results were not available at the producer organisation level, the Rapid Soil and Terrain Assessment (RASTA) methodology (Cock, 2010) together with pH strips has been used to be able to define soil organic matter (SOM) and soil pH figures.

3.3.3 Time frame

How the research is executed over time and in which countries is displayed in the form of a Gantt chart (Table 8).

Table 8: Gantt chart of the research time frame.



3.4 Analysis design

3.4.1 Analysis step I: GHG quantification

The data collected was processed at individual farm level. Consequently the data from each farm was analysed individually with the CFT GHG quantification model. The CFT is able to quantify with the data collected at each coffee farm the amount of green house gas emissions arising from a whole series of practices on farm level. The input data that is needed has been elaborated on in the methodology chapter and as well in Annex I and II one can get a complete overview of the farm level input data that was needed for the quantifications. One can gain a better idea of how the CFT is working by studying Table 9. In this table the function of the CFT in translating a wide variety of input data in to its CO_2 equivalence is illustrated by listing the input and output data for each emission and sequestration factor on coffee production level.

Table 9: Overview on the function of the CFT in transforming data.

Emission/sequestration factor	**Input data needed**	**Output data by CFT**
Pesticide production	# of applications	kg CO_2-e/ha^{-1} / kg CO_2-e/kg^{-1}
Gas use	Liters / kg	kg CO_2-e/ha^{-1} / kg CO_2-e/kg^{-1}
Diesel use	Liters / km	kg CO_2-e/ha^{-1} / kg CO_2-e/kg^{-1}
Electricity use	KwH	kg CO_2-e/ha^{-1} / kg CO_2-e/kg^{-1}
Off-farm transport	Km / weight / mode	kg CO_2-e/ha^{-1} / kg CO_2-e/kg^{-1}
Crop residue management	Kg / management practice	kg CO_2-e/ha^{-1} / kg CO_2-e/kg^{-1}
Waste water production	Liters / management practice	kg CO_2-e/ha^{-1} / kg CO_2-e/kg^{-1}
Fertiliser induced N_2O	Fertiliser type / # and kg of application / management practice	kg CO_2-e/ha^{-1} / kg CO_2-e/kg^{-1}
Fertiliser production	Fertiliser type / # and kg of application	kg CO_2-e/ha^{-1} / kg CO_2-e/kg^{-1}
Carbon sequestration	Tree species / DBH / D / # per ha / # cut down or planted	kg CO_2-e/ha^{-1} / kg CO_2-e/kg^{-1}

Although Table 9 gives a clear picture of how the CFT translates input data it remains unclear how the actual calculations are done in the model. GHG calculations range from rather straightforward such as calculation the GHG emission from pesticide production and fossil fuel use such as gas, diesel and electricity and transport. These calculations can be done using IPCC default values for the different emission factors. Things get more complex when quantifications of emissions arising from fertiliser induced N_2O and carbon sequestration in biomass are required. Rather than just applying the CFT model it is of fundamental importance to understand how this model performs the quantifications on the background. To this end one important quantification—the quantification of carbon sequestration in above and below biomass of coffee plants—is used as an example and completely worked out:

I was found by Segura et al., (2006) that the amount of carbon sequestered in *Coffea arabica* is equal to:

$$Y = 0.0659 * D^{1.991}$$

Where:

Y = aboveground dry matter, kg $(tree)^{-1}$

D = diameter at 15cm from ground, cm

For example during field data collection one coffee plant is encountered and measured and this results in a D value of 9 cm. The Y value is then calculated by:

$$Y = 0.0659 * 9^{1.991}$$

$$Y = 5.235 \text{ kg } (tree)^{-1}$$

To quantify this Y value into a kg CO_2-e value for the above ground biomass in the respective coffee plant the following proposition is applied:

$$AGB = 44/12 * CF * WD * Y$$

Where:

AGB = above ground biomass, kg CO_2-e

CF = carbon fraction

WD = wood density

Y = aboveground dry matter, kg $(tree)^{-1}$

The values for the carbon fraction (CF) and wood density (WD) are given for *Coffea arabica:* CF = 0.5 and WD = 0.5. Thus the final proposition for the above ground biomass quantification of the respective coffee plant is:

$$AGB = 44/12 * 0.5 * 0.5 * 5.235$$

$$AGB = 4.79 \text{ kg } CO_2\text{-e}$$

Now that the above ground biomass for the coffee plant is calculated the biomass of the same coffee plant sequestered below ground (in roots) can be quantified. For this purpose the following proposition is applied:

$$BGB = 44/12 * R{:}SR * CF * WD * Y$$

Where:

BGB = below ground biomass, kg CO_2-e

R:SR = root:shoot ratio

CF = carbon fraction

WD = wood density

Y = aboveground dry matter, kg $(\text{tree})^{-1}$

The only new independent variable in this proposition is the root:shoot ratio (R:SR). The same as with the CF and the WD variables the R:SR is known for *Coffea arabica:* 0.24. Now that all the variables are defined the quantification the remaining below ground biomass of the coffee plant is equal to:

$$BGB = 44/12 * 0.24 * 0.5 * 0.5 * 5.235$$

$$BGB = 1.15 \text{ kg } CO_2\text{-e}$$

By adding the above and below ground biomass carbon sequestration values (4.79 + 1.15) the total amount of sequestered carbon in the coffee plant is now defined: 5.94 kg CO_2-e. This result of 5.94 kg CO_2-e would the CFT model have given immediately by simply entering (one) coffee plant and a (9) cm D value. Of course the calculated example coffee plant is only one species. For an *Inga* spp. shade tree the latter calculations for above and below ground biomass would have been different due to a different capacity of *Inga* spp.

in sequestering carbon. As well this example still deals only with one aspect of the all the sequestration and emission factors as listed in Table 9. This illustrates the complexity of carbon sequestration and emission accounting in agriculture and as well the need for a comprehensive GHG quantification model: making sequestration and GHG quantification applicable for wider research and decision support within a reasonable timeframe.

3.4.2 Analysis step II: data comparison

In paragraph 3.4.1 it was thus illustrated how the field data is quantified into a GHG equivalence figure. Although this part of the analysis is time intensive it still does not come close to answering the stated research questions. In order to answer the stated research questions supported by empirical evidence data, further analysis is needed in the form of extensive comparisons between the data sets. As tool for this second analysis and data visualisation Microsoft Excel has been used. Three main groups of data are generated by the first stage in the data analysis with the CFT:

1. Carbon stock in above and below ground biomass.
2. Carbon footprint measured on a per hectare basis.
3. Carbon footprint measured on a per unit product basis.

Within these three groups the data is compared according the four coffee production systems distinguished by Moguel and Toledo (1999) and the different voluntary standards (see paragraph: 1.2 Research formulation). Besides this main core of the analysis additional results have been generated such as coffee yield comparisons and exploratory comparisons of individual cases to create supportive examples at certain statements in the result chapters.

3.5 Study boundaries

3.5.1 Conversions

During the field data collection a wide variety of different units of measurements were encountered. As well different conversions and default values have been maintained for certain processes in coffee production stages. Table 10 gives a complete overview of the different units conversions, ratios and default values used throughout the study.

Table 10: Conversion ratios and default values maintained throughout the study.

Conversion / item	Ratio / value	Reference
Manzana:hectare	1:0,7	www.convertunits.com
Manzana:cuadra	1:16	www.convertunits.com
Quintal:kilogram	1:45	http://buscon.rae.es
Libra:kilogram	1:0,45	Skinner, (1952)
Cherry:parchement	1:0,2	Apecafé, (2011) El Salvador
Parchment:green coffee	1:0,8	Apecafé, (2011) El Salvador
Engergy use de-pulper diesel	0,11 l/ kg parchment coffee	Coltro et al. (2005) Brazil
Energy use de-pulper electric	0,22 kWh/kg parchment coffee	Coltro et al. (2005) Brazil
Water use of manual de-pulping in an ecological process	4,4 l/kg parchment coffee	Prodecoop, (2011) Nicaragua
Water use of de-pulping in a standard process	28,8 l/kg parchment coffee	Acoderol, (2011) Guatemala
Water use of cherry de-pulping and parchment fermentation in a traditional fully washed process	80 l/kg parchment coffee	Biomat, (1992) Nicaragua
Content ¨bomba¨ (spray container for foliar fertilisation)	18 l	Coffee farmer, (2011) Guatemala

3.5.2 Assumptions

In the calculation procedures of the study several assumptions have been made for certain factors in the coffee production process for all the four production systems researched.

Table 11: Amount of residue in different production systems.

Production system	Leaf litter and pruning residue from coffee plants	Leaf litter and pruning residue from shade trees	Total amount of Leaf litter and pruning residue	Reference
Traditional polyculture	2000 kg/ha	10.000 kg/ha	12.000 kg/ha	Beer, (1988) and Coltro et al. (2005)
Commercial monoculture	3000 kg/ha	7500 kg/ha	10.500 kg/ha	
Shaded monoculture	4000 kg/ha	5000 kg/ha	9000 kg/ha	
Unshaded monoculture	5000 kg/ha	-	5000 kg/ha	

Although the assumptions are based on peer-reviewed science it is still necessary to present them. Table 11 shows the amount of leaf litter pruning residues coming from coffee plants and shade trees in the different production systems. It can be noted that the monoculture have a higher residue amount coming from coffee plants as the plants are better nourished in this system. The polycultures have a higher amount of residue coming from shade trees as the amount of shade trees is in these systems much higher compared to the monocultures. Table 12 presents the annual biomass increase in shade trees and coffee plants. Net biomass increase on an annual basis is due to pruning activities close to zero as can be seen in the table. The biomass in shade trees is variable depending on which coffee production system is researched. The values are higher for the monocultures compared to the polycultures (Table 12) as the monocultures present more space and light for trees to develop and are less carbon saturated like dense polycultures.

Table 12: PAI values used in different production systems.

Production system	**Periodic Annual Diameter increment (PAI) in coffee plants**	**Periodic Annual Diameter increment (PAI) in shade trees**	**Reference**
Traditional polyculture	0,0 cm^{-1} yr^{-1}	0,4 cm^{-1} yr^{-1}	Silva and Lopes, (2004)
Commercial monoculture	0,0 cm^{-1} yr^{-1}	0,6 cm^{-1} yr^{-1}	Somarriba, (1990)
Shaded monoculture	0,0 cm^{-1} yr^{-1}	0,8 cm^{-1} yr^{-1}	
Unshaded monoculture	0,0 cm^{-1} yr^{-1}	0,0 cm^{-1} yr^{-1}	

Table 13: Allometric equation models used in different production systems.

Production system	**Allometric equation model used for coffee plants**	**Allometric equation model used for shade trees**
Traditional polyculture	$Y = 0.0659 * D^{1.991}$ Where: Y = aboveground dry matter, kg $(tree)^{-1}$ D = diameter at 15cm from ground, cm For all production systems the above allometric equation model developed by Segura et al. (2006) for *Coffea arabica* has been used. This model was developed using empirical data from Matagalpa, Nicaragua and is thus highly representative for the geographical context of this study (Mesoamerica). This equation is further explained in paragraph 3.4.1	$Y = 0.1466 * DBH^{2.223}$ Where: Y = aboveground dry matter, kg $(tree)^{-1}$ DBH = diameter at breast height, cm For all production systems the above allometric equation model developed by Segura et al. (2006) for *Cordia alliodora*, *Juglans olanchana*, *Inga tonduzzi and Inga punctata* has been used. This model was developed using empirical data from Matagalpa, Nicaragua and is thus highly representative for the geographical context of this study (Mesoamerica).
Commercial monoculture		
Shaded monoculture		
Unshaded monoculture		

To quantify the amount of sequestered carbon in coffee plants and shade trees two allometric equations developed by Segura et al., (2006) have been used (Table 13). A further explanation en complete worked out example for the equation for one *Coffea arabica* plant can be found in paragraph 3.4.1.

3.5.3 Scope and limitations

This study sets out to quantify the effects of different coffee production systems and voluntary standards on climate change. Consequently only emissions occurring on coffee production level have been taken into account. The system boundary has been defined as; the delivery of dried coffee parchment to the location where dry-milling takes place and the dried coffee parchment is processed into green coffee.

This study only takes into account emission associated directly with coffee production. This means that for example; gas that is used to prepare meals for plantation workers and private pick-up trips not used for coffee transport by smallholder farmers are excluded from the assessment. This departs from the assumption that the emissions arising from these activities also occur if there is none or less coffee produced by these farmers.

Very few cases of Land Use Change (LUC) have been encountered and almost always the land use was constant for over a period of 20 years or more. Timber wood extraction was in the researched smallholder farming systems always balanced against shade tree planting activities. For this reason land use change has not been taken along in the assessment as this would have given a bias in the results that would have not been typical for the different production systems.

The quantification of existing carbon stocks in soils requires extensive soil sampling and laboratorial analysis. During the field work access to such laboratories has been very poor and therefore this aspect of carbon sequestration has been left out of the assessment.

Some farms researched—especially commercial polycultures—produce besides coffee as a main product a variety of co-products. Examples include banana, plantain, avocado, mango, orange, mandarin, lemon and vanilla. Despite this variety of products coming from one farm still all the emissions are in the assessment allocated to the production of coffee. This has been done to enable comparison with other systems.

4 RESEARCHED COFFEE SYSTEMS

In this chapter the four different coffee production systems researched are briefly described and visually presented. This overview on the different coffee production systems will help the reader to distinguish better between the four systems while reading the results chapters 5 up to and including 9.

4.1 Traditional polyculture

Traditional polycultures are characterised by a high density of shade trees as can be noted in Figure 3. This coffee production system presents as well the highest amount of different shade tree species per hectare. The amount of shade trees that deliver co-products such as different sorts of fruits is rather low in this production system.

Figure 3: Traditional polyculture.

As can be seen in the left picture in Figure 4 the canopy height of shade trees in a traditional polyculture can exceed 30 meters. Indigenous shade tree species are dominant in this system and these trees (right picture Figure 2) are characterised by high Diameter at Breast Height (DBH) values. Due to the amount and size of the shade trees present in the traditional polyculture the number of coffee plants per hectare is the lowest of all four systems researched. Pesticide use is not encountered in the traditional polyculture and the level of fertilisation is very low. The traditional polyculture is very often an organic farming system. Traditional polycultures that are organic by default (without certification) are encountered during the field work.

Figure 4: Traditional polyculture.

Coffee plants are due to the low fertilisation level small and present less leaves in the traditional polyculture (coffee plant on the foreground of the right picture in Figure 4). Coffee yields in the traditional polyculture are the lowest of all systems researched. The processing of the coffee is exclusively done using the dry process and often ecological processing systems that save on water use are noted.

4.2 Commercial polyculture

In the commercial polyculture coffee production systems researched very few indigenous shade tree species were encountered.

Figure 5: Commercial polyculture.

Instead the shade cover of this system is made up of trees that are almost all used commercially. Examples include banana plants, avocado trees, mango trees and different citrus fruits trees (Figure 5). As indigenous shade trees are seldom seen in the commercial polyculture the canopy height does typically not exceed 15 meters. This allows for more space for coffee plants that are found in higher numbers in the commercial polyculture compared to the traditional polyculture.

Figure 6: Commercial polyculture.

Fertilisation is practiced more often in this system and this results in better developed coffee plants (right picture in Figure 6). Coffee yields are higher in this system compared to the traditional polyculture. In the commercial polycultures researched the processing of the coffee coming was done using the dry processing methodology.

4.3 Shaded monoculture

The shaded monoculture coffee production system uses only one single shade tree species (right picture in Figure 8). Very often *Inga* spp. are encountered as shade trees, a species that remains rather low in DBH figures. The canopy height of the shaded monocultures researched was always below 15 meters. This rather open structure in shaded monocultures (left picture in Figure 7) gives a lot of space for coffee plants which are found in high numbers in this coffee production system. A high amount of fertiliser use is noted in the unshaded monoculture system. Almost exclusively synthetic fertilisers are applied.

Figure 7: Shaded monoculture.

Usually different forms of fertilisation such as soil application and leaf application by spraying (foliar-fertilisation) are combined. Due to the optimal nutrition of the coffee plants yields are in the unshaded monoculture the highest of all researched systems.

Figure 8: Shaded monoculture.

In the researched shaded monocultures the wet coffee processing methodology is applied more often. As well artificial mechanical drying installations that replace sun drying have been encountered.

4.4 Unshaded monoculture

The unshaded monoculture coffee production system abolishes completely the use of shade trees and only coffee plants are found on farms that use this system (Figure 9 and 10). The number of coffee plants is for the latter reason very high. A high amount of fertiliser use has been encountered in the unshaded monocultures researched.

Figure 9: Unshaded monoculture.

Due to the absence of shade trees in the unshaded monoculture the use of tractors for fertilisation, spraying and weeding practices is possible and this has been noted during the field work. The coffee yields in the unshaded monoculture are high.

Figure 10: Unshaded monoculture.

In the unshaded monoculture coffee production systems researched the processing was done using the dry process combined with sun drying of the parchment coffee on patios.

5 DIFFERENCE BETWEEN COFFEE SYSTEMS

In this chapter analysed primary data is presented and discussed. The chapter sets out to answer the following sub research questions:

1. What is the difference between four different coffee production systems distinguished by Moguel and Toledo (1999) regarding on-farm carbon stocks and the carbon footprint?
3. How is the yield level of different coffee production systems impacting on climate change?

5.1 Difference in the on-farm carbon stock

The comparison between the four researched coffee production systems (Figure 11) shows that on farm carbon stocks in both shade trees and coffee plants increase from a mean 17,3 t CO_2-e/ha^{-1} at unshaded monocultures to a mean 91 t CO_2-e/ha^{-1} at traditional polycultures. This is the case as traditional polycultures combine a high number of trees per hectare with high DBH figures, which is a consequence of a high tree age and the use of many indigenous species. Thus traditional polycultures contain the highest on farm carbon stock of all the systems researched.

Commercial polycultures also show high amounts of trees per hectare although the DBH figures are lower in this systems due to lower tree age and an increased use of *Inga* spp., a shade tree that remains smaller compared to indigenous species. Furthermore a high use of *Musa* spp. (banana and plantain) is observed in this production system, plants that have a very limited carbon sequestration capacity compared to tree based shade systems (Roshetko et al., 2002). Consequently commercial polycultures show a lower on-farm carbon stock compared to traditional polycultures.

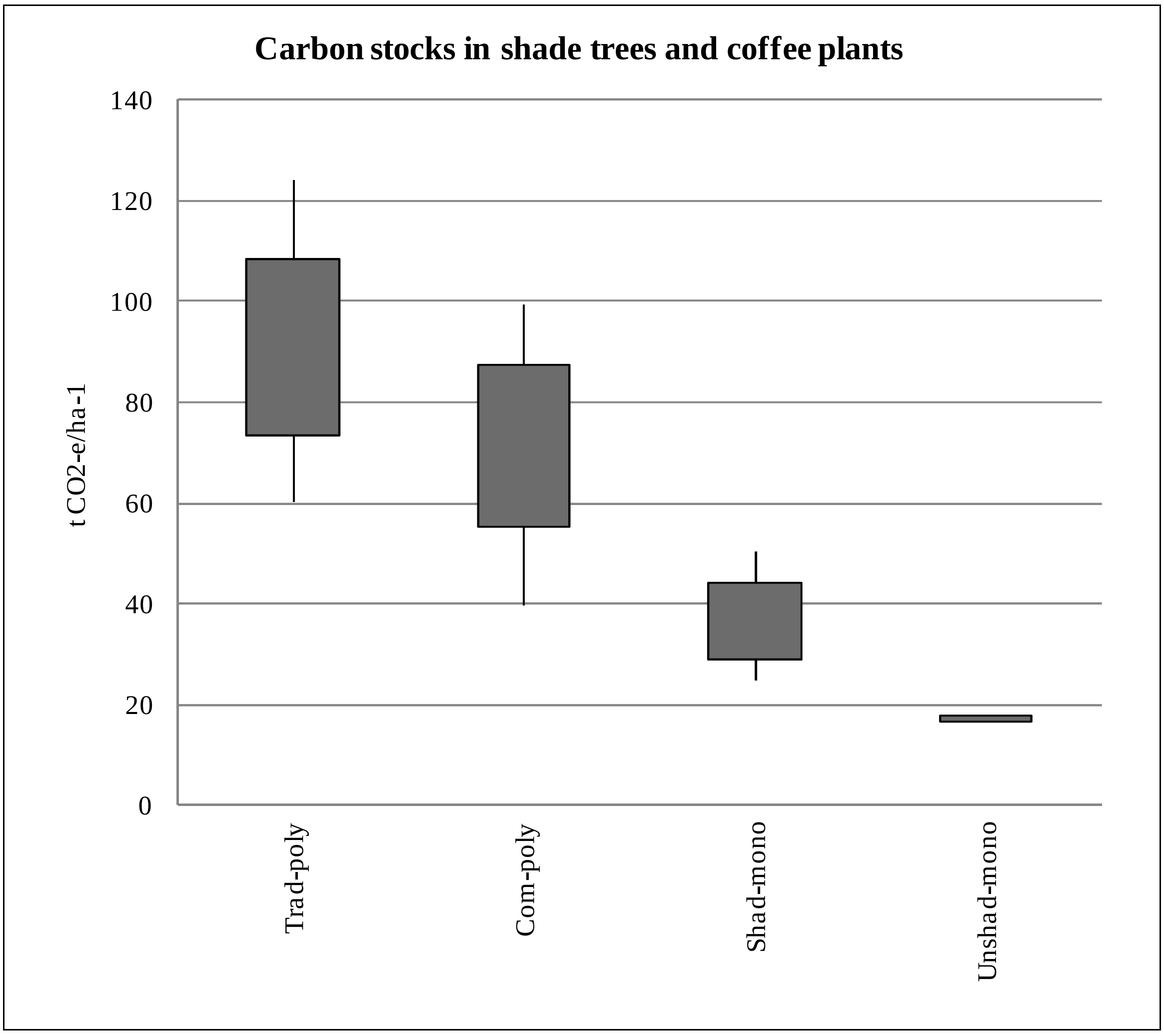


Figure 11: Mean on-farm carbon stocks in shade trees and coffee plants.
The heights of the boxes indicate the mean maximum and mean minimum values and the ends of the lines the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation. The numbers of observations in each group are; Trad-poly = 29, Com-poly = 27, Shad-mono = 8, Unshad-mono = 2.

Shaded monocultures abolish completely the indigenous trees that can be found in the latter systems. Instead a shaded monoculture system uses one species only—often *Inga* spp., or *Gliricidia sepium*—these shade trees show very low DBH figures compared to indigenous species. Furthermore the maximum canopy height is only a fraction of the canopy height that can be reached by the indigenous shade tree species in both polycultures researched. For this reason shaded monocultures show a drastic decrease in on-farm carbon stocks compared to the two polyculture production systems.

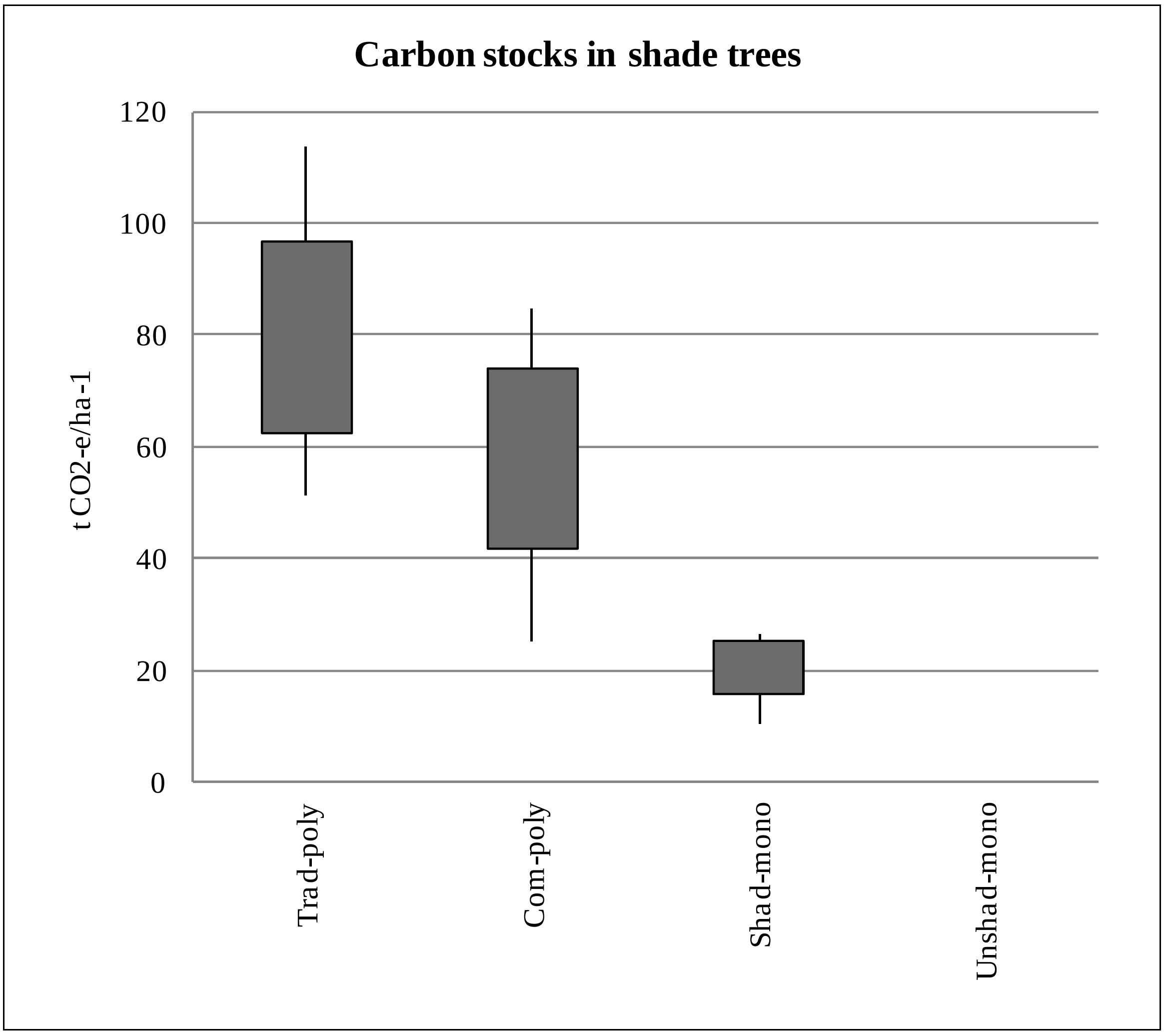


Figure 12: Mean on-farm carbon stocks in shade trees.
The heights of the boxes indicate the mean maximum and mean minimum values and the ends of the lines the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation. The numbers of observations in each group are; Trad-poly = 29, Com-poly = 27, Shad-mono = 8, Unshad-mono = 2.

As can be seen from the zero value in Figure 12 at unshaded monocultures, these systems get do not have shade trees altogether. Therefore carbon sequestration in biomass in this production system can only be observed in coffee plants. The amount of sequestration in coffee plants is limited (Figure 13) and for this reason the unshaded monoculture shows the lowest amount of total on-farm carbon sequestration of all systems researched.

When only the carbon sequestered in coffee plants is taken into account the picture is completely different; on-farm carbon stocks in coffee plants decrease from a mean 17,3 t CO_2-e/ha^{-1} at unshaded monocultures to a mean 11,5 t CO_2-e/ha^{-1} at traditional polycultures (Figure 11).

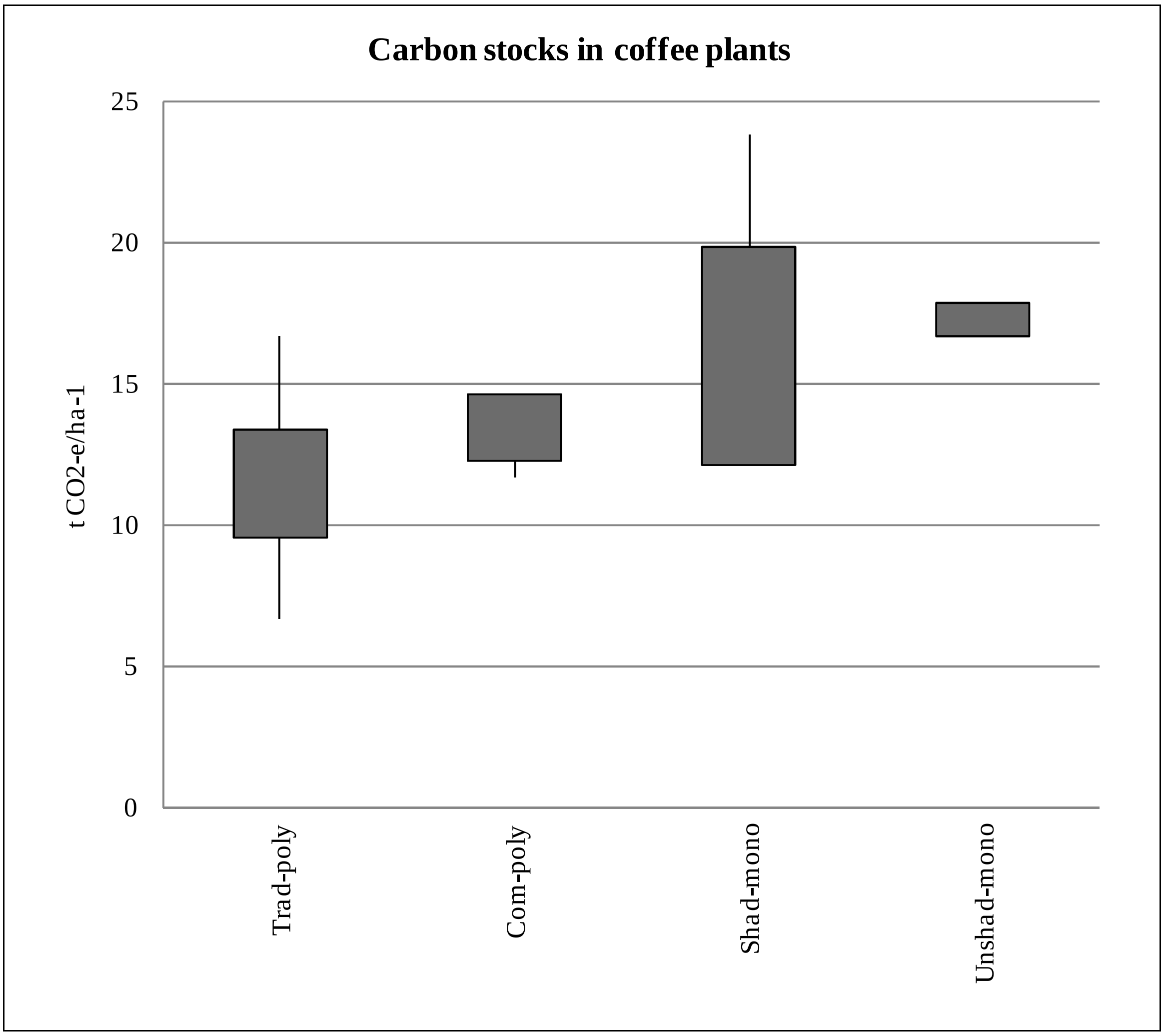


Figure 13: Mean on-farm carbon stocks in coffee plants.
The heights of the boxes indicate the mean maximum and mean minimum values and the ends of the lines the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation. The numbers of observations in each group are; Trad-poly = 29, Com-poly = 27, Shad-mono = 8, Unshad-mono = 2.

This phenomenon is a result of the nature of the four different production systems. Especially the traditional but also the commercial polyculture contain different strata of shade trees with canopy heights that can exceed 30 meters. Consequently ground level there is less space and light available for coffee plants. Therefore much lower amounts of coffee plants per hectare are observed. Meaning a direct reduction in the total amount of carbon stored in the coffee plants.

Unshaded and shaded monocultures present a completely different appearance. All the tree species that require high amounts of space and block too much light are removed in the shaded monoculture. The unshaded monoculture does not contain additional shade trees at all. This presents opportunities for coffee plants that can be found in numbers here up to more than two times higher compared to the polyculture production systems. This results in a higher amount of carbon stored in coffee plants in monoculture systems compared to polyculture systems.

So far the carbon stocks that can be found in different coffee production systems have been evaluated. These stocks are build-up over a long time. When looking to the amounts of carbon that is sequestered in shade trees per coffee crop cycle (annually) interesting dynamics have been observed. Figure 14 reveals that; the mean annual amount of sequestered carbon in shade trees is: 0,6 t CO_2-e/ha^{-1} yr^{-1} (Shad-mono), 0,7 t CO_2-e/ha^{-1} yr^{-1} (Com-poly) and 0,7 t CO_2-e/ha^{-1} yr^{-1} (Trad-poly).

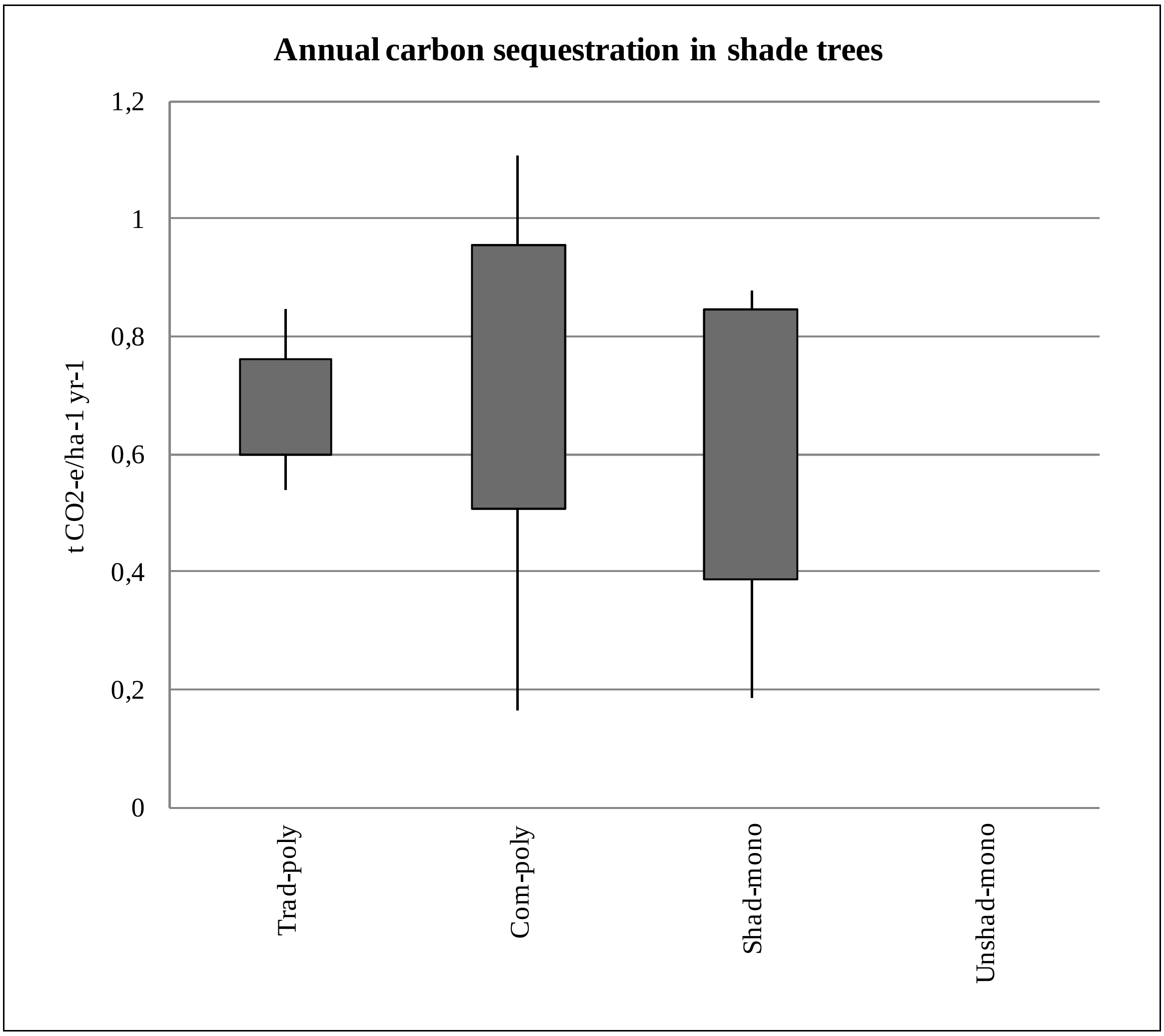


Figure 14: Mean annual sequestered carbon in shade trees.
The heights of the boxes indicate the mean maximum and mean minimum values and the ends of the lines the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation. The numbers of observations in each group are; Trad-poly = 29, Com-poly = 27, Shad-mono = 8, Unshad-mono = 2.

This means that although the existing on-farm carbon stock in shade trees is up to four times higher at traditional polycultures compared to shaded monocultures, the annual carbon sequestration in not significantly higher. This goes against the reasoning that because of a high amount of shade trees combined with high DBH figures, a traditional polyculture should be able to show also a significantly higher amount of annual carbon storage compared to the unshaded monoculture system. The observation that is presented in the results can be explained by looking at the shade tree growth dynamics in the four different coffee production systems. Silva and Lopes (2004) found that the Periodic Annual diameter Increment (PAI) value of trees in dense systems such as traditional polycultures is 0,4 cm^{-1} yr^{-1}. Whereby Somarriba (1990) reports a 0,6 cm^{-1} yr^{-1} PAI value for systems that can be compared with commercial polycultures and a 0,8 cm^{-1} yr^{-1} PAI value for systems that can be compared with shaded monocultures. Thus other researchers found that shade trees in shaded monocultures grow twice as fast compared to traditional polycultures. This is the reason that shaded monocultures can—in terms of annual carbon sequestration—still compete with their traditional polyculture counterparts.

5.2 Difference in the carbon footprint

5.2.1 Carbon footprint per unit area

The comparison of the carbon footprint per unit area of coffee parchment produced in four different coffee production systems in Mesoamerica (Figure 15) shows that the mean carbon footprint is: 2216 kg CO_2-e/ha^{-1} (Trad-poly) 3978 kg CO_2-e/ha^{-1} (Com-poly) 8720 kg CO_2-e/ha^{-1} (Shad-mono) and 6388 kg CO_2-e/ha^{-1} (Unshad-mono).

Traditional polyculture

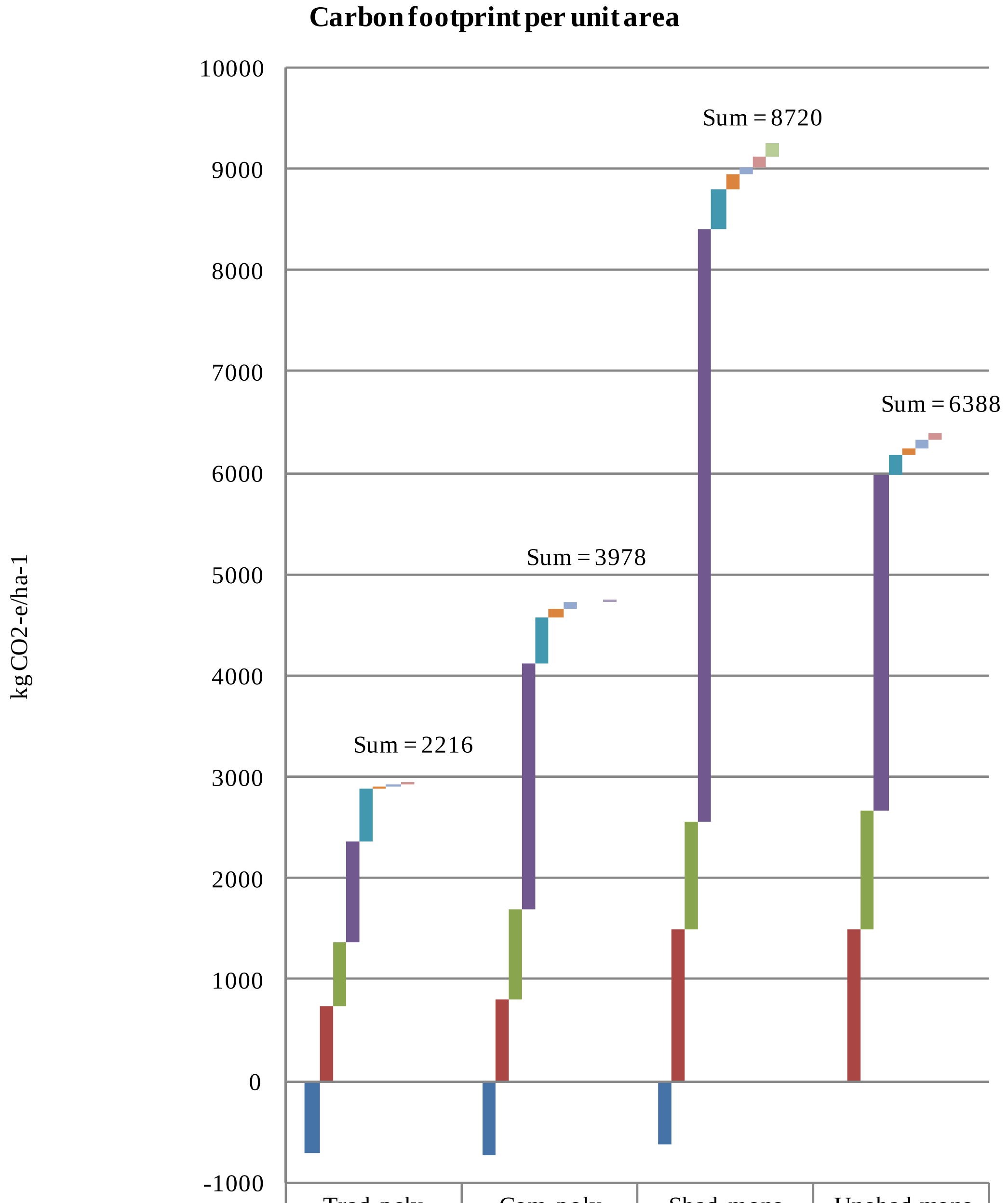
The carbon footprint of coffee parchment produced in traditional polycultures is the lowest of all systems. The driving background reasons are discussed:

1. Low fossil fuel use. Due to manual de-pulping installations and farmers who carry coffee cherries to processing plants rather than using pick-up trucks.
2. Low amount of wastewater generation. In traditional polycultures exclusively the dry coffee processing method is used. Often in combination with ecological de-pulping installations that achieve a further reduction in water use.
3. Low amount of fertilisers used. Traditional polycultures are very often organic farming systems by default. Organic farms without certification are observed.
4. High amount of carbon sequestration. Traditional polycultures store high amounts of carbon due to a high amount of old indigenous shade tree species on the farms.

Commercial polyculture

The carbon footprint of coffee parchment produced in commercial polycultures is higher compared to the traditional polyculture but still lower compared to the two monocultures. The driving background reasons are discussed:

1. Low fossil fuel use. Due to manual de-pulping installations and farmers who carry cherries to processing plants rather than using pick-up trucks.
2. Intermediate amount of wastewater generation. Various processing methods are observed in the commercial polyculture. Resulting in an average generation of wastewater.
3. Low amount of fertilisers used. Commercial polycultures show an increased amount of fertilisers used compared to traditional polycultures but the fertilisation level is still low and often organic.



	Trad-poly	Com-poly	Shad-mono	Unshad-mono
Pesticide production	0	2	0	0
Gas use	0	0	115	0
Diesel use	1	0	124	54
Electricity use	19	52	62	104
Off-farm transport	25	100	140	46
Crop residue managment	515	451	386	215
Waste water production	1009	2422	5860	3293
Fertiliser induced N2O	620	884	1057	1180
Fertiliser production	739	807	1499	1497
Biomass shade	-713	-740	-617	0

Figure 15: Mean carbon footprint measured on a per hectare basis.
The numbers of observations in each group are; Trad-poly = 29, Com-poly = 27, Shad-mono = 8, Unshad-mono = 2.

4. High amount of carbon sequestration. Commercial polycultures store the highest amounts of (annual) carbon due to a relatively high amount of trees per hectare combined with a higher tree growth rate compared to the traditional polyculture.

Shaded monoculture

The carbon footprint of coffee parchment produced in the shaded monoculture is the highest of all systems researched. The driving background reasons are discussed:

1. High fuel use. Due to electrical or diesel powered de-pulping, artificial mechanical drying installations powered by diesel and gas and transport of cherries and parchment often with pick-up trucks.
2. High wastewater use. The wet processing method is observed more often in the shaded monoculture system, which increases the generation and discharge of wastewater tremendously.
3. High amount of fertilisers used. Shaded monocultures are high-input farming systems that rely on an extensive use of (often) synthetic fertilisers.

Unshaded monoculture

The carbon footprint of coffee parchment produced in the unshaded monoculture is high compared to the two polycultures. The driving background reasons are discussed:

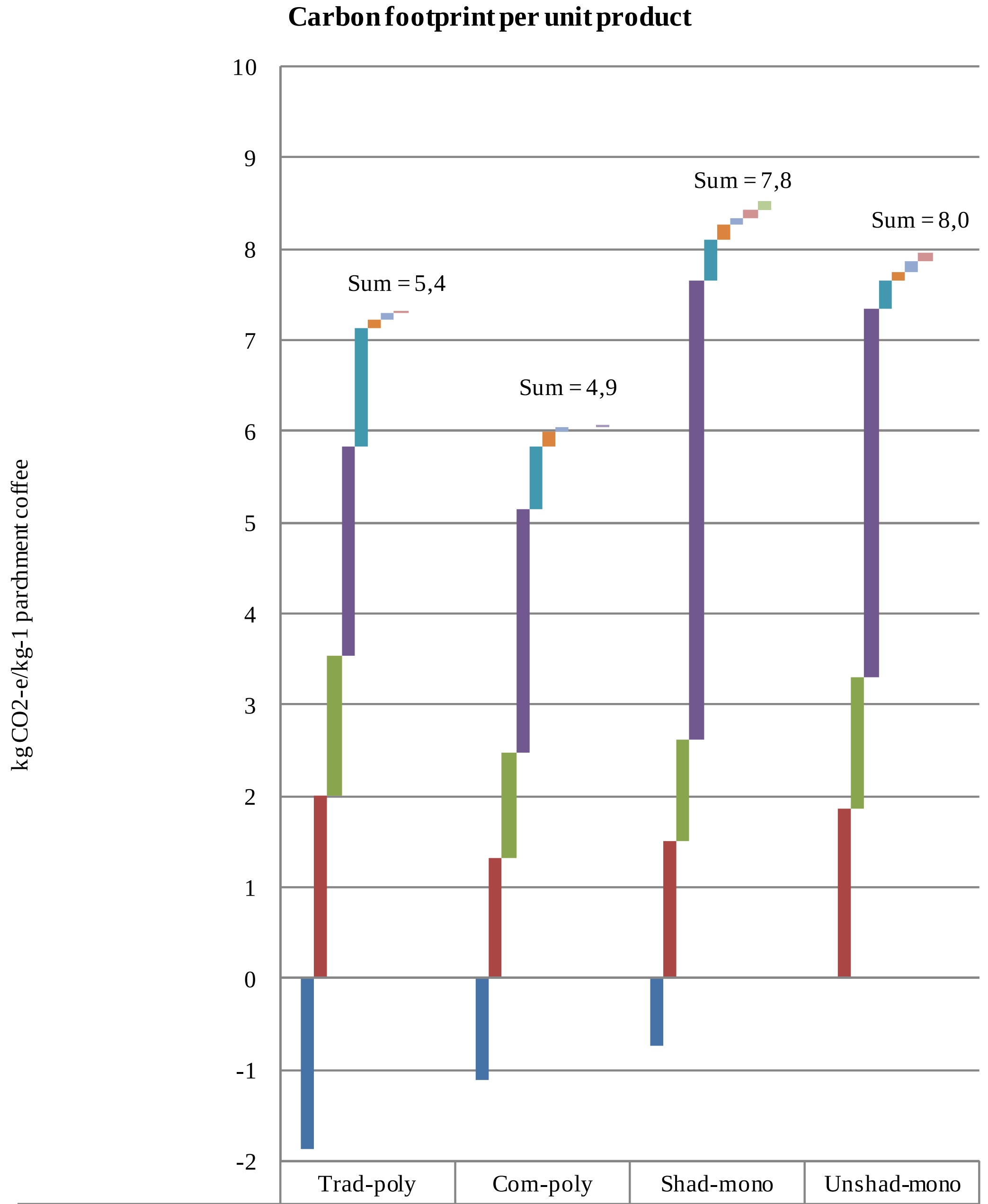
1. Intermediate fuel use. De-pulping is done with electricity in this system. The systems researched used tractors for practices such as weeding, fertilisation and spraying in between the coffee rows.
2. High wastewater use. De-pulping is done in the traditional system that shows higher amounts of wastewater production compared to for example ecological de-pulping processes.
3. High amount of fertilisers used. Unshaded monocultures are high-input systems that rely on an extensive use of (often) synthetic fertilisers.
4. No carbon sequestration. Unshaded monocultures lack on-farm shade trees that sequester carbon during the annual coffee crop cycle. The unshaded monoculture is therefore unable to compensate for some of its emissions by means of on-farm carbon sequestration.

5.2.2 Carbon footprint per unit product

The comparison of the carbon footprint per unit product of coffee parchment produced in four different coffee production systems in Mesoamerica (Figure 16) shows that the mean carbon footprint is: 5,4 kg CO_2-e/kg^{-1} (Trad-poly) 4,9 kg CO_2-e/kg^{-1} (Com-poly) 7,8 kg CO_2-e/kg^{-1} (Shad-mono) and 8,0 kg CO_2-e/kg^{-1} (Unshad-mono).

Showing the carbon footprint of Mesoamerican coffee production as well calculated on a per unit product basis (PCF) is highly relevant. This is the case as PCF´s are used internationally to communicate on the performance of different products regarding their effects on climate change (BMU and Öko-Institut e.V, 2009). When calculating the carbon footprint of coffee parchment production in Mesoamerica on a per unit product basis different dynamics are found. The results show that commercial polycultures perform best by emitting the lowest amount of GHG´s of all production systems. Shaded monocultures show in the overview in Figure 16 an increased efficiency compared to the data in the per hectare calculations (Figure 15).

This difference in the carbon footprint per unit product compared to the carbon footprint per unit area can be explained by looking closer to an important factor that drives a product carbon footprint which is the production level or yield. All GHG emissions arising from a production system are in the PCF methodology allocated to the amount of coffee produced. This explains why the unshaded monoculture—that uses a high amount of fertilisers, fossil fuels and water—shows a lower carbon footprint per unit product; simply because this system on average yields twice as much coffee compared to the traditional polyculture systems (Figure 17).



	Trad-poly	Com-poly	Shad-mono	Unshad-mono
Pesticide production	0,0	0,0	0,0	0,0
Gas use	0,0	0,0	0,1	0,0
Diesel use	0,0	0,0	0,1	0,1
Electricity use	0,1	0,1	0,1	0,1
Off-farm transport	0,1	0,2	0,2	0,1
Crop residue managment	1,3	0,7	0,5	0,3
Waste water production	2,3	2,7	5,0	4,1
Fertiliser induced N2O	1,5	1,2	1,1	1,5
Fertiliser production	2,0	1,3	1,5	1,9
Biomass shade	-1,9	-1,1	-0,8	0,0

Figure 16: Mean carbon footprint measured on a per unit product basis.

The numbers of observations in each group are; Trad-poly = 29, Com-poly = 27, Shad-mono = 8, Unshad-mono = 2.

Traditional polycultures—often certified organic farming systems or organic by default—show a high amount of emissions arising from fertiliser production and application. This is the case as these emissions are allocated to the amount of produce coming from this system which is markedly low (Figure 17). One can thus state that a PCF applied in agriculture gives insight in the optimal ¨input-output¨ balance of production systems regarding climate change. In this light it is concluded that commercial polycultures show the best input-output level of all systems researched. This is definitely the case when one takes into account that besides coffee this system can bring banana, plantain, avocado, mango, orange, mandarin, lemon and vanilla to the table.

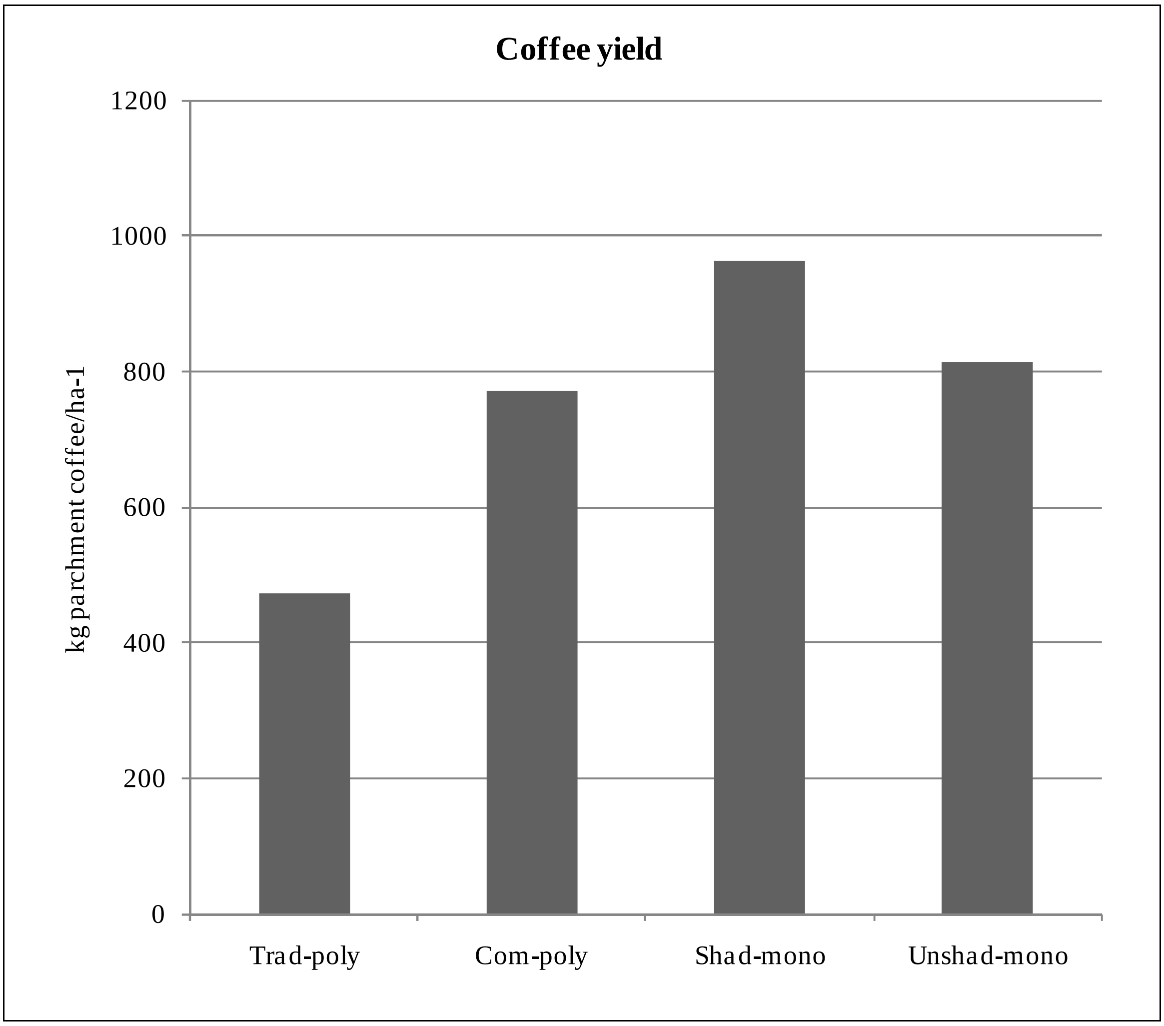


Figure 17: Mean yield for four different coffee production systems.
The numbers of observations in each group are; Trad-poly = 29, Com-poly = 27, Shad-mono = 8, Unshad-mono = 2.

5.3 Overall evaluation

This efficiency thinking that is triggered by the PCF methodology helps in drawing conclusions regarding which production system is most desirable in the Mesoamerica region from a climate change perspective. A question that will certainly arise when evaluating all the results regarding on-farm carbon stocks, carbon footprints per hectare and product carbon footprints together.

The traditional polyculture is the absolute winner when looking at emission per hectare and on-farm carbon stocks. Still this system shows a slightly decreased performance in the PCF of coffee coming from such farms. This is because the production levels are remarkably low. A broader consequence is that producing a comparable volume of coffee in such systems requires much more land. Increased need for land often comes with deforestation and entering into protected areas or national parks, something that should be avoided. Shaded and unshaded monocultures present high GHG emissions in both carbon footprint methods combined with very low on-farm carbon stocks. This is an undesirable combination when climate change mitigation is on the agenda.

Commercial polycultures present a low carbon footprint per unit land, the lowest product carbon footprint and still conserve a mean 71,3 t CO_2-e/ha^{-1} in shade trees and coffee plants. Furthermore this system shows the highest level of farm diversification which results in a whole range of co-products besides coffee only. Based on the discussed findings it is stated that diversified commercial polycultures are the future in producing coffee with the least amount of pressure on our climate. As well it is expected that the negative impacts on farmer livelihoods resulting out of low coffee prices or extreme weather events are decreased to a minimum by commercial polycultures due to their high crop diversification.

6 INFLUENCE OF VOLUNTARY STANDARDS

In this chapter analysed primary data is presented and discussed. The chapter sets out to answer the following sub research questions:

2. To what extend have organic, Rainforest Alliance and UTZ certification systems an impact on the on-farm carbon stocks and the carbon footprint?
3. How is the yield level of different coffee production systems impacting on climate change?

6.1 Influence on the on-farm carbon stock

The comparison between the researched voluntary standards (Figure 18) shows that on farm carbon stocks in both shade trees and coffee plants are: 83,4 t CO_2-e ha^{-1} (Organic), 85,2 t CO_2-e ha^{-1} (Rainforest Alliance/UTZ) and 77,9 t CO_2-e ha^{-1} (Conventional).

Based on these results it can be concluded that on-farm carbon stocks do not differ significantly among different types of standard systems. For the comparison all the organic, Rainforest Alliance/UTZ and conventional farms sampled in the traditional polyculture and commercial polyculture are used. This has been done firstly as the certified farms sampled were concentrated in these groups. Secondly this strategy has been chosen as the same kind of comparison of carbon stocks with the production systems that are distinguished by Moguel and Toledo (1999) show high differences between the group's polycultures/monocultures. Thus by including the voluntary systems from all the Moguel and Toledo (1999) productions systems for comparison one would be measuring the differences between these systems rather than the difference between voluntary standards. Thus in order to measure what was desired to be measured—the difference between voluntary standard systems—the data from both polycultures has been used for comparison.

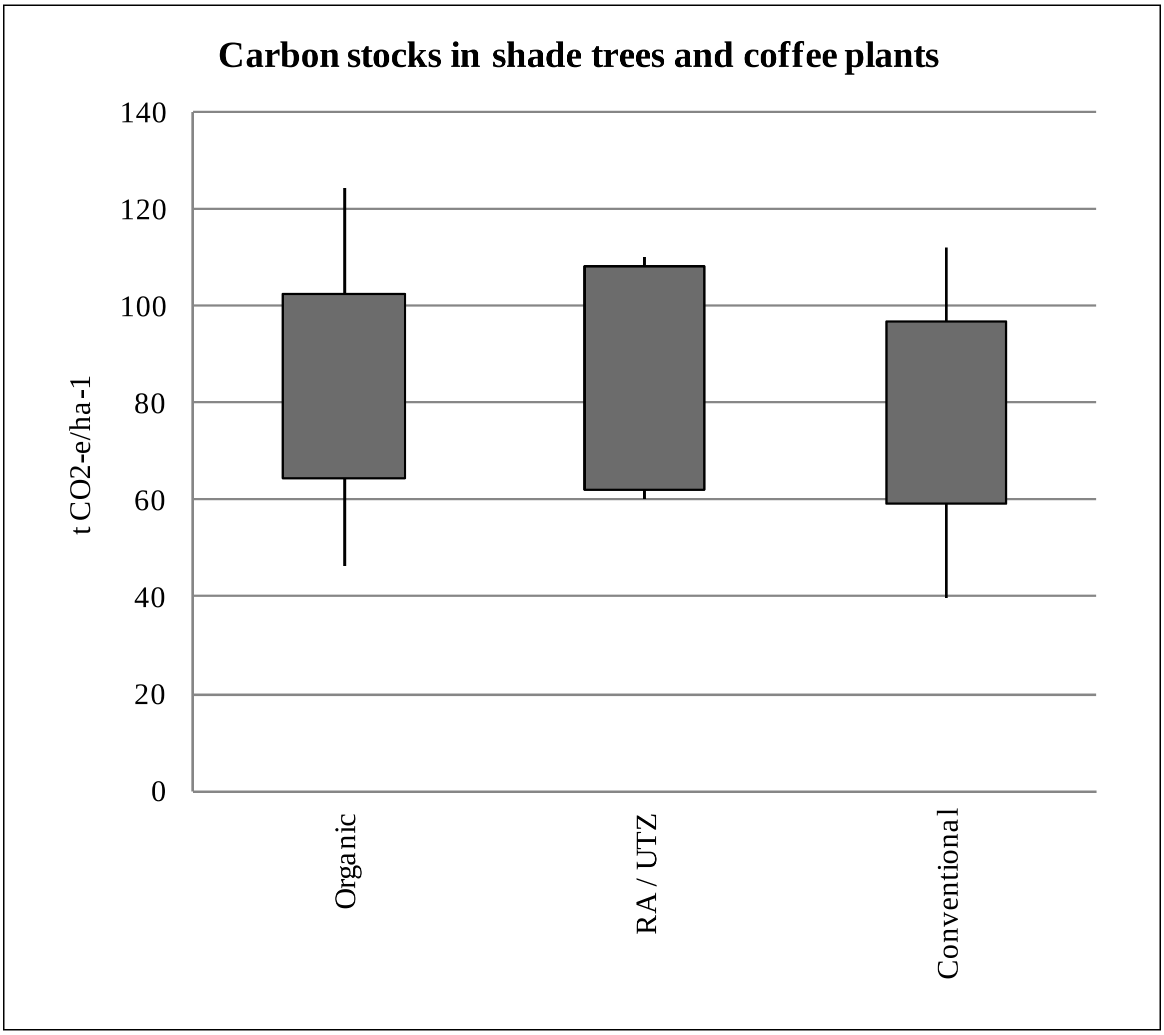


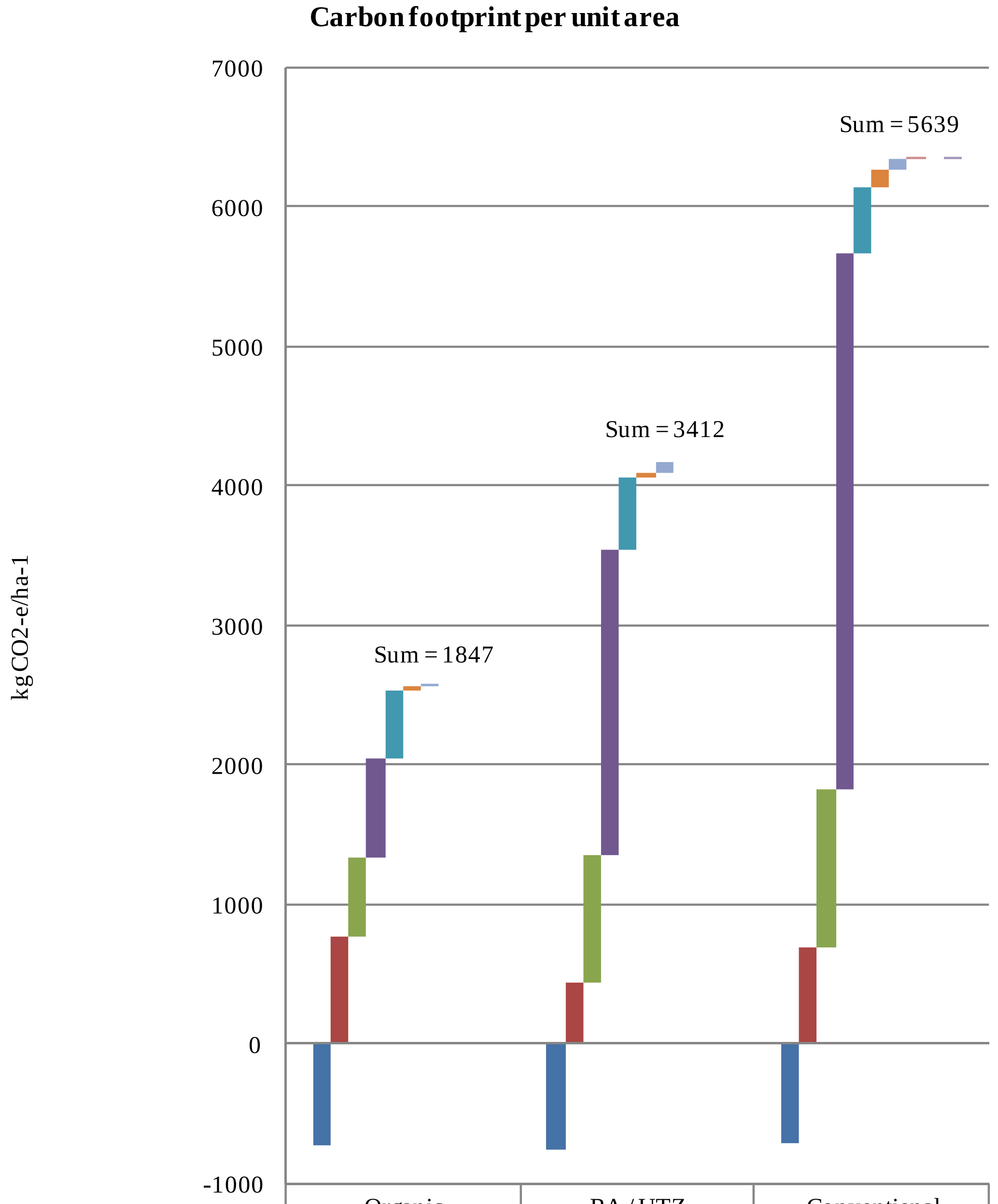
Figure 18: Mean on-farm carbon stocks in shade trees and coffee plants.
The heights of the boxes indicate the mean maximum and mean minimum values and the ends of the lines the maximum and minimum values. The mean maximum and mean minimum values are defined by the mean + or – the standard deviation. The numbers of observations in each group are; Organic = 35, RA/UTZ = 4, Conventional = 15.

6.2 Influence on the carbon footprint

6.2.1 Carbon footprint per unit area

The comparison of the carbon footprint per unit area of the different voluntary standards researched (Figure 19) shows that the mean carbon footprint is: 1847 kg CO_2-e/ha^{-1} (Organic) 3412 kg CO_2-e/ha^{-1} (Rainforest Alliance/UTZ) and 5639 kg CO_2-e/ha^{-1} (Conventional).

This means that Figure 19 shows that organic farming is performing much better compared to conventional farming. This is mainly driven by the low amount of wastewater production that is observed at the organic farms. Conventional farming on the other hand produces a tremendous amount of wastewater, a result of the wet coffee processing method which is often observed in this farming system (see Wastewater production, Figure 19). Furthermore the extensive use and application of fertilisers causes a further rise of the GHG emissions coming from conventional coffee farming systems. The farms that are Rainforest Alliance and UTZ certified score in between organic and conventional production systems regarding GHG emissions.



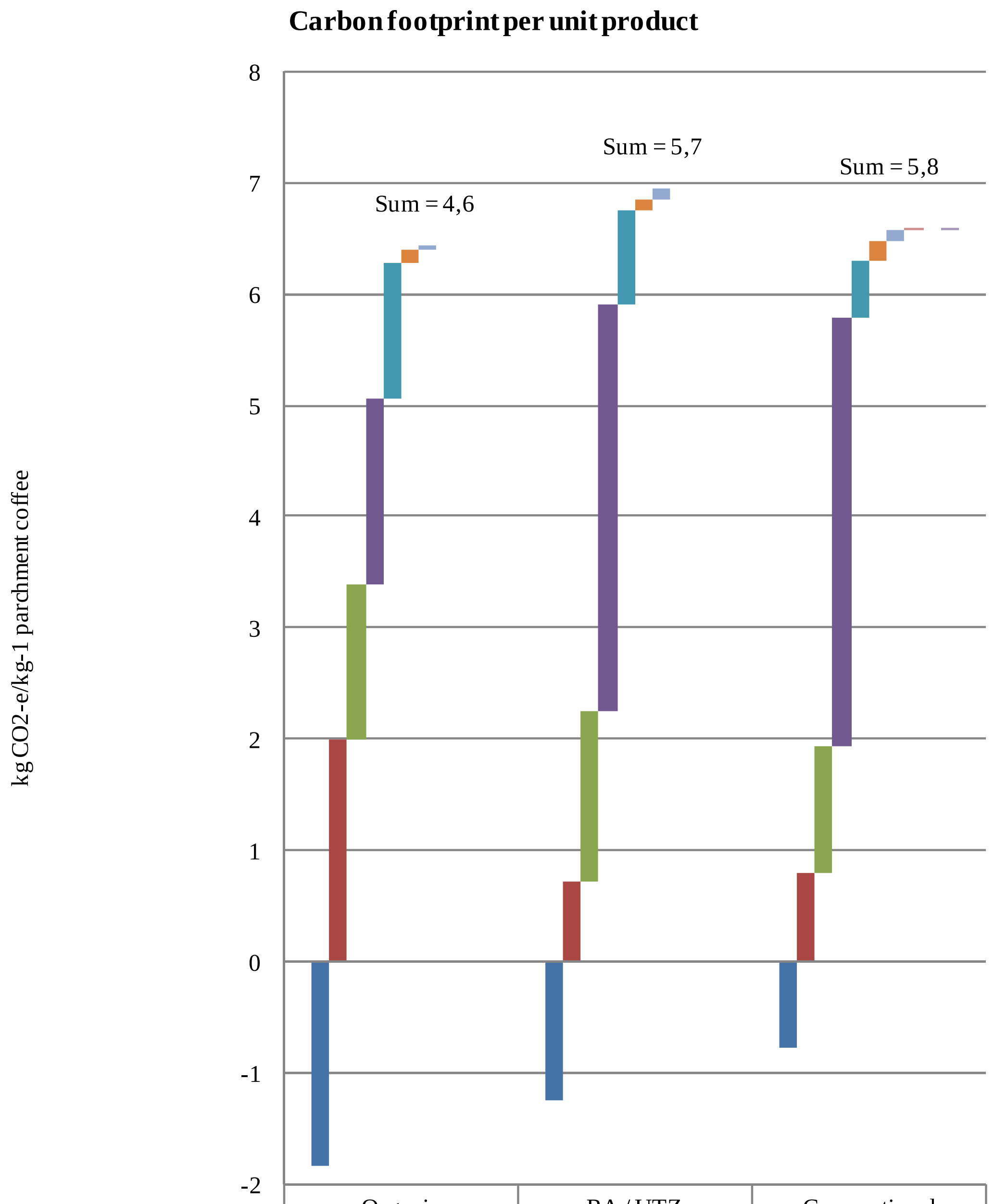
	Organic	RA / UTZ	Conventional
Pesticide production	0	0	4
Gas use	0	0	0
Diesel use	0	0	3
Electricity use	10	77	77
Off-farm transport	36	33	134
Crop residue managment	489	515	468
Waste water production	706	2188	3838
Fertiliser induced N2O	560	916	1139
Fertiliser production	773	441	694
Biomass shade	-727	-758	-717

Figure 19: Mean carbon footprint measured on a per hectare basis.
The numbers of observations in each group are; Organic = 35, RA/UTZ = 4, Conventional = 15.

6.2.2 Carbon footprint per unit product

The comparison of the carbon footprint per unit product of the different voluntary standards researched (Figure 20) shows that the mean carbon footprint is: 4,6 kg CO_2-e/kg^{-1} (Organic) 5,7 kg CO_2-e/kg^{-1} (Rainforest Alliance/UTZ) and 5,8 kg CO_2-e/kg^{-1} (Conventional).

Thus Figure 20 shows that organic coffee farming has the lowest product carbon footprint. Rainforest Alliance and UTZ certified farms score on the same level as conventional farming. When looking at the background factors that determine these figures it is noticed that organic farming has a lower carbon footprint because of a lower amount of wastewater production, and a higher amount of carbon sequestration (per unit product). The question: ¨*How can organic systems present a higher amount of carbon sequestration as it is presented before (Figure 18) that on-farm carbon stocks among the three systems differ not significantly?*¨ arises here. This question is answered by looking at the mean yield figures of the different voluntary standards researched (Figure 21). Organic farming presents a mean yield that is more than two times lower compared to conventional coffee farming. This means that all the annual sequestered carbon is in a per unit product (PCF) calculation allocated to less unit product (coffee parchment). This drives up the carbon sequestration values. For the same reason emissions from fertilisers are at the organic farming system the highest compared to the other two systems.



	Organic	RA / UTZ	Conventional
Pesticide production	0,0	0,0	0,0
Gas use	0,0	0,0	0,0
Diesel use	0,0	0,0	0,0
Electricity use	0,0	0,1	0,1
Off-farm transport	0,1	0,1	0,2
Crop residue managment	1,2	0,9	0,5
Waste water production	1,7	3,7	3,8
Fertiliser induced N2O	1,4	1,5	1,1
Fertiliser production	2,0	0,7	0,8
Biomass shade	-1,8	-1,3	-0,8

Figure 20: Mean carbon footprint measured on a per unit product basis.
The numbers of observations in each group are; Organic = 35, RA/UTZ = 4, Conventional = 15.

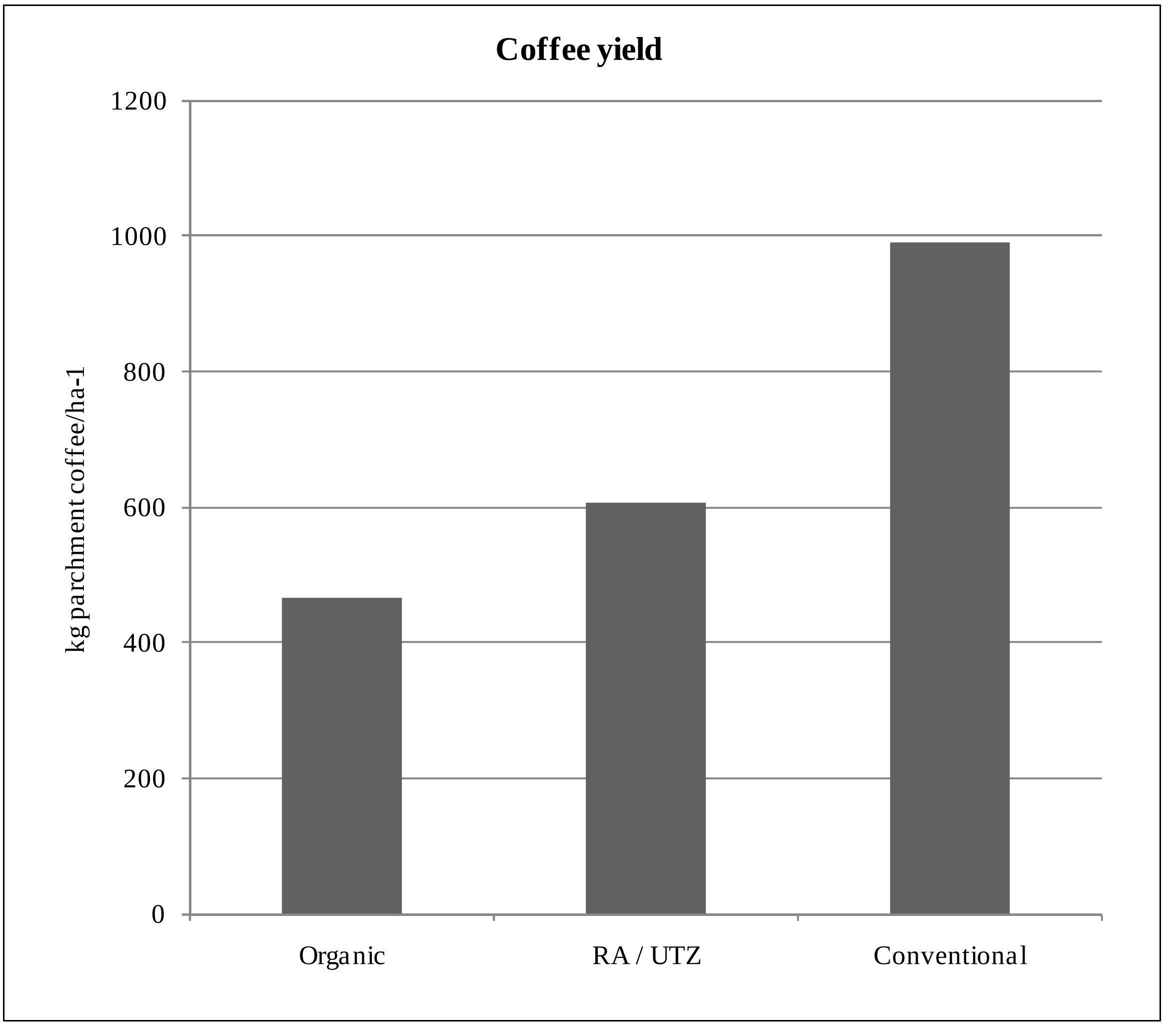


Figure 21: Mean yield for organic, RA/UTZ and conventional production systems.
The numbers of observations in each group are; Organic = 35, RA/UTZ = 4, Conventional = 15.

6.3 Overall evaluation

The factors that indicate the influence of different voluntary standards on climate change have been presented and discussed. It was outlined that on-farm carbon sequestration is not differencing significantly among the researched systems. Regarding the carbon footprints of coffee products that come from the different researched systems it was found and discussed that organic farms present the most favourable figures. Does this mean that organic farming is the solution to climate change mitigation in coffee farming on a broad scale? This cannot be the conclusion when the mean yield figures from the three assessed systems are taken into account. Promoting organic agriculture as the way forward from a climate change perspective would mean more than two times the amount of land currently used for coffee production is needed. This comes with a range of undesirable side-effects such as accelerated land-use change and deforestation. Currently Rainforest Alliance and

UTZ certified farms sit in-between organic and conventional farming regarding both yield and GHG emission figures. This is an interesting combination that touches upon the earlier highlighted input-output line of thinking. In terms of the input-output balance Rainforest Alliance and UTZ certified farms present the most favourable figures for low GHG coffee farming. Although the difference with conventional farming is still small and more needs to be done to upscale the (potential) role of voluntary standards as promoters and validators of climate friendly coffee farming. How this can be done most effectively is presented and discussed in the next chapter (Chapter 7).

7 FRAMEWORK FOR EFFECTIVE MITIGATION

In this chapter analysed primary data is presented and discussed. The chapter sets out to answer the following sub research question:

4. Which agricultural practices are most effective in mitigating the effects of climate change on coffee production level?

7.1 Analytical framework

To design a framework for effective climate change mitigation it is of primary importance to first understand what determines the effectiveness of processes. By analysing organisational problems, In ´t Veld (2002) stated that the effectiveness of a certain process depends on the independent variables in the following proposition:

Effectiveness = Content * Acceptance

This finding is used as the basis of the introduced framework for effective climate change mitigation on coffee production level. The proposition by In ´t Veld (2002) has been adapted into the following proposition that defines the effectiveness of the here introduced climate change mitigation framework:

$$MIT_x = PRC_y * FSB_z$$

Where:

MIT = mitigation, kg CO_2-e

PRC = correct practices

FSB = implementation feasibility

Thus the amount of climate change mitigation in a coffee farming system at location *x* is determined by using the correct agricultural practices at location *y* times the level of implementation feasibility of these practices for farmers at location *z*. To make this analytical mitigation framework functioning still the correct agricultural practices for climate change mitigation need to be defined. As well the feasibility of implementation of those practices needs to be ensured. Both issues are addressed in the next paragraphs.

7.2 Most effective mitigation practices

In defining effective climate change mitigation practices one should focus on those factors that show the highest contribution to the total amount of GHG emissions emitted in coffee production. An overview of the emission factors and their mean share of all Mesoamerican coffee production systems researched is shown in Figure 22.

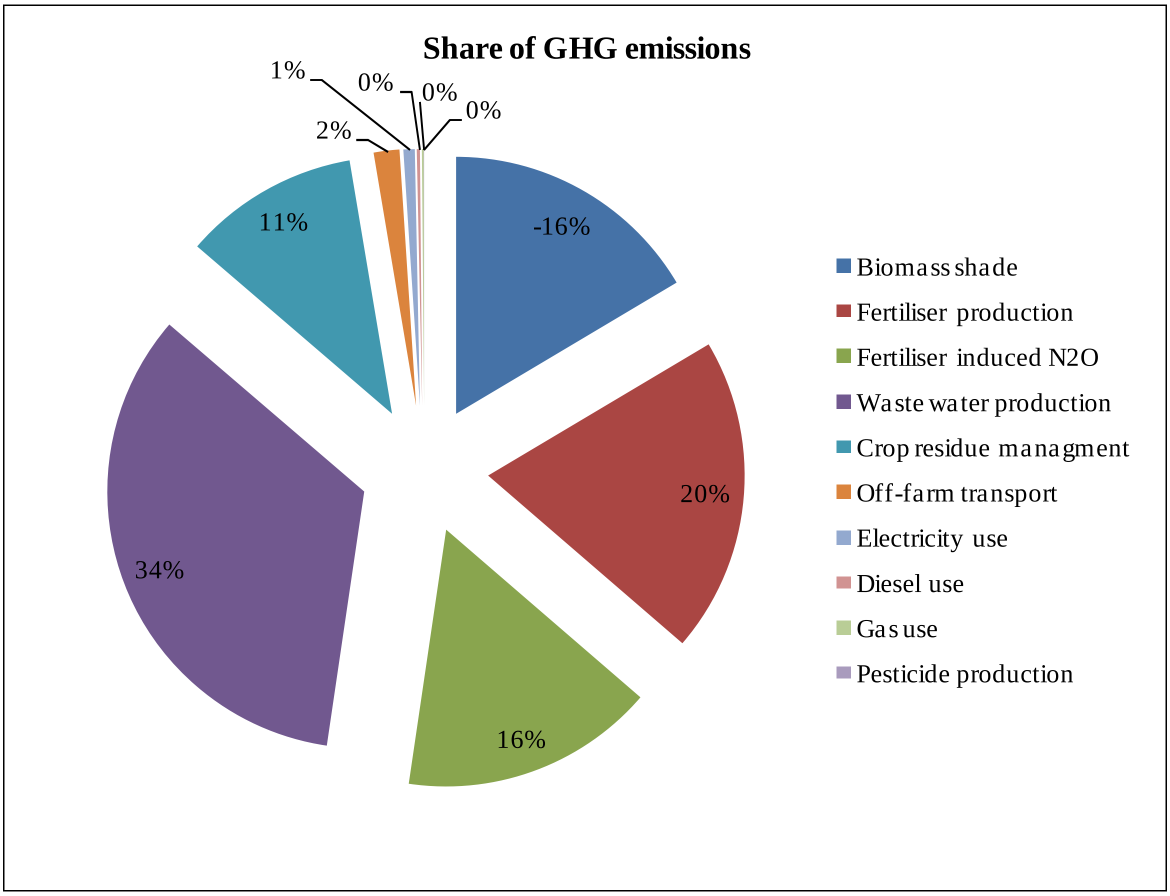


Figure 22: Mean share of GHG emissions for all coffee farms researched.
The number of observations = 66.

In Figure 22 it is brought forward that the factors contributing most to the mean product carbon footprint of all Mesoamerican coffee production systems researched are:

1. Carbon sequestration in on-farm shade tree biomass (16 percent).
2. The production and application of organic and synthetic fertilisers (36 percent).
3. The generation and discharge of wastewater (34 percent).

Subsequently Figure 22 shows that emissions arising from all fossil fuel use and the production of synthetic pesticides contribute with 3 percent total very few to the carbon footprint of Mesoamerican coffee production. From this comparison it is derived that mitigation strategies in Mesoamerican coffee production should concentrate around: (1) conserving and increasing the on-farm carbon stock in biomass, (2) reducing the emissions arising from fertiliser production and application and (3) reducing the emissions arising from the generation and discharge of wastewater.

7.3 Implementation feasibility

From the experience researching 66 coffee farms across Mesoamerica is has been founded that coffee productions systems vary a great deal depending on various factors such as; farm input levels, processing methodologies, geographical location and the organisational level of the respective cooperative or farmer. In this paragraph the need for mitigation strategies that are tailored to the specific nature of the respective coffee production system is illustrated by means of three examples according the three mitigation focus points outlined in paragraph 7.2.

7.3.1 Example I: coffee shading

The difference between different shading systems in coffee farms is visually illustrated in Figure 23. By comparing the effect of these different shading systems on the carbon sequestration per hectare (Figure 24) it is demonstrated that shade systems that are dominated by *Musa* spp. (banana and plantain) store significantly less carbon compared to systems with trees.

Figure 23: Different shading systems in coffee farms.
Banana plants used for shading in a coffee plot (left), versus a coffee farm that makes use of different strata of shade trees (right).

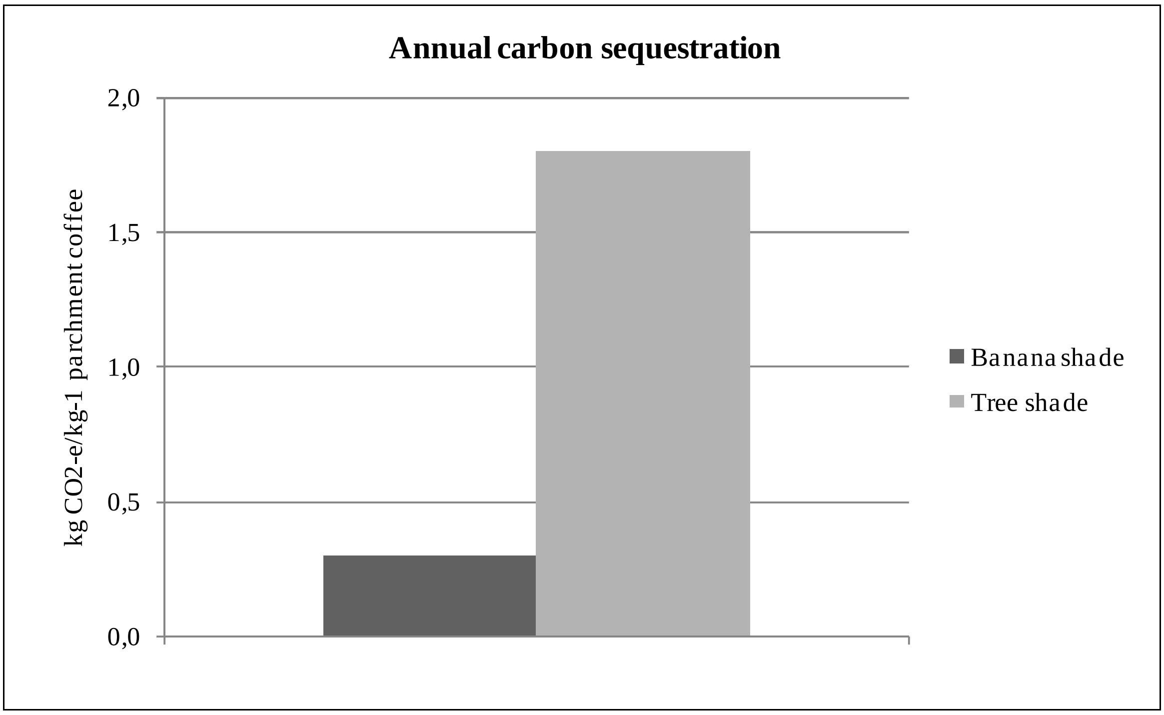


Figure 24: Carbon sequestration in differently shaded coffee farms.
The graph presents two cases from the data collection; a farm using a banana shade system and a farm with a tree shade system.

7.3.2 Example II: coffee fertilisation

A wide variety of fertilisation practices has been encountered in the field. The most contrasting is the difference between high-input systems that make use of various synthetic fertilisers and organic systems that often use composted coffee pulp (Figure 25). The nature of fertilisation has a high impact on the amount of GHG emission emitted from farming systems.

Figure 25: Different ways of fertilising coffee plants.
Urea fertiliser used in high-input coffee production systems (left), versus composted coffee cherry pulp used as fertilisation in organic systems (right).

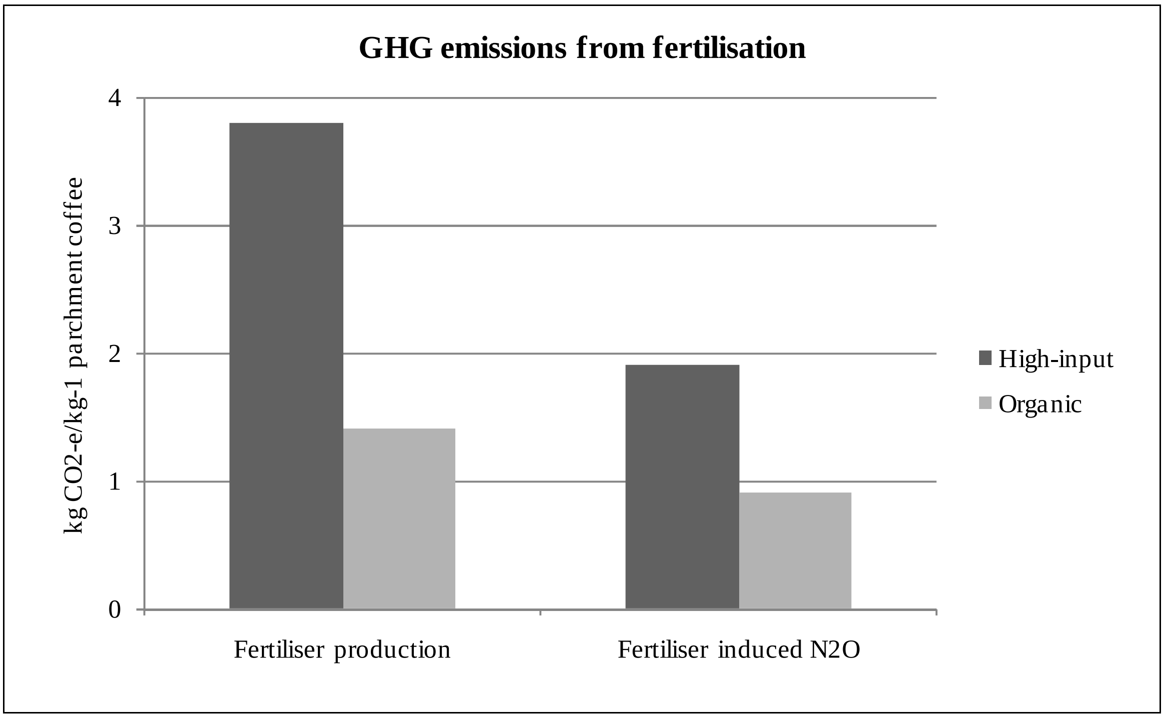


Figure 26: GHG emissions for differently fertilised coffee farms.
The graph presents two cases from the data collection; a high-input farm and an organic farm.

Figure 26 compares a high input coffee farming system versus an organic farming system. The comparison illustrates that high-input systems emit more than two times the amount of GHG´s compared to organic coffee farming.

7.3.4 Example III: coffee processing

Finally the effect of different coffee processing methods is illustrated. Figure 27 and 28 show the differences between the wet and dry processing machinery used.

Figure 27: Processing coffee using the wet process.
Fermentation basins part of the wet coffee processing method (left), combined with an artificial mechanical drying installation (right).

Figure 28: Processing coffee using the dry process.
Ecological coffee processing installation making use of a manual de-pulper (left), combined with a patio for sun-drying parchment coffee (right).

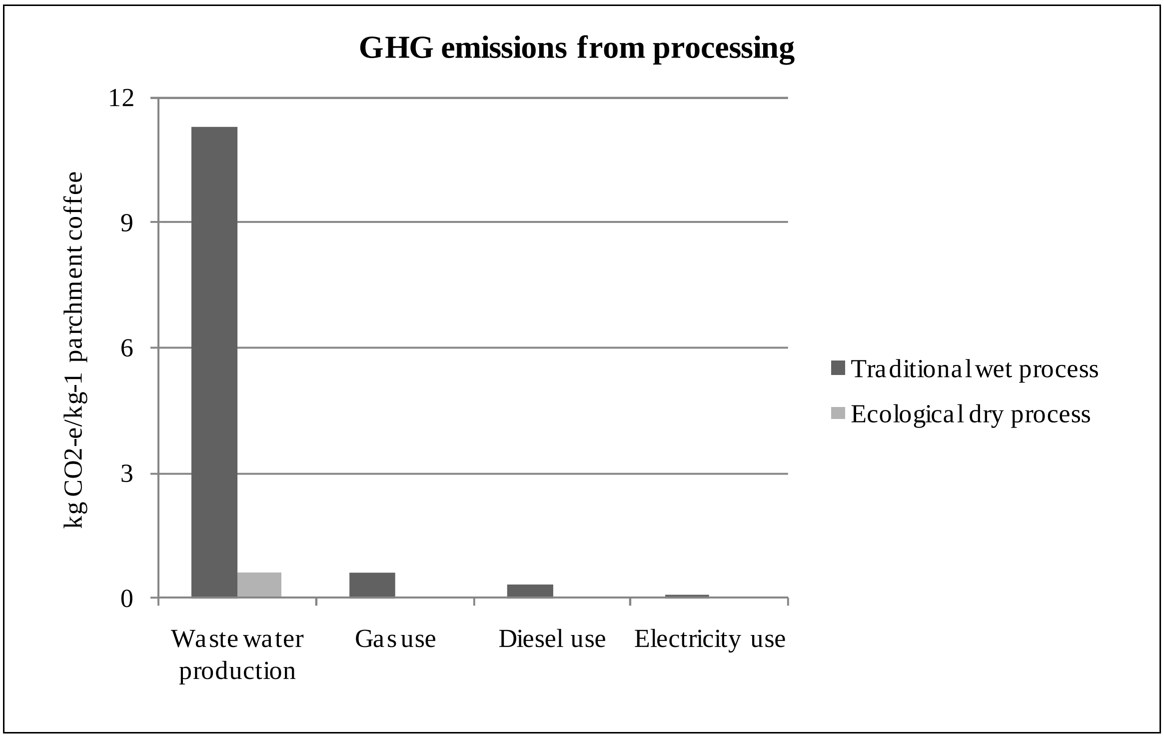


Figure 29: GHG emissions for coffee processed in the wet and in the dry process.
The graph presents two cases from the data collection; a farm using the wet process and a farm using the dry process.

Figure 29 shows the corresponding effect on GHG emissions in the two processing systems researched. The data shows that using the wet process is driving up the GHG emissions arising from coffee farming systems significantly.

It is thus illustrated by means of three examples that GHG emissions arising from coffee production are site-specific. For this reason to most effectively mitigate the effects of climate change from coffee production, a framework called ¨site-specific mitigation¨ is introduced. This means that mitigations strategies should in the core be based on the three most relevant factors found in paragraph 7.2: (1) conserving and increasing the on-farm carbon stock in biomass, (2) reducing the emissions arising from fertiliser production and application and (3) reducing the emissions arising from the generation and discharge of wastewater. Producer organisations and individual farmers can subsequently according to their own performance within these factors identify their site-specific focus area for climate change mitigation.

Site-specific mitigation practices are further desirable as often not all the three focus points for mitigation are within the reach of producer organisations or individual farmers to address. The methods used to process coffee are embedded in the culture and history of cooperatives and often connected to several environmental attributes. A Mexican coffee farmer explains for example that: ¨*Due to the high humidity at this altitude we are unable to completely sundry our parchment and make partly use of mechanical dryers to speed up the process*¨. Some cooperatives produce for high quality nice markets and make use of fermentation basins (washed Arabica coffee) which contributes to the final quality of their product (Calvert, 1998), but this method shows high GHG emissions (Figure 29). Furthermore smallholder coffee farmers in Guatemala explain that they use high quantities of *Musa* spp. (banana and plantain) to shade their coffee and at the same time to decrease the dependency on one crop by diversification. One cannot simply expect these cooperatives and farmers to abolish their processing and farming systems for the sake of climate change mitigation. Instead, in line with the introduced site-specific mitigation framework these farmers can choose for one or two mitigation focus points tailored to their own coffee production systems. In this way the implementation feasibility of low GHG agricultural practices is ensured.

7.4 Low GHG agricultural practices

By connecting practices to the three factors that contribute most to the on-farm GHG emissions it is concluded that the practices that are most effective in mitigating the effects of climate change from Mesoamerican coffee production are:

Practices that increase and conserve the on-farm carbon stock in biomass:

1. Baseline measurement and continuously monitoring of existing shade on-farm shade tree density. Measuring is the start of improvement.
2. Avoidance of land use changes and deforestation. Especially land use changes whereby forests or perennial crops are replaced by annual crops.
3. Implementation of forest and agro forestry management systems that ensure that extracted timber is replaced.
4. Planting additional shade trees in coffee plots that lack shade to build-up carbon stocks in above and below ground shade tree biomass.

Practices that reduce the emissions arising from fertiliser production and application:

1. Implementation of soil and leaf sampling systems, whereby cooperatives can use one sample for various farms due to the small plot size and similar practices.
2. Soil and leaf sample results are used as point for departure in defining synthetic and organic fertiliser type and amount.
3. Application of fertiliser according coffee growing cycle; ¨just-in-time application¨ to ensure rapid fertiliser uptake and to avoid nutrient leaching.

Practices that reduce the emissions arising from the generation and discharge of wastewater:

1. Baseline measurement and continuously monitoring of wastewater generation at coffee processing plants. Measuring is the start of improvement.
2. De-pulping of coffee cherries in ecological de-pulping installations where the generation of wastewater is reduced to a minimum.
3. Recycling water during coffee cherry processing activities. Pulping water can be reused during the de-pulping of the harvest of one day (Grendelman, 2006).
4. Using the dry coffee processing method rather than the wet coffee processing method.
5. Installation of lagoon systems to treat wastewater before it will be discharged to local rivers.

6. Installation of irrigation systems that support utilising wastewater for crop irrigation and to a certain extend fertilisation.
7. Recycling wastewaters in bio-ethanol distillation plants whereby a part of the wastewater can be reused as a fossil fuel.

8 OVERALL CONCLUSIONS

1. Mean on-farm carbon sequestration in shade trees and coffee plants is high in polycultures (81,2 t CO_2-e ha^{-1}) and low in monocultures (27 t CO_2-e ha^{-1}). Conserving the existing carbon stocks in polycultures is of thus of utmost importance.

2. Mean carbon footprints are low in traditional polycultures (5,4 kg CO_2-e/kg^{-1}) and commercial polycultures (4,9 kg CO_2-e/kg^{-1}) and high in shaded monocultures (7,8 kg CO_2-e/kg^{-1}) and unshaded monocultures (8 kg CO_2-e/kg^{-1}).

3. Organic, Rainforest Alliance and UTZ certified farms do not present higher mean on-farm carbon sequestration in shade trees and coffee plants compared to conventional farming systems. Further attention from voluntary standards to promote and validate on-farm carbon sequestration is thus required.

4. Organic, Rainforest Alliance and UTZ certified farms present a lower mean carbon footprints compared to conventional farming systems.

5. Coffee yield levels have a high effect on the carbon footprint measured on a per hectare bases. Low yields drive up the carbon footprints of coffee production as all the occurring emissions are allocated to less produce.

6. To reduce GHG emissions from coffee production most effectively the correct agricultural practices need to be used and the feasibility of implementation of those practices by coffee farmers needs to be insured: ($MIT_x = PRC_y * FSB_z$).

7. Correct agricultural practices (PRC) are: (1) conserving and increasing the on-farm carbon stock in biomass, (2) reducing the emissions arising from fertiliser production and application and (3) reducing the emissions arising from the generation and discharge of wastewater.

8. Ensuring implementation feasibility (FSB) can be done by: allowing coffee farmers to define site-specific mitigation practices that are tailored to their respective coffee farming and processing systems.

9 RECOMMENDATIONS

9.1 Recommendations to CIAT

1. It is recommended to CIAT to continue and increase the scientific support delivered to the voluntary standard setting organisations that started with designing standards that focus on addressing climate change. The results of this research need to be discussed and evaluated together with voluntary standard setting organisations.

2. It is recommended to CIAT to discuss and evaluate the results of this research with Coffee Under Pressure (CUP) private partner; Green Mountain Coffee Roasters (GMCR). The keynote in this discussion should be to convince GMCR to implement climate change mitigation measures in their supply chains according the results of this research. Furthermore the results of this study can be used together with GMCR to identify the most promising locations for carbon financing projects in GMCR´s supply chains.

3. It is recommended to CIAT to connect the carbon stock data for different coffee production systems to existing GIS data. In defining the distribution of the different production systems, the total amount of carbon stored in Mesoamerican coffee production systems can be estimated. Subsequently this data can then be connected to the existing coffee suitability predictions for the year 2020 and 2050 in the region. The loss in carbon stocks under different farmer adaptation scenarios can then be estimated. The results of this recommended study should be presented to Mesoamerican policy designers so that adequate measures can be undertaken in order to prevent environmental degradation on a very large scale.

4. It is recommended to CIAT to initiate further research in low CH4 emitting coffee processing methods and machinery. It is recommended to pay due attention to what happens to coffee quality in processing methods that show wastewater reductions.

5. It is recommended to CIAT to continue data collection as a part of this research in Colombian coffee farming systems with a focus on sampling unshaded monocultures and Rainforest Alliance/UTZ certified farms.

9.2 Recommendations to coffee farmers

1. It is recommended to coffee farmers to conduct a quick assessment of the GHG emission balance on cooperative or individual farm level.

2. It is recommended to coffee farmers to use the site-specific mitigation concept as presented in this research according the results of the GHG emission assessment that has been undertaken on farm level.

3. It is recommended to coffee farmers to use the best mitigation practices that are described in this research for each of the three mitigation focus points presented.

9.3 Recommendations to standard setting organisations

1. It is recommended to standard organisations to include GHG emission assessments on farm level as a part of their respective standard.

2. It is recommended to standard organisations to use the site-specific mitigation concept as presented in this research to define which entry point for improvement regarding GHG emissions needs to be addressed at farms that are to be certified.

3. It is recommended to standard organisations to identify if the best mitigation practices that are described in this research can be integrated in their existing standard.

4. It is recommended to standard organisations to include trainings and workshops regarding climate friendly coffee farming as a part of the benefits for certified coffee farms.

9.4 Recommendations to Mesoamerican policy designers

1. It is recommended to policy designers in Mesoamerica to recognise the invaluable importance of coffee polycultures in conserving high amounts of carbon stocks. Accordingly adequate measure to maintain and possibly increase these carbon stocks should be undertaken in the region.

2. It is recommended to policy designers in Mesoamerica to work together with the coffee private sector and the cooperative sector to extend to grass-root level how climate friendly coffee farming can be accelerated according the findings of this research.

9.5 Recommendations to carbon footprint standard setting organisations

1. It is recommended to carbon footprint standard organisations to pay due attention to how carbon sequestration in agriculture should be included in carbon footprint calculations. This study reveals that (annual) carbon sequestration are biased towards certain production systems that store high amounts of carbon on a annual cycle but do not necessarily maintain high build-up on-farm carbon stocks. In this way traditional polyculture production systems that have conserved carbon stocks up to 120 t CO_2-e/ha^{-1} in shade trees and coffee plants for years—but show for this reason a lower annual increase in carbon stocks—are not rewarded for the important role these systems play in conserving existing carbon stocks.

2. It is recommended to carbon footprint standard organisations to factor in existing on-farm carbon stocks in calculation methodologies and standards rather that the amount of carbon stored annually in coffee production systems.

10 REFERENCES

Aguirre, C.M. 2006. Servicios ambientales: Captura de carbono en sistemas de café bajo sombra en Chiapas, México. Tesis de grado. Universidad Autónoma Chapingo. Chapingo, México. 91 p.

Anim-Kwapong, G.J., and K. Osei-Bonsu. 2009. Potential of natural and improved fallow using indigenous trees to facilitate cacao replanting in Ghana. Agroforest Syst. 76:533-542.

ASABE, 2006a. Agricultural Machinery Management Data. American Society of Agricultural and Biological Engineers Standard ASAE EP496.3. ASABE, St Joseph, MI, USA, pp. 385e390.

ASABE, 2006b. Agricultural Machinery Management Data. American Society of Agricultural and Biological Engineers Standard ASAE EP496.3. ASABE, St Joseph, MI, USA, pp. 391e398.

Beer, J. 1988. Litter production and nutrient cycling in coffee (Coffea arabica) or cacao (Theobroma cacao) plantations whith shade trees. Agroforestry systems 7: 103-114.

Bellarby, J., Foereid, B., Hastings, A. and Smith, P. 2008. Cool farming: Climate impacts of agriculture and mitigation potential. Greenpeace International, Amsterdam.

Bernoux, M., G. Branca, A. Carro, L. Lipper, G. Smith, and L. Bockel. 2010. Ex-ante greenhouse gas balance of agriculture and forestry development programs. Sci. Agric. (Piracicaba, Braz.), v.67, n.1, 31-40.
See also: http://www.fao.org/tc/exact/ex-act-home/en/

BIOMAT. 1992. Estudio y diseño de la Planta de Tratamiento de los Desechos del Café en la finca "San Luis". Alcaldía de Matagalpa and Oficina Biogás y Saneamiento Ambiental. Matagalpa, Nicaragua.

BMU, and Öko-Institut e.V. 2009. Product Carbon Footprint Memorandum. Position statement on measurement and communication of the product carbon footprint for international standardization and harmonization purposes. Berlin, December 2009.

Bouwman, A.F. 1990. Land use related sources of greenhouse gases. Present emissions and possible future trends. Land Use Policy 7:154-164.

Bouwman, A.F., Boumans, L.J.M., Batjes, N.H. 2002. Modeling global annual N2O and NO emissions from fertilized fields, Global Biogeochem. Cycles 16 (4), 1080, doi:10.1029/2001GB001812.

Brus, D.J., and J.J. De Gruijter. 1997. Random sampling or geostatistical modelling? Choosing between design-based and model-based sampling strategies for soil. Geoderma 80:1.

Calvert, K.C. 1998. The Microbiology of Coffee Processing, part 1. PNGCRI Coffee Research Newsletter

Castellanos, E., A. Quilo, and D. Pons. 2010. Estudio de línea base de carbono en cafetales. Universidad del valle de Guatemala centro de estudios ambientales.

CLA. 2006. CLA CALM Calculator. Country Land and Business Association (CLA) and Savills. http://www.calm.cla.org.uk/

Cock, James H. 2010. RASTA Rapid Soil and Terrain Assessment: Guía práctica para la caracterización del suelo y del terreno / James H. Cock, Diana M. Alvarez, Marcela Estrada. Versión 2. Cali, CO : Centro Internacional de Agricultura Tropical (CIAT); Corporación BIOTEC, 2010. 62 p.

Coltro, L., A.L. Mourad, P. Oliveira, J. Paulo, O.A. Baddini, and R.M. Kletecke. 2005. Environmental profile of Brazilian green coffee. CETEA. Packaging Technology Center. Institute of Food Technology. Campinas, SP, Brazil.

Davidson, A., and I.A. Janssens. 2005. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature 440, 165-175.

Deepa, G.B., Chanakya, H.N., de Alwis, A.A.P., Manjunath, G.R. and Devi, V. 2002. Overcoming Pollution of Lakes and Water Bodies Due to Coffee Pulping Activities with Appropriate Technology Solutions. In: Proceedings "Symposium on Conservation, Restoration and Management of Aquatic Ecosystems", paper 4. Centre for Ecological Sciences, Indian Institute of Science (IIS) and the Karnataka Environment Research Foundation [KERF], Bangalore and Commonwealth of Learning, Canada.

Del Grosso, S.J., Parton, W.J., Mosier, A.R., Hartman, M.D., Keough, C.A., Peterson, G.A., Ojima, D.S., Schimel, D.S. 2001. Simulated effects of land use, soil texture, and precipitation on N gas emissions using DAYCENT. In: R.F. Follett, R.F., Hatfield, J.L. (Eds.), Nitrogen in the Environment: Sources, Problems, and Management. Elsevier Science Publishers, The Netherlands, pp. 413-431.
See also: http://www.nrel.colostate.edu/projects/daycent/index.html

Dobermann, A., and T. Oberthur. 1997. Fuzzy mapping of soil fertility - A case study on irrigated rice land in the Philippines. Geoderma 77:317.

Ecoinvent Centre. 2007. Ecoinvent data v2.0. Ecoinvent reports No. 1e25, Swiss Centre for Life Cycle Inventories, Dübendorf, 2007.
Retrieved from: www.ecoinvent.org.

EPA. 2007. Inventory of U.S. Greenhouse gas emissions and sinks: 2001-2005. U.S. Environmental Protection Agency. April 2007. USEPA #430-R-11-005.

Flynn, H and Smith, P. 2010. Greenhouse gas budgets of crop production – current and likely future trends. International Fertilizer Industry Association.

Granli T., and O.C. Bøckman.1994. Nitrous oxide from agriculture. Norwegian Journal of Agricultural Science Supplement. p. 1-128.

Grendelman, E.R. 2006. Tratar las Aguas Mieles. Wageningen University, sub-departments: Irrigation & Water Engineering Group and Environmental Technology. Unpublished internship paper. Wageningen University, Netherlands.

Hillier, J., C. Walter, D. Malin, T. Garcia-Suarez, L. Mila-i-Canals, and P. Smith. 2011. A farm-focused calculator for emissions from crop and livestock production. Environmental Modeling & Software 26, no. 9 (September): 1070-1078. doi: 10.1016/j.envsoft.2011.03.014.
See also: http://www.growingforthefuture.com/content/Cool+Farm+Tool

Hultgreen, G., and P. Leduc. 2003. The effect of nitrogen fertiliser placement, formulation, timing, and rate on greenhouse gas emissions and agronomic performance. Saskatchewan Department of Agriculture and Food. Final Report Project No. 5300G, ADF#19990028. Regina, Saskatchewan, Canada.

In 't Veld, J. 2002. Analyse van organisatieproblemen. Wolters-Noordhoff. Educatieve Partners Nederland. ISBN-10: 9020730657.

IPCC. 1997. IPCC 1996 Revised Good Practice Guidelines for Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change (IPCC), Institute for Global Environmental Strategies, Tokyo, Japan.

IPCC. 2001. Climate change 2001 : impacts, adaptation, and vulnerability : contribution of Working Group {II} to the third assessment report of the Intergovernmental Panel on Climate Change. Ed. James McCarthy. Cambridge, UK; New York, USA: Cambridge University Press.

IPCC. 2006. IPCC 2006 Revised Good Practice Guidelines for Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change (IPCC), Institute for Global Environmental Strategies, Tokyo, Japan.

IPCC. 2007. Summary for Policymakers. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Kongshaug, G. 1998. Energy Consumption and Greenhouse Gas Emissions in Fertilizer Production. IFA Technical Conference Marrakech Morocco. September/October 1998.

Lal, R., N. Uphoff, B. A. Stewart, D. O. Hansen. 2005. Researchable issues and development priorities for countering climate change. In Climate Change and Global Food Security. Edited by R. Lal, N. Uphoff, B. A. Stewart, and D. O. Hansen. Boca Raton, FL: Taylor & Francis CRC.

Li, C., Frolking, S., Harriss, R. 1994. Modelling carbon biogeochemistry in agricultural soils. Global Biogeochem. Cycles 8-3, 237e254.
See also: http://www.dndc.sr.unh.edu/

Lu, Jian; Vecchi, Gabriel A.; Reichler, Thomas. 2007. Expansion of the Hadley cell under global warming. Geophysical Research Letters 34 (6)

Mena, V. 2008. Relación entre el carbon almacenado en la biomasa total y la composición fisionómica de la vegetación en los sistemas agroforestales con café y en bosques secundarios del Corredor Biológico Volcánico Central-Talamanca, Costa Rica, Tesis de Maestría en Agroforestería Tropical. CATIE.

Moguel, P., and Toledo, M. 1999. Biodiversity conservation in traditional coffee systems of Mexico. Conservation Biology 13 (1):11-21.

Nestlé. 2002. Life Cycle Assessment of Nescafé Classic – Incuding a Comparison with Drip-Filter coffee. Journal of Cleaner Production, Volume 7, 447-455.

Nyambo, B. T.; D. M. Masaba, and G. J. Hakiz. 1996. Integrated pest management of coffee for small-scale farmers in East Africa: needs and limitations. Integrated Pest Management Reviews, (1): 125-312.

Ogle, S.M., Breidt, F.J., Paustian, K.. 2005. Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperature and tropical regions. Biogeochemistry 72, 87e121.

Oreskes, N. 2004. BEYOND THE IVORY TOWER: The Scientific Consensus on Climate Change". Science 306 (5702): 1686

Owen L, McNeill A, Callum C. 1992. Quota sampling surveys. British Medical Journal 1998: 317(7160); 728

Rainforest Alliance. 2011. SAN Climate module: criteria for adaptation and mitigation to climate change. Sustainable Agriculture Network (SAN).
See also: www.sanstandards.org

Rao, P., K, Edvardsson, L.T. Ou, R.E. Jessup, P. Nkedi-Kizza, and A.G. Hornsby. 2010. Spacial variability of pesticide sorption and degradation parameters. American chemical society. ACS Symposium series. Vol. 315. Chapter 6, pp. 100-115.

Roshetko, J.M., M. Delaney, K. Hairiah, and P. Purnomosidhi. 2002. Carbon stocks in Indonesian homegarden systems: Can smallholder systesm be targeted for increased carbon storage? American Journal of Alternative Agriculture.

Salomone, R. 2003. .Life cycle assessment applied to coffee production: investigating environmental impacts to aid decision making for improvements at company level. Food, Agriculture & Environment, vol. 1, no. 2, pp. 295-300.

Sangana PPP. 2011. Climate change adaptation and mitigation in the Kenyan coffee sector. Sangana Commodities Limited, German International Cooperation (GIZ), 4C Association, Tchibo GmbH and the World Bank.
See also: http://www2.gtz.de/dokumente/bib-2011/giz2011-0107en-kenya-coffee-sector.pdf

Saunders, M. et al. 2003. Research Methods for Business Students (Third Edition). Pearson Professional Limited.

Segura, M., M. Kanningen, and D. Suárez. 2006. Allometric models for estimating aboveground biomass of shade trees and coffee bushes grown together. Springer Science and Business Media B.V. Agroforest Syst. 68:143-150.

Sharma, A., C.R. Chen, and Nguyen Vu Lan. 2009. Solar-energy drying systems: A review. Renewable and Sustainable Energy Reviews. Volume 13, Issues 6-7, Augst-September 2009. Pg. 1185-1210.

Silva and Lopes. 2004. Growth rate of a terra firme rain forest in Brazilian Amazonia over an eight-year period in respons to logging. Acta Amazonica, 2004 SciELO Brazil.

Skinner, F.G. 1952. "The English Yard and Pound Weight". Bulletin of the British Society for the History of Science 1: 179

Smith, P., Powlson, D.S., Glendining, M.J., Smith, J.U. 1997. Potential for carbon sequestration in European soils: preliminary estimates for five scenarios using results from long-term experiments. Global Change Biol. 3, 67e79.

Somarriba. 1990. Sustainable timber production from uneven-aged shade stands of Cordelia adlliodora in small coffee farms. Agroforestry Systems 10, 253-263, 1990 Kluwer Academic Publishers, Netherlands.

Soto-Pinto, L., Jiménez-Ferrer, G., Vargas, A. De Jong, B., Esquivel-Bazán. 2010. Sin fecha.Experiencia agroforestal para la captura de carbono en comunidades indígenas de México. Revista Forestal Iberoamericana. Vol. 1 Nº 1. Pags. 44 a 50.

Soto-Pinto, L., M. Anzueto, J. Mendoza, G. Jilmenez Ferrer, B. De Jong. 2009. Carbon sequestration through agroforestry in communites of Chiapas, Mexico. Agroforest Syst. 78:39-51.

Tchibo. 2008. Case study Tchibo privat kaffee rarity machare by Tchibo GmbH. PCF Pilot Project Deutchland. November 2008.
See also: http://www.pcfprojekt.de/files/1232962944/pcf_tchibo_coffee.pdf

TSPN. 2010. TSPN Annual conference report. Standards for a sustainable agriculture and the mitigation of climate change. November 17-18, 2010 Bern, Switzerland
See also: http://tradestandards.org/en/Article.229.aspx

UNFCCC. 2009. Kyoto Protocol: Status of Ratification. United Nations Framework Convention on Climate Change. 2009-01-14.

Von Enden, J.C. 2002. Best practices at wet processing pay financial benefits to farmers and processors. GTZ-PPP Project "Improvement of coffee quality and sustainability of coffee production in Vietnam".

Von Enden, J.C. and Calvert, K.C. 2002. Review of Coffee Waste Water Characteristics and Approaches to Treatment.

Von Enden, J.C. and Calvert, K.C. 2002. Limit Environmental Damage By Basic Knowledge of Coffee Waste Waters. GTZ-PPP Project "Improvement of coffee quality and sustainability of coffee production in Vietnam".

Wintgens, J.N. 2009. Coffee: growing, processing, sustainable production. 2nd. Ed. Copyright 2009 WILEY-VCH Verlag GmbH. & Co. KGaA, Weinheim. ISBN: 978-3-527-32286-2.

11 ANNEXES

11.1 Annex I: field questionnaire

GENERAL DATA

Cooperative number		**Farm code**	
Visit data		**Farm ID**	
Name			
Last name		**GPS Latitude**	
Department		**GPS Longitude**	
Municipality		**GPS Altitude**	
Coffee plants/ha		**Parchment production**	
Spacing coffee plants		**Fermentation type**	
Varity		**Fermentation time**	
Area under coffee (m²)		**Certification**	
Area total (m²)		**Mean temperature**	
Cherry production		**Production system**	

Area under other crops on farm		**Notes**

CROP MANAGEMENT

(Q1) Soil structure?		
Fine	Medium	Course

(Q2) Soil Organic Matter (SOM) content?				
Exact:	< 1,72	1,72 – 5,16	5,16 – 10,32	> 10,32

(Q3) Are your soils moist or dry during the growing period (do you irrigate)?	
Moist	Dry

(Q4) How would you describe your soil drainage?	
Good	Poor

(Q5) What is your soil pH?			
< 5,5	5,5 – 7,3	7,3 – 8,5	> 8,5

Which fertilisers are you using?						
#	**Fertiliser** (refer to dropdown **Q6**)	**Nutrient or product** (refer to **Q7**)	**Application rate** *(For manure this should be dry weight. Typically 10 – 15% of fresh weight)*	**Unit** (refer to **Q8**)	**Application method** (refer to **Q9**)	**Emissions inhibitors** (refer to **Q10**)

(Q11) How many pesticide applications do you do in one year?		
(Q12) How is crop residue treated?		
Amount of residue	Unit (refer to dropdown **Q13**)	Method (refer to dropdown **Q14**)

SEQUESTRATION

Has there been a land use change?		
Change (refer to dropdown **Q1**)	How long ago was this change made (years)	Percentage of field that was converted

If conversion from forest:	
Forest type (refer to dropdown **Q2**)	Age when felled
If conversion to forest:	
Forest type (refer to dropdown **Q2**)	Current Age

Has there been a tillage change?		
Change (refer to dropdown **Q3**)	How long ago was this change made?	Percentage of land with practice change?

Has there been a change in the use of cover cropping?		
Change (refer to dropdown **Q4**)	How long ago was this change made?	Percentage of land with practice change?
Has there been a change in the use of composting?		
Change (refer to dropdown **Q5**)	How long ago was this change made?	Percentage of land with practice change?
Has there been a change in the use of manure additions?		
Change (refer to dropdown **Q5**)	How long ago was this change made?	Percentage of land with practice change?
Has there been a change in the use of residue incorporation?		
Change (refer to dropdown **Q5**)	How long ago was this change made?	Percentage of land with practice change?

Annual biomass for trees in cropping system:						
Tree #	Species (refer to dropdown **Q6**)	Density (trees per hectare last year)	Change in density (trees planted or lost, last year compared to this year)	Diameter at Breast Height (DBH) (current year)	Diameter at Breast Height (DBH) (previous year)	Units (refer to dropdown **Q7**)

FIELD ENERGY USE / PRIMARY PROCESSING

Electricity used from grid			
Quantity		Units	
F		kWh	Mj
P		kWh	Mj

Electricity from local hydro renewable energy used			
Quantity		Units	
F		kWh	Mj
P			
Electricity from local wind used			
Quantity		Units	
F			Mj
P			
Electricity from solar (photovoltaic cells)			
Quantity		Units	
F			Mj
P			

Diesel use				
Quantity		Units		
F			US Gallons	Imperial Gallons
P				
Petrol use				
Quantity		Units		
F			US Gallons	Imperial Gallons
P				
Biodiesel use				
Quantity		Units		
F			US Gallons	Imperial Gallons
P				
Bio ethanol use				
Quantity		Units		
F			US Gallons	Imperial Gallons
P				

High density biomass use					
Quantity		Units			
F			Tonnes	Pounds	Tonnes (US short)
P					
Fuel wood use					
Quantity		Units			
F			Tonnes	Pounds	Tonnes (US short)
P					
Coal use					
Quantity		Units			
F			Tonnes	Pounds	Tonnes (US

					short)
P					

Gas use					
Quantity		Units			
F			Therms	Cubic metres	Kg
P					

Oil use				
Quantity		Units		
F			US Gallons	Imperial gallons
P				

Waste water use					
Quantity		Units			Treatment (refer to dropdown **Q7**)
F			US Gallons	Imperial Gallons	
P					

11.2 Annex II: choice options in questionnaire

FERTILISER USE

(Q6) Dropdown	
1	Ammonium Bicarbonate - 30% N
2	Ammonium nitrate - 35% N
3	Ammonium sulphate - 21% N
4	Anhydrous ammonia - 82% N
5	Calcium ammonium nitrate -27% N
6	Calcium nitrate - 15% N
7	Compound NK - 19.5% N; 29.5% K
8	Compound NPK 15%N 15% K2O 15% P2O5
9	Diammonium phosphate - 14% N; 44% P2O5
10	Kainit / Magnesium Sulphate - 11% K2O; 5% MgO
11	Lime - 52% CaO
12	Limestone - 55% CaCO3 / 29%CaO
13	Lime, algal - 30% CaO
14	Monoammonium phosphate - 11% N; 52% P2O5
15	Muriate of potash / Potassium Chloride - 60% K2O
16	Phosphate/Rock Phosphate - 25% P2O5
17	Potassium sulphate - 50% K2O; 45% SO3
18	Super phosphate - 21% P2O5
19	Triple super phosphate - 48% P2O5
20	Urea - 46.4% N
21	Urea ammonium nitrate solution - 32% N
22	Compost (zero emissions) - 1% N
23	Compost (fully aerated production) - 1% N
24	Compost (other non-zero emissions) - 1% N
25	Cattle Farmyard manure - 0,6% N
26	Pig Farmyard manure - 0,7% N
27	Sheep Farmyard manure - 0,7% N
28	Horse Farmyard Manure - 0,7% N
29	Poultry layer manure - 1,9% N
30	Broiler/Turkey litter - 3% N
31	Cattle Slurry - 0,26% N
32	Pig slurry - 0,36% N
33	Separated Pig slurry - liquid part - 0,36% N
34	Separated Pig slurry - solid part - 0,5% N
35	User defined Compost (fully aerated production) based fertiliser
36	User defined Ammonium sulphate based fertiliser
37	User defined Anhydrous ammonia based fertiliser

(Q7) Dropdown	
1	N
2	P
3	K
4	P2O5
5	K2O
6	MgO
7	Na2O
8	Ca
9	CaO
10	CaCO3
11	SO3
12	Product

(Q8) Dropdown	
1	Tonnes/acre
2	Tonnes/ha
3	Kg/ha
4	Kg/acre
5	Pounds/ha (US)
6	Pounds/acre (US)
7	Ounces/ha (US)
8	Ounces/acre (US)
9	Fluid ounces/ha (US)
10	Fluid ounces/acre (US)
11	Tons/acre

(Q9) Dropdown	
1	Apply in solution
2	Broadcast
3	Broadcast or incorporate then flood
4	Broadcast to floodwater at panicle initiation
5	Incorporate

(Q10) Dropdown	
1	None
2	Nitrification inhibitor
3	Polymer coated

CROP RESIDUE MANAGEMENT

(Q13) Dropdown	
1	Tonnes/acre
2	Tonnes/ha
3	Kg/ha
4	Kg/acre
5	Tons/acre

(Q14) Dropdown	
1	Removed; left untreated in heaps or pits
2	Removed; non-Forced Aeration Compost
3	Removed; Forced Aeration Compost
4	Left on field; Incorporated or mulch
5	Burned
6	Exported off farm

SEQUESTRATION

(Q1) Dropdown	
1	No
2	Forest to Grassland
3	Forest to Arable
4	Grassland to Forest
5	Grassland to Arable
6	Arable to Forest
7	Arable to Grassland

(Q2) Dropdown	
1	Tropical rain forest
2	Tropical moist deciduous forest
3	Tropical dry forest
4	Tropical shrubland
5	Tropical mountain system
6	Subtropical humid forest
7	Subtropical dry forest
8	Subtropical steppe
9	Subtropical mountain system
10	Temperate oceanic forest
11	Temperate continental forest
12	Temperate mountain systems
13	Boreal coniferous forest
14	Boreal tundra woodland
15	Boreal mountain system

(Q3) Dropdown	
1	No
2	Conventional to reduced
3	Conventional to no-till
4	Reduced to conventional
5	Reduced to no-till
6	No-till to conventional
7	No-till to reduced

(Q4) Dropdown	
1	No change
2	Started adding
3	Stopped adding

(Q5) Dropdown	
1	No change
2	Started incorporating
3	Stopped incorporating

(Q6) Dropdown	
1	Coffee (arabica)
2	Shade (Cordia alliodora, Juglans olanchana, Inga tonduzzi, I. punctata)
3	Tropical moist hardwood
4	Tropical wet hardwood
5	Temperate/tropical pines
6	Temperate US eastern hardwood
7	Palm (chrysophylla sp)
8	Palm (attalea cohune)
9	Palm (sabal sp)
10	Palm (attalea phalarata)
11	Palm (Euterpe precatoria)
12	palm (Phenakospermun guianensis)

(Q7) Dropdown	
1	Mm
2	Cm
3	Inch
4	Metre