UNIVERSITÀ DEGLI STUDI DELLA TUSCIA DI VITERBO

DIPARTIMENTO DI ECONOMIA E IMPRESA

(DEIM)

CORSO DI DOTTORATO DI RICERCA IN ECONOMIA E TERRITORIO

(XXVIII cycle)

BIO-ECONOMIC ASSESSMENT OF CLIMATE-SMART TEA PRODUCTION IN THE NORTHERN MOUNTAINOUS REGION OF VIET NAM

(AGR/01)

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Viterbo, June 2017

Abstract

Agricultural production in the face of climate change (CC) requires a climate-smart transformation and reorientation at multiple scales. Viet Nam is one of the developing countries that is agriculture-based and severely affected by CC, therefore it is crucial that the agricultural system advances towards the transition. While climate-smart agriculture (CSA) has gained a significant attention at global fora, context-specific evidence is still scarce in Viet Nam. This study examines CSA potentials in tea production systems in the Northern Mountainous Region (NMR) of Viet Nam. Tea cultivation has a crucial role in CSA strategy because it provides an important source to local household (HH) income, while demonstrating a strong potential for CC adaptation and mitigation.

Since CSA concept is multi-dimensional, including food security, adaptation and mitigation, an interdisciplinary analytical framework is employed in this research to assess the economic and biophysical dimensions. Enterprise budgets and representative farms are developed for tea and alternative crops (coffee, maize, rice) as well as livestock (cattle, buffalo and pigs) production to analyze the productivity dimension of food security. In evaluating the adaptation potential of tea production, local farmers' perceptions and experiences of extreme weather events are combined with ERA-Interim data (1989-2013)[1] and HH survey data on income levels. Greenhouse gas (GHG) emissions and carbon sequestration potentials are estimated through partial Carbon Footprint Life Cycle Assessment.

Results show that tea production systems, both under conventional and mini-terracing practices, generate net margins, returns to capital and family labor higher than the alternatives. Farmers therefore have high incentive to switch from other crops to tea production. In face of CC, tea has shown a strong biophysical adaptive capacity compared to other crops in NMR. Tea-producing HHs have higher levels of income and total value of crop production than non-tea producing HHs but mostly under low variability of climate conditions. Tea HHs have demonstrated high potential in buffering climate extremes. Fertilizer application is the single largest GHG emitter at farm level. Tea production systems have a high capability for carbon storage and offsets.

Evidence of strong synergies between food security, mitigation and adaptation is demonstrated for tea production systems in NMR, and potential tradeoffs highlighted where relevant. Policy recommendations are drawn based on combined evidence to support CSA in the region.

[1] Reanalysis dataset taken from the European Centre for Medium-Range Weather Forecasts (ECMWF)

Abstract (Italian version)

La produzione agricola di fronte al cambiamento climatico (CC) richiede una trasformazione intelligente del clima e un ri-orientamento a diversi livelli. Il Vietnam è uno dei paesi in via di sviluppo basato sull'agricoltura, gravemente colpito dal CC, quindi è fondamentale che il sistema agricolo avanzi verso la transizione. Mentre l'agricoltura a clima intelligente (climate-smart agricolture) (CSA) ha guadagnato un'attenzione significativa a livello globale, le prove specifiche nel contesto in Vietnam sono ancora scarse. Questo studio esamina i potenziali CSA nei sistemi di produzione di tè nella regione nordica-montana (Northern Mountainous Region) (NMR) del Vietnam. La coltivazione del tè ha un ruolo cruciale nella strategia CSA, poiché fornisce una fonte importante ai redditi locali (HH), dimostrando un forte potenziale per l'adattamento e la mitigazione del CC.

Dal momento che il concetto CSA è multidimensionale, includendo la sicurezza alimentare, l'adattamento e la mitigazione del CC, in questa ricerca viene impiegato un framework analitico interdisciplinare per valutare le dimensioni economiche e biofisiche. I budget aziendali e le aziende rappresentative sono sviluppati per la produzione di tè e colture alternative (caffè, mais, riso), nonché bestiame (bovini, bufali e suini) per analizzare la dimensione produttiva della sicurezza alimentare. Nella valutazione del potenziale di adattamento della produzione di tè, le percezioni degli agricoltori locali e le esperienze di eventi meteorologici estremi sono combinate con dati ERA-Interim (1989-2013) e dati provenienti da interviste sui livelli di reddito familiare. Le emissioni di gas a effetto serra (GHG) e le potenzialità di assorbimento del carbonio sono stimati attraverso la valutazione parziale del ciclo di vita del carbonio (Carbon Footprint Life Cycle Assessment).

I risultati mostrano che i sistemi di produzione di tè, sia sotto pratiche convenzionali che di mini-terrazzamento, hanno più elevati margini netti, ritorno di capitale di cassa e ritorno di lavoro familiare rispetto alle alternative. Gli agricoltori hanno quindi un forte incentivo a passare da altre colture alla produzione di tè.

Di fronte al CC, il tè ha mostrato una forte capacità di adattamento biofisico rispetto ad altre colture nella zona del NMR. Le HHs che producono tè hanno livelli più elevati di reddito e di valori totali della produzione rispetto alle aziende familiari che non producono tè, ma soprattutto in condizioni di bassa variabilità climatica. Le HHs produttrici di tè hanno dimostrato un elevato potenziale nel bloccaggio degli estremi eventi climatici.

L'applicazione del fertilizzante è il singolo più grande emettitore di GHG a livello aziendale. I sistemi di produzione di tè hanno un'elevata capacità di stoccaggio e compensazioni di carbonio.

La dimostrazione di forti sinergie tra la sicurezza alimentare, mitigazione ed adattamento è dimostrata per i sistemi di produzione di tè nella zona del NMR e potenziali tradeoffs sono evidenziati, dove rilevanti. Le raccomandazioni in materia di politiche sono elaborate in conformità a prove combinate per supportare la CSA nella regione caso di studio.

Acknowledgement

I would like to express my sincerest and most thankful appreciation and deepest gratitude to the following organizations and individuals for their invaluable support, guidance, assistance, and encouragement in the pursuit of my graduate studies:

The Food and Agriculture Organization of the United Nations, under the CSA Project *"Climate-smart Agriculture: Capturing the synergies among Mitigation, Adaptation and Food Security",* for funding my research;

The Department of Crop Production for allowing me to go on a study leave;

Professor Giacomo Branca, my principal supervisor, for his academic advice, support, comments and also patience to guide me throughout the entire process of my studies;

Dr. Aslihan Arslan for her professional advice, comments, contributions, corrections and support since the very first days on this journey;

Associate Professor, Dr. Mai Van Trinh for his valuable comments, support and contributions on my work;

Professor Sorrentino for his helpful and timely support to my entire PhD Program in Italy and Professor Julie Caswell for her invaluable suggestions and hospitality during my exchange period in The University of Massachusetts at Amherst;

The CSA Project team in Viet Nam: Dr. Pham Thi Sen, Dr. Nguyen Van Linh and in Italy: Dr. Leslie Lipper, Dr. Andrea Cattaneo, Dr. Adriana Paolantonio, Dr. Romina Cavatassi, Mr. Alessandro Spairani, Dr. Louis Bockel, and Mr. Uwe Grewer for their valuable support;

Staff and colleagues in Tuscia University, Department of Economics and Business for their support and warm friendships;

Colleagues and friends in Viet Nam for their support during my field work;

My parents and sisters for their love, understanding and encouragement; and

Last but not the least, my wife, Tran Thi Hoai, wonderful daughters, Tran Ngoc Bao An and Tran Bao Chau, for their endless love and sacrifices.

Without support and encouragement from these organizations and individuals, this study would not have been successfully accomplished.

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List of Acronyms

AGB	Above Ground Biomass
BGB	Below Ground Biomass
CC	Climate Change
CFP	Carbon Footprint of Products
CSA	Climate-Smart Agriculture
ERA	ECMWF Reanalysis
EWE	Extreme Weather Event
FGD	Focus Group Discussion
FS	Food Security
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GM	Gross Margin
GSO	General Statistics Office
GWP	Global Warming Potential
HH	Household
IPCC	Intergovernmental Panel on Climate Change
NM	Net Margin
NMR	Northern Mountainous Regions
NPV	Net present value
RF	Representative Farm
SOC	Soil organic carbon
TR	Total Revenue
UNFCCC	United Nations Intergovernmental Panel on Climate Change
VARHS	Viet Nam Access to Resources Household Survey
VND	Viet Nam Dong

CHAPTER 1. INTRODUCTION

1.1. Context of the study

Viet Nam has achieved fast and stable economic growth in the last three decades. The country has made a successful transition from a poor to a dynamic middle-income economy. The poverty rate has dropped remarkably, from almost 60% to 13.5%, in the last two decades (World Bank and MPI, 2016). However, there are still more than 12 million people earning less than $2 per day (World Bank, 2013). Among the country's seven ecological zones, the NMR is one of the poorest, where the poverty rate is about 10% higher the national average.

Agricultural production has achieved impressive progress since the 1990s, when the country was listed as a commodity exporter for the first time in the history. Today, Viet Nam has become one of the top five exporters of coffee, rice, cashew nuts, rubber, tea and cassava. Among these, rice, coffee, cashew nuts, and rubber have export turnovers of more than one billion $ per year, contributing substantially to national GDP. Despite strong competition from other sectors, agriculture continues to be a key contributor to current national GDP and a major source of income for 66.4% of the rural population. Nevertheless, since almost all accessible arable land has presently been converted to agricultural land, the scarcity in land resources could pose a major challenge in the future.

Climate change (CC) refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.[2] Climate has already changed and is now a real threat to ecosystems on earth. Global mean temperature has increased over the last 100 years and is expected to continue rising. Extreme weather events are the most immediately accessible phenomena of CC that are discussed in the literature. Southeast Asia has already experienced CC in terms of temperature and sea level rises over the last 20 years. Viet Nam has been ranked among the five countries most vulnerable to CC, especially to sea level rise. As a result, Viet Nam's agriculture could face more difficulties than other neighboring countries.

Tea plays a significant role in developing countries in terms of poverty reduction and food security (FS), and is one of the most important cash crops globally (FAO, 2015). In Viet Nam, tea is also among the key income generators, especially in the NMR, where more than 70% of Vietnamese tea is grown. Globally, CC has had significant impact on tea growth and production,

[2] IPCC: https://www.ipcc.ch/publications_and_data/ar4/syr/en/mains1.html

since the plant is popularly grown in rain-fed, mono-cropping systems. However, the potential of CC mitigation in tea systems is not yet insightfully understood. Therefore, there is a need to better understand mitigation and adaptation measures in tea production systems, as well as the costs and benefits related to implementing such practices (FAO, 2015).

1.2. Problem statement

Agriculture is the major economic sector in many developing countries, including Viet Nam. As many as 75% of the poor in developing countries live on agriculture and farmers remain the largest group dependent on natural resources on earth (Branca et al., 2009). The central role of agriculture in FS is expected to become even more important and challenging, in the coming decades as the world population is set to increase by 1.5 billion by 2050. At the same time, agriculture is the major contributor to global GHG emissions. Two-thirds of these emissions are reportedly coming from developing nations. Technically, these countries have a high potential to contribute to GHG mitigation.

CC, which is essentially the result of a build-up of GHG emissions (including many anthropogenic sources) has already altered global, regional and national food production systems in various ways at multiple scales. The average global temperature and sea levels are expected to continue rising, threatening crop productivity even further, as well as endangering many low-lying, coastal ecosystems around the world. Among these, Southeast Asia and Viet Nam are the most vulnerable. CC-induced EWEs are expected to increase in terms of frequency and intensity.

Agriculture and food systems are required to transform and re-orient in order to supply adequate food for the increasing world population and at the same time, to consider reducing GHG emissions in fighting planetary warming (Campbell et al., 2014; FAO, 2013; Lipper et al., 2014). CSA is an integrated approach to sustainably drive such system transitions at multiple scales. CSA addresses these challenges by sustainably increasing FS, building CC resilience and contributing to GHG emissions reduction and enhancing carbon sequestration, where possible. Recently, CSA has been increasingly incorporated and repeatedly discussed in many international fora on policies for FS, agriculture and CC. While many agricultural technologies and strategies are reportedly climate-smart, site-specific evidence is still needed to highlight their contributions to CSA objectives, as well as policy implications (Arslan et al., 2015; FAO, 2013).

This research provides evidence to assess such contributions of various tea production systems as a potential CSA practice in Viet Nam, providing an important contribution in filling the knowledge gap, especially in a developing country like Viet Nam.

1.3. Research aim, questions and scope

1.3.1. Aim

The aim of this research is to assess the contribution of various tea production systems to the three pillars of CSA, i.e. productivity, resilience and mitigation, in the Northern Mountainous Region of Viet Nam.

1.3.2. Research questions

Question 1. What are the profitability and economic competitiveness of tea production in the study area?

Question 2. What is the potential for tea production in building adaptive capacity to climate change related shocks?

Question 3. What are mitigation co-benefits in tea production and where is the best opportunity for reducing greenhouse gas emissions and enhancing carbon sequestration?

Question 4. What is the CSA potential of tea production in the study area?

1.3.3. Scope of the Study

This research deals mainly with tea practices and partly with other crops and livestock in the NMR of Viet Nam; our findings are highly context-specific and may not be generalized to the same crop in other settings.

Although fresh tea production is a primary part of the value chain, our research mainly looks at the farm level only. Tea, maize, upland rice and coffee are among targeted crops included in the research. In addition, as livestock is an important part in the mixed farming systems commonly practiced in the NMR, cattle, buffalo and pigs are also studied in terms of their contribution to FS.

1.4. Research design and data

This research comprises three components that address the three pillars of CSA, namely; FS, adaptation and mitigation. A farm model is developed using partial budgets to analyze the economic performance of farm practices as mentioned above. These will be used to evaluate the economic contribution of tea practices in addressing the productivity or FS objective under local climate conditions.

In the second component, local and scientific knowledge are combined to assess the potential of tea production in enhancing adaptation capacity of local farming systems to CC related stressors. The adaptation potential is discussed in three layers: climate trends analysis, HH income and its correlations across HHs that have different production portfolios (tea vs. non-tea) under various climate related shocks to assess their capacity to cope with shocks.

The third component investigates mitigation co-benefits of tea production systems by estimating carbon emissions and sequestration within a defined system boundary. Life cycle assessment (LCA) framework is partially used in this carbon footprint study. In this component, natural organic tea stands are integrated into mitigation assessment in order to see if they have higher mitigation benefits than that of intensive production, particularly in terms of biogenic carbon sequestration.

In the first component, datasets collected by FAO in collaboration with NOMAFSI[3] (FAO-NOMAFSI dataset) on costs and benefits of a large set of farm activities in the region and the 2011 Agricultural Census data are used for analysis. Viet Nam Access to Resources Household Survey (VARHS) datasets are combined with ERA-Interim climate datasets to provide a panel data for adaptation analysis. Results of these analyses are then cross-validated with farmers' perceptions derived from focus group discussions. In mitigation assessment, the same FAO-NOMAFSI dataset is used to quantify different sources of GHG emissions. Data used for estimating carbon sequestration are taken from secondary sources.

1.5. Significance of the study

In Viet Nam, there have been many international and national efforts to deal with the impacts of CC, mainly concentrated in coastal regions, especially in the Mekong River Delta. A number of support projects and programs on rice, shrimp or fruit crops have been implemented in these areas. Although being highly vulnerable to CC, the NMR has not been the focus of these efforts, much less so for research activities on CC and FS. Therefore, this research could be considered as pioneer in the region, where natural systems and people are more disadvantaged.

Since CSA is multi-dimensional and contextual, this research has advanced the topic by successfully employing a multidisciplinary framework into a CSA analysis: farm model for FS

[3] Northern Mountainous Agriculture and Forestry Science Institute

analysis, combination of local knowledge, socio-economic data and satellite based weather data for evaluating adaptation, and a biophysical process for GHG assessment.

This research has been conducted in Viet Nam, which is considered a hotspot of global CC vulnerability. It provides not only a novel multi-disciplinary evidence base to support CSA policies and programs, but also a background for other research and policy development for smallholder farmers.

1.6. Structure

The rest of this dissertation is structured as follows:

Chapter Two reviews key concepts related to CSA and its practices, as well as to its adaptation and mitigation potential. The chapter also discusses the current issues of CSA economics that conceptualize the research framework.

Chapter Three describes methodology and analytical steps. It first explains how farm model analysis is applied for the analysis of gross margins and profitability for crops and livestock. Methods and tools for capturing local knowledge and for describing statistics are also elaborated in the second section. Finally, the chapter presents a partial life cycle assessment approach used to study carbon footprint in tea production systems.

In Chapter Four, background information about the NMR and farming systems is presented and datasets used for analysis are detailed. Lastly, research provinces and boundaries are discussed to set the background of the study.

Chapter Five presents the results of data analysis in which economic parameters of tea production are compared with other crops to evaluate the opportunity cost and viability. Livestock is also considered in enterprise budgets and representative farms in order to capture its added value to farm incomes, as well as adaptation benefits. It also discusses the mitigation potential of tea production systems by evaluating carbon emissions and sequestration in the system boundaries. Lastly, the synergies between productivity, adaptation and mitigation are presented as an evidence base for tea production systems addressing CSA objectives in the NMR of Viet Nam.

In Chapter Six, conclusions are presented in response to the research questions. The chapter also discusses policy implications and study limitations.

CHAPTER 2. BACKGROUND AND LITERATURE REVIEW

2.1. Introduction

This chapter presents the research background and a review of relevant literature. In the first part, background information related to agricultural development in Viet Nam and interactions between climate change and agriculture at all scales are provided. In the second part, the chapter reviews the CSA concept and key assessment tools in order to conceptualize the research framework. Farm activity gross margins, household income, food security issues, mitigation measurements, costs and benefits of different practices, adaptation options and measuring methods are also discussed.

2.2. Agriculture in Viet Nam

2.2.1. The country overview

Viet Nam has achieved fast, stable, and inclusive economic growth in the last three decades since *Đổi Mới* or "Renovation" - the turning point launched in 1986. The country has made a remarkable transition from being one of the poorest nations in the world to being a dynamic middle-income economy, achieving an average real per capita growth rate of 5.5% over the period of 1991-2014. Per capita GDP rocketed from around $100 in 1990 to about $2,200 in 2015 at current prices. (World Bank and MPI, 2016).

Box 1.1. Viet Nam – a snapshot (Source: GSO, 2016).

Population, million (2015)	91
Territory, thousand km^2	331
Life expectancy at birth, total years (2015)	75
Minorities	54
GDP (billion USD, 2015)	193

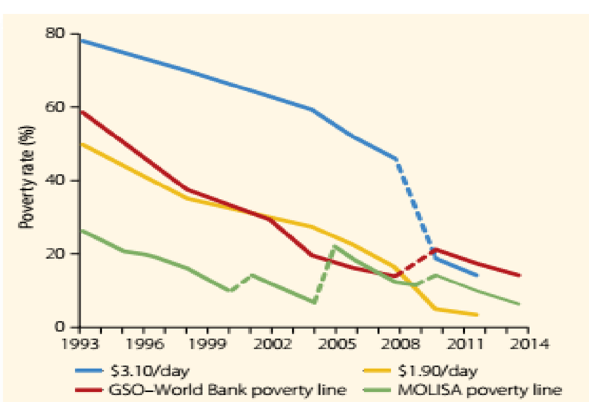

Figure 1.1. Household poverty rate, 1993-2014.
Source: World Bank and MPI (2016)

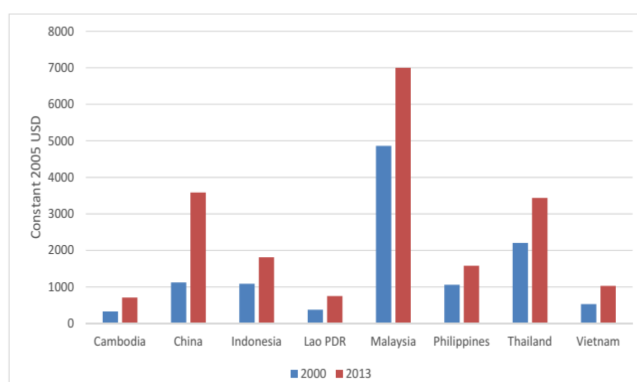

Figure 1.2. Real GDP per capita in Southeast Asian countries.
Source: Tarp et al. (2015) based on World Bank World Development Indicators

The poverty rate has fallen rapidly based on various international and national poverty lines (Figure 1.1). Considering jointly the General Statistics Office (GSO) and World Bank reference line, the poverty rate in Viet Nam dropped from 58% in 1993 to 13.5% in 2014. In the Southeast Asian Region, Viet Nam, however, remains a relatively poor nation with a GDP per capita that is far below that of Malaysia, China, and Thailand, and similar to that of Philippines (Figure 1.2).

2.2.2. Agriculture

Three quarters of the country's territory is made up of mountains and hilly regions. Each year, there is about one million people being born. Therefore, Viet Nam faces a scarcity of agricultural land. Per capita agricultural land is just 0.12 ha, equivalent to just one-sixth of the world average (OECD, 2015). Nonetheless, the 1986 "*Renovation*" and the 1988 "*Farmland De-collectivization*" have triggered fast and impressive progress in agricultural production since the 1990s. In terms of volume, from 1990 to 2013, agricultural production has increased remarkably by 206%, with crop production going up by 189% and livestock production by 282% (Figure 1.3). The annual growth rate of the sector in this period was 4.9% on average, with an impressive rate of 5.5% in 1990-2000, which slightly slowed down to 4.4% in 2001-2010, and 4.2% in 2011-2013. Rice and pigs are among the most important commodities in agriculture, respectively accounting for 35% and 18% of the sector's total production value in 2012 (OECD, 2015).

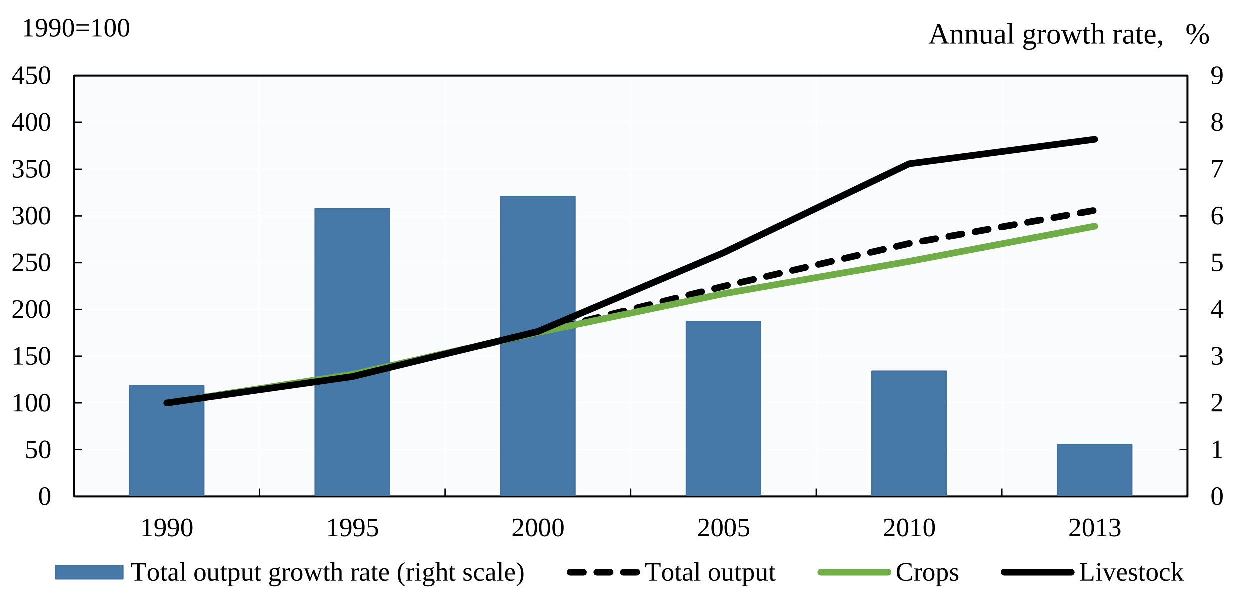

Figure 1.3. Growth in agricultural output in Viet Nam, 1990-2013
Source: Adapted from OECD (2015) based on FAOSTAT (2015),World Development Indicators.

Despite the high growth rate in the last two decades, the sector's share in national GDP and in total employment has declined moderately from 1990 to 2013, because industry, construction and services all have been achieving faster and more substantial growth rates. However, agriculture (including fisheries and forestry) continues to be a key contributor to current GDP, at more than 18% (after falling from 39% in 1990 to 20% in 2004), as well as a major source of income for 66.4% of the rural population. Although agriculture's share in employment fell from 65% in 2000 to 47% in 2013, it is still 2.5 times higher than its share in GDP (Figure 1.4). This implies that the sector has a low level of labor productivity and a high level of agriculture-dependent HHs. In that period, agriculture's share in total exports dropped from 27% to 17%, while its share in total imports increased from 6% to 10%. However, its share of GDP has remained stable at around 20% in recent years.

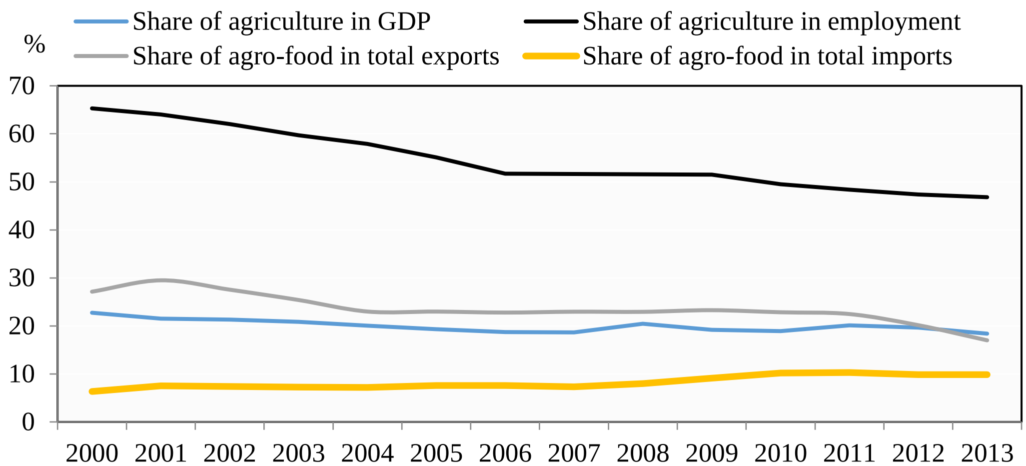

Figure 1.4. The share of agriculture in GDP, employment, total exports and imports, 2000-2013
Source: OECD, 2015 based on World Development Indicators; UN (2015), UN Comtrade Database; GSO (2014), Statistical Yearbook of Vietnam 2013.

In terms of export volume and value, Viet Nam is among the top five leading exporters for commodities listed in Table 1.1. Among these, rice, coffee, cashew, and rubber have turnovers of more than one billion USD. The value of agriculture, forestry, and fishery exports increased rapidly from about \$0.5 billion in 1986 to \$30.9 billion in 2014, achieving a growth rate of 17 percent per year. Yet, most exports are sold at lower prices compared to other leaders. Some Vietnamese commodities such as rice and *Robusta* coffee, in spite of having competitive advantages, are exported at a lower unit value than that of peers. For example, the average value of Viet Nam's tea is \$1,524 ton^{-1} in 2013, 40% lower than that of India's (\$2,688) and Kenya's (\$2,799) tea. All of these indicate that the Vietnamese agricultural sector has a lot of potential for improving value addition in global value chains.

Table 1.1. Ranking of key export commodities (2013)

Commodity	Volume		Value		Rank Among Top Ten Exporters in Unit Value
	000 ton	Rank	000 $	Rank	
Rice	6,722	3	2,986	4	10
Cassava (dried)	1,690	2	364	2	6
Pepper	133	1	890	1	8
Cashews (shelled)	261	1	1,646	1	6
Coffee (green)	1,301	2	2,721	2	10
Tea	141	5	230	7	10
Rubber (natural dry)	647	4	1,533	4	10

Source: GSO (2016) and adapted from World Bank (2016).

In spite of the significant growth in the past decades, Vietnamese agriculture may face several challenges in the future. One of these is the scarcity in land resources since almost all accessible arable land has presently been converted to agricultural land. Further production growth needed by both the increasing domestic population and export markets requires not only land resources but also higher yields and inputs which are already high compared to Asian countries (OECD, 2015).

2.2.3. Tea industry

Today, tea plants are cultivated in 52 countries in all continents with Asia being the largest producer and consumer. In 2012, the total land area under tea cultivation was 3.36 million hectares and production was 4.78 million tons (FAO, 2015). Tea, coffee and cocoa are the three most popular non-alcoholic beverages worldwide. Tea is commonly processed and consumed in one of three typical types, namely green tea (non-fermented); white, yellow or Oolong tea (semi-fermented); or black tea (full-fermented). Black tea is popularly consumed in Asian and some Western countries, accounting for 78% of the global production. Markets for green and Oolong tea are mainly in Asia (Chen et al., 2013).

Tea has been grown in Viet Nam for commercial harvest since the last century and is currently widespread in 30 provinces. The NMR, though being one of the poorest areas with high concentration of ethnic minorities, is the largest tea planting region in the country, accounting for more than 70% of tea production area and output in the country (GSO, 2016a). Nationally, total dried production has increased significantly, from 32 thousand tons in 1990 to 238 thousand tons in 2015, representing an average growth rate of 9% annually. Similarly, harvested area has also grown steadily from 60 thousand ha in 1990 to 116 thousand ha in 2015, at an annual growth rate of 4.5% (GSO, 2000 and 2016). Total production output has achieved a stable annual growth rate of 4.4%, benefiting greatly from varietal, technical and marketing improvements.

Green tea is a traditional and popular beverage in Viet Nam, however, only about 25% of processed tea, mostly green type, is consumed domestically. The majority is for exporting, predominantly in bulk, semi-finished, black tea. Middle East is the most popular market for Vietnamese OTD[4] black tea while Europe and America are common markets for CTC[5] black tea. The green tea, accounting for only 20% of export volume, is mainly exported to Pakistan, Taiwan and China. Viet Nam is the fifth biggest tea exporter in the world, with an export volume of 131 thousand tons in 2016, valued at 217 thousand USD (GSO, 2016b). The current value is about 10 times the value in 1990 (25 million USD), thanks to the real increase of 8% per year the industry has recorded between 1990 and 2011.

2.3. Climate change and agriculture - global, regional and national contexts

2.3.1. Climate change and weather extremes

According to the Intergovernmental Panel on Climate Change (IPCC, 2007a), weather includes daily changes in temperature, precipitation, barometric pressure and wind in response to a series of natural causes. Climate is defined as the average of weather over a period of time. CC refers to uncommon climatic changes and more exactly, the average change of weather conditions observed and recorded over decades or longer. CC is strongly associated with anthropogenic GHG emissions which alter the composition and ratio of carbon dioxide (CO_2) and nitrous oxide (N_2O) in the global atmosphere and thus, cause global warming. Climate has already changed and is now a real challenge to the planetary ecosystem. Global mean temperature has increased by 0.74°C over the last 100 years, and it is expected to rise between 1.1 to 6.4°C by the end of the 21st century, depending on projected scenarios (IPCC, 2007a).

CC differs from climate variability, because CC is characterized by longer term variations of weather conditions and influenced by human activities, whereas climate variability implies variations of natural and shorter-term weather conditions (IPCC, 2007a, 2014). Climate extremes or extreme weather events (EWEs) are the most immediate phenomenon of CC discussed in the literature. EWE is defined as weather conditions that are at the extremes of the range of weather conditions experienced in the past. The definition depends on the area and is based on what

[4] OTD - Orthodox
[5] CTC - Cut, Tear and Curl

deviates from ‘normal’ in a particular area for a particular period at a particular time (IMHEN and UNDP, 2015)[6]. EWEs, though being very contextual, have been observed and projected to increase both in terms of frequency and intensity in many parts of the world (Francisco, 2008; Hoang et al., 2014; Kibue et al., 2016; Vermeulen et al., 2012).

Southeast Asia has already experienced CC in terms of temperature and sea level rises over the last 20 years. Between 1981 and 2005, the average land and sea temperatures have increased by 0.34 and 0.38°C compared to the 1961-1980 period, respectively. It is projected that the sea temperature in the region will continue to increase at a higher rate than global sea temperatures. The region’s land temperature rise is projected to reach 1.59°C in 2050, 1.96°C in 2080 and 2.46°C in 2100 (IPCC, 2014). In terms of sea levels, it is predicted that coastal systems in Southeast Asia will experience a greater impact, being among the most vulnerable coastal regions globally (Lassa et al., 2015).

Viet Nam has been ranked among the five countries likely to be the most vulnerable to CC and especially sea level rise, because a high proportion of its population and economic assets are in coastal lowlands and deltas (Cruz et al., 2007; Dasgupta et al., 2007; World Bank, 2013, 2016). Between 1958 and 2014, annual average temperature in Viet Nam has increased about 0.62°C (0.10°C per decade, lower than global value of 0.12°C). Sea levels have risen at a rate of 3.34 mm per year in the 1993-2014 period (MONRE, 2016). The comprehensive report prepared by the Ministry of Environment and Natural resources (MONRE) entitled "Current Climate Change, Sea Level Rise Scenarios for Viet Nam” shows that annual average temperature will increase by 1.3–2.3°C and the sea level rise will be between 14–36 cm by 2050 (MONRE, 2016). Seasonal variability in precipitation is also projected to increase, causing the wet season to get wetter and the dry season to become drier in some places. Extreme rainfall events and floods are also expected to be more likely, particularly in the northern region where landslides have become more frequent in the face of deforestation (IMHEN and UNDP, 2015).

2.3.2. The threats to agriculture from climate change

At the global scale, recent CC has had widespread and profound impacts on various aspects of natural systems and human livelihood activities (Smith et al., 2014). CC has been altering global food systems, especially agriculture and fisheries, through increasing the frequency and intensity of climate shocks and EWEs. In agriculture, CC impacts are commonly linked with scientific

[6] IMHEN: Institute of Meteorology, Hydrology and Climate Change
UNDP: United Nations Development Program

knowledge on crop, livestock, fishery production and agricultural systems. Globally, six major food crops are estimated to have a climate-related reduction of 40 Mt[7] per year from 1981 to 2002 (Lobell and Field, 2007). Similarly, maize and wheat have been estimated to have suffered a global net loss of 3.8% and 5.5%, respectively, due to the negative impacts of climate trends on major producers in 1980-2008 (Lobell et al., 2011).

In the future, rice yields will decrease by 10%, when the temperature increases by 1ºC and thus, it follows that by 2050 rice yields will be reduced by at least 10% because the global average temperature is estimated to increase by 1ºC. Likely, maize yields will be at 3-6% less (IPCC, 2007b). Looking further ahead, Battisti and Naylor (2009) indicate that the persistent rise in mean temperatures could exceed current extremes in tropical and subtropical regions by 2100. Once that happens, the temperature is more likely to cause further impacts on crop production worldwide, as crop yield will drop dramatically when temperatures exceed critical physiological thresholds. Likewise, small changes in temperature at critical stages of plant growth could damage most crops (FAO, 2013).

In Southeast Asia, sea level rise poses a major concern for rice production since it could submerge the low-lying delta and coastal areas that contain most rice paddies (Lassa et al., 2015). Increases in water levels in rice fields and soil salinity could prevent normal crop growth and grain formation. Greater variability in precipitation and frequency of heavy rainfall events as indicated by IPCC (2014) may increase the risk in rice and other crop production. Apart from floods, droughts, pests and diseases have also caused serious damage to many other cash crops in the region, such as maize, cassava, and soybean.

Being highly vulnerable to CC, agriculture in Viet Nam has been facing more difficulties than in other ASEAN nations. In the period of 1961-2010, various EWEs have been observed to have spatial and temporal impacts across the country's ecological regions and agricultural production (IMHEN and UNDP, 2015), including longer dry seasons and water shortages in the North and Central Regions; longer periods of the West dry winds, and more frequent and intense hot spells in the Central Region (Hoang, 2011). Cold spells, droughts, pests and diseases are likely to be more unpredictable and could become major stressors for food crops (IMHEN and UNDP, 2015). Without adaptation, by 2050 Viet Nam could lose total agricultural value added by 5.8–13.9 % compared with the value in 2010 (World Bank, 2010).

[7] Megatons

2.3.3. Impacts of agriculture and food systems on climate change

Agriculture and food systems are major contributors to the human-induced GHG emissions that drive CC. Therefore, understanding the environmental impacts of agri-food systems is crucial to mitigating CC in a holistic way. If both pre- and post-farm activities are included, agro-food systems globally released 9,800-16,900 megatons of carbon dioxide equivalent ($MtCO_2e$) in 2008, making up 19%-29% of total anthropogenic GHG emissions (Bellarby et al., 2008; Steinfeld et al., 2006; Smith et al., 2007; Blaser et al., 2007; and Chen et al., 2010 cited in Vermeulen et al. (2012)). Today, modern agriculture is largely dependent on inputs such as fertilizers and livestock feeds. Fertilizer production is one of the key sources of GHG emissions in agriculture, reportedly ranging from 284-575 Mt of CO_2e, which result mainly from energy consumption and partly from manufacture of nitrate fertilizers. Postproduction, including processing, storage and retailing activities, is also considered a major contributor to GHG emissions in global food systems (Vermeulen et al., 2012).

Within agri-food chains, agricultural production, through agricultural practices (direct emissions) and land use change (indirect emissions), becomes the largest GHG contributor. Of global anthropogenic emissions, on-farm production totally emits 80%-86%, direct emissions account for approximately 60% of N_2O emissions (through fertilizer application) and about 50% of CH_4 emissions (from livestock and rice production) in 2005 (Smith et al., 2007). In 2010, annual total non-CO_2 GHG emissions from agriculture were estimated at 5.2–5.8 Gigatons (Gt) of CO_2e per year, making up about 10-12% of global anthropogenic emissions (Smith et al., 2014). These figures are similar to estimations made by Smith et al. (2007).

In Viet Nam, according to the Second National Communication to UNFCCC[8] (MONRE, 2010), annual emissions from agriculture have increased significantly from 1994 to 2005. The sector's emissions are projected to rise more in the coming decades since the economy is still relying on agriculture to meet the national food and feed demand, as well as for the international market (Lam, 2016). This trend is aligned with FAO's projection (2013) that as agricultural production continues to increase in the developing world, so are agricultural emissions. Incidentally, per capita GHG emissions in Viet Nam have increased six fold (from 0.3 tons in 1990 to 1.71 tons in 2010), which underlines the need for studies on the mitigation potential of Vietnamese agriculture.

[8] United Nations Intergovernmental Panel on Climate Change

Table 1.2: GHG inventories in Vietnam

Sector	1994[a]		2000[a]		2005[b]	
	million tons of CO_2-e	%	million tons of CO_2-e	%	million tons of CO_2-e	%
Energy	25.6	24.7	52.8	35.0	101.9	56.0
Industries	3.8	3.7	10.0	6.6	14.6	8.0
LULUCF	19.4	18.7	15.1	10.0	-27.0	-14.8
Agriculture	52.5	50.5	62.5	43.1	83.8	46.1
Waste	2.6	2.4	7.9	5.3	8.6	4.7
Total	103.9	100.0	150.9	100.0	181.9	100.0

Source: [a] Second Communication Report, MONRE (2010).
[b] Interim Report, JICA Inventory Capacity Building Project (2014).

2.4. Climate-smart agriculture

2.4.1. Rationale and concept

The Food and Agriculture Organization of the United Nations (FAO, 2013) forecasts that the world’s population will increase by one-third by 2050, or 2.4 billion people, mostly living in developing countries. Meanwhile, agriculture, together with fishery and forestry, is, in the face of increasing demand, driven by socioeconomic trends and of sustaining supply stressed by environmental challenges. CC caused by global warming is one of those environmental stressors. Inversely, agriculture is the main contributor to global warming. It is projected that agricultural production has to increase by 60% by 2050 in order to meet the demands for food and feed. Therefore, CC and its associated impacts will obviously make this task even more challenging (Godfray et al., 2010). Agriculture must become more climate-smart so as to achieve food security while remaining functional and efficient under such multiple stressors (FAO, 2013).

CSA was firstly presented by FAO at the Hague Conference on Agriculture, Food Security and Climate Change in 2010. The CSA concept initially focused on FS only, but later included CC adaptation and mitigation in addressing the interlinked challenges of FS faced by CC (FAO, 2010 and 2013). Since its conception, although it is not clearly defined in the academic literature (Engel and Muller, 2016), CSA has been rapidly incorporated into different international agendas as well as repeatedly highlighted at UNFCCC Conference of the Parties. Today, it has a wide ownership among governments, regional and international agencies, civil society and private sector (FAO and CCAFS, 2014)[9] and is still evolving.

[9] CCAFS - CGIAR Research Program on Climate Change, Agriculture, and Food

CSA integrates several dimensions of sustainable development through addressing FS and climate challenges at the same time. CSA is defined and presented by three objectives or pillars: (i) sustainably increasing agricultural productivity to enhance incomes, FS and development; (ii) adapting and building resilience to CC; and (iii) decreasing GHG emissions from agriculture in relation to past trends and increasing carbon sequestration (FAO, 2010, 2013; FAO and CCAFS, 2014). CSA simultaneously considers these dimensions in the assessment of site-specific contexts to maximize the synergies and minimize trade-offs between FS, and CC adaptation and mitigation (FAO, 2013). While CSA is increasingly recommended as a sound strategy in addressing FS as well as in prioritizing short- and long-term agricultural policies in a less predictable climate, site specific and empirical studies are still needed to determine promising CSA technologies and strategic options under such contextual conditions (Arslan et al., 2017; 2015; Rosenstock et al., 2016).

CSA adopts an integrative approach to identify and operationalize sustainable agricultural development and to mainstream technical, policy and investment arrangements in achieving national and global FS. This approach also aims at strengthening livelihoods and FS, particularly smallholders in developing countries, by improving the management and use of natural resources and adopting appropriate technologies and practices in the food systems (Neufeldt et al., 2013). Nevertheless, the CSA evidence base has been found to have more a farm level than value chain focus. Main bodies of CSA works in the literature are agronomy, agroforestry, livestock, post-harvest management, and energy systems (Rosenstock et al., 2016).

2.4.2. The three pillars of CSA

2.4.2.1. Food security in the CSA context

FS is broadly defined by the World Food Summit (1996) as *"existing when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life"*. FS is built on four pillars: (i) physical availability of food, which addresses the "supply side" of FS and is determined by the level of food production, stock levels and net trade; (ii) economic and physical access to food, including incomes and access to markets; (iii) food utilization, i.e. the way the body makes the most of various nutrients in the food, which is influenced by people's health status; and (iv) stability of FS "at all times", which emphasizes the importance of having to reduce the risk of adverse effects on the other three dimensions.

In CSA terms, the FS objective refers to option and technology that sustainably increase productivity or HH income and at the same time, capture mitigation co-benefits by optimizing crop production per unit area while accounting for social and environmental impacts (Bennett et al., 2014; FAO, 2013; Lipper et al., 2014). Increasing FS could result from changes in availability of food (e.g. increased yield), accessibility of food (e.g. increased income, access to market), utilization of food (e.g. increased food safety, diet diversity), or stability of access to food. In this sense, stability of access also targets the resilience of the system because stability depends on resilience (Rosenstock et al., 2016).

As crop and livestock productivity varies significantly across geographic regions, Godfray et al. (2010) strongly suggests closing the yield gap in order to considerably increase the food supply required by continuing global population and consumption growth. However, the future food production has to minimize the negative "externalities" that include the release of GHG emissions as compared to current trends. Campbell et al. (2014) also highly support integrating sustainable intensification into CSA strategies, because the approach promotes food production from existing farmland while considering lower environmental consequences. Sustainable intensification also addresses both adaptation and mitigation.

2.4.2.2.Adaptation and resilience

According to IPCC (2001), adaptation means *"adjustments in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects and impacts, to moderate potential damages or take advantage of opportunities associated with climate change"*. Adaptation to CC needs to be integrated properly into national development plans. Building resilience through adaptation measures is essential to ensure that development achievements are not compromised or negated by CC. In agriculture, FAO (2013) defines adaptation as *"capacity of agricultural systems, communities, households or individuals to prevent or cope with risk or uncertainty and recover from shocks"*. Interchangeably, resilience is defined as the capacity to adapt to changes and disturbances and, at the same time, maintain core functions. Additionally, adaptive capacity refers to human and ecosystem ability to adjust to CC and carry out adaptation measures to avert negative impacts (Bogdanski, 2012; Francisco, 2008; Hoang et al., 2014).

At the HH level, vulnerability means the degree to which HHs are adversely affected by CC-induced climate extremes. On the other hand, resilience measures how much these impacted HHs could rebound after climate shocks. Such resilient variables are difficult to quantify. Therefore, adaptation metrics in relation to CSA practices should be placed on any biophysical, social or economic resilience which help the practitioner or the system to buffer against shocks and stressors (Descheemaeker et al., 2016). An effective adaptation strategy enables them to systematically implement a set of proactive and reactive actions to cope with current and future changes, such as increased frequency and intensity of EWEs.

FAO (2008) classified three types of adaptations: Anticipatory or proactive adaptation –those undertaken before impacts are observed; Autonomous or spontaneous adaptation; and Planned adaptation. The strategies to build resilience against the potential effects of EWEs and climate variability aim at reducing vulnerability and increasing adaptive capacity at all levels (Taimeh, 2013). For developing countries, UNFCCC (2011) proposes strategies that address a combination of environmental stresses, enhance FS and HH income, improve water availability, and promote sustainable land management (SLM), as the most effective.

2.4.2.3.Mitigation

IPCC (2001) defines mitigation is *"an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases"*. CC mitigation associates with strategies and actions to decrease GHG levels through potential practices that mitigate or remove carbon from the atmosphere and store them in different pools, thereby minimizing the negative impacts to global warming and CC. Measurement and quantification of emission reduction or carbon sequestration are supported by available biophysical models that will be presented in later sections.

GHG emissions can be decreased by: (i) supply-side strategies such as reduction of GHG emissions per unit of product; or (ii) demand-side options, e.g. changing demand for food and fiber products or reducing food waste (Smith et al., 2014). Agriculture has an important role in providing supply-side mitigating options through: (i) improvement biological carbon capture and storage in biomass and soil e.g. increased carbon sequestration per unit area– acting as *"carbon sinks"*, especially in carbon-rich ecosystems and conservation of existing carbon stocks; (ii) reducing direct GHG emissions (CO_2, N_2O, CH_4) by applying good agricultural/CSA practices (e.g. sustainable technologies, improved feeding and livestock husbandry); (iii) improving efficiency of input application (e.g. reducing emissions from fossil energy or fertilizer use); and (iv) reducing carbon losses through switching to better land use models (Engel and Muller, 2016; FAO, 2013; Smith et al., 2014).

On the demand side, GHG emissions could be reduced through changes in food demand, including: (i) reductions of losses and waste in the food supply chain (e.g. enhance post-harvest technology and instruments or increase energy use efficiency in the food chain, in which ~30-40% of all food is lost (Godfray et al., 2010)); (ii) changes in eating habits towards less GHG-intensive food (e.g. increase replacing livestock-based products by plant-based product foods where possible (Godfray et al., 2010; Smith et al., 2014)).

2.4.3. Definition of CSA practices

It is worth noting that CSA is not a new set of practices that could be applied universally, but rather an integrated approach to the implementation of agricultural development policies and programs that promote productivity enhancement and adaptive capacity under the realities of CC, while capturing mitigation co-benefits at the same time (FAO, 2013; Lipper et al., 2014). CSA involves different elements and local contexts. CSA key elements are: (i) farm management for sustainable use of natural resources, to produce more with less input and emissions; (ii) landscape solutions to enhance and conserve ecosystem services; and (iii) services for farmers to enable changes (FAO, 2013; FAO and CCAFS, 2014).

A CSA practice or technology is site-specific and context-based solution that addresses climate or weather related risks while improving FS in the form of yield, farm income, and return on investment. Although CSA practices aim at achieving synergies among the three CSA pillars, it does not mean that every CSA technology implemented in any location has to generate *"triple wins"* (Lipper et al., 2014). Alternatively, a CSA practice could achieve the minimum of two benefits among productivity, resilience and mitigation, in which productivity is the priority in developing countries because of their dependence on agriculture (Lipper et al., 2014; Rosenstock et al., 2016). CSA practices aim to maximize synergies and minimize trade-offs between FS, CC mitigation and adaptation, however, trade-offs should be taken into account, as they very much depend on local priorities. For example, in developing nations, FS is still prioritized for national agricultural growth, and the poor are the most affected by, but not the main contributor to, CC (Lipper et al., 2014).

2.5. Economics of CSA

2.5.1. Availability of CSA options and strategies

There is an increasing growth in the literature promoting agricultural mitigation options for developing countries. Most refer to sustainable agriculture and SLM practices that capture the synergies between FS and CC mitigation and in some cases, adaptation (Branca et al., 2013; 2009; 2011; FAO, 2013; IPCC, 2007b; Lal, 2004; Lipper et al., 2011). Such land-based strategies can be categorized as follows: improved cropland management; improved grassland management; restoration of organic soils; restoration of degraded lands and reducing agricultural expansion. Of which, improved cropland management is the most related option to this research, since it potentially builds resilience in crop production systems with improved agronomic practice, integrated nutrient management, water management, tillage management and agroforestry systems (IPCC, 2007b; Zougmoré et al., 2016). In addition, these practices are strongly recommended in South East Asia, one of the most vulnerable regions to CC, because they have particularly high impacts on FS while providing adaptation co-benefits (Lipper et al., 2011).

2.5.2. Productivity and profitability of CSA options and practices

The review of CSA literature shows that productivity is the foremost driver for the maintenance of on-going practices or adoption of a new technology at the farm level. Assessment of CSA practices in terms of financial viability falls into a broad literature of farm management (Malcolm, 1990). This principle has been applied in studying productivity and/or profitability of various CSA technologies in many regions in the developing world, including organic and conventional coffee farms in Costa Rica (Lyngbæk et al., 2001); conventional and agroforestry in Zambia (Ajayi et al., 2009); direct seeding mulch-based cropping systems in Viet Nam (Affholder et al., 2010); extensive shaded cocoa production systems in Ghana (Gockowski et al., 2013) and maize profitability in conservation agriculture (CA) systems in Zimbabwe (Mafongoya et al., 2016), and also CA in India (Pradhan et al., 2017).

Furthermore, some authors have advanced the enterprise[10] budgeting technique in constructing whole-farm models and evaluating the net economic effects of switching from conventional practices to prospective CA options under: (i) farm-level resource constraints e.g. labor, capital or integration livestock in farm portfolio (Affholder et al., 2010; Mafongoya et al., 2016); and (ii) risk, time-related conditions and farming system complexities (Pannell et al., 2014). In addition, some economists have considered those economic elements in long-term, holistic comparisons by extending their economic analysis (incremental farm profits, enterprise benefits and costs) into different time horizons and scenario-based simulations.

[10] For the purpose of this study, a farm or a household having one or more activities or enterprises. Enterprises are defined as subdivisions of a farm, each devoted for producing one crop or livestock.

Net present value (NPV), one of the most important decision rules in project economic analysis (Nas, 1996), is commonly used as a profitability and viability indicator in the above investigations (Bryan et al., 2013; Flugge and Abadi, 2006; Gockowski et al., 2013). Representative farm or farm modeling techniques have been used in conjunction with farm budget in economic analysis of CA in Australia (Pannell et al., 2014) and in Viet Nam (Affholder et al., 2010). Mathematical programming is another technique being deployed moderately in studying costs and benefits of CSA practices, such as agroforestry in Western Australia (Flugge and Abadi, 2006).

This study will advance these management techniques and methods to formulate a farm model analysis in which selected crops and livestock are evaluated for their economic viability, profitability and income contributions at HH level. Costs and benefits of these conventional and CSA practices are estimated to analyze CSA viability in relation to cropland.

2.5.3. Economics of the mitigation component of CSA

Several mitigation options exist in the agriculture sector: reducing emissions (efficient management of carbon and nitrogen flows significant to decrease CO_2, N_2O and CH_4 released by farm practices); enhancing removals (reserving carbon in ecosystems, particularly soil carbon sequestration and vegetative carbon storage) and avoiding or displacing emissions (converting crops and residues into biofuel) (IPCC, 2007b). Carbon removal and sinks have become the central focus of discussion in the literature on agricultural mitigation, because these practices and technologies potentially provide FS co-benefits.

Soil carbon sequestration transfers atmospheric CO_2, into long-lived pools and prevents its immediate re-emission (Lal, 2004). At the global scale, about 1,500 Gt of carbon is sequestered in the soil pool, 2 times higher than that of the atmospheric pool and 3 times higher than that of the biotic pool. Carbon is sequestered in planetary soil at an estimated rate, though large variations from 0.4 to 1.2 Gt C yr^{-1} and SOC potentially enhance FS globally. For example, an increase of 1 ton of soil carbon pool of degraded farmland soil could increase crop yield by 20 to 40 kg ha^{-1} for wheat, 10 to 20 kg ha^{-1} for maize, and 0.5 to 1.0 kg ha^{-1} for cowpea (Lal, 2004).

Besides SOC, vegetation or plant biomass is considered a significant pool for carbon storage (IPCC, 2007b). Long rotation agricultural systems such as agroforestry, home-gardens and perennial plantations can sequester substantial amounts of carbon in plant biomass and in long-lasting wood products. Such areas on earth could store 1.1 to 1.2 billion tons of carbon for a period of 50 years. Agroforestry systems could sequester from 12 to 228 tons C ha^{-1} (Albrecht and Kandji, 2003). Many mitigation opportunities could be created from current technologies and hence, can be implemented immediately. However, technological development and innovation will play a key role in driving mitigation measures in the future.

There have been several studies investigating the economics of agricultural GHG mitigation, including costs and benefits of carbon farming to practitioners, the efficiency of mitigation strategies and the effectiveness of policy incentives. Recent review of carbon farming economics carried out by Tang et al. (2016) indicate that many carbon farming studies popularly combine biophysical and economic models to evaluate mitigation options in terms of feasibility and practical soundness. The output of biophysical models (e.g. on-farm emission or storage) are then applied in economic models to estimate farm revenues and costs.

Biophysical models

In most cases, biophysical models are constructed from information on soil types, climate, current or past land use records, plant types, and livestock structure. These models estimate, among other things, crop and livestock yields, vegetation growth, GHG emission levels, and soil carbon levels. The popular applied models include: (i) CENTURY, a generalized-biogeochemical ecosystem model simulating nutrient dynamics; (ii) APSIM (Agricultural Production Systems Simulator), a process-based model on a paddock scale; (iii) NCAT (National Carbon Accounting Toolbox), an Australian predictive model for carbon flows in forest and agricultural systems; (iv) EPIC (Environmental Policy Integrated Climate), a model that operates on a daily time step and simulates crop production, soil carbon and nitrogen; and (v) CALM (Carbon Accounting for Land Managers), an online calculator that can be used to estimate GHG emissions on a farm scale. These models commonly estimate soil carbon changes and enable simulating multiple carbon farming practices (crop rotation, fertilization, and tillage). Nonetheless, these models are limited in wide application since they are complex, process- and specific parameter-based. New application requires a large number of variable inputs to reset parameters (Tang et al., 2016).

A part from these models, carbon footprint analysis, a life cycle assessment (LCA)–based approach, has been developed and widely applied in various sectors worldwide to measure sustainability or GHG-intensiveness of any good or service (Franchetti and Apul, 2013). In ISO/TS 14067 standard, carbon footprint of products (CFP) is defined as "*the quantity of GHGs expressed in terms of CO_2-e, emitted into the atmosphere by individual, organization, process,* *product, or event from within a specified boundary*". In principal, the standard can be implemented as a full or partial LCA. CFP is the "*sum of GHGs and removals in a product system, expressed as CO_2 equivalents and based on a life cycle assessment using the single impact category of climate change"* and partial CFP is the *"sum of greenhouse gas emissions and removals of one or more selected process(es) of a product system, expressed as CO_2 equivalents and based on the relevant stages or processes within the life cycle"* (ISO, 2013).

This CFP is originally and intensively applied to assess material and energy in industrial production but recently it has been used widely in agriculture and aquaculture. Several studies have been conducted to investigate all environmental impacts (full LCA) or only global warming potential (a CFP). In aquaculture, examples include: LCA intensive and semi-intensive shrimp farming systems in Hainan Province, China (Cao et al., 2011); LCA eco-labeling in farmed shrimp product (Mungkung et al., 2006); LCA food production in integrated agriculture–aquaculture systems in the Mekong Delta, Viet Nam (Phong et al., 2011); CFP of farmed catfish Viet Nam (Bosma et al., 2011; Henriksson et al., 2015); and LCA organic and conventional mangrove-shrimp farms in Viet Nam (Jonell and Henriksson, 2015).

There are many LCA and CFP studies on agricultural practices published in the literature. Among these, few have focused intensively on carbon footprint, the interest of this research, including CFP wheat production in Australia (Biswas et al., 2008), CFP in banana supply chain in Costa Rica (Svanes and Aronsson, 2013), CFP rice production in California, U.S.A (Brodt et al., 2014), CFP in maize production in China (Wang et al., 2015), and CFP organic and conventional Darjeeling tea in India (Cichorowski et al., 2015). Many of these studies have set their boundaries at the farm-gate and few attempted to go beyond the farm (e.g. Darjeeling tea). For perennial cropping systems, there have been 103 peer-reviewed LCA/CFP studies on 14 products, most also focusing on the farm level (Bessou et al., 2013). LCA/CFP studies on tea production in Southeast Asia and in Viet Nam are extremely scarce. This research contributes to this literature by conducting a partial or "cradle-to-gate" CFP for fresh tea production to evaluate the mitigation potential in this system.

Economic models

The processes of estimation of costs, revenues or trade-offs associated with carbon sequestration or emissions typically involve either econometrics-based simulations or mathematical programming techniques. In econometric models, production functions can be combined with a discrete land use decision simulation. Simulated site-specific data and farm production from biophysical models are used to estimate production functions (net returns, cost and price) for simulating in economic models (Tang et al., 2016). Several studies have used economic simulation models to estimate the economic possibility of carbon sequestration practices and evaluate associations between farm profitability, spatial heterogeneity, and policy incentives (Antle et al., 2003; 2007; Capalbo et al., 2004).

Mathematical programming models have also been applied in analyzing economic optimization of certain mitigation options constrained by farm resources (Tang et al., 2016). Solving the problem of optimal resource allocation provides farmers with sound solutions for integrating climate-smart practices into farm activities. A linear programming model has been used to maximize overall farm GMs and simulate the marginal mitigation costs of GHG in the EU (De Cara et al., 2005; De Cara and Jayet, 2011) and in the UK (MacLeod et al., 2010). Both of them conclude that agriculture could generally lower mitigation costs. Some researchers have tried this technique to maximize overall farm profit rather than GMs in analyzing carbon sequestration in crop production systems (Kragt et al., 2012). González-Estrada et al. (2008) also followed this approach but they integrated FS requirement into the model to ensure food supply for farmers. However, none of the above models take into account potential changes in crop output as a result of changes in SOC levels and vice versa (Tang et al., 2016). Evidence base for carbon farming economics in Asia and Viet Nam is limited in the literature.

Costs of agricultural mitigation options

Agriculture offers a variety of cost-effective, high economic potential GHG mitigation options. According to IPCC (2007b), agricultural actions are found to be cost competitive compared with non-agricultural technologies (e.g., energy, transportation, forestry) in achieving long-run climate targets. Long-term estimations, exception soil carbon management options, show that non-CO_2 crop and livestock abatement options could cost-effectively contribute 270–1520 MtCO_2-e yr^{-1} globally in 2030 with carbon prices up to 20 US\$/tCO_2-e, or 640–1870 MtCO_2-e yr^{-1} with carbon prices up to 50 US\$/tCO_2-e. If all gases are considered, mitigation economic potential from agriculture is estimated to be 1500-1600, 2500-2700, and 4000-4300 MtCO_2-e yr^{-1} at carbon prices of up to 20, 50 and 100 US\$/tCO_2-e, respectively. In which, two-thirds of the potential is from developing countries.

Achieving those potentials, however, requires us to understand and estimate costs associated with the options. McCarthy et al. (2011) categorized costs related to the adoption of SLM technologies into five groups: investment costs (expenditure for on-farm structure); maintenance costs (recurrent expenses and periodic costs); opportunity costs (benefit forgone by allocating own resources to SLM practices instead of to other alternatives); transaction costs (bargaining, negotiation, monitoring and enforcement), and risk costs (uncertainty). Out of these, opportunity costs are the most important in enabling the transitions from conventional to CSA practices. Investment costs, including up-front and maintenance costs, must be satisfied by increased yields in the future and higher benefits than costs discounted over a certain timeline to sustain SLM in the long term (Branca et al., 2009; Lipper et al., 2011; McCarthy et al., 2011). Literature summaries indicate that land-based agricultural mitigation options cost from 0 to 2,060 US\$ ha^{-1} (establishment costs) and from 12 to 814 US\$ ha^{-1} yr^{-1} (maintenance costs) (Lipper et al., 2011). The cost estimates of some carbon farming practices vary between \$3 and \$130/ tCO_2-e in 2012 US dollars (Tang et al., 2016). In short, costs associated with agricultural GHG mitigation options show wide variation, depending on the mitigation strategies, spatial locations and scenario considered.

2.5.4. Adoption barriers for CSA options

Although many GHGs mitigation options in agriculture production systems have been realized to provide FS and adaption co-benefits, the adoption of SLM practices is still very low, especially in vulnerable regions (e.g. sub-Saharan Africa and Southeast Asia). McCarthy et al. (2011) and Lipper et al. (2011) categorized three main groups of barriers for adoption:

(i) Delayed return on investments: CSA practices can increase the output in the medium to long term thanks to soil and water improvement, but in the short run, yields often decrease (Giller et al, 2009 cited in McCarthy et al. (2011)). For smallholder operators, extended transition period and higher opportunity costs are experienced frequently, particularly where no credit and insurance markets existed (Antle and Diagana, 2003);

(ii) Collective action failure: CSA mitigation potentials often value “local public good” and require a minimum scale at particular sites to realize benefits. Collective action is critical in this case and in the case of failure, such abated benefits are not achievable.

(iii) Lack of tenure security: While mitigation benefits are often recognized and compensated in the long term, tenure uncertainty could be disincentive for investing on the land.

Adoption of CSA practices often implies high short-run costs. Lack of credit access is an additional critical challenge that leads smallholder farmers to value such initial costs much stronger than long run benefits. Additionally, small growers often practice risk aversion, meaning that they consider certain short-run investment costs to have much higher value than uncertain future benefits (Lipper et al., 2011). One possible pathway to overcome the problems and more importantly, to help farmers temporarily cover reduced yields in transition years, is to design payment for environmental services (PES) programs (Engel and Muller, 2016; Lipper et al., 2011).

PES is defined in the CSA context as *a positive economic incentive where environmental services (ES) providers can voluntarily apply for a payment conditional on either on ES provision or on activity clearly linked to ES provision* (Engel and Muller, 2016; Engel et al., 2008). The overall objective of a PES scheme is to enable translating at least part of social benefits from increased ES provision into a payment to ES providers. As a result, their total returns (private benefits) from socially serviced actions become higher than under conventional activities (purely income from yields) (Engel and Muller, 2016). CSA practitioners are considered as the ES providers in this case, since their adoption generating carbon sequestration and/or GHG reduction (public good) benefits the community at large. This is further supported by Engel et al. (2008) and Wunder (2013) when they saw PES is a popularly advisable means of addressing external effects. CC mitigation is a global public good and adoption of CSA practices provides external benefits to mankind globally. Hence, PES is hypothetically potential and suitable vehicle to translate societal benefits generated from a change in land use technology into profits for adopters.

Three conditions have to be met to allow a suitable PES scheme in CSA (Engel and Muller, 2016; Wunder, 2013). The first one is that societal benefits exceed the costs of implementation. CSA practices could satisfy this condition since these technologies provide CC mitigation and FS benefits to adopters simultaneously. However, it’s worth noticing that detailed data for profit calculations (costs and benefits) over time is limited in many CSA practice. The second condition is to secure land tenure for CSA practitioners. This could limit the scope of a PES scheme designed for regions where tenure insecurity is common (e.g. sub-Saharan Africa). The third condition requires a satisfactory level of institutional capacity which allows a PES scheme to function in an efficient and cost-effective manner. Once satisfying these conditions, PES needs to meet two additional conditions to be effective: First, the expected NPV of operating current CSA practices should be fundamentally higher than that of the previous one. Second, any incentive for switching back at a later point in time should be absent (Engel and Muller, 2016).

Though societal benefits often outweigh the costs in CSA, a PES scheme only functions effectively when such benefits are translated into actual funding for the payments. ES beneficiaries are often called for but limited in contribution to funding, due to the nature of public good that ES providers offer (Wunder, 2005). Alternatively, carbon finance could come from the voluntary or compliance carbon market[11], from public source or public-private partnerships. In the first option, funding for agricultural activities is potential but marginal because land use related to forest projects are predominant, with more than 50% of credits in the voluntary carbon market. Agroforestry shares a small part, and agricultural projects still remain insignificant (Ecosystem Marketplace, 2015). One of the main reasons is that the estimation and monitoring emission reductions in agricultural activities are very complex and uncertain. Another key is the riskiness of investment in carbon credits from CSA practices, because farmers often require upfront payment to cover their initial investment costs, while carbon mitigation occurs with time lag and emissions removal is potentially reversible (Muller, 2012).

These challenges combined with low carbon price and high heterogeneity in agricultural production have limited the number of CSA investment examples in the literature. Within the framework of the Kyoto Protocol, the Clean Development Mechanism (CDM) provides a model for generating emissions reductions (ERs) in developing countries with technical and financial support from developed countries. However, the CDM only recognizes a limited number of agricultural production technologies (Engel and Muller, 2016; Lipper et al., 2011). Since the eligibility of agricultural activities in major compliance and voluntary markets remains a challenge, the public funding source is an alternative, and likely more promising.

Agriculture and agricultural GHG mitigation technologies have recently emerged in discussion for funding in various international financial mechanisms (e.g. Green Climate Fund, Fast Start Finance) (UNFCCC, 2017a) and national commitments under the Paris Agreement until-and-after 2020 (e.g. “nationally appropriate mitigation actions” (NAMAs), “intended nationally determined contributions” (INDCs) and “National Adaptation Programs of Action” (NAPAs) (UNFCCC, 2017b, c, d). Access to funding from public sources is very promising when CSA policy is concretely mainstreamed in national implementation plans for NAMAs, NAPAs, and INDCs. In addition, since many CSA practices can simultaneously deliver profitability and ecosystem

[11] Carbon market: Institution where carbon offsets can be traded (Muller, 2012)

benefits (e.g. water quality improvements, erosion and flood prevention and biodiversity conservation) (Branca et al., 2009; Branca et al., 2011; Lipper et al., 2011), bundling those ES into a single PES scheme could help to attract sufficient funding from public-private partnerships (Engel and Muller, 2016).

2.5.5. Economics and other knowledge of the adaptation component of CSA

As adaptation is a highly contextual and multi-dimensional concept, this section presents literature related to not only the economics of adaptation to CC, but also local knowledge related to it. The latter will be discussed first to lay out the need of multiple approaches for dealing with adaptation in this research. This also reflects the logical framework in a large body of literature on adaptation to CC that captures indigenous knowledge at the first stage in order to better understand communities' experience with CC-associated risks and their responsive measures. Taking this as a foundation, scientific knowledge can firmly go further.

Local knowledge

Although climate variability is a global phenomenon, its impact is local with more vulnerability posed to developing countries. As a result, farmers and rural communities are likely suffer the most from and bear the costs of CC (Adger et al., 2003; Kibue et al., 2016). Understanding locally embedded knowledge about climate extremes and variability is crucial to build both short- and long-term resilience capacity. Recognizing this vital role, the Fourth Assessment Report of IPCC also acknowledges that traditional knowledge and past experience can support capacity building for CC adaptation and resilience (IPCC, 2007b).

Local knowledge, interchangeably known as indigenous knowledge or traditional knowledge, is acquired, accumulated and shared by communities and societies over generations. The knowledge is an outcome from interactions between local people and their external environment based in a set of technologies, skills and beliefs which are practiced in various livelihood activities such as agriculture and natural resource management (Kasali, 2011). Since the knowledge is closely connected to local biophysical features and social systems, it will be helpful for setting an effective adaptation strategy in which scientific knowledge is not always sufficient (Lebel, 2013).

In this sense, integration of farmers' perception into adaptation studies has been growing considerably worldwide, particular in Africa. However, there has not been much systematic exploration in Asia or Southeast Asia, where EWEs and seasonal monsoon variability are key climate factors (Dang et al., 2014; Francisco, 2008; IPCC, 2007b; Lebel, 2013). Exploring farmers' perception about climate variability and potential barriers is key for adaptation to CC because this is the initial step for a success adaptation process (Deressa et al., 2009; Kibue et al., 2016). Local farmers often interpret changes through past experience or repeated observation of changes and immediate biophysical impacts to farm activities. Farmers' experience with the reactions of plants and livestock to climate extremes could be used as biophysical indicators to anticipate extreme weather, changes in season or variety selection (Lebel, 2013). The viability and utility value of local knowledge could be improved when it is integrated with scientific knowledge (Kasali, 2011).

In light of this literature, Dang et al. (2014) have employed focus group discussions (FGD) and in-depth interviews in exploring farmers' perceptions about climate variability and barriers to adaption in the Mekong River Delta in Viet Nam. The combined analysis of local perceptions with meteorological data has revealed that both farmers, agricultural officers and climate data have basically presented a consistent trend of local CC. Farmers' perceptions about CC have been shaped by the most recent and direct experiences with climate extremes. They also stressed that psychological factors are also the key barriers, besides resource and socio-economic factors, to adaptation, and thus those factors should be carefully considered in preparing a successful adaptation policy.

Similarly, these approaches have also been used in many other regions to capture farmers' perception on changes in rainfall and temperature and their responsive measures, or influencing factors to such changes. Studies on such topics have taken place in states of Maharashtra and Andhra Pradesh, India (Banerjee, 2015), Anhui and Jiangsu regions, China (Kibue et al., 2016), Ha Tinh Province, Viet Nam (Hoang et al., 2014), Pailin and Samlout regions, Northwest Cambodia (Touch et al., 2016), and in Nandi and Keiyo Districts, Kenya (Songok et al., 2011). They share common findings and most of them reaffirm that what farmers perceived about climate variability are often consistent with weather records. Indigenous knowledge is viable to develop an adaptation strategy at the initial stage. However, hybridizing local with scientific knowledge is highly recommended for improving the robustness of adaptation to CC in the long run, where only local knowledge is insufficient (Kasali, 2011).

Diversification

The basic theories in economics suggest that diversification is one of the most fundamental strategies to maximize one's utility in the face of risk and imperfect information. Diversification is a potential pathway in building HH, village, landscape and national adapting capabilities to CC (Arslan et al., 2017). At the HH level, adoption of diversification leads to better management of risk as well as adjustment to smooth consumption aftermath. The empirical evidence also suggests that more diversified HHs have higher incomes and greater consumption per capita. Diversification can be driven by push and/or pull factors. While push factors often refer to the presence of high transaction costs and adverse shocks or the absence of perfect credit and insurance markets, pull factors depend on the attractiveness of non-farm income or availability of new technologies in the farm sector (Reardon, 1997).

Diversification can be measured either by simple count indices such as farm activity count (Jones et al., 2014), HH income portfolios (Lay et al., 2009) or complex indices e.g. accounting for evenness and/or abundance (Smale, 2006). Arslan et al. (2017) use the Gini-Simpson index to analyze various dimensions of crop, livestock and income diversification in Zambian rural HHs under increased rainfall variability and shocks. Their evidence shows that diversification in crop and livestock have increased incomes and in the same time, decreased rural poverty. Therefore, this type of diversification has been demonstrated as a potential CSA strategy in responding to CC. The long run rainfall variation is a push factor for crop, livestock and income diversification.

Similarly, enterprise mix diversification are often practiced by HHs in rural economies and farming systems around the world as an effective strategy to mitigate the adverse impact of CC. Kandulu et al. (2012) have combined Agricultural Production Simulator modeling with Monte Carlo simulation, probability theory, and finance techniques to study the benefits that mix enterprise strategy could provide to Australian rain-fed agriculture. They conclude that diversification has significantly improved the climate-induced variability of long term net returns by reducing the standard deviation by up to A$200 ha^{-1}, or 52% of means of net returns, and increasing the probability of breaking even by up to 20%. A multinomial discrete choice model has been used to analyze the determinants of farm-level adaptation measures in 11 African countries. The result shows that mono-cropping is the most vulnerable to CC and hence, diversifying into multiple crops, mixed crop-livestock systems, and switching from crops to livestock and from dryland to irrigation is highly encouraged (Hassan and Nhemachena, 2008).

Household resilience

By definition, HH adaptation is built from both capacity to cope with and rebound from shocks. While shock effects on HH well-being have been paid great attention, recovery from such events has been discussed occasionally in the literature of vulnerability. Thus, it's worthwhile to understand the resilient pathways in which HHs could recover from climate extremes. Recently, Tran (2015) has employed the theory on income shocks and resilience paths (Carter et al., 2007) to assess post-shock resilience in 2000 rural HHs in Viet Nam. In his study, climate extreme events such as droughts or cold spells are referred to as agricultural shocks. Once faced by such adverse events, rural poor HHs suffer much more than wealthier ones because they are more dependent on their own resources (e.g. savings, livestock) than on external limited credit or insurance. Wealthier households, who possess higher levels of income and stocks of assets, are therefore able to buffer better and recover quicker from shocks, and follow a smoother consumption than their counterparts.

This review has shown that both of scientific and local knowledge are playing a role in building HH resilience and hence, should be hybridized in studying CSA adaptation. Each branch of this knowledge could supplement the other. In this research, local knowledge will be used to explore farmer's perceptions. These are then compared with high resolution climate data and HH level data to understand the adaptation potential of tea practices to NMR's agricultural production systems.

CHAPTER 3. METHODOLOGY

3.1. Introduction

In this chapter, a combination of qualitative and quantitative approach, together with different methods, is presented in order to investigate climate-smartness in tea production systems (Figure 3.1). Firstly, a Farm Model Analysis is constructed for economic assessment of key crops and livestock streaming in the 30-year lifetime of conventional tea plantations. Gross margins and profitability parameters derived from these partial budgets are analyzed and compared among farm enterprises to determine viability of choices under scarce resources. Turning to adaptation, Focus Group Discussion, one of the Participatory Rural Appraisal tools, is employed to capture local knowledge on climate shocks and responsive measures of local HHs and farming systems. Insights from this qualitative method will be overlaid with descriptive statistics obtained from rural surveys. Lastly, the carbon footprint of products, a life cycle assessment approach, is deployed to assess GHG reduction potential within the boundary of tea production systems.

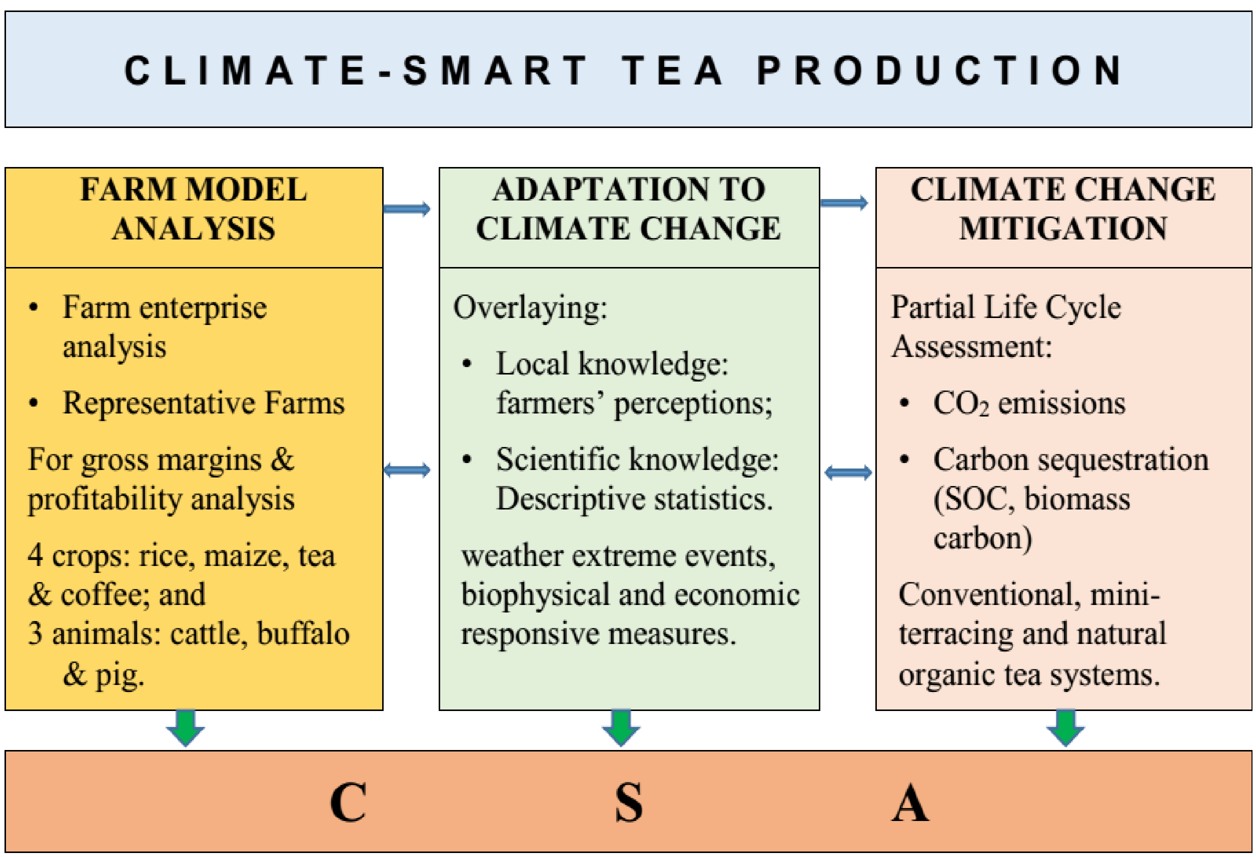

Figure 3.1. Overall Methodological Framework

The three components of CSA in the methodological framework are elaborated in the following analytical steps:

Assessment component	Method	Data	Analytical outputs
1. Farm model analysis	Enterprise budget	FAO-NOMAFSI dataset VARHS dataset FGDs and expert adjustment Secondary	Gross and net margins trends by crop/ livestock and practices GM and profitability indicators
	GMs analysis	FAO-NOMAFSI dataset Enterprise budget	Practice cost effectiveness and efficiency Switching/opportunity costs
	Representative Farms	AgriCensus 2011 Enterprise budgets	Climate-smartness evaluation in relation to farm scale, and crop & livestock combination.
2. Adaptation	Overlaying local and scientific knowledge	FGD data VARHS dataset ERA-Interim climate dataset	Climate trends Household income and income factor in relation to tea practice Household resilience
3. Mitigation	LCA CFPs	FAO-NOMAFSI dataset FGD data Field interview Secondary	Carbon emissions Carbon sequestration Carbon balance Mitigation potential

3.2. Methodology for farm model analysis

The assessment of the CSA pillar on FS is conducted at the farm-level, where tea production is economically evaluated against other enterprises under resource-based HH economics. In the first phase, GMs and profitability of selected farm enterprises are derived using partial budgeting technique, and then turned to evaluate among enterprises. In the second phase, economic parameters from farm activity analysis are used in representative farms to assess the enterprise combination in achieving climate smartness in NMR of Viet Nam.

3.2.1. Farm enterprise analysis

This research employs basic budgeting methods as described by Brown (1982) and Gittinger (1982) in formulating partial budgets for targeted crops and livestock. In this research, a crop or a livestock of these practices is defined as an enterprise.

3.2.1.1. Scope of enterprise and lifetime

Rain-fed farming is fundamental in the NMR of Viet Nam, including maize, rice, tea, and coffee practices. This research targets these key upland crops and also cattle, buffalo and pig enterprises in farm level analysis. Furthermore, besides such conventional technologies, CSA practices such as minimum tillage (MT) in maize production, mini-terracing in tea and Arabica coffee production are also incorporated to study their comparative advantages on enterprise profitability.

In terms of lifetime, since tea is the research focus, all enterprises are consequently modeled in accordance to conventional tea production. Tea yield commonly reaches full development from year 8 and remains stable up to year 25, then gradually declines (Dang, 2002, 2005b). The economic life span of the plant is generally from 40 to 50 years (Chen et al., 2013) and could be more than 40 years in NMR conditions, depending on cultivars and pruning techniques (Do, 2015; Le et al., 1999). Given such variability, in this research, budgeting for conventional tea streams in a 30-year time frame. For other crops and livestock, even though their life cycles are annual (e.g. maize, upland rice, pig) or perennial but shorter than that of tea (e.g. coffee, buffalo, cattle), they will be also streamed in the same time horizon as that of tea for comparison purposes.

Tea and coffee are typical perennial crops in the NMR of Viet Nam which normally require 2-3 years after planting for framing and crown growing (Chen et al., 2013; Le et al., 1999). This is called the initial establishment or investment phase, because it requires intensive inputs and farm management while having little or no economic harvest. Generally, conventional tea plantations have commercial harvest from year 4 and the yield increases rapidly to its peak from year 8 to 10 (Do, 2015; Le et al., 1999). In contrast, conventional coffee plantations need slightly shorter time to bear cherries for economic harvest. Arabica coffee planted from seedlings in the NMR of Viet Nam regularly begins bearing in year 3 and reaches full production at year 6. The economic phase of conventional Arabica coffee lasts around 10 years, then the plant needs a heavy prune so as to re-start the second cycle (Dien Bien DARD, 2012; Vu, 2017). In mini-terracing technology, the plant is projected to have 2 more years in the economic phase than with conventional technology. For annual crops like maize and rice, their partial budgets, although accounted on a yearly base, are extended in parallel to that of perennial crops.

In livestock enterprise, while cattle and buffalo are raised using traditional methods in which both indigenous and cross breeding are conventionally managed for multiple purposes (meat production, draft power and breeding), pig farming is rather intensive whereby both sows, piglets and fatteners are kept in smallholder farmers for meat production and weaner off-takings. In developing countries, cattle and buffalo herds generally reach full development at year 7 (Gittinger, 1982) and female adults normally take 3 years (cattle) or 4 years (buffalo) to start calving (Huyen et al., 2010) and (Nguyen, 2012a), whereas the pig stocking cycle, much likely annual crops, falls within 12 months. Hence, in this study, budgeting for pig husbandry is also repeated every year in the designed time horizon.

3.2.1.2. Technical coefficients and assumptions used in enterprise budgets

3.2.1.2.1. Enterprise budgeting for crops

For annual crops (maize; upland rice), most technical coefficients for yield, input and output are taken from Branca et al. (2017). Some of these have been slightly adjusted to be in line with updated references. For example, reference for unit cost of local labor has followed Viet Nam's Labor Market Update (MOLISA and GSO, 2014). Unit of farm-gate price for upland rice, whose varieties are mainly sticky or local specialty, is about 20% higher than that of normal paddy rice (author's field interview). For perennial crops (tea and coffee), their budgets are assembled from two phases, namely initial establishment and full development. Budgets for the initial phase are developed using coefficients and assumptions obtained from national and provincial extension programs (number of seedlings, shading trees, inputs used per hectare unit). Budgets for the full development phase use coefficients from Branca et al. (2017).

3.2.1.2.2. Enterprise budgeting for livestock

Large ruminant husbandry (cattle and buffalo)

Coefficients for opening stocks, price of inputs (stocks purchased, vaccines, medicines and feed), sale price of output off-taking (live head) are generated from FAO-NOMAFSI dataset (FAO and NOMAFSI, 2014)[12]. Cattle are categorized by sex and age: cows (heifers ≥18 months; reproducing cows); bulls (male cattle ≥18 months); heifers (calf ≥ 6 months) (Huyen et al., 2010). Similarly for buffalos, female adult (heifers ≥21 months; reproducing buffalo); male adult (male heifers ≥21 months); heifers (calf ≥ 9 months). The average calving interval for cattle is 13 months and for buffalo is 18 months (Do, 2010). According to Huyen et al. (2010), cows on small and medium farms are kept as long as they could produce calves and culled at an average

[12] FAO and NOMAFSI have carried out a project called "Climate-smart Agriculture: Capturing the Synergies Between Mitigation, Adaptation and Food Security" – CSA Project

of 12.9 years; bulls are culled depending on their working capacity at an average age of 7.8 years. However, since livestock husbandry is multipurpose and farmers face labor constraint, each year farmers typically just keep a reasonable number of stock and off take the rest for cash earnings. Mortality coefficients for calf, heifer and adult are derived from data analysis of VARHS (2010, 2012 and 2014). Coefficients related to drought power of cattle or buffalo are assumed or based on expert interviews.

Pig husbandry

Pigs are categorized as sow (an adult female pig), piglet (a baby or young pig before it is weaned) and gilt (a young female pig that has not yet had piglets). Like ruminants, coefficients for opening stocks, price of inputs (stock purchased, vaccines, medicines, feed), sale price of output off-taking (live head) for pig finishing are taken from FAO-NOMAFSI dataset (FAO and NOMAFSI, 2014). Nevertheless, similar parameters for sows and piglets as well as sows and litters dynamic are obtained from Vo and Vu (2006). Mortality coefficients for general pig husbandry are also acquired from data analysis of VARHS 2010-2014 (CIEM, 2012-2014)[13]. Coefficients related to sow replacement rate, litter per sow per year, and piglets born live per litter are taken from Vu et al. (2007), Phung et al. (2008), and Lemke and Valle Zárate (2008). A few other coefficients are assumed or based on expert interviews.

3.2.1.3. Gross margins analysis

GMs analysis is the first step in selecting the best option in farming activities. The goal of this step is to make a comparison among different crop and livestock enterprises. Therefore, in GMs analysis, only variable costs are included and all fixed costs can be ignored as they accrue to all alternatives. GMs are calculated using only those costs that are actually paid for by the farmer, and is equal to gross revenue minus cash inputs minus cost of hired labor. However, given that smallholder farmers use limited external hired labor, all labor costs are considered as family labor for the sake of simplicity. Main assumptions:

- Land was not considered as an input because it is a fixed input.
- Total variable costs are those directly applicable to crop production, including cash inputs spending on fertilizers, manure, herbicides, insecticides, and fungicides.
- Prices are considered as farm-gate figures even though some output is either sold at farm gate or at processing gate (tea leaves or coffee cherries). The latter case requires some

[13] Central Institute for Economic Management

costs associated with transportation but they are insignificant. In principle, different prices need to be used for different quantity and quality of produce sold. Also, the price fluctuates monthly or seasonally. However, a stable averaged price is used for calculation.

GMs are calculated for each crop and target technologies over 1-year product cycle. Calculation of GMs are repeated in each year of the project lifetime using the following equations:

$$GM_{jTt} = TR_{jTt} - TVC_{jTt} \tag{1}$$

$$TR_{jTt} = P_j Q_{jTt} \tag{2}$$

$$TVC_{jTt} = \sum_{i=1}^{n} P_{xit} X_{it} \tag{3}$$

$$GM_{jTt} = P_j Q_{jTt} - \sum_{i=1}^{n} P_{xi} X_{iTt} \tag{4}$$

Where:

GM_{jTt} = gross margin (\$/ha)[14], for crop j and technology T of a given year t
TR_{jTt} = total revenue (\$/ha), for crop j and technology T of a given year t
TVC_{jT} = total variable costs (\$/ha), for crop j and technology T of a given year t
Q_{jTt} = crop yield obtained at year t under technologies T (Kg/ha)
P_j = farm-gate price of crop j (\$/kg)
X_{iTt} = quantity of input i (per ha) used at year t in production of crop j, under technology T
P_{xit} = farm-gate price of input i (\$/kg) of a given year t.

The assumptions for GMs analysis conducted in livestock budgets are:

- Access to pastures was not a calculated cost because pastoralists traditionally practice free grazing in common open fields. All kinds of additional feeds are considered as own produced and farmers were asked to estimate such feeding in monetary value per head per year.
- Total variable costs are those directly applicable to livestock husbandry, including cash inputs spending on feed (see above), vaccines and medicines.
- Prices are averaged at farm-gate value and measured per live head, given that farmers could also sell by weight and selling price is closely dependent on the quality of livestock.
- The number of working days as draft power and hired price per day for cattle and buffalo are assumed to estimate non-cash benefit for pastoralists.

$$GM_{lt} = (TR_{lt} - TVC_{lt}) / \sum_{c=1}^{n} Q_{lCt} \tag{5}$$

$$TR_{lt} = \sum_{c=1}^{n} P_{lCt} Q_{lCt} + \sum_{c=1}^{n} Q_{lCt} N_{lCt} P_{DP} \tag{6}$$

$$TVC_{lt} = \sum_{i=1}^{n} P_{xi} Q_{lCt} \tag{7}$$

$$GM_{lt} = \sum_{c=1}^{n} P_{lCt} Q_{lCt} - \sum_{i=1}^{n} P_{xi} Q_{lCt} \tag{8}$$

Where:

GM_{lt} = gross margin (\$/head), for livestock l of given year t

[14] Calculations are based on original Vietnamese currency (VND) and then converted into US dollar. Exchange rate USD/VND = 1 / 20, 950 (State Bank of Viet Nam, 2013)

TR_{lt} = total revenue ($), for livestock *l* of given year *t*
TVC_{lt} = total variable costs ($), for livestock *l* of given year *t*
Q_{lCt} = Total quantity of livestock *l*, category *C* (e.g. weaner, adult) at given year *t* (head)
P_{Ct} = farm-gate price of livestock *l*, category *C* ($/ live head)
P_{xi} = farm-gate unit cost of input *i* (cattle, pig patterning: $/head /year; sows and piglets: $/sow/litter)
N_{lCt} = number of working day as draught power (day/year), for livestock *l* (e.g. cattle or buffalo), category C (e.g. adult male or female) at given year *t*
P_{DP} = sale price of draught power ($/working day; averaged price for both male and female)

3.2.1.4. Profitability analysis

Five profitability parameters are considered here: return to family labor, internal rate of return (IRR), net present value (NPV), benefit-cost ratio (BCR) and annual net margins (NMs). They are calculated through the following formulas:

$$RFL_{pt} = GM_{pt}/FL_{pt} \tag{9}$$

$$NM_{pt} = GM_{pt} - CFL_{pt} \tag{10}$$

$$TC_{pt} = TVC_{pt} + CFL_{pt} \tag{11}$$

$$BCR_{pt} = NM_{pt}/TC_{pt} \tag{12}$$

$$NPV_p = \sum_{t=1}^{n} \left[\frac{NM_{pt}}{(1+r)^y} - \frac{TC_{pt}}{(1+r)^y}\right] \tag{13}$$

$$IRR_p \ when\ NPV_p = 0\ or\ \ \sum_{y=1}^{n} \frac{NM_{pt}}{(1+IRR)^y} - \sum_{y=1}^{n} \frac{TC_{pt}}{(1+IRR)^y} \tag{14}$$

Where:
RFL_{pt} = Return to family labor ($/day) of practice *p* (crop or livestock) of a given year *t*
GM_{pt} = Gross margin ($/ha for crop or $/head for livestock) of a given year *t*
FL_{pt} = Family labor (total person-day/ha for crop or total person-day/head/year for livestock) of a given year *t*
CFL_{pt} = Cost of family labor ($/ha or farm) of practice *p* of a given year *t*
NM_{pt} = Net margin ($/ha or head) of practice *p* of a given year *t*
TC_{pt} = Total costs ($/ha or farm) of practice *p* of a given year *t*
BCR_{pt} = Benefit cost ratio of practice *p* of a given year *t*
NPV_p = Net Present Value of ($/ha or farm) for practice *p*
IRR_p = Internal Rate of Return (%) for practice *p*

Once profitability parameter is obtained, the opportunity cost for switching from other land use alternatives to conventional tea production is evaluated using NMs. The sum of investment ($/ha) in the initial phase of perennial crops is also calculated and separated for analysis costs of investments.

3.2.2. Representative Farms

This research strategically applies the typical farm theory to ground representative farms (RFs) for CSA assessment. The theory was first defined by Elliott (1928) and further developed and re-defined by Day (1963), Plaxico and Tweeten (1963) using statistical concepts. They considered a RF as a typical farm averaged from all the farms in a group. Nevertheless, RFs are not necessarily the mean of all farms for the group being presented, rather RFs are more of a modal concept. In the light of this literature, for the purpose of this research, RFs are modeled by ordering HH data (averages of crop area and livestock head per HH) in increasing magnitude using *p*th percentile. Data of Viet Nam Agriculture and Rural Census, denoted as AgriCensus (GSO, 2011), are used for descriptive statistics. RFs are strategically constructed from the following steps:

Step 1. Extract data of all 15 NMR provinces from AgriCensus (GSO, 2011) which contain variables at provincial level on: (i) total number of agricultural households; (ii) total agricultural land by land use type. These are then merged with provincial data on: (i) cultivated areas of selected crops, and (ii) number of livestock head.

Step 2. Use Excel spreadsheet to average crop area and number of livestock per household as follows:

$$\text{Cultivated areas (ha/HH)} = \frac{\text{total provincial crop areas (ha)}}{\text{total provincial households}} \quad (15)$$

$$\text{Livestock (head/HH)} = \frac{\text{total provincial livestock (head)}}{\text{total provincial households}} \quad (16)$$

Step 3. Calculate the *p*th percentile of provincial HH averages for each crop and livestock with *p* equals to 25%, 50%, and 75%, respectively. Then, RFs are structured as following:

RF 1: representing all values derived at 25th percentiles and denoted as a *small farm*
RF 2: representing all values derived at 50th percentiles and denoted as a *medium farm*, and
RF 3: representing all values derived at 75th percentiles and denoted as a *large farm*.
Step 4. Compute the net income in each of these RFs using the results from enterprise budgets following the scenarios below. In these simulations, family labor demand for each RF, in each scenario, is also included into the analysis.

Scenario 1: RFs include conventional crops and livestock but exclude conventional tea, denoted as "without-tea RFs" and considered as the baseline.

Scenario 2: RFs include conventional crops, livestock, conventional tea, denoted as "with- tea RFs".

Scenario 3: RFs include conventional crops and livestock but replacing conventional tea by mini-terracing tea, denoted as "with-CSA-tea RFs".

Scenario 4: RFs include conventional crops and livestock, plus CSA elements by replacing conventional maize, tea and coffee by MT maize, mini-terracing tea and mini-terracing coffee, denoted as "CSA-RFs".

3.3. Methodology for adaptation assessment

The adaptation component in this research is conducted by overlaying farmers' perceptions with descriptive statistics using household and satellite based weather data to assess the role of tea in contributing to various household welfare outcomes as well as to their capacity to cope with climate shocks. Methodologically, the FGDs are used to explore farmer's perceptions. Descriptive statistics and unconditional t-test are used to assess the resilience potential in tea and non-tea households.

Obviously, CC directly impacts the biophysical systems, where farmers live and operate. Hence, in the first layer of analysis, local knowledge is integrated with climatic trend analysis to understand farmer perceptions and their real levels of exposure to various climatic shocks. More importantly, in the second stage of this analysis, total net income and various income components of tea and non-tea HHs are statistically described to identify the correlations and their statistical differences between tea production and HH income under different climatic shock conditions. This analysis helps to evaluate how better or worse off tea farmers are in buffering against shocks. Next, these results are overlaid with farmer's perceptions about the importance in terms of level and stability of tea production to HH income, to complement the above-explained analysis. These results are also compared with the biophysical potentials of trees and crops in coping with such climate shocks, to understand to what extent the tea crop could biophysically and economically contribute to adaptive potentials.

3.3.1. Overlaying local and scientific knowledge – climate trend analysis

3.3.1.1. Exploring farmer's perceptions

Focus group concept

There are various definitions of a focus group in the literature. Powell et al. (1996) define a focus group as a group of individuals selected and assembled by researchers to discuss and comment on the topic of research, from personal experience. Robinson (1999) defines focus group as an in-depth, open-ended group discussion of 1-2 hours' duration that explore a specific set of issues on a predefined and limited topic. This research method can generate more critical comments than interviews (Watts and Ebbutt, 1987) and the information is expressed in participants' own words and context without having external interference (Robinson, 1999). Thus, the key characteristic which distinguishes focus groups is the insight and data produced by the interaction between participants. This methodology is very useful to cross-cultural work with ethnic minority groups (Hughes and DuMont, 2002; Naish et al., 1994)

In this section, indigenous knowledge or farmer's perception is collected by FGD and then evaluated by simple descriptive, algebraic methods and a simplified weighting method based on the Analytic Hierarchy Process (AHP) principal. Perceptions about EWEs, biophysical adaptable capacity of crops to such EWEs and the role of farm enterprises in leveraging income are progressed in five stages: Design and preparation; Farmer recruitment; Implementation; Transcription; and Data analysis.

Design and preparation

A FGD proposal was developed based on "*The Talking Toolkit: How smallholder farmers and local governments can together adapt to climate change*" (Simelton et al., 2013). Topics chosen for discussion include: (i) Problem tree, (ii) Village history and hazard timeline, (iii) Calendar farming, (iv) List of exposures to extreme weather events, (v) Ranking suitable trees and crops, and (vi) Ranking livelihood income sources. The first three topics are used to explore background information for further insight discussions related to the last three topics. In discussion topic 6, ranking the importance of farm livelihoods to HH income is designed based on "*Decision making with the analytic hierarchy process*" in Saaty (2008).

Farmer recruitment

FGDs are conducted in: (i) Bu Cao Village – Suoi Bu Commune (Van Chan, Yen Bai); (ii) Nam Cuom Village–Nam Bung Commune (Van Chan, Yen Bai); (iii) Tay Son Village, Tien Nguyen Commune– (Quang Binh, Ha Giang; and (iv) Group 12, Viet Lam Town – (Vi Xuyen, Ha Giang). The village and commune are purposefully selected to represent two main technologies popularly found for tea plantations in the NMR, conventional and natural organic systems. In this regard, Nam Bung and Viet Lam Town were selected to represent conventional systems while Suoi Bu and Tien Nguyen communes were chosen as representatives for natural organic systems.

In these communes, 37 farmers in total were invited to participate in 4 FGDs with support from Provincial DARD of Ha Giang and Yen Bai; local district and commune authorities. Each FGD was conducted with participation of 8-10 farmers who were conveniently sampled to represent different age and gender groups. List of participants in each FGD is detailed in Appendix A.

Implementation

Each FGD was started with an opening session about the purpose, timing, method of communication and discussion to create the most comfortable atmosphere. Details for each topic and steps carried out in each FGD are presented in Appendix A. The implementation procedure is summarized as follow:

In discussion topic 1 (Problem tree): participants were asked to list three groups of factors that present the most difficulty for agricultural production. Next, in discussion topic 2 (Village history and hazard timeline), farmers recalled the scale and level of impact due to exposure to past hazard events. Crop calendar and cropping systems in the village is discussed in topic 3. Then, exposures to EWEs was listed in discussion topic 4 in order to use them as criteria to rank the level of suitability of trees and crops in discussion topic 5. Topic 6 deals with pair-wise ranking of the importance of livelihood activities (identified in topic 3) to HH's income.

In this topic, farmers discuss and reveal their perceptions on the criterion – the contribution of farm activity to total income in terms of *level and stability*. Weight of these criterion are assessed by comparing each pair of farming activities using a score of 1 to 5 (degree of importance). Puts 1/1 if each pair of activities has the same or equal importance, 1/3 if the row activity has stronger importance, and 1/5 if the row activity has extreme importance in terms of level or stability to HH income compared to respective activities in the column (Table 3.1). It is worth noting that the shaded cells in the lower triangular table are left empty since the matrix is symmetric and the diagonal cells are left blank because they are self-comparison.

Table 3.1. A pair-wise comparison matrix of importance of livelihood to HH income

livelihood activities	Rice production	Maize production	Shan tea	Cattle husbandry	Other livestock	Off-farm	Other
Rice production		1/3	3/1	1/1	5/1	…	…
Maize production			1/3	…	…	…	…
Shan tea				5/1	…	…	…

Cattle husbandry					…	…	…
Other livestock						…	…
Off-farm jobs							…
Other							

Score for comparison: 1- equal importance 3- stronger importance
5- extremely importance 2, 4 – values for intermediate.

Data analysis

Results from discussion topic 1 to 3 are summarized into different clusters and patterns which serve as a background for evaluating exposures to EWEs in each village. Data outcome from discussion topic 4 and 5 are combined to assess the degree of suitability of tree and crop during exposure to EWEs occurred in the village. This serves for the first layer of adaptation analysis.

Pair-wise comparison data in discussion topic 6 will be processed by AHP excel spreadsheet to derive overall, consistent weightings and rankings of each farm livelihood. Then, these rankings are used to evaluate their contributions to local household income in the second layer of adaptation analysis.

In order to establish the rankings of importance to HH income among livelihoods, synthesize the overall weights and evaluate the consistency of judgments, pair-wise comparison results are processed by AHP excel spreadsheet. This is built following Saaty (2008) and Bunruamkaew (2012).

Step 1. Complete comparison matrix

Enter the weighting scores (as shown in Table 3.1) into the AHP excel worksheet. The lower triangular matrix is filled by computing the pair-wise inputs. If aij is the weighted score of row i column j of the matrix, then the lower diagonal, aji = 1/ aij, is calculated and filled.

Step 2: Normalization of the matrix

Once the matrix is fully filled in Step 1, all numbers in each column are summed. Then, each entry in the column is divided by the column sum to get its normalized value. The sum of all normalized values in each column is 1.

Step 3: Consistency check

Consistency ratio (CR) is calculated to verify the credibility of final judgments obtained by pairwise comparison. If the value of the CR equals 0.1 or less, then the pair-wise comparisons are accepted and reliable. However, if the value is greater than 0.1, meaning that the CRs are indicative of inconsistent judgments, the result is considered unreliable. Procedures and calculations of consistency check are followed (Akalin et al., 2016; Bunruamkaew, 2012).

3.3.1.2. Exploring climatic changing patterns

The aim of this section is to investigate the changing patterns of rainfall and temperature in the four communes where FGDs were conducted and to link these patterns with the occurrence of EWEs e.g. hot spell, cold spell, which have been perceived by local farmers in FGDs. Temperature and rainfall variables are extracted from ERA-Interim/Operational data from 1989 to 2013.

Temperature

Changing patterns of dekadal average, maximum and minimum temperatures in the four communes are studied through describing statistics. Particularly, statistical mean and coefficient of variation of dekadal maximum, minimum and average temperature are generated and graphed to evaluate their trends in the last 25 years.

Rainfall

The distribution of precipitation throughout the season cycle as well as the total annual rainfall is very important to evaluate its impacts to hydrology, ecology, agriculture and water use (Guhathakurta and Saji, 2013). The historical changing in mean annual precipitation and changing pattern of rainfall are both identified in studied communes by computing mean and seasonality index of rainfall. The relative seasonality of rainfall is represented in the degree of variability in monthly rainfall throughout the year (Adejuwon, 2012; Livada and Asimakopoulos, 2005; Walsh and Lawler, 1981). The seasonality index (SI) supports understanding the rainfall regimes based on the monthly distribution of rainfall. The index is a function of mean monthly and annual rainfall and is computed by the following equation (Walsh and Lawler, 1981):

$$\overline{SI} = \frac{1}{\bar{R}} \sum_{n=1}^{n=12} \left| X_n - \frac{\bar{R}}{12} \right| \qquad (17)$$

Where:
X_n is the mean rainfall of month n
$\overline{R}$ is the mean annual rainfall.

Theoretically, the value of $\overline{SI}$ can vary from zero (if all the months have equal rainfall) to 1.83 (if all the rainfall occurs in one month). Table 3.2 shows the different class limits of SI and representative rainfall regimes.

Both temperature and rainfall analysis are performed in STATA 13. The output of 3.3.1.1 and 3.3.1.2 are then matched to verify the credibility of each other.

Table 3.2. Seasonality Index classes and rainfall regimes

Rainfall regime	SI class limits
Very equable	≤ 0.19
Equable but with a definite wetter season	0.20–0.39
Rather seasonal with a short drier season	0.40–0.59
Seasonal	0.60–0.79
Markedly seasonal with a long drier season	0.80–0.99
Most rain in 3 months or less	1.00–1.19
Extreme, almost all rain in 1–2 months	≥ 1.20

Source: Walsh and Lawler (1981)

3.3.2. Overlaying local and scientific knowledge – household income and determinants

This section presents methods for studying HH income and income determinants in tea-categorized HHs in relation with climate shocks. To allow these statistics to successfully describe the topic, HH income data and climate data are extracted, cleaned and merged across three years to make a panel dataset. The following describes the methods and steps approaching the targeted income and climate variables.

3.3.2.1. Methods and steps for income variables

In order to derive income and income components variables, VARHS datasets are used. VARHS was conducted biannually from 2002 to 2014; broadly covering agricultural land, crop agriculture, livestock, forestry, aquaculture, agricultural services and common property resources. The adaptation assessment is based on the last three rounds, namely VARHS10, VARHS12 and VARHS14 that are appended into a panel dataset containing key variables, including total net income (NI) and income determinants, such as total value of crop output (VCO), total amount received from sales (ARS) and income diversification index (IDI). Before merging those variables with climatically categorized communes which are derived from ERA-Interim data, the following steps are conducted in VARHS datasets:

Step1. Categorizing tea and non-tea households

The sections on agriculture are extracted from VARHS datasets for examining agricultural HHs. Since each crop is uniquely coded, it allows STATA software to systematically identify tea and non-tea HHs. In this data section, values on HH's total crop output produced and total amount received from sales are also classified by each category of HHs.

Step 2. Processing key income variables

Once HHs are categorized, the data obtained in Step 1 is merged with other VARHS sections by HH identification code, including HH characteristics (HH size), land use (cropland size), HH income (income, income sources) and expenditure (food expenditure - Foodex). Income variables are processed from HH total income and income sources in the preceding 12 months of each VARHS round. The HH total net income (NI, in 000 VND) is accumulated from 9 sources (all in net value), comprising wage/salary, agricultural activities, common property resources, non-farm non-wage economic activities, rental income, sale of assets, private transfers, public transfers and other sources. Unfortunately, NI from agricultural activities has been summed up in total value only, so that IDI cannot be assessed for different components, e.g. income source from crop, livestock or aquaculture.

As a result, important variables are created in each dataset, comprising household NI, Foodex, VCO and ARS; per capita NI, per capita Foodex, per ha VCO and per ha ARS (all value in 000VND). NI per capita and per capita Foodex are obtained by dividing HH total NI and Foodex by HH size, respectively; per ha VCO and per ha ARS are derived by dividing the relative total HH values by HH cropland size.

Step 3. Panel data

The above steps are conducted in each VARHS dataset and then three VARHS datasets are appended to make one data panel. In order to make the nominal monetary values of different years comparable to each other, 2014 is kept as the base year and the nominal values in 2010 and 2012 are deflated using the deflation rate. In this study, the deflation rate of VND is taken from end-of–year report released by the State Bank of Viet Nam (SBV). Deflation rates of 2011, 2012, 2013 and 2014 are 18.6%; 9.21%; 6.6% and 4.1%, respectively. For example, if X is the nominal value in 2010, then the real value in 2014 is calculated as follows:

$X_{2014} = (((X_{2010} *1.186)*1.092)*1.066)*1.04)$

This process of converting nominal to real value is completed for each year of VARHS survey before they are merged into one panel dataset. In addition, commune variables are checked for consistency before merging with climate data in the next step.

Some of those steps are detailed in the Appendix C in the form of a STATA do file.

3.3.2.2. Methods and steps to prepare climate variables

Step 1. Selection of ERA-interim/Operational data 1989-2013

While the adaptation assessment needs climate variables at the communal level, observation climate data in Viet Nam are station-based and inconsistent in timing. Hence, they are not adequately comparable when merging with VARHS dataset to allow meaningful assessment. ERA-interim/Operational data are alternatively used to create the variables of interest for HH resilience analysis. ERA-interim data could provide confidence in trend estimates for temperature and can be used along with estimates from traditional, observation-only climate datasets to monitor CC (Willet et al., 2010). An advantage of using reanalysis for CC assessment is that the data provide a global view that encompasses many essential climate variables in a physically consistent framework over long periods of time (Dee et al., 2011). In interim data used in this research, communes are categorized as high or low rainfall variability and level; high or low maximum temperature (Tmax) variability and level; high or low average temperature (Tav) variability and level; high or low minimum temperature (Tmin) variability and level. Thus there will be four categories in each climate variable.

Step 2. Creating rainfall variables

Variables of total rainfall level in a certain year are generated by summing up all rainfall of 12 months in that year; the monthly rainfall is the sum of three dekadal rainfalls within that month. Long run (LR) average of rainfall for each commune is calculated from means of total rainfall in 25 years (1989-2013). In addition, standard deviation (Sd) and coefficient of variation (CoV) of this variable are also derived from the same datasets. A commune is categorized as high rainfall level in a certain year if its total rainfall is higher or equal to communal LR average rainfall. Otherwise, it is labelled as low category. Communes whose LR CoV are higher or equal to the average of provincial LR CoV are categorized as high variability and whose LR CoV are lower than the average of provincial LR CoV are categorized as low variability.

Step 3. Creating temperature variables (Tmax, Tmin, Tav)

Average of Tmax/Tmin/Tav in the whole year is the mean of all dekadal maximum temperature in that year. LR average of Tmax/Tmin/Tav for each commune is obtained from the mean of average of Tmax/Tmin/Tav in 25 years. Additionally, Sd and CoV of those variables are also derived from these ERA-interim data. Communes whose LR CoV of Tmax/Tmin/Tav are higher or equal to the respective average of provincial LR CoV are categorized as high Tmax/Tmin/Tav variability. On the other hand, communes whose LR CoV of Tmax/Tmin/Tav are lower than the respective average of provincial LR CoV are categorized as low Tmax/Tmin/Tav variability.

3.3.2.3. Descriptive statistics

Once the two datasets are cleaned, they are merged and further checked for consistency. Income variables (NI per capita, VCO per ha and ARS per ha) are compared for statistical significance between tea and non-tea households under different climatic conditions (high or low rainfall, Tmax, Tmin, Tav level and variability). Each of these income parameters is described in number of observation (N), mean and Sd under a certain climatic category. Descriptive statistics are presented in a two- or three-way tables for analysis of the correlations between income or income determinants and tea HHs and non-tea HHs. The means in the above comparisons are all tested for significant difference between tea and non-tea HHs using two sample t-test with unequal variances.

These descriptive statistics are then compared with farmer's perceptions to evaluate the importance of tea in livelihoods both in terms of the level and the stability of HH income.

3.3.3. Overlaying local and scientific knowledge – household resilience

Agricultural production is generally sensitive to weather conditions which are altered by CC (Nelson et al., 2014). Both temperature and rainfall biophysically impact plant growth and yield potential through which HH income is affected indirectly. In section 3.2.2.2 above, communes have been classified according to their level and variability of temperature (max, min and average) and rainfall. Defining a year to be a good or bad year for agricultural production requires considering all climatic parameters driving weather conditions of that year. In other words, it is a combination of all climate variables that collectively regulate the production potential of a farm enterprise. In this study, a good year is characterized by having a maximum of one climate variable, either temperature (max, min, average) or rain, exceeding its relative LR means. A bad year, on the other hand, is the one having more than one abnormal climate variable. For example, too high or low rainfall compared to LR average and one of the temperature variables (max, min, or average) behaved abnormally in that year. Since ERA-Interim data acquired for this research are from 1989 up to 2013, climate variables used for evaluating 2014 being a good or bad year are substituted by the "End-of-year Hydro-Meteorology Reviews" reported by the National Center for Hydro-Meteorology Forecasts (NCHMF, 2015)

Once years in VARHS datasets have been categorized as good or bad climate conditions, HH income and agricultural/crop output values obtained from descriptive statistics over all survey years (2010, 2012 and 2014) are used to identify their difference (in percentage) between these years. The level of those changes in tea and non-tea HHs across the years will be used to evaluate HH resilience to CC-induced weather extremes. Outcome of this evaluation is then combined with local knowledge obtained from FGDs. In these FGDs, biophysical adaptive capacity is considered as a degree of suitability of trees or crops in coping with EWEs.

3.4. Methodology for mitigation assessment

CC mitigation in agriculture relates to GHG reduction and carbon storage enhancement. GHGs in farming systems generally consist primarily of CO_2, CH_4, and N_2O. All GHGs are aggregated in CO_2-e. To convert CH_4 and N_2O to CO_2-e, the concept of Global Warming Potential (GWP) is used. GWP is an index which approximates the time-integrated warming effect of a unit mass of a given GHG in today's atmosphere relative to that of CO_2 (IPCC, 2007a). This research considers GWP as only one impact category in a LCA study, and therefore follows the framework of ISO/TS 14067:2013 "*Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification and communication"* (ISO, 2013). This LCA-based carbon footprint for tea product is conducted following defined boundary and logical phases:

3.4.1. Goal and scope definition

3.4.1.1. Goal of the study

The overall purpose of this partial Carbon Footprint of Products (CFP) study is to calculate the potential contribution of tea production to GWP by quantifying all significant GHG emissions and removals over the partial tea product's life cycle ("cradle-to-gate"). The CO_2-e of a non-carbon gas is calculated by multiplying the mass of the emission of the gas by its GWP. The GWP of methane is 28 and the GWP of nitrous oxide is 281 (IPCC, 2007a; ISO, 2013).

The results of this CFP could assist to: (i) identify 'hotspots' of GHG emissions in the stage of tea production; (ii) provide an estimation of GHG emissions intensity per unit production within its partial CFP boundary; (iii) provide insight and information to guide changes or readjustment of inputs, material and energy consumption options to encourage low-carbon production; and (iv) provide the basics for the development of a CSA assessment tool regarding emissions intensity of farm product as part of the food chain.

3.4.1.2. Scope of the study

This is a partial or “cradle-to-gate” CFP, covering on-farm and upstream associated activities e.g. fertilizer production. Other stages further downstream the chain, such as tea processing, transportation or exporting, are excluded here.

3.4.1.3. Functional unit

Since fresh shoots are the economic harvest of the tea plant and main input materials for post-harvest processing into different types of dried tea, this CFP study takes one ton of fresh shoots as functional unit (FU) - the basic reference flow throughout the research.

3.4.1.4. System boundary

This partial LCA covers activity related to GHG emission or carbon sequestration in three main sections at farm and pre-farm levels, namely input production & application, biomass carbon uptake and harvesting or pruning (Figure 3.2). Input application accounts for not only type and quantity of inputs (pesticides, fertilizers and fuel consumed by machinery) applied for farm management, but also the upstream indirect emission sources. The latter means emissions occurred in manufacturing of such inputs, defined as the pre-farm stage in this study.

As the tea plant is a perennial evergreen shrub with an average life cycle of 40 years (conventional farming) or more than 100 years (natural Shan stands) (Do, 2006), the accumulation of biogenic carbon captured in above ground biomass (AGB) and below ground biomass (BGB) is also estimated in the second section of the CFP boundary. The third section deals with fuel types and quantity consumed for harvesting tea shoots and pruning at the end of the season. Generally, the first and the last sections deal with GHG emissions in tea production, on the other hand, the second section investigates GHG removal from the atmosphere to storage in the systems above and below ground.

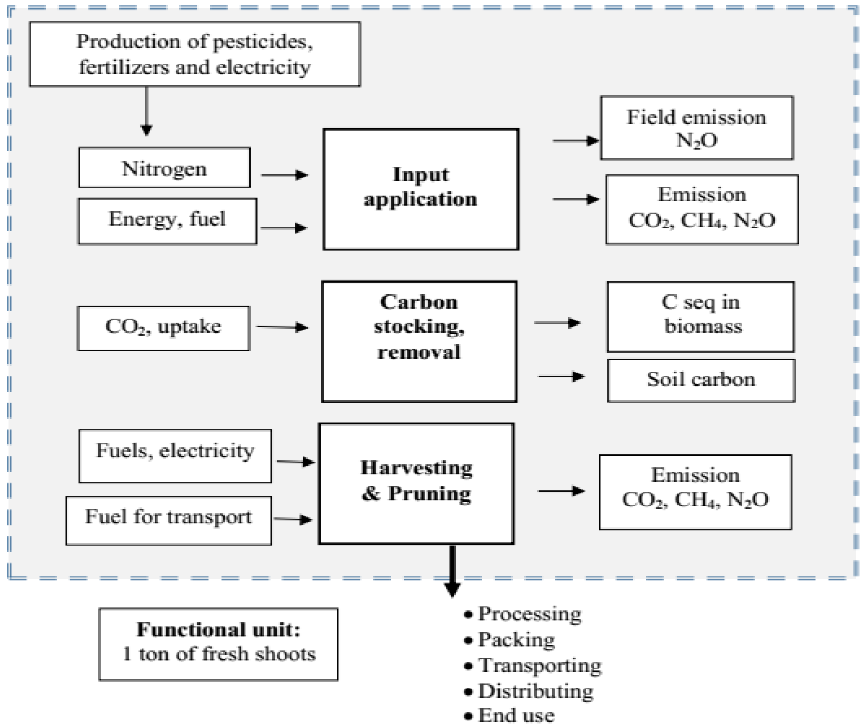

Figure 3.2. System boundary of fresh tea CFP

The geographical boundary of this CFP study covers main tea production areas, including conventional and mini-terracing plantations in Son La, Dien Bien and Yen Bai provinces and natural Shan tea stands in Lao Cai and Ha Giang provinces, NMR of Viet Nam.

3.4.2. Activity data for CFP study

3.4.2.1. Activity data related to emission from farm management

Tea production in the NMR of Viet Nam is classified in two main systems: conventional plantations and natural organic stands. The former is managed under intensive farming techniques with conventional application of agricultural inputs. Whereas in the latter, tea is rather extensively exploited from natural stands and hence could be considered as one special case of agroecology. Detailed descriptions of such farming techniques will be discussed in the next chapter. Organic tea production is practiced without agricultural input, and thus the activity data collection in this section mainly refers to intensive production. Technical coefficients related to type and quantity of fertilizer and pesticide used in conventional and mini-terracing technology tea practices shall be taken from enterprise budgets (farm model analysis) to serve as input activity data or emissions source data for CFP inventory analysis.

3.4.2.2. Activity data related to carbon removal and storage

Regarding carbon sinks in tea production, direct field measurement or destructive method is ideally the most accurate way in quantifying biomass and carbon content. Nonetheless, it is costly and inappropriate in this research. Alternatively, non-destructive method will be employed to estimate carbon sequestered in biomass, as well as carbon content in soils in three production systems (conventional, mini-terracing and organic tea production systems) using secondary data e.g. peer-reviewed literature or published papers.

In conventional tea production, activity data related to tea bushes' density and growth indicators are needed for biomass prediction. Plant density figures are extracted from technical standards released by national or provincial agencies. The figure is then cross-validated in FGD and/or field visits to improve its robustness. Tree growth indicators such as stem diameter are taken from field trial data, in this case from NOMAFSI's experiment with six Shan tea cultivars (from year 1 to year 9) in Van Chan District, Yen Bai Province.

In organic tea production, as Shan stands occur in a naturally scattered distribution in the local topographical conditions, the density and growth figures presented here are the best estimations from available data. For example, a survey dataset on natural Shan tea stands in Lao Cai Province is used to derive tree classifications by diameter. Next, tree density is derived from a field study in Ha Giang Province (Nguyen, 2012b). Since neighboring provinces of Lao Cai and Ha Giang share many common and interchangeable features about organic tea systems, their Shan stands' density and growth are assumed to represent as characteristics of Shan stands in the NMR.

3.4.3. Choice of emission factors

3.4.3.1. Pre-farm stage

In this stage, GHG emissions from production of agricultural inputs used for tea farming are estimated. These are considered as indirect GHG emissions for on-farm activities. The most accurate method is to multiply the amount of the input applied with its emission factor available in the research site or in the country where the CFP study is carried out. Unfortunately, these factors are unavailable from the literature, so alternatively, the estimation of GHG emissions is calculated using emission factors extracted from Ecoinvent (2010)[15] and .IPCC (2006).

[15] Swiss Centre for Life Cycle Inventories

Table 3.3. Emission factors used for quantification of GHG emissions in CFP

Emission source	Unit	Emission factor	Reference
Pre-farm stage			
Fertilizer:			
Ammonium sulphate	kg CO_2-e/ kg N	2.69	Ecoinvent 2.2
Ammonium nitrate	kg CO_2-e/ kg N	8.48	Ecoinvent 2.2, IPCC 2007 GWP 100a[16]
Urea	kg CO_2-e/ kg N	3.28	Ecoinvent 2.2, IPCC 2007 GWP 100a
NPK	kg CO_2-e/ kg N	3.30	Ecoinvent 2.2
	kg CO_2-e/ kg P_2O_5	1.58	Ecoinvent 2.2
	kg CO_2-e/kg K_2O	0.50	Ecoinvent 2.2
Pesticides	kg CO_2-e/ kg	9.40	Ecoinvent 2.2
On-farm stage			
N fertilizer application	kg N_2O-N/ kg N applied per annual per ha	0.01	IPCC (2006)
Fuel			
Gasoline (stationary combustion)	kg CO_2-e/ litre	2.286	IPCC (2006), WRI, 2015[17]
Diesel oil (mobile combustion)	kg CO_2-e/ litre	2.676	IPCC 2006, WRI, 2015

3.4.3.2. On-farm stage

There are two main sources of GHG emissions in tea farming activities. First, the application of nitrogenous fertilizers which emits N_2O and second, the consumption of fossil fuel in farm machines which result in emitting CO_2, N_2O and CH_4 gases. The amount of N_2O released in managed soils depends mostly on the amount of fertilizer applied and partly on the specific characteristics of the site, such as temperature, soil or crop type (Dobbie and Smith, 2003; Dobbie et al., 1999). Site-specific factors of N_2O emissions from fertilizer application in tea or upland crops in Viet Nam are extremely scarce in the literature. Alternatively, IPCC default emission factors are used for the calculation of field emissions (IPCC, 2006).

For on-farm machinery, it is a good practice to use a country-specific emission factor for each gas emitted, with respect to the fuel type and originality (IPCC, 2006). However, such emission factors have been found unavailable in Viet Nam to date, so this study also follows 2006 IPCC Guidelines to estimate GHG emissions in fuel combustion. Emissions of each GHG from stationary sources are calculated by multiplying the fuel consumption amount with corresponding

[16] GWP is relative to CO_2 for the 100-year time horizon according to IPCC Fourth assessment report, 2007.
[17] Values are calculated by GHG Protocol tools for stationary and mobile combustion.

emission factor derived from the GHG Protocol tool for stationary and mobile combustion (World Resources Institute, 2015a, b).

3.4.4. Method used to calculate GHG emissions

In this CFP study, activity data (emission sources) and inventory analysis are processed using Excel spreadsheets. The compilation and quantification of inputs and outputs data are based on the emission factors reported in Table 3.3.

3.4.4.1. Pre-farm stage

GHG emissions are quantified by multiplying agricultural input data to corresponding emission factors. Emissions per unit yield for each type of input are calculated from its total emissions in mass production per hectare.

$$E_{Prefarm} = \sum_{i=1}^{n} AI_i * EF_i \quad (18)$$

Where:
$E_{Prefarm}$ = total GHG emissions of production of agricultural inputs
AI_i = agricultural input i applied e.g. urea
EF_i = emission factor of input i applied ($CO_{2\,e}$)

3.4.4.2. On-farm stage

Similarly, GHG emissions per yield unit are calculated for nitrous fertilizers and fuel consumed in tea farming activities.

$$E_{onfarm} = E_{N20} + E_{GHG,fuel} \quad (19)$$

$$E_{N20} = F_N * EF_N * \frac{44}{28} * 281 \quad (20)$$

Where:
E_{N20} = direct GHG emissions application of N fertilizer
F_N = quantity of N fertilizer applied
EF_N = emission factor of N_2O of N fertilizer on cropped land
44/28 presents the molecular weight of N_2 in relation to N_2O
281 is the figure for the net global warming potential in a 100-year horizon.

$$E_{GHG,fuel} = Fuel\ consumption_{fuel} * EF_{GHG,fuel} \quad (21)$$

Where:
E_{Fuel} = emissions of a given GHG by type of fuel (kg GHG)
Fuel comsumption$_{fuel}$ = amount of fuel combusted (L)
$EF_{GHG,fuel}$ = default emission factor of a given GHG by type of fuel (kg GHG/L).

Carbon footprint calculation per unit yield:

$$CF_Y = E_{onfarm} / Y \quad (22)$$

Where:

CF_Y = carbon footprint per unit yield (kg CO_2/ kg^{-1} yield or ton CO_2/ ton^{-1} yield)
Y = total mass of production

3.4.5. Method used to estimate carbon sequestration

3.4.5.1. Conventional tea production system

Carbon sequestration in living biomass

In conventional and mini-terracing tea production, total tea bush biomass (above and below ground) is estimated using allometric equations (Kalita et al., 2015). Means of tree diameter are obtained from a field experiment where the growth rate of tree diameter in six Shan tea cultivars have been recorded from 2004 to 2013. The trial was carried out in Gia Hoi Commune, Van Chan District, Yen Bai Province (NOMAFSI, 2015). The total tree biomass of single plant is estimated by the following formula:

$$TB = 0.062 \times D^{1.877} \qquad (23)$$

Where:
TB = total tree biomass (kg/tree)
D = tree diameter at 5 cm (cm)

Once individual total biomass is estimated, carbon sequestration per area unit are calculated by multiplying the individual value by tree density. Next, carbon density per area unit is derived by converting carbon biomass using tea carbon content factor of 48.8% (Subramanian et al., 2013).

Carbon sequestration in soils

Soil carbon is an important carbon pool in an evergreen and perennial crop system like tea, both conventional and organic. In this research, soil organic carbon (SOC) is estimated using technical coefficients reported in the literature regarding soil carbon in tea planting areas, and this amount is assumed to represent SOC in both conventional and mini-terracing tea production systems. In this sense, SOC is calculated by the following formula (IPCC, 2003; Shilong et al., 2009):

$$SOC = \sum_{i=1}^{n} D_i \times BD_i \times C_i \times \left(\frac{1C_g}{100}\right) \qquad (24)$$

Where:
SOC is total soil organic carbon (Mg C ha^{-1})
i = a sampled layer
BD_i= soil bulk density of the *i*th layer (g/cm3)
D_i= thickness of the *i*th layer (cm)
C_i = carbon concentration of the *i*th layer (%)
C_g = the volume percentage of the fraction >2 mm at given depth

To enable this calculation, literature related to SOC in the NMR's tea systems is critically reviewed to obtain means of SOC and BD. Sometimes, SOM was is the only value reported in the literature and therefore a default carbon conversion factor is used in the following adjustment to derive SOC values (Mann, 1986):

$$SOC = 0.58 \times SOM \tag{25}$$

Consequently, the above formula now can be simplified as follows:

$$SOC = \sum_{i=1}^{n} D_i \times BD_i \times C_i \tag{26}$$

The resulting estimation will be discussed with similar published studies in the literature on tea carbon sequestration in Viet Nam and in other tea growing countries such as China, Kenya and India.

3.4.5.2. Natural organic tea production system

Carbon sequestration in living biomass

In natural organic systems, since Shan trees are left growing naturally in the local landscape, the estimation of standing biomass is made with an assumption that Shan stands are a form of secondary forests. Then, AGB of single Shan tree is predicted using an allometric equation developed by Ketterings et al. (2001):

$$AGB = 0.11 \times \rho \times D^{0.62} \tag{27}$$

Where:
AGB = above ground tree biomass (kg/tree)
D = tree diameter at breast height (cm)
ρ = average wood density

The mean value of tree diameter used in this equation is calculated from a field survey dataset on Shan tea conducted by Lao Cai Department of Agriculture and Rural Development (2013). In addition, due to the fact that tree diameter in Lao Cai DARD's survey was measured at stump while Ketterings' equation needs diameter figures at breast height (1.3 m), raw data in Lao Cai DARD need to be corrected to bring stump measurements to breast height values. The correction follows an equation recommended by Özçelík et al. (2010):

$$DBH = 0.9481 \times Dst - 1.6408 \tag{28}$$

Where:
DBH = tree diameter at breast height (cm)
Dst = diameter at stump

In Equation 26, the value of wood density is taken from Tillaart (2015), research on Shan tea in Viet Nam, with ρ = 0.54. Also in this Equation, since only AGB is estimated and therefore BGB is needed to account in order to fully obtain individual tree total biomass. BGB is estimated using 2006 IPCC default factor displayed in the equation below:

$$BGB = \frac{20}{100} \times AGB \tag{29}$$

Similar to conventional tea, once individual total biomass is estimated, carbon sequestration per area unit is calculated by multiplying individual value by tree density. Next, carbon density per area unit is derived by converting carbon biomass using tea carbon content factor of 48.8% (Subramanian et al., 2013).

Carbon sequestration in soils

While coefficients on SOM and SOC of conventional tea would be found in published articles or papers, similar values for organic tea stands are extremely scarce in the literature. Therefore, the estimation of SOC in the stands is based on the findings in Indian organic and conventional tea plantations (Subramanian et al., 2013) who indicate that SOC in organic production is 8.2% more than that of conventional production.

CHAPTER 4. STUDY SITES AND DATA

4.1. Introduction

This chapter describes the study area within the Northern Mountainous Region of Viet Nam. Characteristics of tea production systems are provided in greater detail since it is the center of our research. In the second section, we describe data used.

4.2. Study sites

4.2.1. The Northern Mountainous Region of Viet Nam

NMR is one of 7 agro-ecological zones of Viet Nam, comprising of 15 provinces with an area of more than 100 thousand km^2 (37% of the country's territory) and 12 million people (14% of the country's population). Two thirds of the region's area is sloped and has diverse topography (Pham et al., 2012). NMR's rural area is the home for almost 80% of its population.

Table 4.1. Agricultural households, agricultural land by type of land use and size in 2011

Province	Total HHs (000)	Agri_HHs (000)	Agri_land by prov & type of land use (000 ha)					HH agri_land use by size (%)			
			Total	Annual cropland	Perennial cropland	Forest land	Aqua culture	≤ 0.2 ha	0.2-0.5 ha	0.5-2 ha	≥ 2 ha
National total	15,343.9	9,534.7	26,226.4	6,437.6	3,688.5	15,366.5	689.8	34.7	34.3	24.8	6.2
NMR total	2,363.9	1,889.7	7,724.3	1,233.4	388.2	6,050.9	50.6	28.2	37.5	29.6	4.7
Hà Giang	127.4	119.6	684.2	123.0	29.6	530.4	1.1	9.2	27.1	56.4	7.3
Lào Cai	103.3	88.1	413.8	64.6	19.4	327.8	2.1	17.1	29.4	49.0	4.5
Yên Bái	145.8	122.1	584.3	64.7	43.1	474.7	1.6	34.2	37.2	25.8	2.7
Phú Thọ	292.5	200.5	282.2	57.1	41.7	178.3	5.0	46.9	42.2	10.5	0.4
Điện Biên	86.1	78.7	758.1	143.4	11.2	602.5	1.0	14.5	21.5	45.6	18.4
Lai Châu	62.3	57.4	490.9	75.9	13.2	401.2	0.5	12.9	26.7	51.5	9.0
Sơn La	202.0	185.8	888.4	226.0	35.4	624.4	2.5	7.5	15.1	53.3	24.1

Source: AgriCensus (GSO, 2012). Data in provinces related to this research are presented.

The region's total agricultural land, including forest land, is more than 7.7 million ha, accounting for 29.5% of the country total (Table 4.1). Forest land makes up the largest proportion of the NMR's total (78.3%), annual cropland is the second largest (16%), and perennial cropland is in third position (5%). Agricultural HHs are typically smallholders and more than 90% of HHs own less than 2 ha, 65% less than 0.5 ha. The region remains one of the most vulnerable areas in Viet Nam with the highest poverty rate (NMR 28.5%, 10% higher than national average of 18%) (World Bank, 2013).

4.2.2. Key farming systems in NMR

NMR comprises four main production systems: permanent uplands, paddy rice, livestock husbandry and agroforestry. Permanent upland cultivation and livestock production are key systems for agriculture-based households.

- Permanent upland cultivation: Traditionally, especially before 2000s, shifting or 'slash and burn' was the most common farming system in NMR. However, since then the Government has issued a number of policies aiming at promoting sustainable development in the mountains e.g. Permanent Agriculture, Livestock Husbandry, Irrigation and Credit in Mixed Agriculture, and Sedentarizing Upland Ethnic Minority (Tran, 2003). As a result, many areas have been transformed into farming systems dominated by permanent upland cultivation (e.g. upland rice or perennial crops).
- Paddy rice systems: These systems are also popular in the NMR where the rice fields are irrigated or seasonally inundated. Paddy systems are commonly found in the valley floors and on terraced hillsides. Sometimes, shifting or fallow cultivation is combined in paddy systems (Leisz et al., 2007).
- Livestock husbandry systems: Livestock husbandry is found as a component of all of the farming systems in the region, with key elements being cattle production, water buffalo rearing, and pig raising. All these practices are traditionally free-ranging and recently more intensive (pigs) and semi-intensive (buffalo and cattle) (Leisz et al., 2007).
- Agroforestry systems: In most of these systems, farmers in the NMR often incorporate some type of agroforestry by extracting forest products in the form of timber or non-timber for domestic consumption or for sale (Hoang et al., 2013) and (Leisz et al., 2007).

4.2.3. Production of main crops and livestock in the NMR

Rice, maize, sweet potato, cassava, peanut and soybean are the main annual food crops; tea, fruits and coffee are the key perennial cash crops in the region (GSO, 2016a). Figure 4.1 and 4.2 illustrate the growth of annual crops in terms of area and output volume the last 15 years.

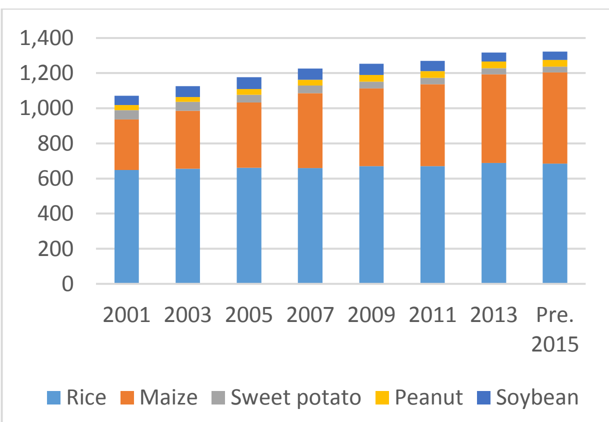

Figure 4.1. Annual crop area (000 ha)
Source: GSO (2016a)

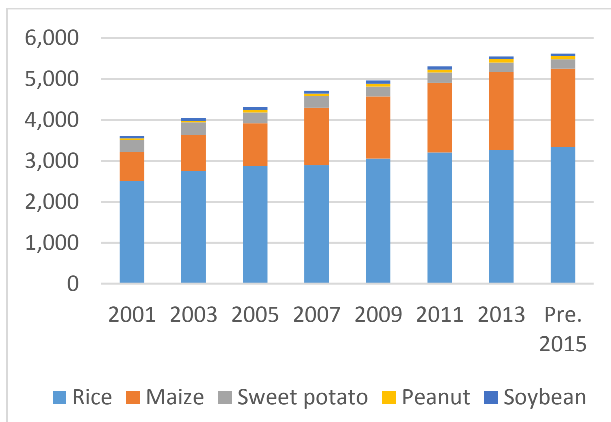

Figure 4.2.Annual crop production (000 ton)
Source: GSO (2016a)

The overall trend in both graphs is a continuous growth. However, the production grows at a higher rate than that of cultivated area, thanks to increased yields in both rice and maize as well as the rapid growth of area sown in corn throughout the period. Rice (paddy and upland) and maize are the dominant crops, accounting for roughly 90% of the total food crops, both in terms of area and production.

Compared to annual crops, the total area of perennial crops is much smaller. Nonetheless, some crops play a vital role in supplying nutrients for domestic consumption (e.g. mango, citrus) as well as cash income (e.g. tea, coffee). Tea is the largest planted crop, both in terms of area and production in the region, accounting for more than 50% of total perennial area (Figure 4.3) and output (Figure 4.4). Nevertheless, the plant's growth rate is stable over the last 5 years. Citrus (orange and mandarin) has recorded a remarkable and steady increase recently, covering almost 24 thousand ha and producing more than 100 thousand tons in 2015 (GSO, 2016). Coffee is also on the increase, but its proportion is small in the perennial total and the yields fluctuate slightly due to its stricter requirements regarding climate conditions than other crops in the NMR (Department of Crop Production, 2011). While coffee, mango and longan found more in northwestern provinces of Son La and Dien Bien, citrus is planted more in the northeastern provinces of Tuyen Quang, Ha Giang and Lang Son.

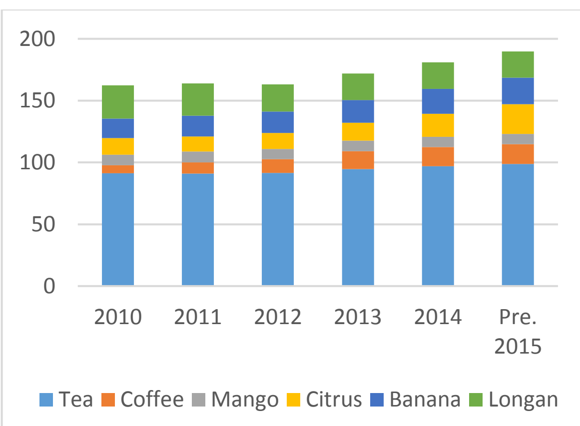

Figure 4.3. Perennial crop area (000 ha)
Source: GSO (2016a)

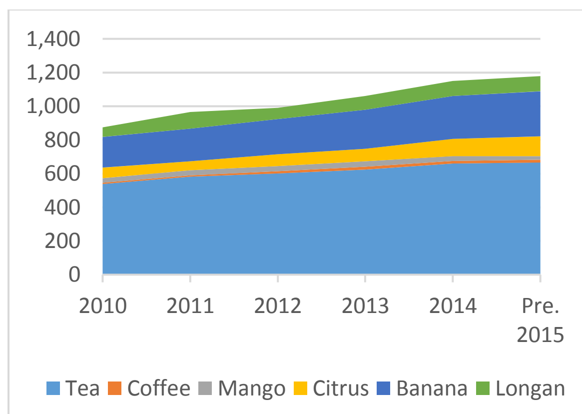

Figure 4.4. Perennial crop production (000 ha)
Source: GSO (2016a)

In the livestock sub-sector, cattle, buffalo, pigs and poultry are the four major livestock species regularly kept in most HHs. Poultry, mainly chickens and ducks, is the biggest industry in head terms. The industry has increased by roughly two folds, from 40.4 million heads in 2001 to 70.6 million heads in 2015 (GSO, 2016). However, in terms of capital value, cattle, buffalo and pigs are among the most important livestock. While the number of pigs has recorded a sharp increase in the last 15 years, increasing from nearly 4.6 million in 2001 to 6.8 million in 2015, both cattle and buffalo numbers remain generally stable in the same period. Currently, there are around 900 thousand head of cattle and 1.4 million head of buffalo (Figure 4.5).

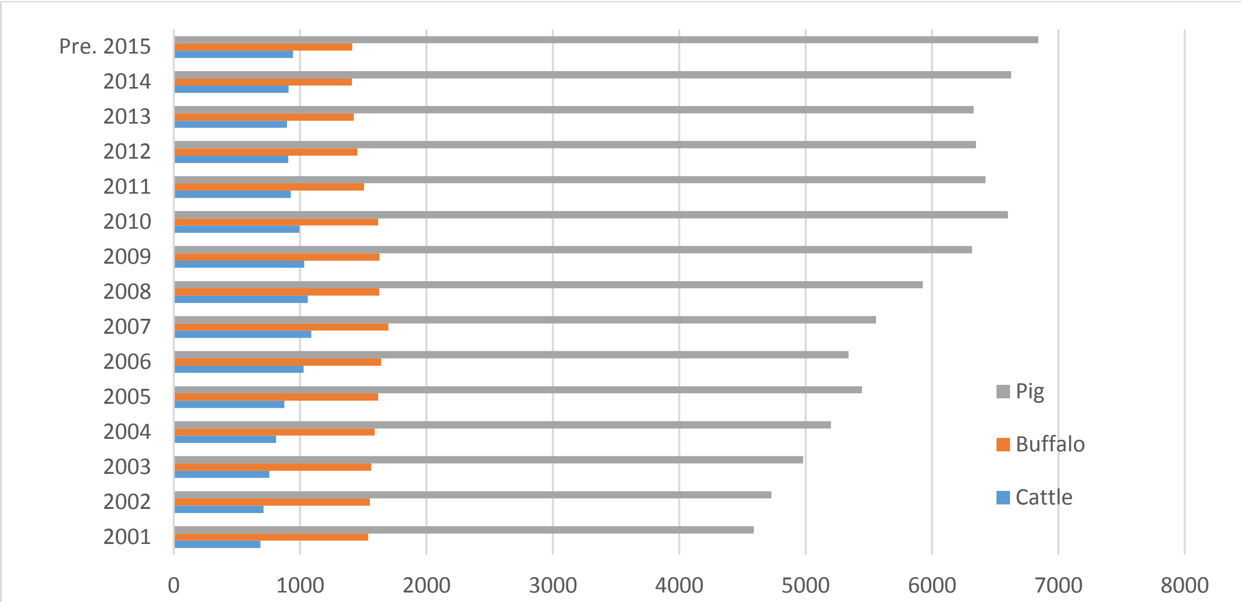

Figure 4.5. Livestock production (000 head) from 2001 to 2015
Source: GSO (2016a)

Among those crops and livestock, rice (paddy and upland), tea, coffee, and maize are the most important plants in crop production and similarly, pigs, cattle and buffalo are the key livestock in the region. This research focuses on tea production, however, the crop will be evaluated at HH level which considers other potential alternatives in terms of land use e.g. maize and upland rice. Livestock component is also integrated to assess its role in securing HH income.

4.2.4. Tea production systems in the NMR

According to the Department of Crop Production (2012), NMR is the largest tea producer in Viet Nam. In 2015, tea area in the region has reached almost 100 thousand ha, output is more than 650 thousand tons, some 73% of the total area and 67% of total production nationally (GSO, 2016). In terms of genotype, 52% of tea plantations are covered by clonal improved cultivars such as LDP1, LDP, PH1 and purified Shan Tuyet (Shan) varieties; 48% of tea gardens are grown traditionally with seeds of indigenous cultivars such as Shan and '*Trung du'* or *"hilly variety"*. Out of these varieties, Shan is an out-standing cultivar and has been popularly planted in six mountainous provinces of Yen Bai, Ha Giang, Lao Cai, Son La, Lai Chau and Dien Bien. The area of Shan tea has reached about 28,000 hectares, accounting for 66% of the total tea production area in these provinces (Department of Crop Production, 2012; Le et al., 2011).

Overall, the majority of tea area in the NMR is *C. sinensis (L.) O. Kuntze var. sinensis* which is genetically embedded in small-leaf, upright growth habit, dense sprouting and small shoots (Do, 2012).

In the NMR, tea plant is mainly grown in hilly or mountainous areas at slopes from 5-25° (Do and La (Do and Nguyen, 2005). Therefore, farm design or field arrangement before tea planting is crucial because this will affect the development and economic performance of tea plantations throughout their entire life time. In conventional production systems, tea rows, particular those planted on steep slopes (15-25°) are still arranged in straight lines in some places, although contour plantings have been highly recommended. Consequently, soil erosion is not well prevented due to accelerated surface water runoff. Whereas, mini-terracing techniques have improved these shortcomings by arranging plantations into contour terraces. Natural organic stands, on the other hand, are managed in mixed gardens rather than in mono-crop tea plantations.

Table 4.2. Main characteristics of natural organic and intensive tea production in the NMR

Characteristic	Natural organic	Conventional and mini-terracing
Genetic origin	Shan tea (*Camellia Sinensis var. Shan*). A big woody stem; large broad elliptic shaped leaves, big and plump buds which coated with snow-like hairs.	Shan tea and other cultivars (*Camellia sinensis)*. Small-leaf, small woody stem, leaf with or without snow-like hairs.
Geographical distributions	Distributed at altitude > 800 meter above sea level (m.a.s.l), popular 1,000-1,300 m.a.s.l.	Distributed at altitude < 1,000 m, popular at 600-800 m.a.s.l (Shan) and lower (other varieties)
Main province and area of production (ha)	Ha Giang: about 9,000; Lao Cai: 700-1,000; Yen Bai: about 1,500; Dien Bien: about 500; Son La: about 100; *Total: 12,100*	Shan tea: Ha Giang 9,000; Lao Cai 1,500; Yen Bai 600-800; Son La 2,800; Lai Chau 2,800. *Total: 14,100* Other cultivars: Phu Tho, Tuyen Quang, Quang Ninh, Yen Bai and Bac Giang Provinces. *Total: 73,800*
Density	Density from 1,000 to 3,000 trees per ha. Trees are grown for a long time and saved from generation to generation (ancient Shan trees). Shan stands grown scattered over diverse topography and at various densities.	Plantations are grown by seedlings or cuttings, density: 10,000 – 16,000 bushes per ha, depending on techniques.
Mixed plantation as an agroforestry	Trees are mixed with secondary forests, fruits or food crops in their local landscape.	Shading and windbreak trees (e.g. Cassia) is normally intercropped in tea plantations.
Farm management	Local people limit the tree height from	Tea bushes are pruned annually to

	2.5 to 3.0 m for harvesting convenience. Stands are tall and more natural growing. Plantations are not well designed and use little or no agricultural inputs at the initial period. little or no pesticide application	limit the height <1 m to encourage crown and branch growth for harvesting convenience, high yields. Plantations are well designed and invested with agricultural inputs at the initial period. From year 3, begin commercial stage. On average each year: 3-4 times of fertilizer application, 10-15 times of pest control and plant regulator application.
	Mountainous Shan has three or four harvests per year, in March-April; June-July-August and September-October; average yield: 1-1,5 tons per ha.	Plantations yield 14 to 15 harvests per year, output around 10 tons per ha (hand picking); 6-9 harvests (machine picking), output around 12 tons per ha.
Practitioners	Practiced by ethnic minorities (i.e. H'mong, Thai, Dao). Such minority groups have lived in the region for ages.	Mainly practiced by family-based economies of Kinh people (Vietnamese) and some minorities.

Source: Adapted from Do (2006), Nguyen (2011) and Nguyen (2013).

4.2.5. Climatic conditions in the NMR

While southern Viet Nam is characterized by more tropical climate with distinct rain and dry seasons, the northern part of the country is characterized by sub-tropical conditions with four seasons. Based on the ERA-Interim/Operational data, overall trends of the two most important climatic variables (average temperature, total rainfall) in the 25-year period are presented in Figure 4.6.

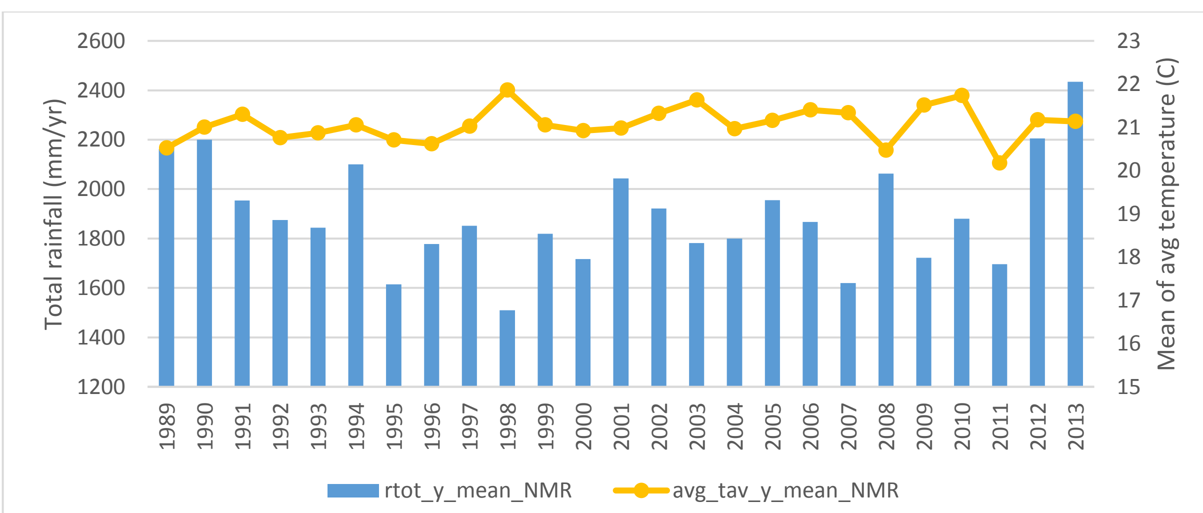

Figure 4.6. Trend of average total rainfall (left scale) and average temperature (right scale) in NMR

Source: ECMWF, 2013

The mean of average temperature in all communes fluctuated around 21^{0}C and was more stable from 1989 to 2007. Nevertheless, since 2008, this climatic variable has demonstrated a steeper fluctuation. In terms of rainfall, the average long term rainfall is 1,896.6 mm per year and has shown an unstable trend all over the period. Accordingly, within year variation of rainfall has also displayed a bigger value than that of temperature. This implies that the rainfall variable could play a more crucial role in regulating agricultural practices, especially those are rain-fed.

4.2.6. Study provinces

Tea is mainly produced in the following provinces: Ha Giang, Tuyen Quang, Lao Cai, Yen Bai, Thai Nguyen, Phu Tho, Son La and Lai Chau[18]. The analysis of this dissertation is based on data collected from six out of the above provinces, plus Dien Bien province (one of small tea producers in the region). This combination could provide a representation of the NMR tea industry since large, medium and small province producers are included.

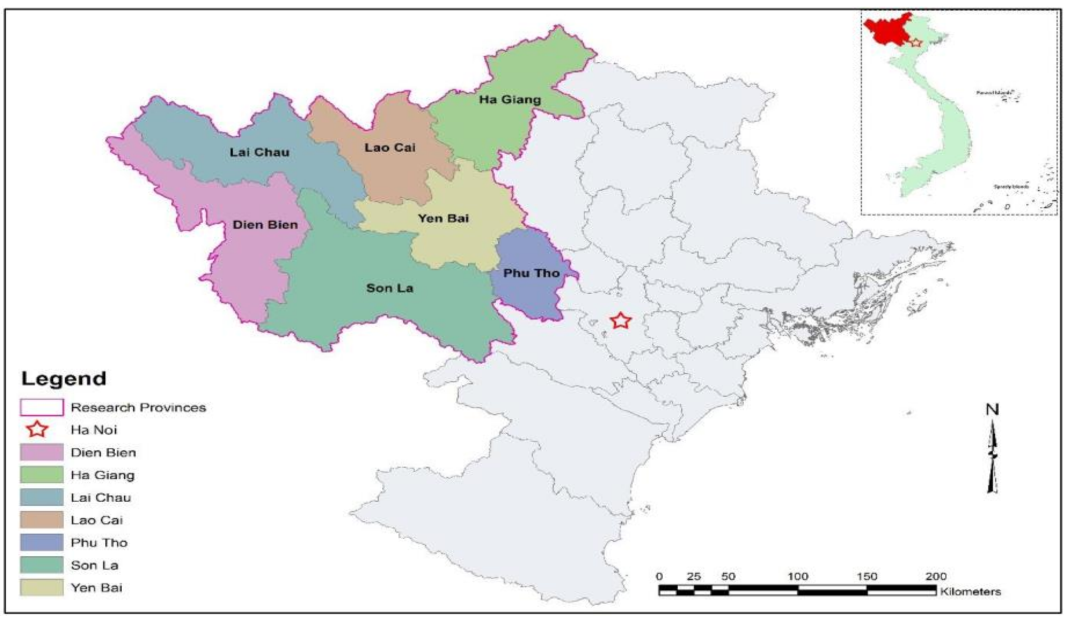

Figure 4.7. Research provinces in the NMR of Viet Nam

4.3. Data sources

Three main datasets have been used in our research:

(i) HH dataset on the costs of farm practices, generated though a survey conducted by FAO and NOMAFSI (2014) in Yen Bai, Son La and Dien Bien (Figure 4.7).

(ii) Partial VARHS datasets collected from Lao Cai, Phu Tho, Dien Bien and Lai Chau provinces, combined with ERA-Interim data to assess HH income and resilience

[18] The administrative system in Viet Nam includes four levels: national, provincial, district and communal.

under climate extremes. Farmers' perceptions were collected in Ha Giang and Yen Bai provinces to provide supplementary data for adaptation analysis.

(iii) LCA inventory data for intensive tea production systems are extracted from the FAO-NOMAFSI survey data mentioned above. Other LCA inputs are supplemented by *ad hoc* author's field surveys in Ha Giang, Lao Cai and Yen Bai provinces.

4.3.1. Data used for food security assessment

4.3.1.1. Dataset used for enterprise budget

In dealing with the economic assessment of tea and other selected crops and livestock practices and developing related enterprise budgets, we relied on the dataset collected by FAO and NOMAFSI (2014). Previous analytical work conducted using this dataset can be found in Branca et al. (2017). Technical and cost coefficients have been extracted and processed using STATA software[19].

FAO-NOMAFSI data collection consisted of a survey of 900 households in three provinces of Dien Bien, Son La and Yen Bai (the details are presented in Tables 4.3 and Table 4.4). In addition to it, the author also uses technical coefficients reported in peer-reviewed articles, government reports and extension guidelines.

Table 4.3. FAO-NOMAFSI survey summary

Features		Dien Bien	Son La	Yen Bai	Total
Number of communes surveyed	#	9	8	8	25
Households (farms)	#	235	314	351	900
Farm practicing only conventional farming	#	128	84	99	311
Farm practicing only sustainable farming	#	13	28	74	115
Farm practicing sustainable and conventional farming	#	94	202	178	474
Average farm size	ha	1	2.65	1.19	1.65
% of HHs with livestock	%	86.81	80.57	87.46	84.89

Source: Branca et al. (2017)

Table 4.4. FAO-NOMAFSI survey: percentage of fields recorded by crop in the main season

Crop	% of fields	Crop	% of fields
Paddy rice	31.16	Longan	0.08
Upland rice	4.02	Mango	0.28
Maize	28.12	Litchi	0.08

[19] The list of STATA commands used to build the key variables, run models and generate inferential statistics is presented in Appendix C

Cassava	6.42	Tea	10.53
Soybean	0.2	Coffee	7.32
Peanut	0.08	Grass	3.63
Rapeseed	0.06	Cinnamon	2.48
Mung bean	0.06	Acacia	0.65
Canna	0.53	Eucalyptus	0.11
Vegetables	0.03	Other	3.88
Plum	0.28	*Total*	*100*

Source: Branca et al. (2017)

4.3.1.2. Agricultural Census datasets

Agricultural Census (AgriCensus) dataset (2011) are used in conjunction with 2011 statistical data on crop area and livestock head (GSO, 2012) to derive three representative farms resulting from three levels of statistical percentiles. AgriCensus was conducted nationwide in 2011. This is a large-scale, complex and national census which covers 16.15 million households in rural areas and agricultural, forestry and fishery households in urban areas and 9,071 communes. For the purpose of this study, only statistical data related to agricultural land use and number of HHs at provincial level are extracted for analysis.

4.3.2. Data used for adaptation assessment

The analysis in this adaptation component is based on three datasets. The first one is collected by the author in four FGDs. The second comes from biannual rural surveys in 12 provinces in Viet Nam collected by the CIEM. ERA-Interim climate data is the last dataset being used for adaptation component analysis. This data is first processed to classify HHs and communes into low or high climatic conditions, and then merged with the VARHS dataset to create the main panel data set for analysis.

4.3.2.1. Focus group discussions

FGDs were conducted in four communes in Yen Bai and Ha Giang provinces following the steps discussed in Chapter III, with details in Appendix A. FGD data are transferred from A0-sized papers (which were immediately noted during the discussion) into an excel spreadsheet for analysis. In each FGD, farmers' perceptions related to: problems faced by local farmers; local crop calendar; EWEs and crop suitability; and importance of crop or livestock to the level and stability of income, are noted and the data cleaned, synthesized and processed for analysis.

4.3.2.2. Viet Nam Access to Resources Household Survey datasets

VARHS was firstly piloted in 2002 with 930 HHs to study HH access and lack of access to productive resources in rural Viet Nam. From 2006 the survey was carried out with increased coverage and provincial representation to 12 provinces and more than 2,000 HHs (Table 4.5). VARHS was jointly conducted by the Central Institute for Economic Management (CIEM), Institute of Policy and Strategy for Agriculture and Rural Development, the Institute of Labor Science and Social Affairs, the University of Copenhagen and Danish Development Agency, and systematically carried out every two years (e.g. 2008, 2010, 2012 and 2014). More importantly, VARHS has surveyed mostly the same rural HHs overtime to provide truly unique, balanced panel data which could empirically measure changes in the life and work of rural families across regions in Viet Nam.

Table 4.5. The 2010-2014 total and balanced sample of households in VARHS data

Province	2010		2012		2014		2010-2014 balanced sample	
	No. of HHs	% of sample	No. of HHs	% of sample	No. of HHs	% of sample	No. of HHs	% of sample
Ha Tay	479	14.96	593	16.01	589	16.15	451	15.29
Lao Cai	286	8.93	302	8.15	295	8.09	271	9.19
Phu Tho	304	9.49	388	10.48	385	10.55	272	9.22
Lai Chau	303	9.46	322	8.69	320	8.77	288	9.76
Dien Bien	303	9.46	326	8.80	317	8.69	266	9.02
Nghe An	192	6.00	230	6.21	228	6.25	186	6.31
Quang Nam	290	9.06	341	9.21	338	9.27	276	9.36
Khanh Hoa	75	2.34	113	3.05	108	2.96	58	1.97
Dak Lak	330	10.31	353	9.53	350	9.59	319	10.81
Dak Nong	287	8.96	317	8.56	307	8.42	246	8.34
Lam Dong	67	2.09	80	2.16	78	2.14	59	2.00
Long An	286	8.93	339	9.15	333	9.13	258	8.75
Total	3,202	100	3,704	100	3,648	100	2,950	100

Source: Adapted from VARHS data file (CIEM, 2012-2014)

The VARHS questionnaires cover communal and HH levels. At the latter, 12 sections have been comprised in the HH questionnaire, including HH characteristics, agricultural land use, crop agriculture and other income-generating activities, employment and occupation, extension services, food expenditure, expenses and savings, social capital and networks. However, in this research, only some sections of VARHS10, VARHS12 and VARHS14 datasets, e.g. crop agriculture, income, HH size and food expenditure in the 4 provinces of Lao Cai, Phu Tho, Dien Bien and Lai Chau, are extracted for analysis. The performances of these interest variables are compared among tea and non-tea HHs under climate shocks. In total, there are 3,527 crop agriculture-based HHs selected for analysis, comprising 3,369 non-tea HHs and 158 tea-HHs (Table 4.6).

Table 4.6. Total number of HHs by tea category and year

Year	Non-tea HHs	Tea HHs
2010	1,081	63
2012	1,173	44
2014	1,115	51
Total	3,369	158

Source: VARHS data files

In addition, VARHS datasets are also used to generate technical coefficients on livestock husbandry (e.g. mortality rate of cattle, buffalo and pig) for livestock enterprise budgets. STATA software is also used for processing these data.

4.3.2.3. ERA-Interim data

According to (Dee et al., 2011), ERA-Interim is the latest global atmospheric reanalysis dataset. Reanalysis is a process by which model information and observations of many different sorts are combined in an optimal way to produce a consistent, global best estimate of the various atmospheric, wave and oceanographic parameters. ERA-Interim is characterized by a higher resolution and improvements in the humidity analysis. In this study, an ERA-Interim dataset, including rainfall, temperature (average, maximum, minimum) are extracted from the ECMWF database for analyzing trends of those variables in studied provinces and communes. The dataset has the following features: (i) coverage of 2,654 communes in all 15 provinces in NMR of Viet Nam; (ii) high resolution: 0.25 degree (~28km); (iii) arrangement in 10-day intervals (dekadal) with provincial, district, and communal codes for convenient use in data processing in Stata software; and (iv) length in 25 years, from 1989 to 2013 (data from 1989 to 2012 are ERA-interim, data in 2013 are ERA-Operational).

4.3.3. Data used for mitigation assessment

4.3.3.1. Activity data for GHG emissions

This CFP study, as discussed in the scope of LCA, accounts for only emissions that result from fossil source production and consumption, comprising input and fuel manufacturing (pre-farm), input application in the field and consumption of fuel in farm operations (on-farm). Activity data related to transportation of fuel or fertilizer from manufacturer or importer to the point of local retailer or warehouse is excluded or outside from the boundary of the study. In this regard, inventory data are collected from three production systems, namely conventional, mini-terracing and organic. These results are presented in the following table.

Table 4.7. Averaged inventory data on emission sources used for CFP study

Emission source	Unit	Conventional	Mini-terracing	Organic
Urea*	kg/ha	465	321	
NPK 5:10:3*	kg/ha	575	616	
Pesticides *	kg/ha	13.0	15.5	
Gasoline for transportation **	L/ha	13.6	16.3	5.0
Gasoline for pruning **	L/ha	5	5	

Source: * Calculation from FAO-NOMAFSI dataset (FAO and NOMAFSI, 2014)
** FGD conducted by the author

4.3.3.2. Activity data for carbon sequestration

GHG removed from the atmosphere and stored in tea production systems as carbon sinks is estimated to evaluate the abatement potential of tea system to CC. GHG removals, together with GHG emissions, will serve as key inputs for investigating carbon balance at a certain point of time or throughout the life span. The estimation of dry matter biomass and carbon sequestered in biomass are mainly based on tree diameter measured at the base (conventional plantations) or at the breast height (natural stands). Table 4.8 presents field measurement data on the growth of stem diameter of 6 new Shan tea cultivars in Yen Bai Province in a 10-year experiment which was conducted under conventional farming. Diameter data are averaged from 30 trees to derive the means for each cultivar each year. Since these field data are available up to year 9 only, biomass estimation of conventional tea has to be projected from year 10 on-wards using coefficients analyzed from Dang (2005a; 2002).

Table 4.8. Tree diameter of new Shan tea cultivars in Gia Hoi, Yen Bai Province from 2004-2013

Year	Shan cultivar* (cm)							
	LP	HG	MC2	SL	TC4	LC	Mean	Sd
1	0.40	0.35	0.41	0.35	0.44	0.42	0.40	0.04
3	2.27	2.02	2.07	2.02	2.74	2.56	2.28	0.31
5	4.30	4.00	4.06	4.01	4.24	4.18	4.13	0.13
7	6.17	6.31	6.01	6.00	6.21	6.10	6.13	0.12
9	7.57	7.51	7.67	7.51	7.77	7.61	7.61	0.10

Source: NOMAFSI (2015). N=30 for each cultivar
* LP, HG, MC, SL2, TC4, LC are abbreviated names of cultivars;

For organic tea, LCA inventory is taken from a Shan tea dataset which was carried out by Lao Cai Department of Agriculture and Rural Development (Lai Cai DARD, 2013). This survey was conducted in 5 districts in the province where almost 850 thousand trees have been recorded. Summary of this dataset is displayed in Table 4.9, detail is provided in Appendix H.

Table 4.9. Summary distribution of Shan tea stands by diameter class in Lao Cai Province

District	Total (tree)	Diameter class (cm)					
		< 10	11-20	21-30	31-40	41-50	> 51
Total	846,160	204,921	466,787	116,270	38,852	17,210	2,120
Si Ma Cai	129,260	35,670	59,040	26,800	6,430	1,250	70
Bac Ha	408,510	96,090	255,488	36,520	12,442	7,370	600
Muong Khuong	159,690	30,680	79,630	30,470	10,990	6,630	1,290
Bat Xat	99,050	31,127	42,883	17,810	5,660	1,480	90
Sa Pa	49,650	11,354	29,746	4,670	3,330	480	70

Source: Lao Cai DARD (2013)

The second pool for carbon removal that is worth noting is soil organic carbon (SOC). In this CFP study, SOC in tea land is estimated using technical coefficients reported in literature. The below table summarizes coefficients of related variables of 12 published papers. These will be assembled in Equation 25 (Chapter III) to predict carbon stock in tea soils.

Table 4.10. Soil organic carbon in some tea plantations in the NMR of Viet Nam

Age of plantation/ province	BD (g/cm3)	h (cm)	SOC (%)	SOM (%)	References
1-yr	*1.07*		*1.91*	*3.30*	
Thai Nguyen	0.95	0 - 10	2.48	4.28	Dang (2005b)
Thai Nguyen	1.13	10 - 20	1.92	3.31	Dang (2005b)
Thai Nguyen	1.13	20 - 40	1.34	2.31	Dang (2005b)
~10 yr	*1.14*		*1.55*	*2.61*	
Phu Tho		0-30	1.45	2.50	Le et al. (1996)
Thai Nguyen	0.87	0-40	2.15	3.70	Duong et al. (2010)
Hoa Binh			1.45	2.50	Dau et al. (2001)
Thai Nguyen	1.14	0 - 10	1.96	3.38	Dang (2005b)
Thai Nguyen	1.27	10 - 20	1.25	2.16	Dang (2005b)
Thai Nguyen	1.27	20 - 40	1.02	1.76	Dang (2005b)
~25 yr	*1.21*		*1.56*	*2.69*	
Thai Nguyen	1.21	0 - 10	2.07	3.57	Dang (2005b)
Thai Nguyen	1.28	10 - 20	1.3	2.24	Dang (2005b)
Thai Nguyen	1.28	20 - 40	0.97	1.67	Dang (2005b)
Lai Chau			1.87	3.23	Thai and Nguyen (2002)
Lai Chau			1.31	2.26	Thai and Nguyen (2002)
Thai Nguyen	0.90	0-20	1.83	3.15	Phan et al. (2010)

Thai Nguyen	1.30	0-30			Dang and Pham (2011)
Thai Nguyen	1.28	0-20			Tran and Dang (2007)
~40 yr	*1.29*		*1.32*	*2.28*	
Thai Nguyen	1.28	0-20			Tran and Dang (2007)
Thai Nguyen	1.2	0 - 10	1.87	3.22	Dang (2005b)
Thai Nguyen	1.33	10 - 20	1.16	2.00	Dang (2005b)
Thai Nguyen	1.33	20 - 40	0.93	1.60	Dang (2005b)

Note: BD= soil bulk density; D= thickness of soil layer;
SOC= soil organic carbon; SOM = soil organic matter.

CHAPTER 5. RESULTS

5.1. Introduction

This chapter presents the results of our analysis. It begins with the farm model analysis where economic results of farm practices are presented and discussed. Second section focuses on adaptation assessment based on: climate trends analysis, household income and its correlation with tea practices, and household resilience in coping with shocks. The third section discusses mitigation potential of tea systems. Synergies between the three pillars of climate-smart agriculture will be presented in the last section.

5.2. Farm model analysis

5.2.1. Enterprise crop budgets

This section presents outputs of enterprise budgets for four targeted crops (upland rice, maize, tea, and coffee).

Upland maize

Maize area in the NMR is about half million ha, accounting for 50% of national total area. The crop is mainly grown in conventional systems and partly in minimum tillage practice. In this research, data were collected from Son La (the biggest producer) and Yen Bai provinces. MT is a sustainable farming technique besides conventional method which normally uses plowing for land preparation. Table 5.1 shows that MT maize has lower yields, gross revenue and GMs, but achieves higher profit, rate of return, and labor productivity than that of conventional technology, thanks to lower production costs and labor consumed.

Table 5.1. Budget indicators by crop and technology

Indicators[20]		Unit	Maize		Upland rice	Tea		Coffee	
			Conv.[21]	MT	Conv.	Conv.	MTERR	Conv.	MTERR
Yield[22]	Y	kg/ha	4,767	4,543	1,246	7,401	8.996	4.288	6,512
Gross revenue	A	$/ha	1,251	1,193	571	1,943	2,362	1,875	2,868
Cash inputs	B	$/ha	378	368	207	602	549	827	750
Gross margin	C=A-B	$/ha	873	825	364	1,341	1,813	1,048	2,117
Labor cost	D	$/ha	854	692	1,690	995	1,207	1,098	1,315
Net margin	E=C-D	$/ha	19	133	-1,326	346	606	-50	802
Production costs	B+D	$/ha	1,233	1,060	1,897	1,597	1,756	1,925	2,065

[20] Tea and coffee: GM indicators are averages of years in full development.
[21] Conv = Conventional; MT = Minimum tillage; MTERR = Mini-terracing.
[22] Yield: tea shoots and coffee cherries are in fresh; maize and rice are sun-dried.

Production costs per unit	(B+D) /Y	$/kg	0.26	0.23	1.52	0.22	0.20	0.45	0.32
Initial costs		$/ha				1,342	1,954	1,839	3,466
Return to cash capital	A/B	$/$	3.31	3.24	2.75	3.23	4.30	2.27	3.82
Total family labor	F	person-day/ha	179	145	354	209	253	226	276
Return to family labor	C/F	$/person-day	4.9	5.7	1.0	6.4	7.2	4.6	7.7
Labor productivity	Y/F	Kg/person-day	26.6	31.3	3.5	35.5	35.6	19.0	23.6

Source: Own elaborations.

Upland rice

In NMR, paddy rice on irrigated land is the most important crop for human food, followed by upland rice in rain-fed conditions. Even though its area has declined from 450,000 ha in 1990 to 130,000 ha in 2015 (Nguyen, 2015), it still plays an important role in supplying special rice to local people and markets (Nguyen et al., 2014). Since requiring high labor intensiveness (354 person-day ha^{-1} or $1,690 ha^{-1}), the crop yields are very low (1,246 kg ha^{-1}), resulting in negative NMs. BCR and NPV indicators (Table 5.2 below). This reaffirms that the practice is less attractive and may be crucial only for resource-poor smallholders (Branca et al., 2017).

Tea and coffee

In studied sites, tea and coffee plantations have been established as conventional practices. However, many plantations in both practices are aging and some areas, especially those on steeper hills, have been planted without sustainable design at the beginning (e.g. planted in parallel to hillsides or non-terraced contours, or freely planted). Consequently, soil fertility has rapidly degraded due to erosion in the rainy seasons (Bui, 2004). Mini-terracing is more sustainable technology for both of these crops, particularly in steeper than 15° uplands. In terms of profit, both mini-terracing tea and coffee show higher yields, gross revenue, GMs and NMs than that of conventional tea and coffee, even though they have higher production costs and family labor requirements.

Overall, mini-terracing coffee has the biggest revenue, GMs and NMs; compared to mini-terracing tea and conventional tea. In terms of return to family labor, the order from the highest to the lowest is mini-terracing coffee, mini-terracing tea, conventional tea, MT maize, conventional maize, conventional coffee, and upland rice.

In more details, Figure 5.1 and 5.2 report HH gross and net margins by crop and farm practice throughout a 30-year time horizon. Annual crops (e.g. maize) show constant yields, production costs and margins. On the contrary, perennial crops margins show a sharp increase in the initial cropping phase, a smooth increase at full development, and a gradual decrease at the end of the cycle.

Analytical assumptions are reported in what follows. Conventional tea yields will decrease by 5% from year 26; mini-terraced tea yields will start declining from year 28, due to aging. Enterprise budget for coffee reflects two economic cycles. In the first one, the plant reaches full development in year 6 and starts declining in year 13 under conventional, and in year 15 under mini-terracing (Dien Bien DARD, 2012; Vu, 2017). After that, coffee trees are heavily pruned in order to trigger a new growth of stems, branches and leaves. It commonly takes one and a half years to allow the trees to start bearing cherries again in this second economic cycle (Vu, 2017). Also, according to Dien Bien DARD (2012), yields normally reduce considerably in the last two years (years 13 and 14) of the first cycle, with decreases projected at 10% compared to the yield of the previous year.

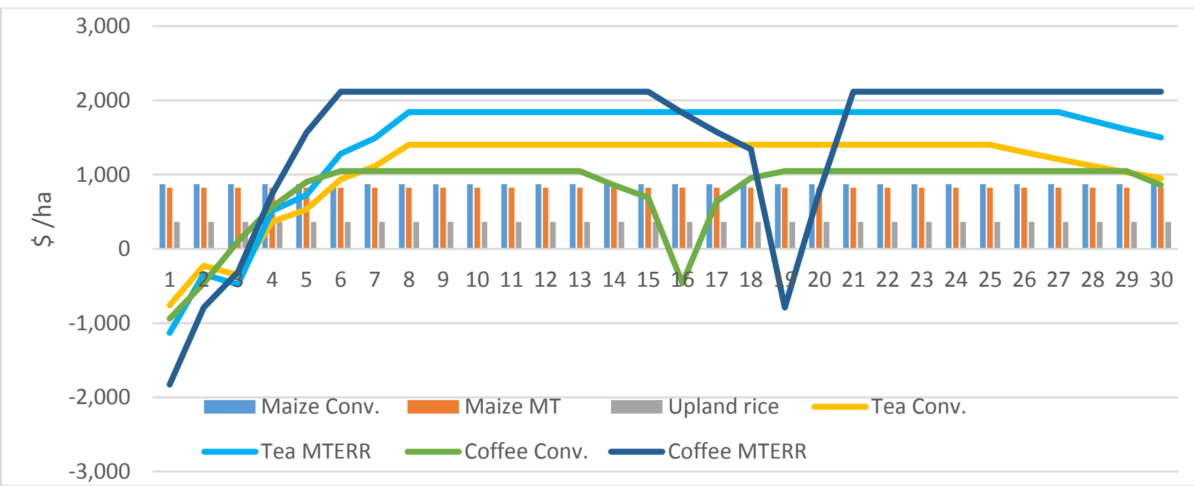

Figure 5.1. Gross margins over 30-year time horizon by crop and technology
Source: Own elaborations.

In the initial years, all crops perform a gross gain excepting tea and coffee (loss from -\$1,342 ha^{-1} for conventional tea to -\$3,466 ha^{-1} for mini-terracing coffee). However, at full development, perennial crops guarantee better economic results than annual crops. Also, for both tea and coffee crops, mini-terracing practices gain higher GMs than that of conventional ones, while conventional and MT maize practices have roughly similar GMs of about \$850 ha^{-1}. This indicates that perennial crops can improve HH incomes with respect to annual crops, and that CSA practices are effective in improving incomes from perennial crop production.

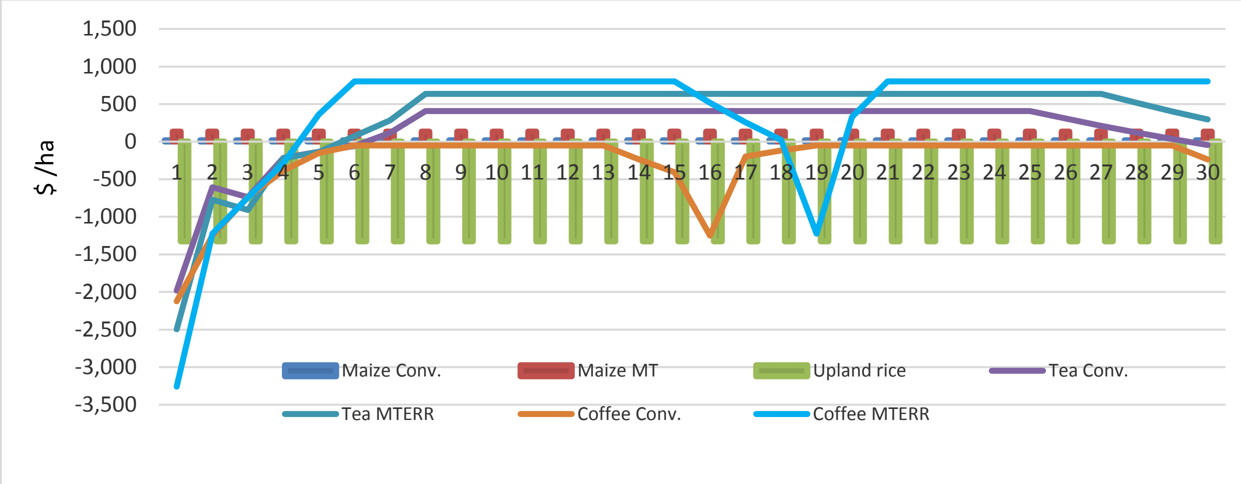

Figure 5.2. Net margin over 30-year time horizon by crop and technology
Source: Own elaborations.

When family labor is taken into account results show that only conventional tea, mini-terracing tea and mini-terracing coffee have significant positive margins at their full development phase. It is thanked to higher labor productivity and return to labor in these crops than that of the others. However, both crops show a net loss from year 3 (for coffee) and year 4 (for tea) to year 6 or 7 because their yields have not achieved the high and stable levels as displayed at maturity of the investment. Both conventional and MT maize show a net gain of \$19 ha^{-1} yr^{-1} and \$133 ha^{-1} yr^{-1}, respectively. These margins are much smaller than those computed for perennial crops. Additional details are reported in Appendix E.

Three indicators (NPV, BCR and IRR) are presented and compared for evaluating profitability in all crops (Table 5.2). GM analysis is conducted using typical crop management models in order to guarantee a minimum acceptable level of statistical significance, meaning that only types of farm management with highest frequency in the sample are included for calculation.

In all practices, only upland rice and conventional coffee show BCR values less than 1, implying that their profits are not attractive for investment. negative NPV also confirms the unattractiveness of these practices as compared to other annual crops (e.g. upland maize). In maize practices, BCRs are greater than 1 and their NPVs are all positive at 8% interest[23]. However, in conventional tea and coffee, their NPVs are both negative, indicating that these

[23] The opportunity cost of capital, is assumed at 8%, based on interest rate in Viet Nam

practices are less attractive than mini-terracing practices, though BCR for tea conventional is still greater than 1. In mini-terracing tea and coffee practices, IRRs are both greater than 8% and NPVs are both positive, showing their high level of profitability among the perennial and annual crops included in this research under local farming systems.

Table 5.2. Profitability indicators by crop and technology

Indicators	Unit	Maize		Upland rice	Tea		Coffee	
		Conv.	MT		Conv.	MTERR	Conv.	MTERR
BCR		1.02	1.12	0.30	1.22	1.34	0.97	1.39
NPV at 8%	$	210	1,492	-14,929	-853	38	-4,982	209
IRR	%				5.52	8.08		8.40
Opportunity cost *(NI, from alternatives to conv. tea)*	$/ha	327	213	1,672	-	-260	396	-456

Source: Own elaborations.

Opportunity cost

In this research, opportunity cost refers to the NMs of a crop forgone when switching to conventional technology. In terms of land use type, paddy rice seems permanently cultivated, but for the upland crops such as, maize, upland rice, tea and coffee, they could be changed from one to the other after its cycle of production. Results of opportunity cost analysis in Table 5.2 show that when switching to conventional tea, opportunity costs of mini-terracing tea and mini-terracing coffee are negative. For all other alternatives (e.g. MT and conventional maize, upland rice and conventional coffee), their opportunity costs is positive. These demonstrate a clear incentive for farmers in switching from other crops to tea production, CSA tea production is higher incentive than conventional tea.

Apart from opportunity costs, upfront investment is another important factor that smallholder farmers consider when deciding what type of crop to grow. Particular in this case is the costs invested in the initial phase if they grow perennial tea or coffee. Table 5.3 below presents totals and details of such investment costs that range from $1,341 ha^{-1} to $3,674 ha^{-1} depending on the use of conventional or mini-terracing technologies. Practicing mini-terracing is more costly than conventional in the investment phase because in mini-terracing practices, producers have to spend $524 ha^{-1} or 27% (for tea), and $1,415 ha^{-1} or 40% (for coffee), more than conventional farmers for terracing construction and maintenance. These amounts are considered a large investment for small holders, especially poor resource-based farmers. Thus, investment costs represent a barrier to adoption of the improved practices.

Table 5.3. Investment costs in the initial phase of tea and coffee production

Costs	Unit	Tea		Coffee	
		Conv.	MTERR	Conv.	MTERR
Total	$/ha	1,342	1,954	1.839	3,466
Seedlings	$/ha	280.7	320.8	252.6	300.7
Shading tree	$/ha	11.5	11.5	11.5	11.5
Manure	$/ha	280.7	320.8	315.8	375.9
Urea	$/ha	264.2	271.2	446.2	549.4
Phosphate (Lam Thao)	$/ha	241.5	241.5	373.3	373.3
Potassium	$/ha	161.3	161.3	319.7	319.7
Pesticides (spraying)	$/ha	91.6	91.6	103.1	103.1
Pesticides (soil app.)	$/ha	11.0	11.0	16.5	16.5
MTERR_contruction	$/ha	-	289.9		776.3
MTERR_maintainance	$/ha	-	234.2		639.3

Source: Own elaborations.

It can be concluded that conventional and mini-terracing tea have higher NMs, return to cash capital, and return to family labor than maize (both under MT and conventional technology), upland rice, or conventional coffee at full development. In terms of opportunity costs, switching from other crops and practices to conventional tea, mini-terracing tea and mini-terracing coffee result in negative costs. All other alternatives (e.g. MT and conventional maize, upland rice and conventional coffee) experience positive costs. When looking at the whole life time of enterprise budgets, conventional tea show lower profitability than that of mini-terracing tea and coffee.

5.2.2. Enterprise livestock budgets

In this section, output of budgeting for cattle, buffalo and pig will be presented and discussed. Obviously these are estimations based on the hypotheses made when building the models. Details are displayed in Appendix F.

Figure 5.3 illustrates GM results of enterprise budgeting for livestock in the 30-year time horizon. While GM trends in buffalo and pigs enterprise budgets show a clear cycle (3-4 years for buffalo and 5-years for pigs), GM from cattle rearing rise steadily from year 2 to year 17 and could grow even more rapidly afterwards. In pig farming, sows and pigs finishing are commonly combined at the same time in most rural HHs to self-supply piglets for meat production, the surplus piglets are sold for cash income (Phung et al., 2008; Vo and Vu, 2006). Finishing pigs need 4-6 months for off-taking and piglets need 2 months to sell as weaners, however, both types are budgeted on a yearly basic for simplicity. Consequently, GMs in pig practices are \$240 yr^{-1} and \$652 yr^{-1} in years 7, 13, 19, and 25, in which old sows are culled and sold out for meat.

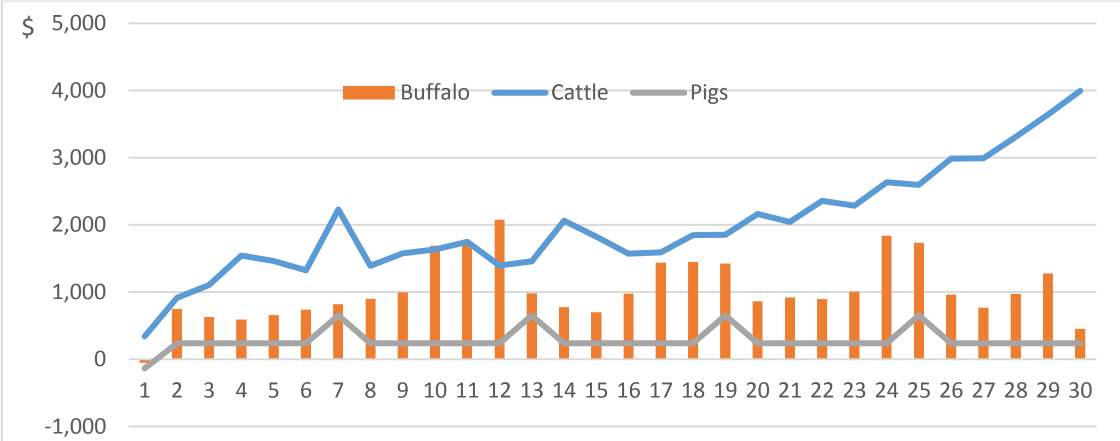

Figure 5.3. Livestock gross margins over 30-year time horizon
Source: Own elaborations.

When incorporating family labor into cost structure, NMs have declined dramatically for all livestock (Figure 5.4) as compared to their GMs in the previous figure. However, NMs from cattle raising remain a net gain over the entire of time frame, with values averaging from \$ 339 yr^{-1} in year 2 to \$1,350 yr^{-1} in year 30. Excepting three net gain periods (corresponding to the peaks shown in Figure 5.3), NMs from buffalo husbandry perform a net loss in three periods: year 4 - 9, year 13 - 16, and year 26 - 27. It can be explained that in buffalo budgeting, stocks at the beginning year are lower than that of cattle and, more importantly, that female buffaloes take on average 1.5 years for calving, 0.5 years longer than cattle. Therefore, buffaloes need 8-9 years to reach full herd development and several years to regain full development after off-taking. In pig enterprise budgets, the trend of NMs is similar to that of GM, however, NM values are mostly negative due to cost increases when labor is taken into account.

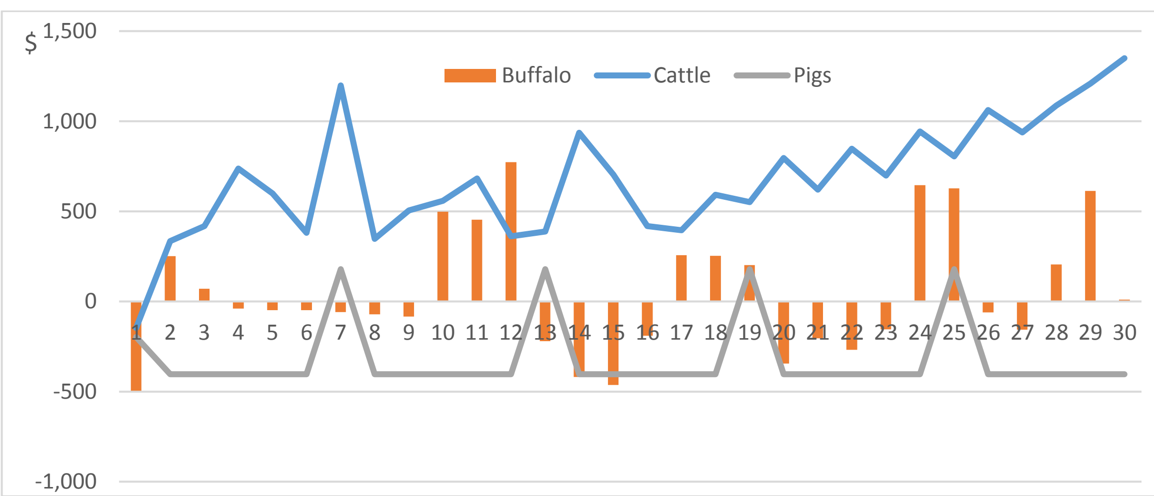

Figure 5.4. Livestock net margins over 30-year time horizon
Source: Own elaborations.

The results of livestock husbandry show annual net gains at full development (cattle and buffalo) and on a yearly basis (pigs). Nonetheless, large ruminant husbandry presents a much larger gain of annual net benefit compared to that of pig production. Cattle and buffalo, by nature, have much heavier body weight per head than pigs. However, their relative GM indicators such as net income per head do not directly reflect that fact. Instead, the real value of such ruminants, as perceived by farmers, is in their role as reserve capital and draught power. Pig husbandry shows a higher labor intensive rate but lower returns to family labor as compared to cattle and buffalo husbandry.

Table 5.4. Summary of profitability indicator by livestock

Livestock	Return to family labor ($/day)	IRR (%)	NPV at 8% ($)	B/C ratio	Annual Net margins ($)	Gross margins ($/head)	Net margins ($/head)	Capital value ($/head)
Cattle	7.2	67%	5,413.5	1.32	749.6	128.2	43.7	687.1
Buffalo	5.2	12%	-342.6	1.04	77.0	108.3	8.0	992.1
Pigs	2.7	-	-3,580.7	0.84	-323.5	43.9	-17.1	-

Source: Own elaborations.

While cattle raising shows a positive NPV, buffalo and pig practices present a significant negative NPV. In terms of return to investment rate, BCRs for cattle and buffalo are both greater than 1. Cattle has the highest annual net margins per herds and per head among the three livestock categories.

Family labor is a very important factor to study HH income and to investigate enterprise profitability. When this factor is incorporated into total costs, perennial crops (tea and coffee) and large ruminants (cattle) at full development show higher NMs as compared to their alternatives.

5.2.3. Representative farms

5.2.3.1. Representative farm construction

This section presents the output of the representative farms (RFs) formulation which has integrated both crop and livestock production for a whole farm analysis. Details are presented in Appendix G.

Table 5.5. Structuring Representative Farms

Rep. Farm*	Cropland (ha)	Upland rice (ha)	Maize (ha)	Tea (ha)	Coffee (ha)	Cattle (head)	Buffalo (head)	Pig (head)
*p*25th -Farm 1	0.62	0.04	0.11	0.01	0.00	0.20	0.69	3.26
*p*50th -Farm 2	0.88	0.04	0.28	0.05	0.04	0.43	0.89	3.51
*p*75th -Farm 3	1.28	0.05	0.38	0.08	0.05	0.53	1.31	4.02

Source: Own elaborations.

* RF1, RF2 and RF3 represent averaged values derived at 25th, 50th and 75th percentiles and denoted as *small*, *medium*, and *large* farms, respectively.

5.2.3.2. Representative farm analysis

In order to evaluate the impacts of conventional tea, mini-terracing tea and other CSA practices on the total net income in each RF, the four scenarios ("without-tea" as the baseline, "with-tea", "with-CSA tea" and "with-all CSA practices") have been tested for each of the three representative farms, namely small, medium and large farms (Table 5.5). In each RF, the area of each crop or number of head is multiplied by their relative NMs per ha unit (presented in GMs and profitability sections) to get NMs by activity. Farm total NI is the sum of activity NMs. The results of the RF simulations are presented in the following figure.

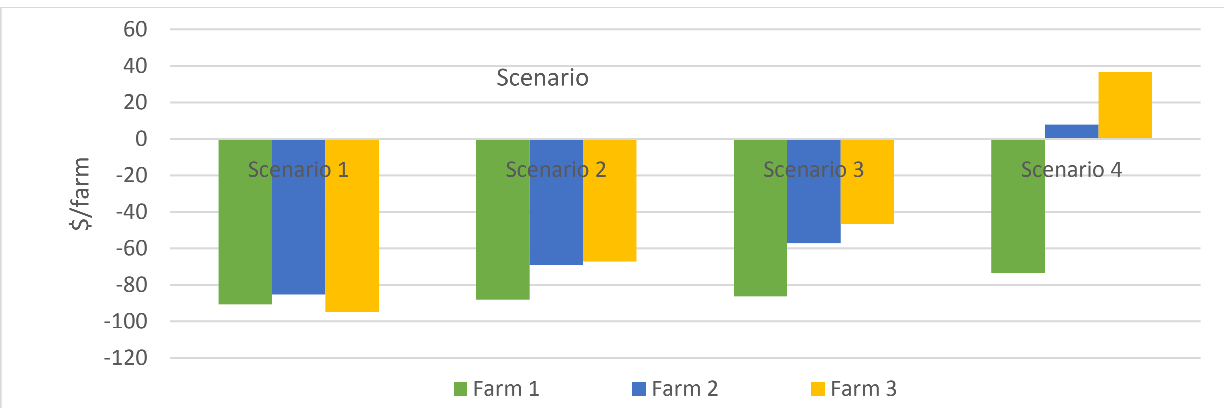

Figure 5.5. Net income by RF and scenario
Source: Own elaborations.

The total NIs in Farm 1 (*small farms*) are -\$91, -\$88, -\$86, and -\$74 in Scenario 1 to 4, respectively. Similar trends are observed in Farm 2 (*medium size*) and Farm 3 (*large farms*). However, NIs change linearly by farm sizes, where the bigger farms have relatively higher incomes. This can be seen clearly in Scenario 4 when NIs of Farm 2 have shifted from negative in Scenario 3 to positive in Scenario 4. This trend is even clearer in NIs in Farm 3. These results indicate that tea has contributed positively and significantly to farm income when it is integrated (Scenario 2). This positive contribution is even higher in Scenario 3 (when mini-terracing tea is integrated) and in Scenario 4 (when all CSA practices: mini-terracing tea, mini-terracing coffee, MT maize are included in the farm). Since the total NIs are negative in most scenarios, these significant contributions can be better seen if indexed (scenario 1 is used as base) using percentage terms.

Table 5.6. Net income index, by RF and scenario

RFs	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Farm 1	100	97	95	81
Farm 2	100	81	67	-9
Farm 3	100	71	49	-39

Source: Own elaborations.

As compared to NIs of base scenario, NIs in Scenario 2-4 decrease significantly in every farm. For instance, NI of Farm 2 decreases from 100 in Scenario 1 to 81 in Scenario 2, 67 in Scenario 3 and 9 in Scenario 4. In the same scenario, bigger farms have smaller percentage of net loss (or net negative NI).

However, once the farm size increases, family labor required by these farms increase accordingly (Figure 5.6). The amount of labor required by Farm 2 and Farm 3 increased by almost 50% and 100% in all scenarios. In contrast, the amount of labor required by each farm is almost unchanged across scenarios, including the baseline. When comparing the rate of change of among RFs within a scenario (Figure 5.6) to that of income Figure 5.5, it indicates that the rate of NI increased in each farm is lower than the rate of labor required. In other words, when the farm size increased, NIs also increase, but at a lower rate than the labor required.

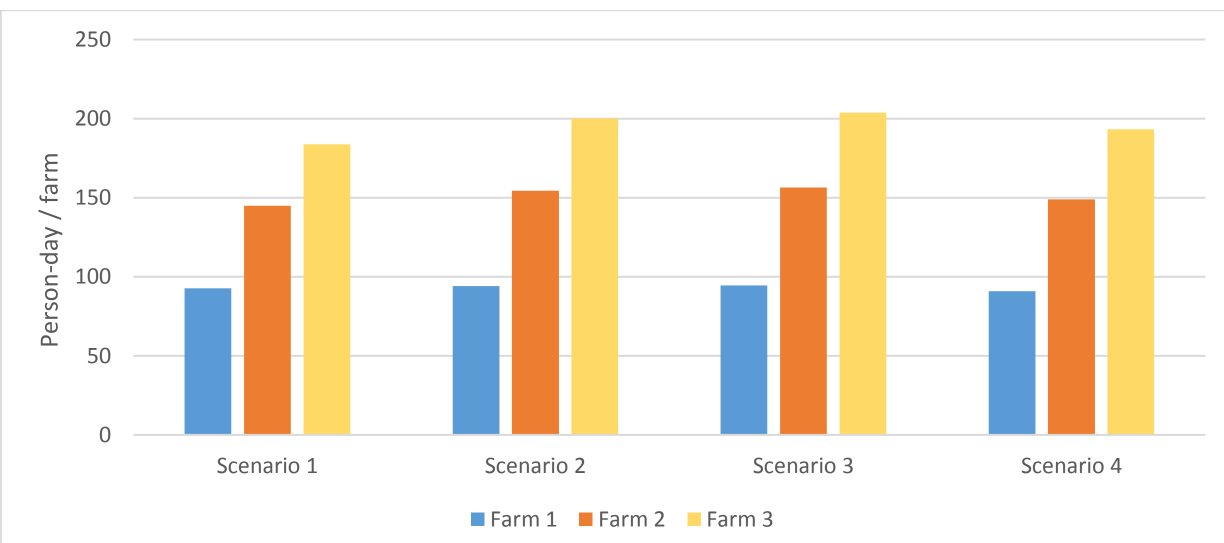

Figure 5.6. Family labor required by RF and scenario
Source: Own elaborations.

Figure 5.6 also shows that in the same RF (either Farm 1 or 2 or 3), labor requirement is very similar among scenarios. It indicates that incorporating CSA practices into RFs does not require more labor while it could help improving farm income significantly (Figure 5.5).

GMs and profitability analysis in crop and livestock sections show that family labor is an important factor determining the total farm GMs and NMs, indicating that farm activity in the study area is labor intensive., conventional tea shows high profitability and low switching costs as compared to conventional coffee, maize and upland rice. In livestock production, cattle husbandry shows a higher level of profitability and NM than its alternatives.

5.3. Adaptation assessment

5.3.1. Climate trend analysis: Overlaying local and scientific knowledge

5.3.1.1. Weather extremes

The output of problem tree shows that tea farmers are facing a number of difficulties in agricultural production, including pest and diseases, weather extremes and lack of improved agronomical techniques. Among these, extreme weather events are taken into consideration for further discussion because they are closely linked to CC-induced phenomena experienced by local people. Table 5.7 shows the ranking of the most important EWEs faced by farmers in study communes including droughts, floods, frost, cold spells, and hot spells. These are the types of EWEs that are expected to become more frequent and intense under CC, underlining the importance of incorporating CC into evidence to support agricultural HHs in these areas.

Table 5.7. List of EWEs and their importance rankings in tea communes

Ranking*	Suoi Bu Commune	Nam Bung Commune	Tien Nguyen Commune	Viet Lam Town
1	Cold spells Flood, landslides and flash floods Hot spells	Laos' winds[24]	Floods and landslides	Drought or water shortage
2	Storm, rain and typhoon	Frost and Cold spells	Droughts	White frost & Cold spells
3	Droughts	Droughts and hot spells	Hail	Hot spells
4	Hail	Storm, rain and typhoon Flood, landslides	Strong winds White frost & cold spells	Floods and landslides Hail & acid rain

Source: Own elaborations from FGDs. *Ranking is from the most to the least important

[24] Dry, hot air winds blowing from Laos People Democrat Republic, a western neighboring country of Viet Nam.

5.3.1.2. Connecting farmers' observations with climate data

Temperature trends

Results from the discussion topic 2: (Village history and EWEs) conducted in Bu Cao and Nam Cuom villages show that two severe cold spells happened in winter of 2007/08 and 2011/12. For example, in Bu Cao Village, the cold spell in 2007/08 was prolonged abnormally up to nearly 40 days, killing many buffaloes in Suoi Bu Commune. The total death toll in Bu Cao Village had reached about 20 heads or roughly 30% of village buffalo herds. Similarly, a cold spell was observed in Nam Cuom Village in 2012, killing more than 40 cattle and buffaloes as well as heavily damaging some upland crops. Figure 5.7 and 5.8 display the transcripts of Vietnamese notes taken from FGDs.

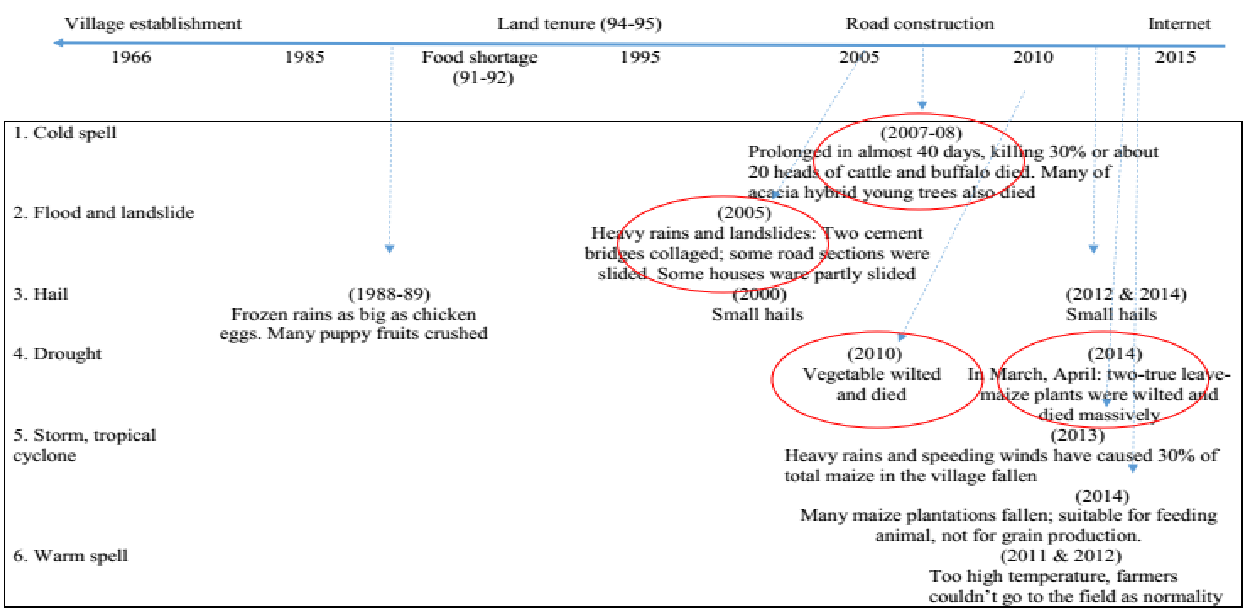

Figure 5.7. Farmer's perception about EWEs occurring in the history in Bu Cao Village *(Suoi Bu Commune, Van Chan, Yen Bai)*

Source: Own elaborations from FGDs

In these transcripts, time and brief description of important events have been circled in red. In these discussions, description of floods, landslides, droughts, and other EWEs have been expressed in farmer's own words. Rain-related events are closely connected to site-specific rainfall patterns in which disparities have been observed among participants. However, farmers have perceived a clearer, more consistent pattern about extreme temperature events, especially cold or hot spells. In general, most of them agreed that droughts, floods and a few other EWEs seem to be occurring more frequent today than that in past 20-30 years.

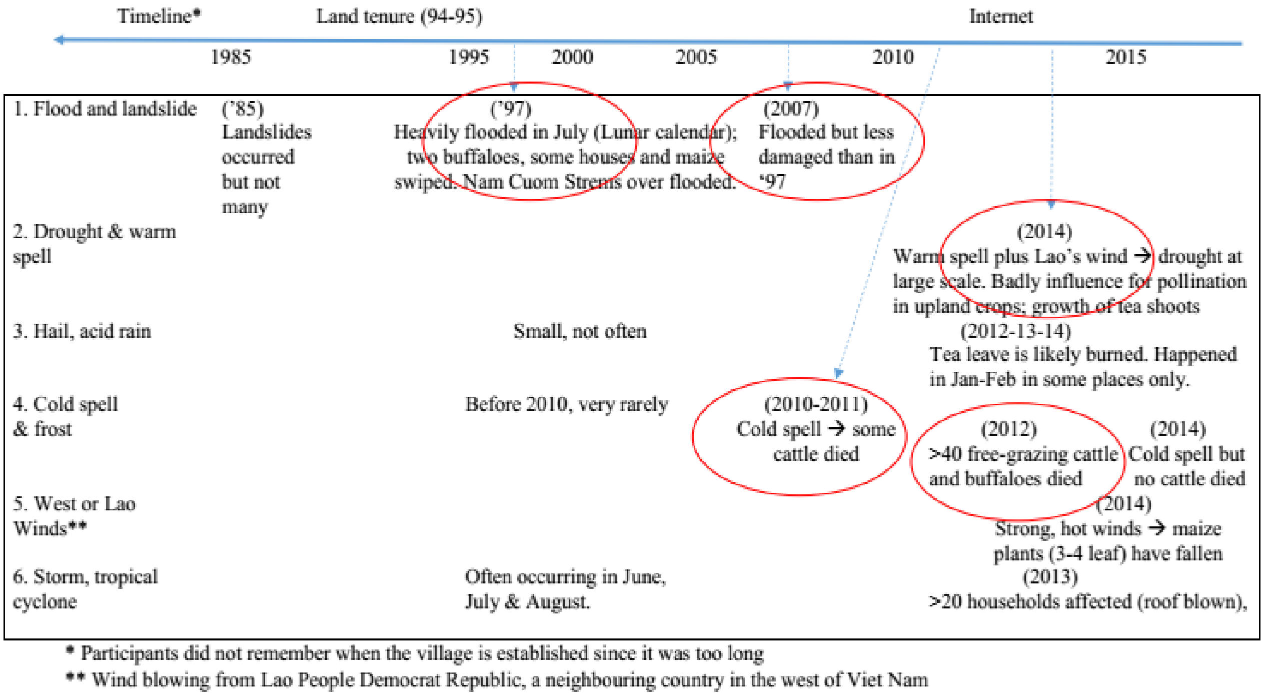

Figure 5.8. Farmer's perception about EWEs occurring in the history in Nam Cuom Village *(Nam Bung Commune, Van Chan, Yen Bai)*

Source: Own elaborations from FGDs

In order to link farmer observations with objective weather data, I have analyzed the trends in observed temperatures in the same communes where I organized FGDs using ERA-Interim data over the past 25 years.

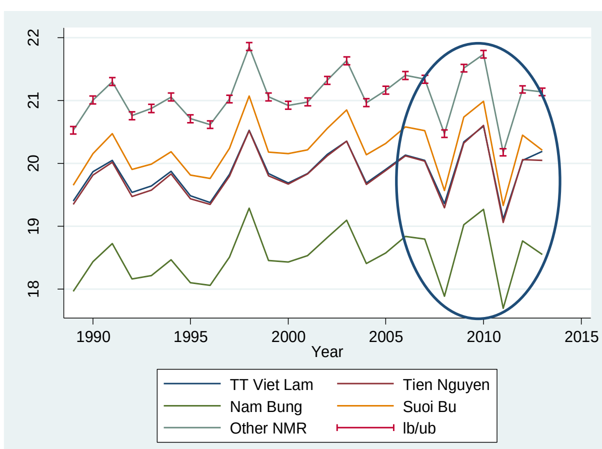

Figure 5.9. Mean of dekadal average temperature (1989-2013)
Source: Own elaborations from ERA data

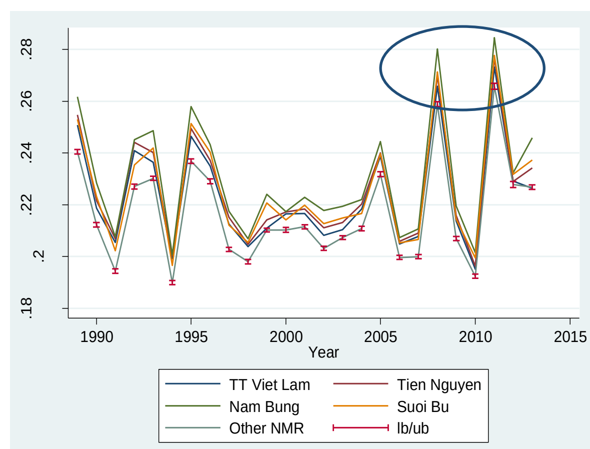

Figure 5.10. Coefficients of variation of dekadal average temperature (1989-2013)
Source: Own elaborations from ERA data

Figure 5.9 shows the changing patterns in mean dekadal average temperatures since 1989: average dekadal temperature has recorded two historic lows, one in winter-spring between 2007 and 2008 and another one in 2012, in all four communes of Viet Lam, Nam Bung, Tien Nguyen and Suoi Bu. In addition, within year temperature variability was analyzed by documenting the patterns of CoV of dekadal average temperature throughout the whole year (Figure 5.10). The CoV has reached new peaks in the same years when the average temperatures recorded extreme low values, indicating that within year variability has increased, adding to the unpredictability of incomes dependent on agriculture.

In terms of rainfall, the total annual rainfall has changed more sharply in the last 10 years as compared to that of a period from 1996 to 2007 (Figure 5.11). Changing patterns for yearly seasonality index (Figure 5.12) demonstrates a slightly increasing trend from 1997 to present, showing that rainfall regimes in the 4 study communes, as well as in the NMR region as a whole, have probably changed from "*rather seasonal with a short drier season*" to "*more seasonal*" as compared to Walsh and Lawler SI class limits.

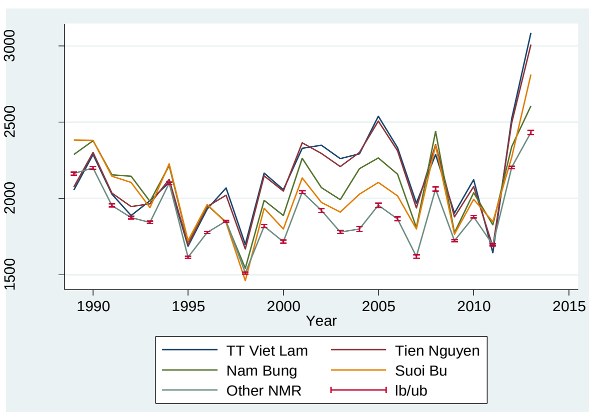

Figure 5.11. Year rainfall total in 1989-2013
Source: Own elaborations from ERA data

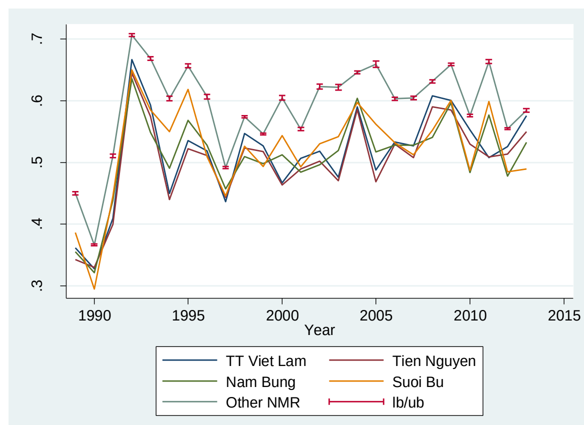

Figure 5.12. Yearly rainfall SIs 1989-2013
Source: Own elaborations from ERA data

Analysis of historical rainfall and temperature data has shown similar extreme events as farmers have discussed in FGDs, especially cold spells.

5.3.2. Overlaying local and scientific knowledge – household income and determinants

In this layer of adaptation analysis, descriptive statistics about HH income (per capita NI) and other indicators of income (per ha value of crop output (VCO), per ha amount received from crop sales (ARS) and per capita food expenditure (Foodex)) will be presented and analyzed before cross validating them with farmers' perceptions, in order to understand how well tea and non-tea HHs fare under different climate scenarios. Prior to this step, results of t-test to check the differences in the distribution of these income indicators between HHs in low and high variability conditions for rainfall, Tmax, Tmin, and Tav have indicated that in most cases, means of HH income and other income indicators in low variability environments are statistically significantly higher than that in high variability environments (detail presented in Appendix D). This provides suggestive evidence that high variability, either in terms of temperature or rainfall, is posing difficulty for farm-based HHs.

5.3.2.1. Descriptive statistics

Rainfall variability

Since most production systems in the NMR's uplands are rain-fed, rainfall levels and variability are important and decisive factors for crop growth and yield. Table 5.8 shows descriptive statistics of the three most vital income factors between tea and non-tea HHs under low and high rainfall variability conditions. Tea HHs have shown a statistically significantly higher per capita NI than that of non-tea HHs in 2010, and in pooled 3 years under both low and high rainfall variability conditions, and in 2014 under high rainfall variability condition. In terms of VCO, tea HHs also have a statistically significantly higher average values than that of non-tea HHs in all years, but in low variability condition only. For Foodex (an indicator also representing HH income), statistics show that tea HHs have higher Foodex than that of non-tea HHs not only on average across all 3 years (both low and high rainfall variability), but also in given years, i.e. 2010 (low variability), and 2012 (high variability).

Table 5.8. Per capita net income, per ha total value of crop output, per capita food expenditure (000 VND) by rainfall variability and tea category household

Year	Descriptive statistics	Rainfall variability and category household			
		Low		High	
		Non-tea HH	Tea HH	Non-tea HH	Tea HH
2010	N	625	41	447	22
	Per capita NI	18,044	27,770***[25]	16,696	26,462***
	Per ha VCO	35,503	63,069***	36,350	43,667
	Per capita foodex	215	327***	180	239
2012	N	692	26	473	18
	Per capita NI	12,229	13,234	11,126	12,426
	Per ha VCO	35,080	52,242*	35,027	36,550
	Per capita foodex	289	360	231	352**
2014	N	655	35	452	16
	Per capita NI	18,127	16,359	11,682	26,138**
	Per ha VCO	41,166	52,141*	30,786	38,662

[25] **** means in the same row and category are statistically significantly different at α=0.01*
*** means in the same row and category are statistically significantly different at α=0.05*
** means in the same row and category are statistically significantly different at α=0.1*

	Per capita foodex	258	299	228	350**
Total	N	1,972	102	1,372	56
	Per capita NI	16,031	20,149**	13,124	21,858***
	Per ha VCO	37,236	56,560***	34,061	39,949
	Per capita foodex	255	326***	213	307***

Source: Own elaborations from VARHS data files

Maximum temperature variability

Table 5.9 shows the results of similar comparisons under low and high Tmax variability conditions. Tea HHs have a statistically significantly higher average per capita NI than that of non-tea HHs when 3 years are pooled (both low and high Tmax variability), in 2010 (both low and high Tmax variability), 2012 & 2014 (low Tmax variability).

Table 5.9. Per capita NI, per ha VCO, per capita Foodex (000 VND)
by variability of Tmax and tea category

Year	Descriptive statistics	Tmax variability and category household			
		Low		High	
		Non-tea HH	Tea HH	Non-tea HH	Tea HH
2010	N	500	49	572	14
	Per capita NI	17,060	26,896***[26]	17,851	28,774*
	Per ha VCO	35,185	49,440***	36,443	80,282**
	Per capita Foodex	201.0	302.9***	199.6	274.3*
2012	N	563	37	602	7
	Per capita NI	12,906	13,112	10,728	11,801
	Per ha VCO	36,646	48,936*	33,574	29,365
	Per capita Foodex	287.2	376.7**	244.8	248.4
2014	N	525	43	582	8
	Per capita NI	14,481	20,161**	16,411	15,481
	Per ha VCO	38,042	50,919*	35,922	31,752
	Per capita Foodex	252.8	321.9**	239.4	279.6
Total	N	1,588	129	1,756	29
	Per capita NI	14,735	20,697***	14,932	21,010*
	Per ha VCO	36,648	49,788***	35,287	54,604*
	Per capita Foodex	248.7	330.4***	228.3	269.5

Source: Own elaborations from VARHS data files

In terms of VCO and Foodex, their statistics share the same pattern, where tea HHs have statistically significantly higher average values of those income indicators than that of non-tea HHs in 2010 (both categories), in 2012 and in 2014 (low variability). Nonetheless, this pattern has changed when all years are pooled, where only VCO in tea HHs is statistically significantly higher than that of non-tea HHs in both low and high Tmax temperature. HH Foodex, on the other hand, shows a significance in low variability of Tmax only. Overall, tea HHs have a

[26] Same as footnote 5

statistically significantly higher average NI and other indicators of income (VCO and Foodex) mostly in low variability conditions, indicating that tea may not be a resilient crop to high temperature variations.

Average temperature variability

In addition to Tmax variability, NI and other income indicators are also evaluated under low and high Tav variability. Table 5.10 shows that tea HHs have a statistically significantly higher NI than that of non-tea HHs in 2010 and pooled 3 years. Differently, all other income indicators in tea HHs are statistically significantly higher than that of non-tea HHs in any single year and in pooled 3 years. However, these significances are found at low variability conditions only, suggesting that tea is unlikely to be a resilient crop to high average temperature variability either.

Table 5.10. Per capita NI, per ha VCO, per capita Foodex (000 VND) by variability of Tav and tea category household

Year	Descriptive statistics	Tav variability and Category household			
		Low		High	
		Non-tea HH	Tea HH	Non-tea HH	Tea HH
2010	N	654	45	418	18
	Per capita NI	16,331	27,476***[27]	19,283	26,905
	Per ha VCO	31,180	50,495***	43,173	70,790
	Per capita Foodex	198.8	307.4***	202.4	269.3
2012	N	720	34	445	10
	Per capita NI	12,288	13,431	10,960	11,111
	Per ha VCO	32,373	50,598**	39,404	29,586
	Per capita Foodex	276.0	391.3***	248.0	237.3
2014	N	673	39	434	12
	Per capita NI	17,244	20,641	12,785	15,483
	Per ha VCO	35,142	51,717***	39,698	35,547
	Per capita Foodex	250.4	330.1***	238.4	267.1
Total	N	2,047	118	1,297	40
	Per capita NI	15,209	21,170***	14,253	19,530*
	Per ha VCO	32,902	50,929***	40,717	49,916
	Per capita Foodex	242.9	339.1***	230.1	260.6

Source: Own elaborations from VARHS data files

[27] Same as footnote 5

Minimum temperature variability

Apart from analyzing NI and other indicators under Tmax and Tav environments as shown above, these indicators are also compared among tea and non-tea HHs under categorized Tmin variability conditions. Mostly similar to Tav variability, tea HHs have exhibited statistically significantly higher levels of all indicators than that of non-tea HHs in any year from 2010 to 2014 and also in pooled 3 years, but at low variability only. Surprisingly, in the high variability category, results in Table 5.11 demonstrate an opposite sign of difference between tea and non-tea HHs in 2012, where both NI and Foodex of non-tea HHs are statistically significantly higher than that of tea HHs. This implies that tea HHs could be able to cope with the variability of Tmin better than non-tea HHs do, but only in a low Tmin variability condition.

Table 5.11. Per capita NI, per ha VCO, per capita Foodex (000 VND) by variability of Tmin and tea category household

Year	Descriptive statistics	Tmin variability and Category household			
		Low		High	
		Non-tea HH	Tea HH	Non-tea HH	Tea HH
2010	N	654	46	418	17
	Per capita NI	17,349	29,250***[28]	17,691	22,072
	Per ha VCO	35,740	55,350***	36,038	58,847
	Per capita Foodex	185.2	305.9***	223.8	271.2
2012	N	722	33	443	11
	Per capita NI	11,353	14,308*	12,477**	8,689
	Per ha VCO	35,972	50,382*	33,571	32,145
	Per capita Foodex	257.7	405.4***	277.7**	208.8
2014	N	696	44	411	7
	Per capita NI	16,022	20,364	14,605	13,537
	Per ha VCO	37,245	49,666**	36,391	36,890
	Per capita Foodex	241.4	333.8***	253.0	198.7
Total	N	2,072	123	1,272	35
	Per capita NI	14,814	22,062***	14,878	16,159
	Per ha VCO	36,326	51,984***	35,293	46,063
	Per capita Foodex	229.4	342.6***	252.0	237.0

Source: Own elaborations from VARHS data files

Besides NI, VCO and Foodex statistical analysis as shown above, descriptive statistics have been conducted for the per ha amount received from sales (ARS). Results of ARS t-test between tea and non-tea HHs (Appendix D) have indicated similar trends to that of NI and VCO shown above. For instance, mean values of ARS in tea HHs are statistically significantly higher than that

[28] Same as footnote 5

of non-tea HHs under both low and high rainfall variability conditions. However, the values of ARS are statistically significantly different between HHs only under the low Tmax variability condition.

In summary, the analysis in this section solely based on descriptive statistics where unconditional averages and simple t-test are conducted. Econometric analysis could not be conducted due to data limitations. Results of comparing income and other income indicators such as VCO, Foodex and ARS among categorized HHs under different climate variability conditions (rainfall, temperature) have indicated that tea HHs are better off under difficult climate, mostly in communes with low variability of climate conditions. In order to make tea practice as part of a CSA solution in these communes and also become resilient in high climate variability environments, other factors need to be considered in evaluation, such as income diversification and the importance of integrating other livelihoods into HH income.

5.3.2.2. Exploring farmer's perception on livelihood importance to HH income

In addition to HH income exploration in tea communes, this section also deals with HH income, but more qualitatively, since the analysis uses farmers' perceptions and insights to assess the importance of different livelihood activities to their HHs' incomes. In each FGD, the AHP-based decision marking tool was applied to rank each income generating activity according to its contribution to the *level* and the *stability* of HH's income as compared to the other ones. These pair-wise comparisons are transferred, weighted, normalized, and consistency checked to ensure the validity of results. Details of such processes are presented in Appendix B.

Results of importance of HH's livelihood activities for the level and the stability of income in all four FGDs are synthesized and presented in Table 5.12. These results show that tea (including Shan and other cultivars) has achieved the highest rankings in most communes where FGDs have been conducted. This indicates that tea has performed the most important role, both in terms of level and stability to HH's income, for both HHs participating in conventional and organic production systems. Interestingly, tea, buffalo and rice share similar importance in natural organic production systems, both in terms of level and stability to HHs income. In such mountainous production systems, farmers are likely poorer than their peers in the lowland and hence, rice is vital for HH's daily food needs, while tea provides cash for ordinary expenses and cattle is the reserve capital. This implies that a rice-tea-livestock system is likely an income and risk-management strategy for smallholders in the uplands, while tea is the single most important income in lowland, intensive tea producers, since they are more tea-specialized HHs.

Table 5.12. Ranking livelihood's importance to HH income[29]

Income generator	Tien Nguyen (Ha Giang)		Viet Lam (Ha Giang)		Suoi Bu (Yen Bai)		Nam Bung (Yen Bai)	
	Level	Stability	Level	Stability	Level	Stability	Level	Stability
Rice	2	3	6	4	3	1	3	2
Maize	6	7	5	3	1	3	5	4
Shan tea	3	1	1	1	1	2	1	1
Soybean & Peanut	8	6	-	-	-	-		
Cassava	7	4	7	2	-	-	6	6
Buffalo	1	2	-	-	2	1	2	3
Cattle	4	4	-	-	-	-	-	-
Pig	-	-	4	6	-	-	4	5
Chicken & duck	5	5	3	5	4	4	-	-
Ginger	9	8	-	-	-	-	-	-
Off-farm	-	-	2	7	-	-	-	-

Source: Own elaborations from AHP analysis using FGDs
Note: blank cell refers to unavailable enterprise

5.3.3. Overlaying local and scientific knowledge – household resilience

5.3.3.1. Household resilience to CC - statistical assessment

HH resilience to CC is conceptually referred to as the capability of HHs to cope with and recover from climate shocks or in other words, bad conditions. Based on the narrative about good or bad year presented in Chapter III, 2010 and 2014 are considered good years because there was only one climate shock in each year, either rainfall or temperature (i.e. Tmax exceeding the LR average). On the other hand, 2012 is classified as a bad year since it had both rainfall and temperature shocks occurring at the same year (i.e. too much rainfall and too high average temperature as compared to the long term values).

HH level data on agricultural income and VCO have been processed and statistically described for analyzing their difference between years in each HH category (tea versus non-tea). These income variables (real values) are selected, as they are sensitive and rather affected directly by climate conditions. This analysis is based on VARHS unbalanced panel data to evaluate changes of income variables in tea and non-tea HHs across the years.

[29] Rankings are synthesized from AHP standardized and normalized eigenvalues; range goes from the most important (1^{st}) to the least important (i^{th}) with *i* is the number of livelihood activities in the village.

Table 5.13. Per capita income from agriculture (000 VND)

Year	Overall climate conditions	Tea HH			Non-tea HH		
		N	000 VND	Difference between years %	N	000 VND	Difference between years %
2010	Good	63	25,529		1,072	21,286	
2012	Bad	44	25,195	-1.3	1,165	20,420	-4.1
2014	Good	51	25,693	2.0	1,107	20,785	1.8

Source: Own elaborations from VARHS data file

Table 5.13 shows that real per capita income in tea HHs was reduced by 1.3% in a bad year (2012) compared to that in 2010 (a good year), and increased by 2.0% in 2014 (a good year) compared to 2012. Whereas in non-tea HHs, a similar pattern has been recorded but the percentage of difference is quite significant. In a bad year, non-tea HHs lost more income and in a good year, gained less, than tea HHs do in percentage terms. The trend is slightly different when HHs total VCO is evaluated, tea HHs have demonstrated a bigger loss in a bad year as compared to that of non-tea HHs. However, tea HHs have recovered faster and at a much higher level than that of non-tea HHs (Table 5.14). Generally, tea HHs have buffered moderately in coping with climate shocks, but they do recover better from shocks than non-tea HHs.

Table 5.14. Per household total value of crop output (000 VND)

Year	Overall climate conditions	Tea HH			Non-tea HH		
		N	000 VND	Difference between years %	N	000 VND	Difference between years %
2010	Good	63	9,840		1,072	6,014	
2012	Bad	44	5,542	-43.7	1,165	4,494	-25.3
2014	Good	51	6,480	16.9	1,107	4,760	5.9

Source: Own elaborations from VARHS data file

5.3.3.2. Household resilience – farmers' perception assessment

As seen in the analysis of information from FGDs, farmers need to cope with increasing EWEs in their farming activities. They were also asked to voice out their perceptions on adaptive potentials of various trees and crops during exposure to those EWEs. Degree of suitability or level of sensitivity is used in facilitating such adjustments. The reason behind this exercise is that engagement of a tree/crop with high degree of suitability (low sensitivity) means that HHs have a higher potential in dealing with climate shocks, as the tree/crop can buffer shocks better than others do.

Table 5.15. Rating suitability of crops and trees to EWEs

Commune	Crops and trees	Ranking suitability* to EWEs							Average
		Flood, Landslide/ flash slide	Drought	Hot spell	Hail	Frost & Cold spell	Laos' wind	Storm, rain/ typhoon	
Tien Nguyen Commune (Ha Giang)	Rice	2	1	-	1	-	-	-	1.3
	Tea	2	5	-	3	-	-	-	3.3
	Maize	3	2	-	2	-	-	-	2.3
	Soybean	3	2	-	2	-	-	-	2.3
	Peanut	3	2	-	2	-	-	-	2.3
	Cassava	2	5	-	5	-	-	-	4.0
Viet Lam Commune (Ha Giang)	Tea	4	4	5	-	4	-	-	4.3
	Rice	1	2	2	-	2	-	-	1.8
	Maize	1	2	3	-	3	-	-	2.3
	Cassava	1	5	5	-	5	-	-	4.0
Suoi Bu Commune (Yen Bai)	Maize	2	-	2	-	4	-	2	2.7
	Rice	3	-	3	-	3	-	5	3.0
	Tea	4	-	3	-	5	-	5	4.0
Nam Bung Commune (Yen Bai)	Rice	-	3	3	-	3	4	-	3.3
	Maize	-	2	2	-	5	2	-	2.8
	Tea	-	3	3	-	5	3	-	3.5
	Cassava	-	5	5	-	5	4	-	4.8

Source: Own elaborations from FGD
* Degree of suitability: 1- unsuitable; 2- less suitable; 3- suitable; 4- more suitable; and 5- very suitable.
Note: blank cell refers to unavailable EWEs

Tea and cassava are perceived to have a high level of suitability to EWEs, whereas main food crops such as rice and maize have lower degrees of suitability. Rice and maize are among the most important food crops for the local people, nevertheless, they ranked at the lowest degrees of suitability to EWEs, indicating their high vulnerability to CC. Agronomically, it is also because rice and maize are shallow-rooted grass species which require more favorable soil moisture and certain level of temperature during seeding and flowering. Overall, Shan tea is ranked at the highest degree of climatic suitability to these EWEs, especially to droughts and cold spells, as compared to other crops, showing its strong adapting potential to extreme events.

In conclusion, this component has employed local and scientific knowledge in multiple layering analyses. In the first layer, analysis of historical rainfall and temperature data have shown similar climate trends, particularly EWEs as farmers have perceived in FGDs. These forms of EWEs are expected to increase both in terms of frequency and intensity under CC, indicating the importance of incorporating them into studying agricultural and HH adaptation. In the second layer, comparisons of NI and other income indicators under different climate environments have pointed out that tea HHs are better off mostly in low variability conditions. Nevertheless, farmers have perceived that tea production, together with rice production and buffalo husbandry, are among the most important contributors to HH income, both in terms of level and stability. These findings have been further confirmed in the third layer of analysis, where real average values of agriculture income and crop output in tea HHs have gained more in a good year and lost less in a bad year, in percentage terms, than non-tea HHs. This implies that tea HHs could buffer climate shocks as well as rebound from such conditions better than non-tea HHs.

5.4. Mitigation assessment

In this research, assessment of CC mitigation in tea production systems focuses on GHG emission and sequestration quantification. The analysis of mitigation potential is based more on conventional and mini-terracing tea practices (intensive production systems) where compilation and quantification of GHG emission and storage are more empirical and systematic. The similar assessment conducted for natural organic stands purposely serves as suggestive evidence for mitigation evaluation.

5.4.1. GHG emissions in tea production systems

In this section, carbon emissions in all three production systems are studied in parallel to ease the comparison among them. Table 5.16 below presents GHG emissions by source and by production stage (CO_2-e per ha unit and per ton of fresh tea produced) in conventional, mini-terracing and organic production systems. Details for each activity data in above-mentioned production system are provided in Appendix H. The result of life cycle inventory analysis for each production system is also presented in Appendix H. Data in Table 5.16 show that conventional and mini-terracing production systems present an outweighed, high level of emissions as compared to that of organic tea production, both at pre-farm and on-farm stages. This trend remains the same when GHG emissions are measured as ton of carbon dioxide equivalent per hectare (tCO_2-e ha^{-1}) and as ton of carbon dioxide equivalent per functional unit (tCO_2-e FU^{-1}).

Table 5.16. Average CO_2-e emission by source and production stage

Parameter	Conv.		MTERR		Organic	
	tCO_2-e ha^{-1}	tCO_2-e FU^{-1}	tCO_2-e ha^{-1}	tCO_2-e FU^{-1}	tCO_2-e ha^{-1}	tCO_2-e FU^{-1}
Pre-farm stage:	*1.851*	*0.243*	*1.418*	*0.156*	*0.003*	*0.001*
Ammonium sulphate						
Urea	1.525	0.200	1.053	0.116		

NPK 5:10:3						
N in NPK	0.095	0.012	0.102	0.011		
P_2O_5 in NPK	0.091	0.012	0.097	0.011		
K_2O in NPK	0.009	0.001	0.009	0.001		
Pesticides	0.122	0.016	0.145	0.016		
Gasoline	0.010	0.001	0.011	0.001	0.002	0.001
Diesel oil					0.001	
On-farm production:	*1.114*	*0.146*	*0.836*	*0.092*	*0.011*	*0.008*
N-fertilizer application	1.071	0.140	0.788	0.086		
Gasoline for transport	0.031	0.004	0.037	0.004	0.011	0.008
Gasoline for pruning	0.011	0.001	0.011	0.001		

Source: Own elaborations.

In intensive farming, GHG emissions at the pre-farm stage are more than that of on-farm activities (Figure 5.13). Overall, emission rate from producing one ton of fresh shoots in conventional and mini-terracing practices are 0.39 tCO_2 and 0.25 tCO_2, respectively. Also, mini-terracing practice can could reduce GHG emissions by 0.14 tCO_2e FU^{-1} compared to conventional practice. Mini-terracing practice consumes lower fertilizer and pesticides, but gains higher yields compared to conventional technology, leading to lower GHG intensiveness per FU.

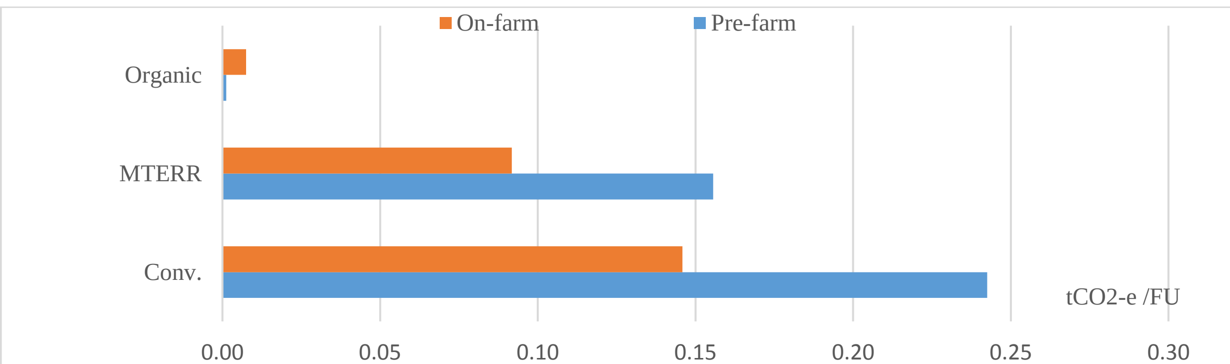

Figure 5.13. GHG emissions by production technology pre-farm and on-farm
Source: Own elaborations

Pre-farm GHG emissions

Results displayed in Table 5.16 and Figure 5.13 also imply that the pre-farm stage, including activities related to fertilizer and pesticide manufacture and transportation to farm gate, is one of the main GHG emission hotspots. Therefore, emissions induced from these operations need to be investigated in greater detail.

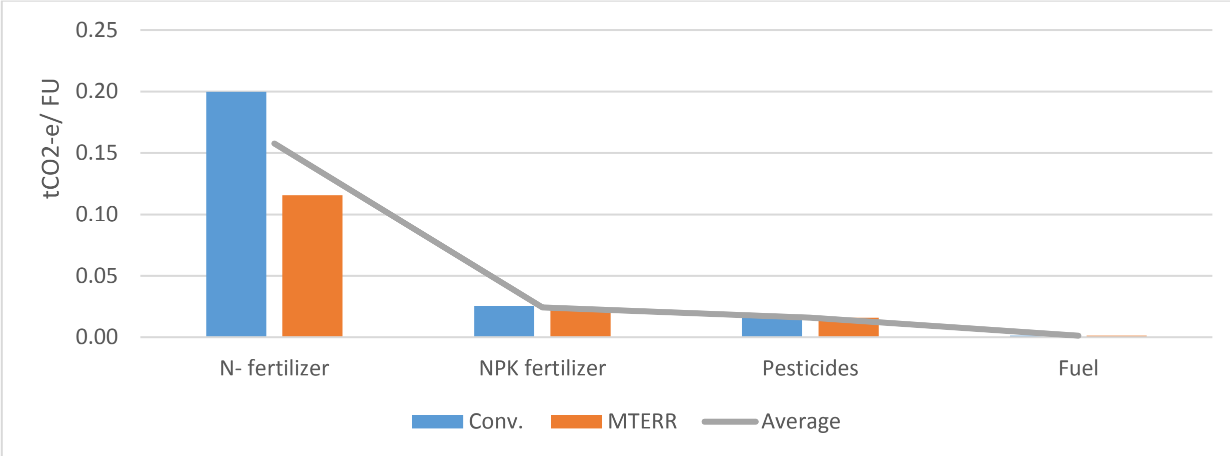

Figure 5.14. Emission of GHG by source in pre-farm stage
Source: Own elaborations

Figure 5.14 above illustrates the detail of GHG emissions accounted from the production of nitrogenous fertilizer (e.g. urea), NPK, pesticides and fuel before these agricultural inputs enter into farm activities. GHGs associated with manufacturing of N-fertilizer demonstrate the highest amount in both conventional and mini-terracing systems. While NPK fertilizer and pesticide show moderate contributions to total emission at the pre-farm stage, fuel presents a negligible level of emission in all systems because fuel is just used in a small amount for pruning machines and product transportation. Many other farm operations are done manually.

In pooled data of both conventional and mini-terracing (Figure 5.15), nitrogen fertilizer graphically presents the largest GHG emitter at the pre-farm stage, accounting for 79% of the total GHG emissions per FU. Fuel, on the other hand, emits just 1% of total GHGs. To sum up, fertilizer is the single largest contributor to pre-farm GHG emissions.

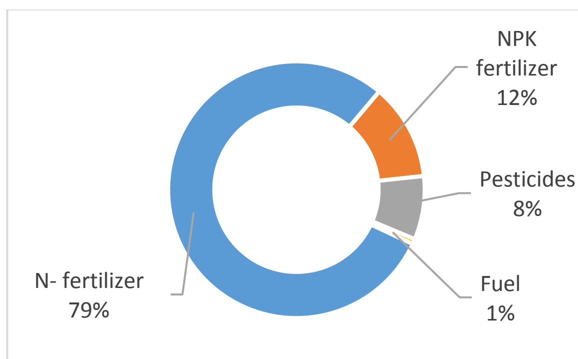

Figure 5.15. Pre-farm GHG emissions
Source: Own elaborations

On-farm GHG emissions

At farm level, nitrogenous fertilizers (urea, ammonium sulphate, NPK) are the predominant sources for N_2O emissions when they are applied to the soils of conventional and mini-terracing practices. In conventional production systems, the higher amount of fertilizer application (per ha unit) leads to a higher level of emission per FU compared to that of mini-terracing (Figure 5.16).

Numerically, conventional practice has emitted 0.054 tCO_2-e FU^{-1} more than that of mini-terracing practice. In averaging the two systems, nitrogenous fertilizer applications generally contributed 95% of total GHG emissions at farm level. The remaining emissions resulted from fuel combustion in farm machines.

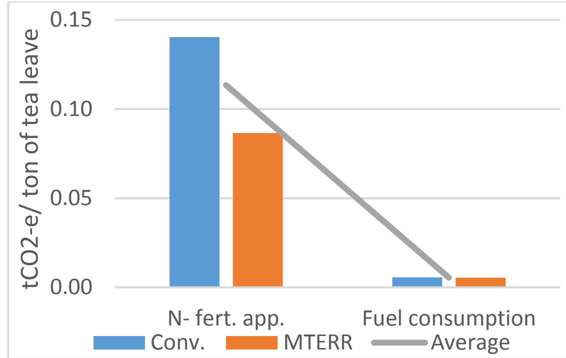

Figure 5.16. GHG emissions at farm stage
Source: Own elaborations

Value chain GHG emissions

Fresh tea shoots are materials for post-harvest processing and if GHG emissions are considered at value chain level, the situation changes (Figure 5.17). The results in our initial study indicate that producing one kg of green tea in the conventional tea value chains and one kg of black tea in organic tea value chains could emit 3.39 kg CO_2e and 3.50 kg CO_2e, respectively. Energy consumption in the post-farm processing, mostly from coal burning, is the largest GHG emitter in both types of products and value chains.

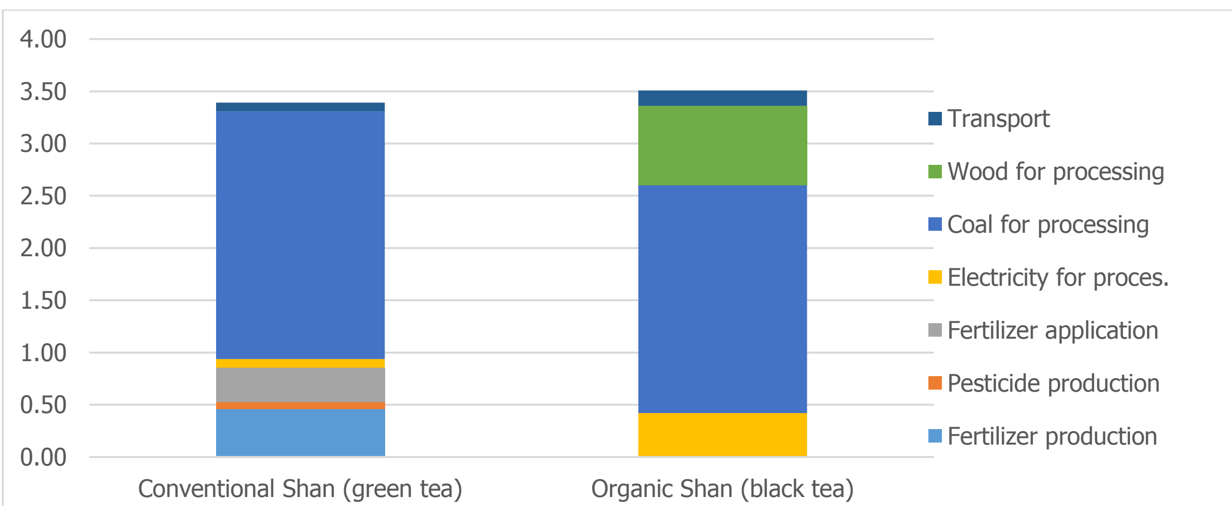

Figure 5.17. Emission of GHG by production stage in selected tea value chains
Source: Tran et al. (2016)

5.4.2. Carbon sequestration in tea plants

5.4.2.1. Conventional production system

The estimation of the amount of carbon sequestered in biomass of the conventional and mini-terracing production systems is modeled in three periods: (i) from year 1 to year 10; (ii) from year 10 to year 25; and (iii) from year 25 to year 40. This projection lifetime is not the same as that in enterprise budget on tea production because the carbon estimation model is mainly based on the annual growth rate reported by (Dang, 2002 and 2005a) for tea production in the NMR of Viet Nam. According to his study, dry biomass in tea production at the periods (ii) and (iii) has grown by 0.554 ton yr^{-1} ha^{-1} and 0.420 ton yr^{-1} ha^{-1}, respectively. In this study, the rate is assumed to represent the generic intensive tea production in the NMR and hence, has been used to estimate carbon content in both conventional and mini-terracing tea systems from year 10. To predict carbon biomass in the period (i), Kalita's allometric equation (2015) has been deployed to calculate carbon content per plant and per hectare using NOMAFSI's experimental data (2015).

Figure 5.18 shows the result of carbon content estimations in tCO_2-e ha^{-1} in conventional and mini-terracing practices for all three periods. Since the model in the two systems accounts the same growth rate (dry matter) from year 10 and field measurements from year 1 (exception made to plant density), carbon estimated amounts and growth trends are very likely. Hence, for the sake of simplicity, from this stage of mitigation analysis, carbon sequestration in biomass refers to both conventional and mini-terracing systems, and is denoted as intensive production system.

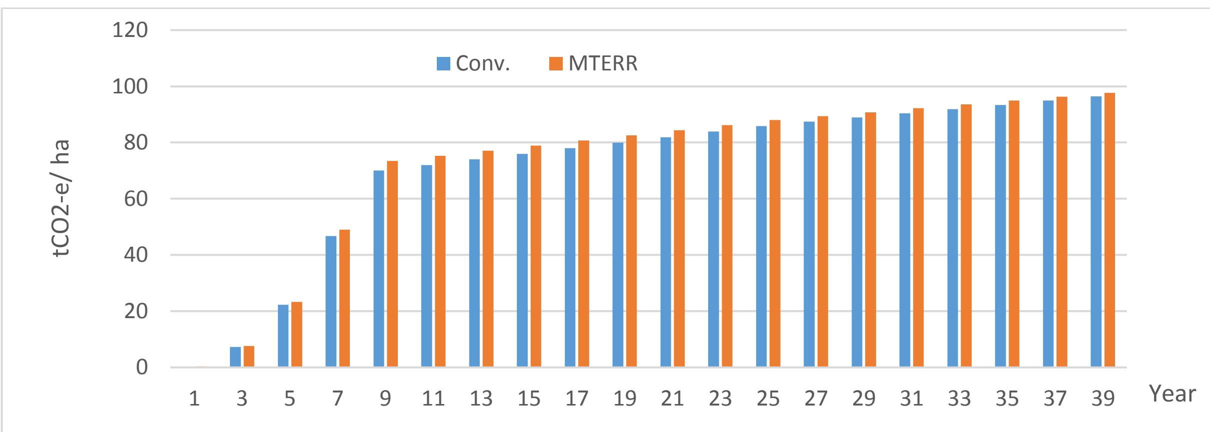

Figure 5.18. Estimation of carbon in biomass of conventional and mini-terracing practices
Source: Own elaborations

The estimated amount of carbon sequestered in tree biomass increases continuously throughout the lifetime of plantations. The growth rate of carbon sequestration increases sharply from year 1 to year 9, achieving around 20 tons carbon (tC) content or 70 tons CO_2-e ha^{-1}. However, it then rises gradually from year 10 onwards because the tea plant has entered its full development period, and in addition, the yield declines moderately from year 25 as mentioned in the enterprise budgets.

5.4.2.2. Organic production system

In natural organic Shan tea, the estimation of carbon sequestration is more complicated because of its nature as mentioned in Chapter IV. Table 5.17 below summarizes the processes and indicators which have been used to estimate: AGB, BGB, biomass dry matter (DM), carbon content and carbon sequestration in CO_2-e. Since the stands of organic Shan tea are made up of various tree classes and ages, the estimation displayed here represents the typical stands in research provinces.

Table 5.17. Estimation of carbon sequestration in Shan tea stands

Indicator	Unit	Diameter size (cm)						Total
		< 10	11-20	21-30	31-40	41-50	> 51	
Percentage of trees in diameter class	%	24.22	55.17	13.74	4.59	2.03	0.25	100
Diameter at stump (average)	cm	10.0	15.0	25.0	35.0	45.0	50.0	
Diameter at breast height	cm	7.8	12.6	22.1	31.5	41.0	45.8	26.8
AGB	kg/tree	13.1	45.2	196.8	502.2	999.9	1331.6	
Stand density by class	tree/ha	372.1	847.6	211.1	70.5	31.2	3.8	1536.4
AGB	ton/ha	4.9	38.3	41.6	35.4	31.2	5.1	156.5
BGB	ton/ha	1.0	7.7	8.3	7.1	6.2	1.0	31.3
Biomass DM	ton/ha	5.8	46.0	49.9	42.5	37.5	6.2	187.8
Carbon content	ton/ha	2.9	22.4	24.3	20.7	18.3	3.0	91.7
CO2-e sequestration	ton/ha	10.5	82.2	89.2	76.1	67.1	11.0	336.1

Source: Own elaborations

On average, one hectare of organic Shan tea (with an average stand density of 1536.4 trees) could sequester 187.8 tons of DM, equivalent to 91.7 tC content or 336.1 tCO_2-e. The figures are much greater to those of intensive tea plantations, given that both systems are assumed at maturity age.

5.4.3. Carbon sequestration in tea soils

5.4.3.1. Conventional production system

Carbon capture and storage in tea soils is in the form of soil organic carbon (SOC). In this section, SOC for both conventional and mini-terracing is estimated using Equation 26 (Chapter III). Input variables for this equation are averaged coefficients derived from reviewed data in Table 4.11 (Chapter IV). Results of SOC calculations in tea production systems are presented in below table.

Table 5.18. Summary of SOC calculation in tea production system by age

Age of plantation	BD (g/cm3)		D (cm)	SOC (%)		SOC (ton/ha)
	Mean	Sd		Mean	Sd	
year 1	1.07	0.10	30	1.91	0.57	61.42
year 10	1.14	0.19	30	1.55	0.43	52.76
year 25	1.21	0.15	30	1.56	0.43	56.50
year 40	1.29	0.06	30	1.32	0.49	50.89

Source: Own elaborations.
Note: BD= soil bulk density; D: thickness of soil layer. Sd: standard deviation.

To derive these results, the following adjustments have been made. Since soil carbon data were reported at different plant ages, they are grouped into four reference ages: year 1, year 10, year 25 and year 40 as suggested by Dang (2005a). In other words, means of soil bulk density or soil carbon content for year 10, for example, are averaged from data either in year 8, 9, 10, 11 or 12. Similar approach is applied for values in year 25 and year 40. Collected values for thickness of soil layer also vary (from 10 to 40 cm) so the value D=30 cm is consistently used for the calculation as recommended by IPCC (2003).

Table 5.18 shows that SOC in tea plantation decreased significantly from year 1 to year 10. Nevertheless, soil carbon gradually increased again in the next 15 years before slightly declining from year 25 to year 40.

5.4.3.2. Natural organic production system

In this study, SOC in natural stands is roughly estimated based on Subramanian et al. (2013) who reported that SOC in organic tea is about 8% higher than that of conventional tea, under similar planting and climate conditions. While the above SOC values are presented for certain ages, Shan stands, on the other hand, are mixed ages as the trees were freely planted. Therefore, it is assumed that SOC estimation here represents the majority of organic stands at full development.

Following these assumptions, SOC in Shan tea stands at full development equals SOC in conventional tea production systems at full development plus 8%:

$$
\begin{aligned}
SOC_{organic}\ (\text{ton/ha}) &= \text{average } SOC_{conv.}\ (\text{year 10, 25 and 40}) * 1.08 \\
&= 53.38 * 1.08 \\
&= 57.65
\end{aligned}
$$

Soil carbon sequestration = 57.65 * 44/12 = 211.4 (tCO2-e/ha)

5.4.4. Carbon balance in tea systems

5.4.4.1. Intensive production system

In this section, carbon balance is assessed by weighting GHGs emitted and sequestered in the production system at full development, using results presented above. In the side of carbon storage, only biomass carbon in the annual harvest is accounted to see if this amount could compensate the emissions caused by input application in the same year. To enable this, it is assumed that carbon content in harvested fresh shoots, after being processed into final tea products and consumed, have returned to soil (in the same tea area or elsewhere) in the form of soil organic matter. Results of carbon balance analysis show that overall, carbon storage in harvested tea leaves outweighs the emissions, though performing a small net loss in conventional production (Table 5.19).

Table 5.19. Assessment annual carbon balance at full development (tCO2-e/ha)

Carbon balance	Conventional	Mini-terracing	Average
Annual emissions:			
Pre-farm	1.85	1.42	1.63
On-farm	1.11	0.84	0.98
Total (1)	2.97	2.25	2.61
Annual sequestration:			
Yield (ton fresh shoots/ha)	7.63	9.11	8.37
Yield (dry matter/ha)	1.70	2.02	1.86
Carbon content in harvest (2)	2.79	3.33	3.06
Carbon balance = (2)-(1)	-0.18	1.07	0.45

Source: Own elaborations.
Dry matter = fresh/dry ratio = 4.5 (author's field survey)
Carbon content in the harvest: 48.8% (Subramanian et al., 2013); CO_2= C content*44/12

Carbon balance evaluation also indicates that at full development, carbon storage in tea shoots, which have been harvested every year, can compensate the annual GHG emissions and even perform a net gain. This implies that any other carbons sequestered in the production systems (e.g. carbon in frame, branches and soil) are considered a net gain, both in physical and economic terms. The figure below demonstrates those gains in physical amounts throughout the economic life of tea plantations.

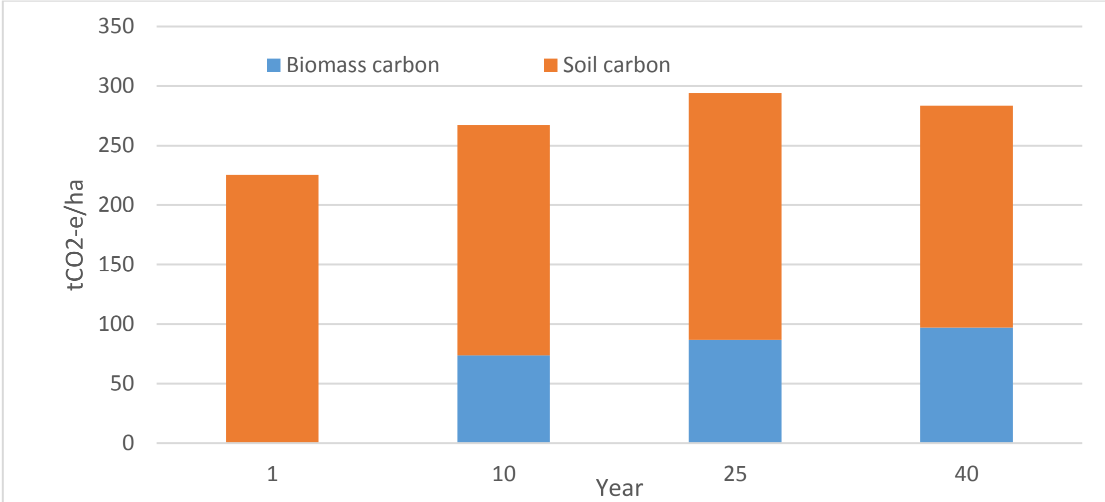

Figure 5.19. Total net carbon storage in intensive tea production system
Source: Own elaborations.

Soil carbon declines considerably in the initial or investment phase of the plantations but then gradually increases in the full development phase when more crop residues returned to the soils. In the whole life span, soil carbon amount has recorded a net loss of 6.9 tCO_2-e ha^{-1} in 40 years or 0.17 tCO_2-e ha^{-1} yr^{-1}. However, carbon in biomass that has increased continuously throughout the life time, could compensate this loss and positively contribute to an overall increase of carbon storage in tea production systems. For instance, total carbon sequestered in the system has increased steadily from 267.1 tCO_2-e ha^{-1} in year 10 to 294.1 tCO_2-e ha^{-1} in year 25, and slightly reduced to 283.6 tCO_2-e ha^{-1} in year 40. On average, tea production systems store 267.6 tCO_2-e ha^{-1} every year over the life span, after subtracting GHG emissions.

5.4.4.2. Organic production system

In this system, the GHG emissions caused by the application of inputs or consumption of fuel is very insignificant, accounting for only 0.003 tCO_2-e ha^{-1} (Section 5.5.1). Therefore, organic production systems perform a net carbon sequestration at any stage of the life time.

Total carbon storage = biomass carbon + soil carbon
= 336.1 + 211.4
= 547.5 (tCO2-e/ha)

5.4.5. Comparison of carbon storage between different tea plantations

In this section, the results of carbon storage obtained in this study are compared with that of other studies in the literature. Table 5.20 shows that C content in biomass and soil of intensive plantations (year 40 in this study) is similar or higher than that of other tea plantations in Viet

Nam. However, these C contents are much lower than that of tea plantations in China and Kenya. There are several reasons for the difference between these systems, including plant density, soil type, plant growth habit and farm management. Among those, plant density is the key factor. This can be seen clearly in tea plantations in China (Li et al., 2011), high density (from 29,000 to 37,000 plant per ha) have resulted in a double amount of biomass carbon to that of tea plantations in Viet Nam, where the density is popularly around 14,000 plants per ha, half of that in China. This implies that carbon content are mostly equal between tea plantations grown in Viet Nam and China if same density is applied.

Table 5.20. Carbon content (ton ha^{-1}) in biomass, soil and total system

Sites	Biomass	Soil	Total system	Source
China	48.93-52.89	131.6-145.0	185.3-201.5	Li et al. (2011)
Kenya	43-72	-	-	Kamau et al. (2008)
Viet Nam (year 20)	21.96	35.00	56.96	Tran et al. (2011)
Viet Nam (year 40)	25.74	50.2	75.94	Dang (2005a)
Viet Nam (year 40)	26.83	50.9	77.73	This study

5.5. CSA assessment

This section brings together the three analytical strands used to assess the three pillars of CSA. It discusses the synergies between different pillars and highlights the potential tradeoffs that need to be taken into account in any investments or projects in tea systems in the NMR of Viet Nam.

Tea farming contributes to HH income through cash earnings. In this research, the CSA pillar on food security is assessed by looking at profitability of tea practices in local farming systems. Results show that tea conventional and mini-terracing systems have: (i) better economic results and returns than maize (both minimum tillage and conventional practices), upland rice, and coffee; and (ii) low or negative switching costs to other crops or practices e.g. coffee conventional or maize mini-terracing. Tea under mini-terracing system has also better returns to investments than conventional tea farming. Thus, incorporating tea into farming systems could contribute positively to increasing HH incomes.

In all representative farms total net incomes have positively increased when tea is integrated. Results of comparing income and other welfare indicators under different climate variability conditions indicate that tea HHs are better off mostly in low climatic variability conditions, indicating that if climatic conditions become more variable in the future a shift into extensive tea system to cash on the income gains documented may introduce tradeoffs with the adaptation pillar. On the other hand, results from farmers' perception analysis show that income diversification to livestock is a sound strategy in contributing to resilience. In this mixed system, tea is still considered as one of the most important cash generators, but when it is combined with livestock and paddy rice, would form a more comprehensive adaptive strategy to enhance HH resilience.

Results of carbon balance in LCA indicate that tea is a net carbon sequester, under both conventional and mini-terracing. Tea growers could create gains of 268 tCO_2e ha^{-1} yr^{-1} or 73 tC ha^{-1} yr^{-1}, on average. These carbon offsets translate into \$730 ha^{-1} yr^{-1} (estimated using C price at \$10 ton^{-1})[30]. If it could be capitalized on, this would bring about a 38% increase in gross income for tea farmers. This thesis demonstrated that, by incorporating tea into farming practices, productivity and total incomes can increase and at the same time, mitigation co-benefits can be achieved. If a carbon credit system were in place, resulting carbon storage in the tea systems could also further increase the total HH income.

Mitigation options using perennial crops often provide adaptation co-benefits since perennial trees could serve as a cover crop all year round, preventing and/or reducing soil erosion and water runoff that leads to erosion as well. However, quantifying such benefits is beyond the scope of this research. Instead, tea has been assessed in terms of its contribution to biophysical and economic resilience, particularly in building HH income and affecting its variability. The analyses in the above sections have indicated that tea practices are profitable and competitive compared to other alternatives in commonly observed production systems in the NMR. As a result, farmers practicing conventional and mini-terracing tea cultivation could positively earn more income than they would from other alternatives in the local economy. This has the potential to indirectly enhance HH resilience capacity in the face of climate difficulties as discussed in the third layer of analysis in adaptation component. This component has demonstrated that real average values of agricultural income and crop output in tea HHs have increased more in a good year and have decreased less in a bad year compared to that of non-tea HHs in percentage terms.

[30] This is assumed that carbon offsets are tradable and carbon gains have satisfied the requirements from carbon market e.g. tea planting area is large enough or storage commitment is 50 years.

CHAPTER 6. CONCLUSIONS

This interdisciplinary work has been conducted to simultaneously address the three CSA components using multiple approaches. Though causal evidence has not been produced in some parts due to data limitations, this study is the first one so far to provide evidence of the benefits of CSA in an area where poverty as well as vulnerability to climate change, are significant challenges. Based on the thesis findings, we can now answer to the research questions.

1. What are the profitability and economic competitiveness of tea production in the study area?

Enterprise or 'activity' budgets for crops have shown that tea is a profitable farming activity crop in the study area, contributing positively to HH incomes. This is true for both 'conventional' and 'improved' practices analyzed as they both show higher net margins, return to cash capital, and return to family labor than maize, upland rice and conventional coffee at full development. Farmers therefore have high incentive to switch from other crops to tea production. However, 'improved' or mini-terracing is found to be more economically viable at full development, guaranteeing better returns to the investments than possible alternatives. Therefore the incentive is bigger for improved tea farming. Nevertheless, mini-terracing tea practice requires more upfront investment in the initial or growth phase, which could represent a barrier to adoption for smallholders since many of them are resource-poor and credit is not always available and easy to access. It is confirmed from the analysis of the representative farms that tea producing HHs have higher income levels than non-tea producers. The adoption of 'improved' tea production practices can generate better gains in terms of HH incomes with almost the same labor requirement. The analysis of representative farms also indicates positive returns to scale, since larger farms achieve higher incomes than smaller ones, per unit of production. However, larger farms also require relatively higher labor than smaller farms, posing a considerable constraint to farmers, especially in labor-scarce regions (like the study area) and time.

2. What is the potential for tea production in building adaptive capacity to climate change related shocks?

We looked at climatic patterns in the study area and their possible effects at farm level. The analysis of farmers' perceptions as well as observations from climatic data show that in the study area, extreme weather events are expected to increase, both in terms of frequency and intensity. This is consistent with international projected trends, particularly for countries more vulnerable to climate change like Viet Nam. Tea is a resilient crop and tea HHs are better off than non-tea HHs under difficult climate conditions, but mostly in communes with low variability of rainfall or temperature. Therefore, in high variability climate conditions, the contribution of tea to adaptation needs to be examined from a whole farm perspective since tea is among the most important contributors to the level and stability of HH income. In assessing such contribution, we found that tea production, in combination with rice cropping and buffalo, could formulate a best adaptation strategy in the upland, tea-based communes. Indeed, tea production is a backbone of the mixed crop and livestock farming system which characterizes the study area. Buffalo and cattle are important in contributing to the level and stability of HH incomes. In addition, income diversification could play an essential role in adaptation. Indeed, integration of livestock in the farming system can contribute significantly to farm total income (meaning higher potential to buffer shocks) and diversified livelihoods (adding more income source to farm portfolio). In terms of resilience to climate change, tea helps reducing income losses in bad years and tea HHs rebound faster in the face of climate difficulties, implying that tea could play a positive role in building resilience. Farmers' observations and perceptions have indicated that tea has a higher degree of suitability when coping with climate stressors than that of maize, rice and other crops. This contributes positively to the biophysical adaptive capacity of local production systems when tea is integrated, though this potential has been documented more strongly for low-variability conditions.

3. What are mitigation co-benefits in tea production and where is the best opportunity for reducing greenhouse gas emissions and enhancing carbon sequestration?

Tea production under both conventional and mini-terracing practices can provide significant mitigation benefits (positive externalities) as tea fields can be net carbon sinks. GHG emissions related to manufacturing and transportation of inputs before the farm gate are bigger than on-farm emissions. In terms of carbon storage, the carbon content in tea biomass of both conventional and mini-terracing practices can greatly contribute to the total carbon sequestration in the systems, as well as the net carbon gains after balancing with the annual emissions. Carbon sequestered could potentially be translated into dollar values, further increasing HH incomes. Besides studying carbon sequestration in intensive tea production systems, we have conducted additional study in natural organic tea systems. This result shows that natural organic Shan stands could sequester even more carbon in their systems than that of conventional or mini-terracing practices. In terms of carbon sequestration, natural organic tea systems hold more potential than conventional systems.

4. What is the CSA potential of tea production in the study area?

Our findings indicate that tea production systems in the NMR of Viet Nam have CSA potential given the synergies between productivity, adaptation and mitigation. Mini-terracing practices are more climate-smart than conventional ones, but need more up-front investment in order to be accessible for smallholders.

In current extension programs[31] supporting tea production, seedlings, shading trees and basic inputs in the first three years have been included for funding. However, costs for terracing construction and maintenance are excluded. Evidence in this research strongly recommends the integration of such costs into agricultural development policies, especially for diverse and difficult areas like the NMR. Mixed tea-livestock systems are resilient farming systems. Income from livestock breeding is an important source of income diversification. Buffalo are still perceived to have higher importance in providing draft power and capital value than cattle. Nonetheless, results of livestock enterprise budgets in this study indicate that cattle rearing is more profitable than buffalo stocking. Therefore, if large ruminants are considered for funding (either from governmental or non-governmental mechanisms) to farm operations, cattle are highly recommended and should be prioritized.

Some limitations of the analysis are reported in what follows. Rice is the staple food in the study area and one of the most important food crops in Viet Nam. Rice cultivation is practiced in paddy or rain-fed systems. Although paddy rice is more popular in the NMR, this research takes only upland rice into account as it is more compatible for studying profitability and competitiveness in relation to other rain-fed crops in the uplands. Therefore, representative farms are presented and analyzed without paddy rice, which is a limit of this study that may reduce the validity of its results.

In enterprise budgets for crops and livestock, total yield output and other coefficients are averaged from a one-shot survey and assumed to represent values for other years at full

[31] National and some provincial extension programs on new plant variety application under Government Decree 02/2010/ND-CP.

development. Tea yields, for example, in pre- and after-full development periods (e.g. year 4-7 or year 25-30) have been based on coefficients reported in the literature or modeled. Similar assumptions have been made for livestock enterprise budgets. The validity of our analysis therefore depends on such assumptions.

Ideally, adaptation analysis should be conducted using an econometric model. Farm level agricultural production data (from cross-sectional survey) and budgets would be used to compute net benefits related to farm and activity models. Climate data would be associated with the net benefits and they would be regressed on the climate variables associated. Regression coefficients would be used to derive how much a unit increase in a climate variable will shift net benefits per unit land. Therefore, knowing how much the climate (temperature and precipitation) in the area will change, we could have used such results to predict the loss or gain in agricultural net benefits per unit land.

VARHS data used in this study, however, had limited number observations on tea households and made no distinction between organic, conventional or mini-terracing systems, which did not allow for such econometric analysis. Alternatively, unconditional means tests are used to test for the significance of differences in income and other welfare indicators between tea and non-tea HHs. This analysis has also been repeated by dividing the sample into low and high climate variability, as well as good and bad weather years for tea production, in order to deduce the adaptation benefits from tea cultivation to the extent possible given data limitation. This approach provides suggestive evidence, even if not causal evidence, of adaptation benefits, especially combined with FGDs that also highlighted the adaptation benefits from tea farming.

Literature shows that diversification is a potential adaptation strategy. Income diversification indices were planned to be analyzed to assess whether tea households were more diversified, therefore potentially more resilient, using VARHS data. However, all income from agriculture, livestock and fishery are merged into one single income variable in the data. This limits the analysis of diversification strategies as originally planned. Future work should aim at addressing these limitations and build on this research in expanding the evidence base on adaptation assessment.

Local knowledge assessment based on farmers' perceptions may have a potential bias, since people are able to recall recent events better than past events, as well as extreme events better than slow-onset changes. The author is aware of these limitations and has cross checked with other research in the field to assess the validity of the findings from FGDs. For example, results of EWEs are similar to the findings in Simelton et al. (2015), where over 60% of interviewees (n=661) in Ha Tinh and Yen Bai provinces stated that they were affected by cold spells at least once per year and at least 40% were affected by hot spells, droughts and floods.

This CFP follows ISO/TS 14067: 2013 approach and 2006 IPCC Tier 1 guidelines to study the carbon footprint of tea produce in the "cradle-to-gate" phase. It is good practice to use measurements from a particular field and on-site emission factors in compilation and quantification. However, this was impossible in the scope of this research. Therefore, regional or international default factors are used. This would potentially reduce the accuracy of the study. Nevertheless, given that no similar work has been carried out in the area so far, this study serves as a starting point for future research. Tea practices are shown to have potential as carbon sinks, and tradable carbon projects may be considered to capitalize on this potential. More empirical work, however, is needed to enable translation of such environmental benefits into real earnings.

Since the CFP limits its scope up to farm level, the issue of pre-farm and post-farm emissions should be carefully discussed, because these GHGs could be the responsibility of the industry sector rather than farm operations. Our initial LCA study at the value chain level could provide suggestive evidence that the post-farm stage is the largest GHG hotspot.

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APPENDIX A. PREPARATION AND CONDUCTING FOCUS GROUP DISCUSSION

A.1. List of farmer participants in focus group discussions

FGD 1: Cao Sơn Village, Tien Nguyen Commune– Quang Binh District, Ha Giang Province
Conducted on 27/1/2015 by Tran The Tuong and Ly Van Hai – Technical Staff

No.	Full name	Age	Gender	Level of education	Ethni-city	Main sources of income
1	Trieu Mui Phay	20	Female	9/12 secondary school	Dao	Rice, tea, cattle
2	Lo Van Chau	21	Male	9/12 secondary school	Dao	Rice, tea, maize, cattle
3	Lo Chiu To	43	Male	9/12 secondary school	Dao	Rice, tea, maize, cattle
4	Phan Quay Chau	35	Male	5/12 primary school	Dao	Rice, tea, maize, cattle
5	Lo Mui Phan	26	Female	9/12 secondary school	Dao	Rice, tea, maize, pig
6	Lo Mui Chieu	28	Female	9/12 secondary school	Dao	Rice, tea, maize, cattle, pig, off-farm
7	Lo Phu Sin	57	Male	4/10 primary school	Dao	Rice, tea, cattle
8	Lo Mui Phay	28	Female	9/12 secondary school	Dao	Rice, tea, maize, cattle, cassava
9	Lo Mui Mui	22	Female	9/12 secondary school	Dao	Rice, tea, cattle

FGD 2: 12 Group, Viet Lam Town– Quang Binh District, Ha Giang Province

Conducted on 29/1/2015 by Tran The Tuong and Thai Thi Thuan (an extension officer)

No.	Full name	Age	Gender	Level of education	Ethni-city	Main sources of income
1	Hoang Van Luong	56	Male	7/10: secondary school	Kinh	Tea, chicken
2	Nguyen Manh Khoi	59	Male	7/10: secondary school	Kinh	Tea, livestock, retired salary
3	Nguyen Van Tho	53	Male	7/10: secondary school	Kinh	Tea
4	Duong Van Chien	46	Male	6/10: Secondary school	Kinh	Tea, raising cattle
5	Le Thi Hao	49	Female	7/10: secondary school	Kinh	tea, maize, rice
6	Nguyen Thi Quang	46	Female	10/10: high school	Kinh	Rice, tea, maize
7	Nguyen Xuan Hung	42	Male	7/10: secondary school	Kinh	Rice, tea, maize
8	Hoang Thi Sau	52	Female	7/10: secondary school	Kinh	Rice, tea
9	Pham Thi Anh	44	Female	7/10: secondary school	Kinh	Rice, tea, maize

FGD 3: Bu Cao Village–Suoi Bu Commune (Van Chan District, Yen Bai Province)

Conducted on 3/2/2015 by Tran The Tuong and Sung A Chu – Staff of Suoi Bu commune and translator; Le Viet Dung– Researcher, Nomafsi.

No.	Full name	Age	Gender	Level of education	Ethnicity	Main sources of income
1	Vang A Lao	45	Male	9/10:secondary school	H'mong	Maize, rice, tea, cinnamon, livestock husbandry
2	Vang A Chao	43	Male	Illiteracy	H'mong	Maize, rice, tea,
3	Mua Chang Gia	35	Male	Illiteracy	H'mong	Maize, rice, tea, pig
4	Sung A Tung	50	Male	Illiteracy	H'mong	Maize, rice, tea
5	Vang A Thao	30	Male	9/10: secondary school	H'mong	Maize, rice, tea
6	Mua A Chang	38	Male	9/12:secondary school	H'mong	Maize, rice, tea, salary (Head of village)
7	Vang Thi Dua	37	Female	Illiteracy	H'mong	Maize, rice, tea
8	Lo Thi XU	23	Female	9/12:secondary school	H'mong	Maize, rice, tea, cattle
9	Mua A Trinh	27	Male	7/10:secondary school	H'mong	Maize, rice, tea, cattle

FGD 4: Nam Cuom Village–Nam Bung Commune (Van Chan District, Yen Bai Province)

Conducted on 5/2/2015 by Tran The Tuong and Hoang Xuan Quynh (extension officer)

No.	Full name	Age	Gender	Level of education	Ethnicity	Main sources of income
1	Ha Quang Toi	35	Male	10/12: high school	Thai	Tea, pig
2	Lo Thi Thao	30	Female	10/12: high school	Thai	Tea, rice
3	Hoang Van Lech	45	Male	Illiteracy	Thai	Tea, rice, livestock raising
4	Hoang Thi Pon	37	Female	Illiteracy	Thai	Tea, Maize, pig,
5	Ha Xuan Lieng	56	Male	5/10: primary school	Thai	rice, tea, livestock raising
6	Ha Van Tinh	31	Male	12/12: high school	Thai	Maize, rice, tea, livestock raising
7	Lo Thi Hoai*	29	Female	12/12: high school	Thai	Rice, tea, livestock raising
8	Lo Van Tuc	38	Male	7/10: secondary school	Thai	Maize, rice, tea
9	Lo Van Truong	34	Male	7/10: secondary school	Thai	Maize, rice, tea, cattle
10	Ha Thi Huong	19	Female	9/12: secondary school	Thai	Rice, tea, cattle

*President of commune's women union

A.2. Proposals of topics and procedures in each FGD

Topic 1. Problem tree

Step 1. Facilitating participants to talk about "What are the main factors that generally/overall limit a good harvest of crops in this village? Each participant writes their answers (3-5) in note papers and then stick on the A0 paper.

Step 2. When the list is completed, answers are clustered according to their causal factors (weather, pests or market access) basing on discussion and consensus with participants.

Step 3. Ask participants to voice out three groups of factor that are the most difficult for agricultural production. Notes will be taken for those having dominant crop or large/small land size.

Topic 2. Village history and hazard timeline

Step 1. This section is started by drawing a table on A0 paper. At the top line, indicating a timeline, beginning from when the village established or 20-30 years to present. The 2nd and 3rd lines are rooms to mark the main natural hazards and their relative impacts to livelihood activities.

Step 2. Researcher and assistant facilitate participants to discuss on the topic and identify area of high exposure to natural hazards into lines 1, 2, 3 above; notes are carefully taken on scale/level of severe impacts due to exposure to past events. This result is critical in order to discuss about EWEs.

Topic 3. Crop calendar and/or cropping systems

Drawing a calendar of a year (months of a year) and discuss with participants to obtain information on types of crop/cropping system and their relative timeframe in the local. This result could be used for topic 4 and 5.

Topic 4. List of exposures to EWEs

Step 1. Basing on the previous discussion, some of exposures to EWEs could be generated. The researcher may clarify some points related to exposures and ask farmers to provide more details if they are confused about the events. Focus should be placed on EWEs rather than their impacts. After that participants are facilitated to produce a list of possible EWEs together with information related to when and where such events occurred, in which months and what crops impacted. EWEs could be added or dropped accordingly to flow of discussion.

Step 2. When the list of exposures and time of occurrence is completed, ask for the local definition (name) of each exposure to find out any difference.

Step 3. Ask participants to vote in order to select the top 3 or 4 EWEs that are the most important to the village. Each participant is given 3-5 beans (maize seed or candy are possible alternatives) and then are placed on a square named EWE. After that, bean in each square are calculated to find out the most important EWEs.

Topic 5. Ranking suitable trees and crops

Step 1. Drawing a table on A0 paper, along the left-hand column, list all the crops/ cropping systems (e.g—Shan tea, paddy rice) as discussed in Tool 3; along the top row of the table, list all the names of EWEs have been identified in Tool 4.

Step 2. Discuss with participant about the suitability of crops/ crop systems with EWEs by weighting point, starting from 1 (unsuitable) to 5 (very suitable) as shown in the sample below. Suitability is defined as how suitable is this tree/crop during an EWE and level of affected in terms of yield, grain, growth or quality.

Topic 6. Pair-wise ranking the importance of livelihood activities to household's income

Step 1. Facilitating participants to list of main existing income generating activities in the village.

Step 2. Once the list completed, preparing a pair-wise comparison matrix for two criteria: importance of livelihood activity for (i) level of income and (ii) stability of income. Each of livelihood activity in an upper hierarchical level of is used to compare with each of the other activities in the lower level of hierarchy with respect to criterion.

Table A.1. A pair-wise comparison matrix of importance of livelihood to HH income

livelihood activities	Rice production	Maize production	Shan tea	Cattle husbandry	Other livestock	Off-farm	Other
Rice production		1/3	3/1	1/1	5/1	…	…
Maize production			1/3	…	…	…	…
Shan tea				5/1	…	…	…
Cattle husbandry					…	…	…
Other livestock						…	…
Off-farm jobs							…
Other							

Score for comparison: 1- equal importance 3- stronger importance
5- extremely importance 2, 4 – values for intermediate.

Step 3. Facilitating farmers to discuss and to reach a consensus for weighting. Results are filled in the matrix for analysis. These matrixes are then completed, normalized and consistency checked through procedures presented in Section 3.3.1.1, Chapter III.

Within a FGD, other topics (e.g. crop calendar) are also employed to understand the environment in which farmers practice tea in relation to other enterprises in farming systems.

APPENDIX B. PROCESSING AND OUTPUT OF FOCUS GROUP DISCUSSION

B.1. Main problems faced by tea farmers

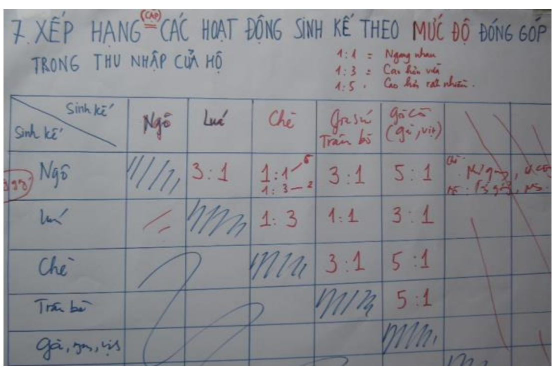
Problem /difficulty	Bu Cao Village – Suoi Bu Commune	Nam Cuom Village – Nam Bung Commune	Tay Son Village - Tien Nguyen Commune	Group 12, Viet Lam Town
Land resources	Lacking of good land for rice & maize production	N/A	Overexploitation of forest, water shortage for paddy rice.	N/A
Pest and disease	aphis on maize, more pests on rice.	More frequent in rice & tea.	More frequent in tea & rice	More pest (termite) & new fungi disease in tea, rice.
Weather extremes	hot spells, landslides, & soil erosions.	Hot spell, cold spell, drought, & hail.	Droughts, landslides, and floods	Frost, hail, droughts
Technical issue	Yielding improvement for tea, pest treatment, etc.	Improper use of pesticides & other inputs.	Low tea yielding.	Tea plantations getting old and degraded. Nutrient deficiency.
Infrastructure	Bad road conditions.	N/A	N/A	N/A
Input & output market	High price of seed & fertilizer for maize; unstable price for maize.	Unstable market for corn, cassava & tea. Fake fertilizer	Low tea price, lacking of fertilizer for rice production.	Low & unstable price for tea & maize, fake fertilizer

Source: Own elaborations from FGDs.

B.2. AHP procedure and output of FGD in Bu Cao Village, Suoi Bu Comm., Yen Bai Province

1. Importance of livelihood to HH income level

Step 1: Completion of pair-wise comparison matrix



Livelihood	Maize	Rice	Tea	Buffalo	Poultry
Maize	1.00	3.00*	1.00	3.00	5.00
Rice	0.33	1.00	0.33	1.00	3.00
Tea	1.00	3.00	1.00	3.00	5.00
Buffalo	0.33	1.00	0.33	1.00	5.00
Poultry	0.20	0.33	0.20	0.20	1.00
SUM	2.87	8.33	2.87	8.20	19.00

* Note: This cell presents pair-wise comparison result between maize (column livelihood) and rice (row livelihood) as 3:1, meaning that maize has stronger importance in terms of level to HH income than that of rice. 3.00 equals 3 dividing by 1.

Step 2: Normalization *Step 3: Consistency check*

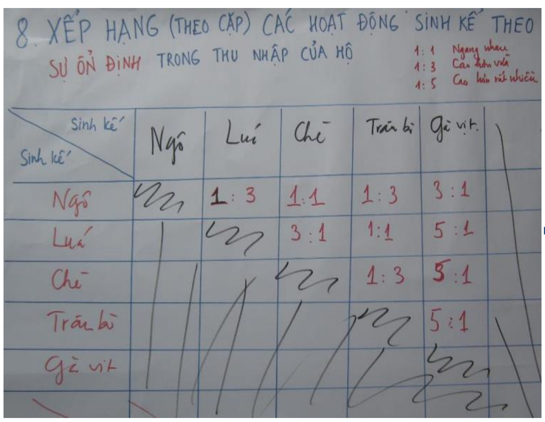
Livelihood	Maize	Rice	Tea	Buffalo	Poultry	Total normalized score	Average score	Consist. measure	Ranking
Maize	0.35	0.36*	0.35	0.37	0.26	1.69	0.34	5.20	1
Rice	0.12	0.12	0.12	0.12	0.16	0.63	0.13	5.16	2
Tea	0.35	0.36	0.35	0.37	0.26	1.69	0.34	5.20	1
Buffalo	0.12	0.12	0.12	0.12	0.26	0.74	0.15	5.12	3
Poultry	0.07	0.04	0.07	0.02	0.05	0.26	0.05	5.03	4
SUM	1.00	1.00	1.00	1.00	1.00		CI=	0.04	
							RI (n=5):	1.12	
							CR=	0.03	

*Normalized score of this cell equals to 3.00 divided by 8.33 (SUM of its column)

CI= Consistency Index; RI= Random Index; CR=Consistency Ratio (CR = 0.1 or below is acceptable).

2. Importance of livelihood to HH income stability

Step 1: Completion of pair-wise comparison matrix



Livelihood	Maize	Rice	Tea	Buffalo	Poultry
Maize	1.00	0.33	1.00	0.33	3.00
Rice	3.00	1.00	3.00	1.00	5.00
Tea	1.00	0.33	1.00	0.33	5.00
Buffalo	3.00	1.00	3.00	1.00	5.00
Poultry	0.33	0.20	0.20	0.20	1.00
SUM	8.33	2.87	8.20	2.87	19.00

Step 2: Normalization *Step 3: Consistency check*

Livelihood	Maize	Rice	Tea	Buffalo	Poultry	Total normalized score	Average score	Consist. measure	Ranking
Maize	0.12	0.12	0.12	0.12	0.16	0.63	0.13	5.16	3
Rice	0.36	0.35	0.37	0.35	0.26	1.69	0.34	5.20	1
Tea	0.12	0.12	0.12	0.12	0.26	0.74	0.15	5.12	2
Buffalo	0.36	0.35	0.37	0.35	0.26	1.69	0.34	5.20	1
Poultry	0.04	0.07	0.02	0.07	0.05	0.26	0.05	5.03	4
SUM	1.00	1.00	1.00	1.00	1.00		CI=	0.04	
							RI (n=5):	1.12	
							CR=	0.03	

Source: Own elaborations from AHP analysis of FGD data.

B.3. AHP procedure and output of FGD in Nam Cuom Village, Nam Bung Comm., Yen Bai

1. Importance of livelihood to HH income level

Step 1: Completion of pair-wise comparison matrix

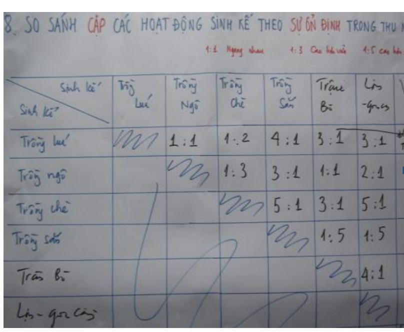
Liveli-hood	Rice	Maize	Tea	Cass-ava	Large ruminant	Pig & poultry
Rice	1.00	3.00	0.20	5.00	1.00	3.00
Maize	0.33	1.00	0.20	5.00	0.33	0.50
Tea	5.00	5.00	1.00	5.00	3.00	4.00
Cassava	0.20	0.20	0.20	1.00	0.20	0.20
Large ruminant	1.00	3.00	0.33	5.00	1.00	4.00
Pig & poultry	0.33	2.00	0.25	5.00	0.25	1.00
SUM	7.87	14.20	2.18	26.00	5.78	12.70

Step 2: Normalization *Step 3: Consistency check*

Liveli-hood	Rice	Maize	Tea	Cass-ava	Large ruminant	Pig & poultry	Total norm-alized score	Avg. score	Consist. measure	Ran-king
Rice	0.13	0.21	0.09	0.19	0.17	0.24	1.03	0.17	6.90	3
Maize	0.04	0.07	0.09	0.19	0.06	0.04	0.49	0.08	6.34	5
Tea	0.64	0.35	0.46	0.19	0.52	0.31	2.47	0.41	6.94	1
Cassava	0.03	0.01	0.09	0.04	0.03	0.02	0.22	0.04	6.26	6
Large ruminant	0.13	0.21	0.15	0.19	0.17	0.31	1.17	0.20	6.88	2
Pig & poultry	0.04	0.14	0.11	0.19	0.04	0.08	0.61	0.10	6.46	4
SUM	1.00	1.00	1.00	1.00	1.00	1.00	CI=		0.13	
							RI (n=6):		1.24	
							CR=		0.10	

b) Importance of livelihood to HH income stability

Step 1: Completion of pair-wise comparison matrix



Livelihood	Rice	Maize	Tea	Cass-ava	Large ruminant	Pig & poultry
Rice	1.00	1.00	0.50	4.00	3.00	3.00
Maize	1.00	1.00	0.33	3.00	1.00	2.00
Tea	2.00	3.00	1.00	5.00	3.00	5.00
Cassava	0.25	0.33	0.20	1.00	0.20	0.20
Large ruminant	0.33	1.00	0.33	5.00	1.00	4.00
Pig & poultry	0.33	0.50	0.20	5.00	0.25	1.00
SUM	4.92	6.83	2.57	23.00	8.45	15.20

Step 2: Normalization *Step 3: Consistency check*

Livelihood	Rice	Maize	Tea	Cass-ava	Large ruminant	Pig & poultry	Total norma-lized score	Average score	Consist. measure	Ran-king
Rice	0.20	0.15	0.19	0.17	0.36	0.20	1.27	0.21	6.81	2
Maize	0.20	0.15	0.13	0.13	0.12	0.13	0.86	0.14	6.54	4
Tea	0.41	0.44	0.39	0.22	0.36	0.33	2.14	0.36	6.57	1

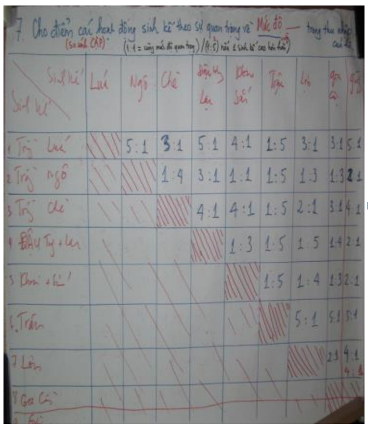
Cassava	0.05	0.05	0.08	0.04	0.02	0.01	0.26	0.04	6.14	6
Large ruminant	0.07	0.15	0.13	0.22	0.12	0.26	0.94	0.16	6.74	3
Pig & poultry	0.07	0.07	0.08	0.22	0.03	0.07	0.53	0.09	6.28	5
SUM	1.00	1.00	1.00	1.00	1.00	1.00		CI=	0.10	
								RI (n=6):	1.24	
								CR=	0.08	

Source: Own elaborations from AHP analysis of FGD data.

B4. AHP procedure and output of FGD in Son Tay Village, Tien Nguyen Comm., Ha Giang

1. Importance of livelihood to HH income level

Step 1: Completion of pair-wise comparison matrix



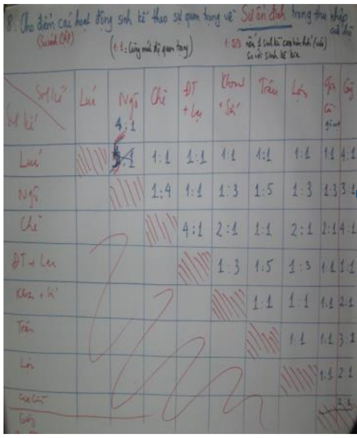
Liveli-hood	Rice	Maize	Tea	Soy-bean	Cas-sava	Buff-alo	Pig	Pou-ltry	Gin-ger
Rice	1.00	5.00	3.00	5.00	4.00	0.20	3.00	3.00	5.00
Maize	0.20	1.00	0.25	3.00	1.00	0.20	0.33	0.33	2.00
Tea	0.33	4.00	1.00	4.00	4.00	0.20	2.00	3.00	4.00
Soybean	0.20	0.33	0.25	1.00	0.33	0.20	0.20	0.25	2.00
Cassava	0.25	1.00	0.25	3.00	1.00	0.20	0.25	0.33	2.00
Buffalo	5.00	5.00	5.00	5.00	5.00	1.00	5.00	5.00	5.00
Pig	0.33	3.00	0.50	5.00	4.00	0.20	1.00	2.00	4.00
Poultry	0.33	3.00	0.33	4.00	3.00	0.20	0.50	1.00	4.00
Ginger	0.20	0.50	0.25	0.50	0.50	0.20	0.25	0.25	1.00
SUM	7.85	22.83	10.83	30.50	22.83	2.60	12.53	15.17	29.00

Step 2: Normalization *Step 3: Consistency check*

Liveli-hood	Rice	Maize	Tea	Soy-bean	Cass-ava	Buff-alo	Pig	Pou-ltry	Gin-ger	Tot. score	Avg. score	Consist. measure	Ran-king
Rice	0.13	0.22	0.28	0.16	0.18	0.08	0.24	0.20	0.17	1.65	0.18	10.75	2
Maize	0.03	0.04	0.02	0.10	0.04	0.08	0.03	0.02	0.07	0.43	0.05	9.45	6
Tea	0.04	0.18	0.09	0.13	0.18	0.08	0.16	0.20	0.14	1.19	0.13	10.33	3
Soybean	0.03	0.01	0.02	0.03	0.01	0.08	0.02	0.02	0.07	0.29	0.03	9.37	8
Cassava	0.03	0.04	0.02	0.10	0.04	0.08	0.02	0.02	0.07	0.43	0.05	9.45	7
Buffalo	0.64	0.22	0.46	0.16	0.22	0.38	0.40	0.33	0.17	2.99	0.33	11.07	1
Pig	0.04	0.13	0.05	0.16	0.18	0.08	0.08	0.13	0.14	0.99	0.11	9.92	4
Poultry	0.04	0.13	0.03	0.13	0.13	0.08	0.04	0.07	0.14	0.79	0.09	9.62	5
Ginger	0.03	0.02	0.02	0.02	0.02	0.08	0.02	0.02	0.03	0.26	0.03	9.73	9
SUM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	CI=		0.12	
										RI (n=9):		1.46	
										CR=		0.08	

2. Importance of livelihood to HH income stability

Step 1: Completion of pair-wise comparison matrix



Liveli-hood	Rice	Maize	Tea	Soy-bean	Cass-ava	Buff-alo	Pig	Pou-ltry	Gin-ger
Rice	1.00	4.00	1.00	1.00	1.00	1.00	1.00	1.00	4.00
Maize	0.25	1.00	0.25	1.00	0.33	0.20	0.33	0.33	3.00
Tea	1.00	4.00	1.00	4.00	2.00	1.00	2.00	2.00	4.00
Soybean	1.00	1.00	0.25	1.00	0.33	0.20	0.33	1.00	1.00
Cassava	1.00	3.00	0.50	3.00	1.00	1.00	1.00	1.00	2.00
Buffalo	1.00	5.00	1.00	5.00	1.00	1.00	1.00	1.00	3.00
Pig	1.00	3.00	0.50	3.00	1.00	1.00	1.00	1.00	2.00
Poultry	1.00	3.00	0.50	1.00	1.00	1.00	1.00	1.00	2.00
Ginger	0.25	0.33	0.25	1.00	0.50	0.33	0.50	0.50	1.00
SUM	7.50	24.33	5.25	20.00	8.17	6.73	8.17	8.83	22.00

Step 2: Normalization *Step 3: Consistency check*

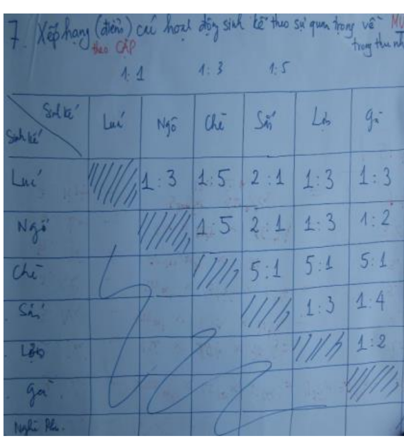
Liveli-hood	Rice	Maize	Tea	Soy-bean	Cass-ava	Buff-alo	Pig	Pou-ltry	Gin-ger	Tot. score	Avg. score	Consist. measure	Rank-ing
Rice	0.13	0.16	0.19	0.05	0.12	0.15	0.12	0.11	0.18	1.23	0.14	9.48	3
Maize	0.03	0.04	0.05	0.05	0.04	0.03	0.04	0.04	0.14	0.46	0.05	9.50	7
Tea	0.13	0.16	0.19	0.20	0.24	0.15	0.24	0.23	0.18	1.73	0.19	9.48	1
Soybean	0.13	0.04	0.05	0.05	0.04	0.03	0.04	0.11	0.05	0.54	0.06	9.40	6
Cassava	0.13	0.12	0.10	0.15	0.12	0.15	0.12	0.11	0.09	1.10	0.12	9.60	4
Buffalo	0.13	0.21	0.19	0.25	0.12	0.15	0.12	0.11	0.14	1.42	0.16	9.73	2
Pig	0.13	0.12	0.10	0.15	0.12	0.15	0.12	0.11	0.09	1.10	0.12	9.60	4
Poultry	0.13	0.12	0.10	0.05	0.12	0.15	0.12	0.11	0.09	1.00	0.11	9.47	5
Ginger	0.03	0.01	0.05	0.05	0.06	0.05	0.06	0.06	0.05	0.42	0.05	9.38	8
SUM	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	CI=		0.06	
										RI (n=9)		1.46	
										CR=		0.04	

Source: Own elaborations from AHP analysis of FGD data.

B.5. AHP procedure and output of FGD in Group 12, Viet Lam Town, Ha Giang

1. Importance of livelihood to HH income level

Step 1: Completion of pair-wise comparison matrix



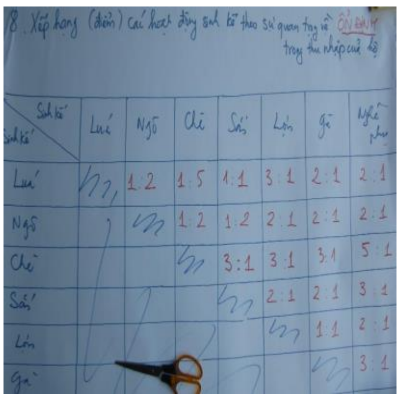
Liveli-hood	Rice	Maize	Tea	Cas-sava	Pig	Chic-ken	Off-farm
Rice	1.00	0.33	0.20	2.00	0.33	0.33	0.20
Maize	3.00	1.00	0.20	2.00	0.33	0.50	0.33
Tea	5.00	5.00	1.00	5.00	5.00	5.00	5.00
Cassava	0.50	0.50	0.20	1.00	0.33	0.25	0.20
Pig	3.00	3.00	0.20	3.00	1.00	0.50	1.00
Chicken	3.00	2.00	0.20	4.00	2.00	1.00	0.50
Off-farm	5.00	3.00	0.20	5.00	1.00	2.00	1.00
SUM	20.50	14.83	2.20	22.00	10.00	9.58	8.23

Step 2: Normalization *Step 3: Consistency check*

Livelihood	Rice	Maize	Tea	Cass-ava	Pig	Chic-ken	Off-farm	Tot norma-lized score	Avg. score	Consist. measure	Rank-ing
Rice	0.05	0.02	0.09	0.09	0.03	0.03	0.02	0.35	0.05	7.19	6
Maize	0.15	0.07	0.09	0.09	0.03	0.05	0.04	0.52	0.07	7.35	5
Tea	0.24	0.34	0.45	0.23	0.50	0.52	0.61	2.89	0.41	8.10	1
Cassava	0.02	0.03	0.09	0.05	0.03	0.03	0.02	0.28	0.04	7.34	7
Pig	0.15	0.20	0.09	0.14	0.10	0.05	0.12	0.85	0.12	7.67	4
Chicken	0.15	0.13	0.09	0.18	0.20	0.10	0.06	0.92	0.13	7.60	3
Off-farm	0.24	0.20	0.09	0.23	0.10	0.21	0.12	1.19	0.17	7.65	2
SUM	1.00	1.00	1.00	1.00	1.00	1.00	1.00		CI=	0.09	
									RI (n=7):	1.32	
									CR=	0.07	

2. Importance of livelihood to HH income stability

Step 1: Completion of pair-wise comparison matrix



Liveli-hood	Rice	Maize	Tea	Cass-ava	Pig	Chic-ken	Off-farm
Rice	1.00	0.50	0.20	1.00	3.00	2.00	2.00
Maize	2.00	1.00	0.50	0.50	2.00	2.00	2.00
Tea	5.00	2.00	1.00	3.00	3.00	3.00	5.00
Cassava	1.00	2.00	0.33	1.00	2.00	2.00	3.00
Pig	0.33	0.50	0.33	0.50	1.00	1.00	2.00
Chicken	0.50	0.50	0.33	0.50	1.00	1.00	3.00
Off-farm	0.50	0.50	0.20	0.33	0.50	0.33	1.00
SUM	10.33	7.00	2.90	6.83	12.50	11.33	18.00

Step 2: Normalization *Step 3: Consistency check*

Liveli-hood	Rice	Maize	Tea	Cass-ava	Pig	Chic-ken	Off-farm	Tot. norma-lized score	Avg. score	Consist. measure	Rank-ing
Rice	0.10	0.07	0.07	0.15	0.24	0.18	0.11	0.91	0.13	7.42	4
Maize	0.19	0.14	0.17	0.07	0.16	0.18	0.11	1.03	0.15	7.52	3
Tea	0.48	0.29	0.34	0.44	0.24	0.26	0.28	2.34	0.33	7.64	1
Cassava	0.10	0.29	0.11	0.15	0.16	0.18	0.17	1.15	0.16	7.33	2
Pig	0.03	0.07	0.11	0.07	0.08	0.09	0.11	0.57	0.08	7.20	6
Chicken	0.05	0.07	0.11	0.07	0.08	0.09	0.17	0.64	0.09	7.19	5
Off-farm	0.05	0.07	0.07	0.05	0.04	0.03	0.06	0.36	0.05	7.40	7
SUM	1.00	1.00	1.00	1.00	1.00	1.00	1.00		CI=	0.06	
									RI (n=7):	1.32	
									CR=	0.05	

Source: Own elaborations from AHP analysis of FGD data.

APPENDIX C. STATA DOFILEs

C.1. STATA dofile for descriptive statistics using VARHS & climate panel data

```
***Appending data
use "D:\a PhD\Data analysis\Adapt\VARHS dang lam\2010_tea_cat_inc_subinstr_for_append.dta", clear
describe
append using "D:\a PhD\Data analysis\Adapt\VARHS dang lam\2012_tea_cat_inc_subinstr_for_append.dta"
append using "D:\a PhD\Data analysis\Adapt\VARHS dang lam\2014_tea_cat_inc_subinstr_2_for_append.dta"
save "D:\a PhD\Data analysis\Adapt\VARHS dang lam\all_tea_cat_inc_subinstr_appended.dta", replace

***Merging with climate data
** Load and check VARHS data before merging
use "D:\a PhD\Data analysis\Adapt\VARHS dang lam\all_tea_cat_inc_subinstr_appended.dta", clear
replace xa_new = subinstr(xa_new, "Ban Xen", "Ban Sen",.) /*Some other corrections made */
**Load and check climate data before merging
use "D:\a PhD\Data analysis\Adapt\Climate\allclimdata_subinstr_for_merge.dta", clear
* Replacing some vars still misnamed
replace xa_new = subinstr(xa_new, "Noong Luong", "Noong Het",.)
sort tinh_new xa_new
save "D:\a PhD\Data analysis\Adapt\Climate\allclimdata_subinstr_for_merge_2.dta", replace
*Merging tea_cat_inc with allclimate:
use "D:\a PhD\Data analysis\Adapt\VARHS dang
lam\all_tea_cat_inc_subinstr_appended_for_merge.dta", clear
sort t tinh_new xa_new
merge m:1 tinh_new xa_new using "D:\a PhD\Data
analysis\Adapt\Climate\allclimdata_subinstr_for_merge_2.dta"
drop if _merge<3
sort t tinh quan xa ma_h0 hhid tinh_new xa_new
drop _merge
save "D:\a PhD\Data analysis\Adapt\VARHS dang lam\all_tea_cat_inc_allclimate_merged.dta", replace

** Merging with hh foodexp and cropland (revised 27/12/2016)
use "D:\a PhD\Data analysis\Adapt\VARHS dang lam\all_tea_cat_inc_allclimate_merged.dta", clear
drop tea_cat2
la var t "year"
la var tinh "Province"
la var quan "District"
la var xa "Commune"
la var ma_h0 "Household code"
sort t tinh quan xa ma_h0 hhid tinh_new xa_new
merge 1:1 t hhid using "D:\a PhD\Data analysis\Adapt\VARHS dang
lam\all_foodexp_cropland_appended_for_merge.dta"
*Testing to see tea hh: keep if tea_cat3_D==1 /* OKKK problem fixed */
drop if _merge<3 /* 190 observations deleted*/
drop _merge
bys hhid: gen p35q10pc=p35q10/hhsize
bys hhid: gen hhp16q2_pha=hhp16q2_/hhcropland
bys hhid: gen hhp16q5a_2_pha=hhp16q5a_2/hhcropland
sort t tinh quan xa ma_h0 hhid tinh_new xa_new
la var p35q10pc "Per capita net income TOTAL (000VND)"
la var hhp16q2_pha "Per ha total value of output produced (000VND) by household"
la var hhp16q5a_2_pha "Per ha total amount received from sales (000VND) by household"
** Creating rainfall, average tmax, tav, tmin for descstats:
```

```
* Rainfall of current year t
gen rtot_t=rtot_10_level if t==2010
replace rtot_t=rtot_12_level if t==2012
la def rtot_t 1"High" 0"Low"
la val rtot_t rtot_t
la var rtot_t "Rainfall of current year"
*Average dekadal tmax of current year t
gen avg_tmax_t=avg_tmax_10_level if t==2010
replace avg_tmax_t=avg_tmax_12_level if t==2012
la def avg_tmax_t 1"High" 0"Low"
la val avg_tmax_t avg_tmax_t
la var avg_tmax_t "Mean of dekadal maximun temperature of current year"
save "D:\a PhD\Data analysis\Adapt\VARHS dang
lam\all_tea_cat_inc_allclimate_fodexp_cropland_merged.dta", replace
```

******Descriptive statistics:**

```
*** Load data
use "D:\a PhD\Data analysis\Adapt\VARHS dang
lam\all_tea_cat_inc_allclimate_fodexp_cropland_merged.dta", clear

***RAINFALL -Part I
**Rain variability & per capita total income:
table t r_vari, c(n p35q10pc mean p35q10pc sd p35q10pc) format(%10.0fc) sc row cellwidth (12)
ttest p35q10pc, by(r_vari) unequal /* 0.01 */
ttest p35q10pc if t==2010, by(r_vari) unequal /* NS */
ttest p35q10pc if t==2012, by(r_vari) unequal /* NS */
ttest p35q10pc if t==2014, by(r_vari) unequal /* 0.01*/
table t tea_cat3_D r_vari, c(n p35q10pc mean p35q10pc sd p35q10pc) format(%10.0fc) sc row cellwidth (12)
ttest p35q10pc, by(tea_cat3_D) unequal  /* 0.01 */
ttest p35q10pc if t==2010, by(tea_cat3_D) unequal /* 0.01 */
ttest p35q10pc if t==2012, by(tea_cat3_D) unequal /* NS*/
ttest p35q10pc if t==2014, by(tea_cat3_D) unequal /* 0.1*/
ttest p35q10pc if r_vari==1, by(tea_cat3_D) unequal /* 0.01 */
ttest p35q10pc if r_vari==1 & t==2010, by(tea_cat3_D) unequal /* 0.01 */
ttest p35q10pc if r_vari==1 & t==2012, by(tea_cat3_D) unequal /* NS */
ttest p35q10pc if r_vari==1 & t==2014, by(tea_cat3_D) unequal /* 0.05*/
ttest p35q10pc if r_vari==0, by(tea_cat3_D) unequal  /* 0.05*/
ttest p35q10pc if r_vari==0 & t==2010, by(tea_cat3_D) unequal /* 0.01*/
ttest p35q10pc if r_vari==0 & t==2012, by(tea_cat3_D) unequal /* NS*/
ttest p35q10pc if r_vari==0 & t==2014, by(tea_cat3_D) unequal /* NS*/

**Rain variability and per ha value produced (similar to the above commands)
**Rain variability and per ha amount received from sale (similar to the above commands)
**Rain variability and per capita food expenditure (similar to the above commands)

**TMAX -Part II
* Variability in mean of dekadal Tmax & per capital total income:
table t tmax_vari, c(n p35q10pc mean p35q10pc sd p35q10pc) format(%10.0fc) row cellwidth (12)
ttest p35q10pc, by(tmax_vari) unequal /* NS */
ttest p35q10pc if t==2010, by(tmax_vari) unequal /* NS */
ttest p35q10pc if t==2012, by(tmax_vari) unequal /* 0.01 */
ttest p35q10pc if t==2014, by(tmax_vari) unequal /* NS */
table t tea_cat3_D tmax_vari, c(n p35q10pc mean p35q10pc sd p35q10pc) format(%10.0fc) row cellwidth (12)
```

```
ttest p35q10pc if tmax_vari==1, by(tea_cat3_D) unequal /* 0.1*/
ttest p35q10pc if tmax_vari==0, by(tea_cat3_D) unequal  /* 0.01*/
ttest p35q10pc if tmax_vari==1&t==2010, by(tea_cat3_D) unequal /* 0.1*/
ttest p35q10pc if tmax_vari==1&t==2012, by(tea_cat3_D) unequal /* NS */
ttest p35q10pc if tmax_vari==1&t==2014, by(tea_cat3_D) unequal /* NS */
ttest p35q10pc if tmax_vari==0&t==2010, by(tea_cat3_D) unequal /* 0.01*/
ttest p35q10pc if tmax_vari==0&t==2012, by(tea_cat3_D) unequal /* NS*/
ttest p35q10pc if tmax_vari==0&t==2014, by(tea_cat3_D) unequal /* 0.05*/
```

Similar t-tests were conducted to the followings:
* Variability in mean of dekadal Tmax & per ha total value produced:
* Variability in mean of dekadal Tmax & per ha total amount from sale:
* Tmax of current year & per capita total income:
* Tmax of current year & per ha value produced:
* Tmax of current year & per ha amount received from sales:
* Variability in mean of dekadal Tmax & per capita food expenditure:
* Variability in mean of dekadal Tmax & per capita food expenditure quintile:

**TAV- Part III and Tmin –Part IV are similar.

C.2. STATA commands used to generate coefficients for coffee and livestock

C.2.1. Cost and benefit for coffee

```
**Cofee: use "D:\a PhD\Fieldwork\CBA\data & do files\coffee_forcba.dta", clear
preserve
use"D:\a PhD\Fieldwork\CBA\OUT\SEC2_2.dta", clear
keep if swtype==1 & st00a==2
g MTERR_constcost_lab=st02*st03
g MTERR_constcost_mat=st04
g MTERR_maintcost_lab=st06
g MTERR_maintcost_mat=st05
collapse (sum) MTERR_constcost_lab MTERR_constcost_mat MTERR_maintcost_lab
MTERR_maintcost_mat, by(hhid)
recode MTERR_constcost_lab MTERR_constcost_mat MTERR_maintcost_lab MTERR_maintcost_mat (0=.)
sort hhid
tempfile MTERRcosts
save `MTERRcosts', replace
restore
preserve
keep if maincrop==33
sort hhid
merge m:m hhid using `MTERRcosts'
tab _m
drop if _m==2
drop _m
egen MTERR_constcost=rsum(MTERR_constcost_lab MTERR_constcost_mat)
egen MTERR_maintcost=rsum(MTERR_maintcost_lab MTERR_maintcost_mat)
for var MTERR_constcost MTERR_maintcost: replace X=. if MTERR==0
for var MTERR_constcost MTERR_maintcost: g X_pha=X/tot_area_a
foreach var of varlist MTERR_constcost_pha MTERR_maintcost_pha {
        recode `var' (0=.)
        su `var', d
        g `var'_med=r(p50)}
g dloc=local_varD
```

```
g dnonloc=(impnonhyb_varD==1 | hybrid_varD==1)
rename pureCONVcoffee_D pureCONV
for var INTERC LEGINT MTERR pureCONV: g X_low=(X==1 & dloc==1)
for var INTERC LEGINT MTERR pureCONV: g X_hig=(X==1 & dnonloc==1)
su orgfertprice_pkgtrim, d
g orgfertprice_pkgtrim_median=r(p50)
su orgfertprice_pkgtrim, d
g orgfertprice_pkgtrim_mean=r(mean)
su costseed_maincrop_phatrim, d
g costseed_median=r(p50)
su costseed_maincrop_phatrim, d
g costseed_mean=r(mean)

local varcoffee yield_pha costseed_mean npk_kg_phatrim kcl_kg_phatrim urea_kg_phatrim
orgfertq_phatrim ///npk_price_pkgtrim kcl_price_pkgtrim urea_price_pkgtrim orgfertprice_pkgtrim_mean
///costchemical_phatrim costlime_phatrim ///f_nday_lanpr_phatrim f_nday_sowpl_phatrim
f_nday_weedi_phatrim f_nday_ferta_phatrim f_nday_pestc_phatrim ///f_nday_othcm_phatrim
f_nday_harve_phatrim f_nday_irrig_phatrim h_nday_lanpr h_nday_sowpl h_nday_weedi h_nday_ferta ///
h_nday_pestc h_nday_othcm h_nday_harve h_nday_irrig hani_cost_lanpr_phatrim
hmec_cost_lanpr_phatrim hmec_cost_othcm_phatrim ///hmec_cost_harve_phatrim
hmec_cost_irrig_phatrim MTERR_constcost_pha MTERR_maintcost_pha

quietly {
tabstat `varcoffee' if MTERR==1, s(count mean median) c(s) save
matrix T4=r(StatTotal)'
tabstat `varcoffee' if pureCONV==1, s(count mean median) c(s) save
matrix T5=r(StatTotal)'
mat def COFFEE3=T4, T5
putexcel A1=matrix(COFFEE3, names) using "D:\a
PhD\Fieldwork\CBA\TABLES\coffee_MTERR&CONV4.xlsx", replace
}
restore
exit
```

C.2.1. Cost and benefit for cattle, buffalo and pigs

```
***Revision*****************
use "D:\a PhD\Fieldwork\CBA\Tuong\SEC4_1and4_2_2.dta", clear
tabstat r03 r04 r05a r05b r06 r07a r07b r07c r08, by(raise) stat (n mean cv p50) nototal col(stat) long
tabstat lsma1 lsma2 lsma3 feed1 feed2 feed3 feed4 main1 main2 main3 main4, by(lstype) stat (n mean cv
p50) nototal col(stat) long

****Dynamics of livestock
use "D:\a PhD\Fieldwork\CBA\out\SEC4_1.dta", clear
table raise, c(mean r06) f(%9.2f)
table raise, c(mean r03 mean r04 mean r05a mean r05b mean r06) f(%9.2f)
g cowcalves_owned=(r01) if raise==1
g cows_owned=(r01) if raise==2
g bulls_owned=(r01) if raise==3
g buffalocalves_owned= (r01) if raise==4
g buffalo_owned=(r01) if raise==5
g chickens_owned=(r01) if raise==6
g pigs_owned=(r01) if raise==7
```

```
collapse (min) cowcalves_owned- pigs_owned, by(hhid)
isid hhid
recode _all (.=0)
foreach var in bulls buffalo cows cowcalves buffalocalves pigs chickens {
	la var `var'_owned "# of `var' owned in head unit"}
egen CATTLE_total=sum(cowcalves_owned+bulls_owned), by (hhid)
la var CATTLE_total "# of cows, bull and calves owned"
egen BUFFALO_total=sum(buffalocalves_owned+buffalo_owned), by (hhid)
la var BUFFALO_total "# of buffalos and calves owned"
save "D:\a PhD\Fieldwork\CBA\Tuong\SEC4_1_dynamic.dta", replace

**Ls dynamics **
use "D:\a PhD\Fieldwork\CBA\Tuong\SEC4_1_dynamic.dta", clear
preserve
sort hhid
local varlivestock cowcalves_owned cows_owned bulls_owned buffalocalves_owned buffalo_owned
chickens_owned pigs_owned CATTLE_total BUFFALO_total quietly {
tabstat `varlivestock', s(count mean median) c(s) save
matrix T1=r(StatTotal)'
mat def LSDYNAMIC=T1
putexcel A1=matrix(LSDYNAMIC, names) using "D:\a PhD\Fieldwork\CBA\Tuong\ls_dynamic2.xlsx",
replace }
restore
preserve
sort hhid
recode _all (0=.)
local varlivestock cowcalves_owned cows_owned bulls_owned buffalocalves_owned buffalo_owned
chickens_owned pigs_owned CATTLE_total BUFFALO_total
quietly {
tabstat `varlivestock', s(count mean median) c(s) save
matrix T1=r(StatTotal)'
mat def LSDYNAMIC=T1
putexcel A1=matrix(LSDYNAMIC, names) using "D:\a PhD\Fieldwork\CBA\Tuong\ls_dynamic3.xlsx",
replace}
restore
***Cost and benefit per head of lstype: 17.5.2016
use "D:\a PhD\Fieldwork\CBA\Tuong\SEC4_1and4_2_2.dta", clear
bys hhid lstype: egen ls_total=sum(r01)
lab var ls_total "# of livestock by type at hh level"
* Option 1
foreach var of varlist r07a r07b r07c r08 {
	g `var'_phead = `var'/(r01)
	lab var `var'_phead "`var' per head" }
egen avg_value= rowtotal(r07a_phead-r07c_phead)
lab var avg_value "average value of livestock by head" /*ok for benefits*/
foreach i of varlist lsma1 lsma2 lsma3 feed1 feed2 feed3 feed4 main1 main2 main3 main4 {
	g `i'_phead = `i'/ls_total
	lab var `i'_phead "`i' per head"}
save "D:\a PhD\Fieldwork\CBA\Tuong\SEC4_CBA.dta", replace
exit					/*ok for CBA*/
*Option 2 on 31/5/2016 --> Test if change (0=.) make sense?
foreach var of varlist r07a r07b r07c r08 {
	recode `var' (0=.)
```

```
        g `var'_phead = `var'/(r01)
        lab var `var'_phead "`var' per head"}
egen avg_value= rowtotal(r07a_phead-r07c_phead)
lab var avg_value "average value of livestock by head"
foreach i of varlist lsma1 lsma2 lsma3 feed1 feed2 feed3 feed4 main1 main2 main3 main4 {
        recode `i' (0=.)
        g `i'_phead = `i'/ls_total
        lab var `i'_phead "`i' per head"}
save "D:\a PhD\Fieldwork\CBA\Tuong\SEC4_CBA2.dta", replace
exit

** Revised 30/5/2016
use "D:\a PhD\Fieldwork\CBA\Tuong\SEC4_CBA2.dta", clear
*CATTLE:
preserve
keep if lstype==1
sort hhid
duplicates report
duplicates drop hhid, force
local varcattle ls_total lsma1_phead lsma2_phead lsma3_phead feed1_phead feed2_phead feed3_phead ///
feed4_phead main1_phead main2_phead main3_phead main4_phead
quietly {
tabstat `varcattle', s(count mean median) c(s) save
matrix T1=r(StatTotal)'
mat def CATTLE=T1
putexcel A1=matrix(CATTLE, names) using "D:\a PhD\Fieldwork\CBA\Tuong\cattle_CBA2.xlsx",
replace }
restore /* OK, su dung: cattle_CBA2.xlsx*/

*BUFFALO & PIGS: (similar steps)
```

APPENDIX D. ADDITIONAL COMPARISONS OF INCOME & OTHER INDICATORS

D.1. Per capita net income, per ha total value of crop output, per capita food expenditure (000 VND) by rainfall variability

Descriptive statistics	Low rainfall vari (N=2,074)	High rainfall vari (N=1,428)
Per capita NI	16,234***	13,466
Per ha VCO	38,186***	34,292
Per capita Foodex	258.5***	217.1

Source: Own elaborations from VARHS data

D.2. Per capita net income, per ha total value of crop output, per capita food expenditure (000 VND) by variability of Tav

Descriptive statistics	Low variability of Tav (N=2,165)	High variability of Tav (N=1,337)
Per capita NI	15,534*	14,411
Per ha VCO	33,885	40,992***
Per capita Foodex	248.2**	231.0

Source: Own elaborations from VARHS data

D.3. Per hectare amount received from sales (000 VND) by rainfall variability and tea category household

Year	Descriptive statistics	Rainfall variability and category household			
		Low		High	
		Non-tea HH	Tea HH	Non-tea HH	Tea HH
2010	N	285	36	317	20
	Mean	21,917	58,735**	21,374	38,799*
2012	N	371	22	336	18
	Mean	18,525	28,350	30,921	40,346
2014	N	313	34	283	16
	Mean	27,176	44,449**	21,177	55,637**
Total	N	969	92	936	54
	Mean	22,317	46,190***	24,741	44,303***

Source: Own elaborations from VARHS data

D.4. Per hectare total amount received from sales by variability of Tmax and tea category

Year	Descriptive statistics	Variability of mean of Tmax and tea category household			
		Low		High	
		Non-tea HH	Tea HH	Non-tea HH	Tea HH
2010	N	302	44	300	12
	Mean	15,089	47,709***	28,217	65,936
2012	N	345	33	362	7
	Mean	25,599	34,651	23,289	29,491
2014	N	278	42	318	8
	Mean	26,226	51,228***	22,668	31,235
Total	N	925	119	980	27
	Mean	22,356	45,330***	24,596	46,205

Source: Own elaborations from AHP analysis of FGD data.

**** means in the same row and category are statistically significantly different at α=0.01*
*** means in the same row and category are statistically significantly different at α=0.05*
** means in the same row and category are statistically significantly different at α=0.1*

APPENDIX E. ENTERPRISE BUDGETS FOR CROPS

E.1. Input parameters and assumptions for maize and upland rice budgets

Parameters and assumptions	Unit	Conv. maize	MT maize	Upland rice	Source
Unit quantities					
NPK fertilizer	Kg/ha	527	515	381	Branca et al., 2017
Urea	Kg/ha	256	228	136	Branca et al., 2017
Land preparation	person-day/ha	33	28	77	Branca et al., 2017
Sowing	person-day/ha	35	30	68	Branca et al., 2017
Fertilizer application	person-day/ha	15	13	80	Branca et al., 2017
Pesticides application	person-day/ha	19	10	12	Branca et al., 2017
Weeding	person-day/ha	29	22	11	Branca et al., 2017
Harvesting	person-day/ha	48	42	106	Branca et al., 2017
Output	kg/ha	4767	4543	1246	Branca et al., 2017
Unit prices					
Output price, farm gate	000 VND/Kg	5.5	5.5	9.6	Branca et al., 2017
NPK fertilizer	000 VND/Kg	5.3	5.26	5.5	Branca et al., 2017
Urea	000 VND/Kg	11.3	11.419	11.9	Branca et al., 2017
Other input unit cost					
Seeds (lump sum)	000 VND/ha	1,762.9	1791.285	269.3	Branca et al., 2017
Pesticides (lump sum)	000 VND/ha	508.1	606.582	356.9	Branca et al., 2017
Manual labor	000 VND/ person day	100	100	100	MOLISA and GSO, 2014

E.2. Conventional maize enterprise budgets

Items	Unit	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6-30
Yield	Kg/ha	4,767	4,767	4,767	4,767	4,767	4,767
Plot size	ha	1	1	1	1	1	1
NPK fertilizer	Kg	527	527	527	527	527	527
Urea	Kg	256	256	256	256	256	256
Seeds (lump sum)	000 VND	1,763	1,763	1,763	1,763	1,763	1,763
Pesticides (lump sum)	000 VND	508	508	508	508	508	508
Land preparation	person-day	33	33	33	33	33	33
Sowing	person-day	35	35	35	35	35	35
Fertilizer application	person-day	15	15	15	15	15	15
Pesticides application	person-day	19	19	19	19	19	19
Weeding	person-day	29	29	29	29	29	29
Harvesting	person-day	48	48	48	48	48	48
Financial Budget							
Total production	000 VND	26,219	26,219	26,219	26,219	26,219	26,219
NPK fertilizer	000 VND	2,771	2,771	2,771	2,771	2,771	2,771
Urea	000 VND	2,886	2,886	2,886	2,886	2,886	2,886
Seeds (lump sum)	000 VND	1,763	1,763	1,763	1,763	1,763	1,763
Pesticides (lump sum)	000 VND	508	508	508	508	508	508
Family labour	000 VND	17,900	17,900	17,900	17,900	17,900	17,900
Gross margin	000 VND	18,290	18,290	18,290	18,290	18,290	18,290
	$	873	873	873	873	873	873
Net margin	000 VND	390	390	390	390	390	390
	$	19	19	19	19	19	19
Returns to family labour	000 VND/day	102	102	102	102	102	102
Benefit/Cost Ratio		1.02	1.02	1.02	1.02	1.02	1.02

E.3. Minimum tillage maize enterprise budgets

Items	Unit	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6-30
Yield	Kg/ha	4,543	4,543	4,543	4,543	4,543	4,543
Plot size	ha	1	1	1	1	1	1
NPK fertilizer	Kg	515	515	515	515	515	515
Urea	Kg	228	228	228	228	228	228
Seeds (lump sum)	VND	1,791	1,791	1,791	1,791	1,791	1,791
Pesticides (lump sum)	VND	607	607	607	607	607	607
Land preparation	person-day	28	28	28	28	28	28
Sowing	person-day	30	30	30	30	30	30
Fertilizer application	person-day	13	13	13	13	13	13
Pesticides application	person-day	10	10	10	10	10	10
Weeding	person-day	22	22	22	22	22	22
Harvesting	person-day	42	42	42	42	42	42
Financial Budget							
Total production	000 VND	24,987	24,987	24,987	24,987	24,987	24,987
NPK fertilizer	000 VND	2,709	2,709	2,709	2,709	2,709	2,709
Urea	000 VND	2,604	2,604	2,604	2,604	2,604	2,604
Seeds (lump sum)	000 VND	1,791	1,791	1,791	1,791	1,791	1,791
Pesticides (lump sum)	000 VND	607	607	607	607	607	607
Family labour	000 VND	14,500	14,500	14,500	14,500	14,500	14,500
Gross margin	000 VND	17,276	17,276	17,276	17,276	17,276	17,276
	$	825	825	825	825	825	825
Net margin	000 VND	2,776	2,776	2,776	2,776	2,776	2,776
	$	133	133	133	133	133	133
Returns to family labour	VND	119	119	119	119	119	119
Benefit/Cost Ratio		1.12	1.12	1.12	1.12	1.12	1.12

E.4. Conventional upland rice enterprise budgets

Items	Unit	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6-30
Yield	Kg/ha	1,246	1,246	1,246	1,246	1,246	1,246
Plot size	ha	1	1	1	1	1	1
NPK fertilizer	Kg	381	381	381	381	381	381
Urea	Kg	136	136	136	136	136	136
Seeds (lump sum)	000 VND	269	269	269	269	269	269
Pesticides (lump sum)	000 VND	357	357	357	357	357	357
Land preparation	person-day	77	77	77	77	77	77
sowing/planting	person-day	68	68	68	68	68	68
weeding	person-day	80	80	80	80	80	80
fertilizer application	person-day	12	12	12	12	12	12
pesticides application	person-day	11	11	11	11	11	11
harvesting	person-day	106	106	106	106	106	106
Financial Budget							
Total production	000 VND	11,962	11,962	11,962	11,962	11,962	11,962
NPK fertilizer	000 VND	2,100	2,100	2,100	2,100	2,100	2,100
Urea	000 VND	1,617	1,617	1,617	1,617	1,617	1,617
Seeds (lump sum)	000 VND	269	269	269	269	269	269
Pesticides (lump sum)	000 VND	357	357	357	357	357	357
Family labour	000 VND	35,400	35,400	35,400	35,400	35,400	35,400
Gross margin	000 VND	7,618	7,618	7,618	7,618	7,618	7,618
	$	364	364	364	364	364	364
Net margin	000 VND	-27,782	-27,782	-27,782	-27,782	-27,782	-27,782
	$	-1,326	-1,326	-1,326	-1,326	-1,326	-1,326
Returns to family labour	VND/day	22	22	22	22	22	22
Benefit/Cost Ratio		0.30	0.30	0.30	0.30	0.30	0.30

E.5. Input parameters and assumptions for tea budgets

Parameters and assumptions	Unit	Conv. tea	MTERR tea	Reference
Year 1-3:				
Seedlings	Nr seedling/ha	14,700	16,800	NCAE (2009)
Shading tree	tree/ha	200	200	NCAE (2009)
Manure	ton/ha	15	17	Adapted from Kon Tum PPC , 2015
Urea	Kg/ha	70	70	NCAE (2009); Kon Tum PPC, 2015
Phosphate	Kg/ha	600	600	NCAE (2009); Kon Tum PPC, 2015
Potassium	Kg/ha	80	80	NCAE (2009); Kon Tum PPC, 2015
Pesticides (spray)	l/ha	2	2	NCAE (2009); Kon Tum PPC, 2015
Pesticides (soil ap.)	kg or l /ha	10	10	NCAE (2009); Kon Tum PPC, 2015
Land clearing	person-day/ha	10	10	NCAE (2009); Kon Tum PPC, 2015
Land preparation	person-day/ha	96	116	NCAE (2009); Kon Tum PPC, 2015
Planting	person-day/ha	70	70	NCAE (2009); Kon Tum PPC, 2015
Weeding	person-day/ha	45	55	Assumption
Other crop ma.	person-day/ha	35	35	Assumption
Year 4-30:				
Urea	Kg/ha	465	321	Branca et al., 2017
NPK	Kg/ha	575	616	Branca et al., 2017
Weeding	person-day/ha	37.5	36.0	Branca et al., 2017
Fertilize app.	person-day/ha	18.0	25.0	Branca et al., 2017
Pest control	person-day/ha	27.2	25.0	Branca et al., 2017
Other crop manag.	person-day/ha	12.0	13.9	Branca et al., 2017
Harv& posthar	person-day/ha	124.7	153.0	Branca et al., 2017
Output (yr 4-30)				
year 4	kg/ha	2,700	3,213	Do and Nguyen (2005)
year 5	kg/ha	3,490	4,153	
year 6	kg/ha	5,860	6,973	
year 7	kg/ha	6,530	7,771	
year 8-25	kg/ha	7,634	9,111	Branca et al., 2017
year 26-30	kg/ha	-5%	-5%	Adapted from Dang (2005)
Unit price:				
Output price, f.gate	000 VND/Kg	5.5	5.5	Branca et al., 2017
Seedling, pur.price	000VND/seedl	0.4	0.4	NCAE (2009); Kon Tum PPC, 2015
Shading tree, pur.price	000VND/seedl	1.2	1.2	NCAE (2009); Kon Tum PPC, 2015
Manure	000 VND/ton	400	400	NCAE (2009); Kon Tum PPC, 2015
Urea	000 VND/kg	11.3	11.6	Branca et al., 2017
Phosphate	000 VND/kg	2.3	2.3	Branca et al., 2017
Potassium	000 VND/kg	13.0	13.0	Branca et al., 2017
NPK	000 VND/kg	5.2	5.5	Branca et al., 2017
Pesticides (spray)	000 VND/kg, l	240	240	Field survey, 2014
Pesticides (soil ap.)	000 VND/kg	23	23	Field survey, 2014
Manual labour	VND/pers.day	100	100	MOLISA and GSO, 2014
Pesticide and other chemical (lump sum, from yr 4)	000 VND/ha	3,119.6	3,726.2	Branca et al., 2017
MTERR_contruction	000 VND/ha		6,074.3	FAO and NOMAFSI, 2014
MTERR_maintainance	000 VND/ha		2,453.7	FAO and NOMAFSI, 2014
Hired machine crop manag.	000 VND/ha	1,103.48	649.45	FAO and NOMAFSI, 2014

E.6. Conventional tea enterprise budgets

Items	Unit	1	2	3	4	5	6	7	8 - 25	26	27	28	29	30
Yield	Kg/ha	0	0	0	2,700	3,490	5,860	6,530	7,634	7,252	6,890	6,545	6,218	5,907
Plot size	ha	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Seedlings	seedling	14,700	0	0	0	0	0	0	0	0	0	0	0	0
Shading tree	tree	200	0	0	0	0	0	0	0	0	0	0	0	0
Manure	ton	15	0	0	0	0	0	0	0	0	0	0	0	0
Urea	kg	70	140	280	164	213	465	465	465	465	465	465	465	465
Phosphate	kg	600	600	1,000										
Potassium	kg	80	80	100										
NPK	kg				212	274	600	600	600	600	600	600	600	600
Pesticides (spray)	litter	2												
Pesticides (soil ap.)	kg	10	3	3										
Pesticide (fr. yr 4)	000 VND				3,120	3,120	3,120	3,120	3,120	3,120	3,120	3,120	3,120	3,120
Land clearing	pers-day	10												
Land prep.	pers-day	96												
Planting	pers-day	70												
Weeding	pers-day	45	45	45	37	37	37	37	37	37	37	37	37	37
Fertilize app.	pers-day				18	18	18	18	18	18	18	18	18	18
Pest control	pers-day				15	15	16	16	16	16	16	16	16	16
Other crop manag.	pers-day	35	35	35	7	12	12	12	12	12	12	12	12	12
Harv. & posthar.	pers-day				44	57	125	125	125	125	125	125	125	125
Financial Budget														
Total revenue	000 VND	0	0	0	14,850	19,195	32,230	35,915	41,987	39,888	37,893	35,999	34,199	32,489
Seedlings	000 VND	5,880			0	0	0	0	0	0	0	0	0	0
Shading tree	000 VND	240			0	0	0	0	0	0	0	0	0	0
Manure	000 VND	5,880			0	0	0	0	0	0	0	0	0	0
Urea	000 VND	791	1,581	3,162	1,857	2,401	5,252	5,252	5,252	5,252	5,252	5,252	5,252	5,252
Phosphate	000 VND	1,380	1,380	2,300										
Potassium	000 VND	1,040	1,040	1,300										
NPK	000 VND				1,108	1,432	3,133	3,133	3,133	3,133	3,133	3,133	3,133	3,133
Pesticides (spray)	000 VND	480	720	720										
Pesticides (soil ap.)	000 VND	230												
Fertilizers (l.sum)	000 VND													
Pesticide (fr. yr 4)	000 VND				3,120	3,120	3,120	3,120	3,120	3,120	3,120	3,120	3,120	3,120
Hired machine	000 VND				1,103	1,103	1,103	1,103	1,103	1,103	1,103	1,103	1,103	1,103
Family labour	000 VND	25,600	8,000	8,000	12,161	13,953	20,851	20,851	20,851	20,851	20,851	20,851	20,851	20,851
Gross margin	000 VND	-15,921	-4,721	-7,482	7,661	11,139	19,622	23,307	29,379	27,280	25,285	23,391	21,591	19,881
	$	-760	-225	-357	366	532	937	1,113	1,402	1,302	1,207	1,116	1,031	949
Net margin	000 VND	-41,521	-12,721	-15,482	-4,500	-2,815	-1,229	2,456	8,528	6,429	4,434	2,540	740	-970
	$	-1,982	-607	-739	-215	-134	-59	117	407	307	212	121	35	-46
Retur. fa lab	000 VND /day				63	80	94	112	141	131	121	112	104	95
BCR					0.77	0.87	0.96	1.07	1.25	1.19	1.13	1.08	1.02	0.97

E.7. Mini-terracing tea enterprise budgets

Items	Unit	1	2	3	4	5	6	7	8 - 27	28	29	30
Yield	Kg/ha	0	0	0	3,213	4,153	6,973	7,771	9,111	8,655	8,223	7,812
Plot size	ha	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Seedlings	nr	16,800	0	0	0	0	0	0	0	0	0	0
Shading tree	nr	200	0	0	0	0	0	0	0	0	0	0
Manure	ton	17	0	0	0	0	0	0	0	0	0	0
Urea	kg	70	140	280	113	146	321	321	321	321	321	321
Phosphate	kg	600	600	1,000								
Potassium	kg	80	80	100								
NPK	kg				217	281	616	616	616	616	616	616
Pesticides (spray)	l	2										
Pesticides (soil ap.)	kg	10	3	3								
Land clearing	pers-day	10										
Land prep.	pers-day	116										
Planting	pers-day	70										
Weeding	pers-day	55	55	55	36	36	36	36	36	36	36	36
Fertilize app.	pers-day				25	25	25	25	25	25	25	25
Pest control	pers-day				15	15	25	25	25	25	25	25
Other crop manag.	pers-day	35	35	35	7	14	14	14	14	14	14	14
Harv. & posthar.	pers-day				70	91	153	153	153	153	153	153
Financial Budget												
Total revenue	000 VND	0	0	0	17,672	22,842	38,354	42,739	50,111	47,605	45,225	42,963
Seedlings	000 VND	6,720			0	0	0	0	0	0	0	0
Shading tree	000 VND	240			0	0	0	0	0	0	0	0
Manure	000 VND	6,720			0	0	0	0	0	0	0	0
Urea	000 VND	812	1,623	3,247	1,313	1,697	3,722	3,722	3,722	3,722	3,722	3,722
Phosphate	000 VND	1,380	1,380	2,300								
Potassium	000 VND	1,040	1,040	1,300								
NPK	000 VND				1,200	1,551	3,403	3,403	3,403	3,403	3,403	3,403
Pesticides (spray)	000 VND	480	720	720								
Pesticides (soil ap.)	000 VND	230										
Fertilizers (l.sum)	000 VND											
Pesticides (fr. yr4)	000 VND				3,726	3,726	3,726	3,726	3,726	3,726	3,726	3,726
MTERR_contr.	000 VND	6,074										
MTERR_main.	000 VND		2,454	2,454								
Hired machine	000 VND				649	649	649	649	649	649	649	649
Family labour	000 VND	28,600	9,000	9,000	15,349	18,102	25,290	25,290	25,290	25,290	25,290	25,290
Gross margin	000 VND	-23,696	-7,217	-10,021	10,783	15,219	26,853	31,238	38,610	36,104	33,724	31,463
	$	-1,131	-344	-478	515	726	1,282	1,491	1,843	1,723	1,610	1,502
Net margin	000 VND	-52,296	-16,217	-19,021	-4,566	-2,884	1,563	5,948	13,320	10,814	8,434	6,173
	$	-2,496	-774	-908	-218	-138	75	284	636	516	403	295
Return fa. Lab.	000 VND /day				70	84	106	124	153	143	133	124
BCR					0.79	0.89	1.04	1.16	1.36	1.29	1.23	1.17

E.8. Input parameters and assumptions for coffee budgets

Parameters and assumptions	Unit	Conv. Coffee	MTERR coffee	References
Year 1-3				
Seedlings	Seedling/ha	4,410	5,250	NCAE, 2009
Shading tree	tree/ha	200	200	NCAE, 2009
Manure	ton/ha	13	16	Adapted from Kon Tum PPC, 2015
Urea	Kg/ha	200	200	NCAE, 2009; Kon Tum PPC, 2015
Phosphate	Kg/ha	1,000	1,000	NCAE, 2009; Kon Tum PPC, 2015
Potassium	Kg/ha	150	150	NCAE, 2009; Kon Tum PPC, 2015
Lime	Kg/ha	1,000	1,000	Kon Tum PPC, 2015
Pesticides (spray)	l/ha	2	2.0	NCAE, 2009; Kon Tum PPC, 2015
Pesticides (soil app.)	kg or l /ha	15	15.0	NCAE, 2009; Kon Tum PPC, 2015
Land clearing	person-day/ha	10	10.0	NCAE, 2009; Kon Tum PPC, 2015
Land preparation	person-day/ha	97	104.8	NCAE, 2009; Kon Tum PPC, 2015
Planting	person-day/ha	55	94.5	NCAE, 2009; Kon Tum PPC, 2015
Weeding	person-day/ha	55	45.6	Assumption
Other crop manag.	person-day/ha	45	45	Assumption
Year 4-15				
Urea	Kg/ha	335	257	FAO and NOMAFSI, 2014
NPK	Kg/ha	674	668	FAO and NOMAFSI, 2014
Potassium (KCL)	Kg/ha	155	0	FAO and NOMAFSI, 2014
Org. fertiliser	kg/ha	3782.3	3399.2	FAO and NOMAFSI, 2014
Weeding	person-day/ha	60.1	89.6	FAO and NOMAFSI, 2014
Fertilizer app.	person-day/ha	24.8	28.5	FAO and NOMAFSI, 2014
Pest control	person-day/ha	24.6	30.1	FAO and NOMAFSI, 2014
Pruning	person-day/ha	4.0	0.0	FAO and NOMAFSI, 2014
Other crop manag.	person-day/ha	44.1	32.4	FAO and NOMAFSI, 2014
Harv. & posthar	person-day/ha	72.6	95.1	FAO and NOMAFSI, 2014
Output (yr 4-15)				
Year 3	kg/ha	1250	1250	FAO and NOMAFSI, 2014
Year 4	kg/ha	2500	2500	Dien Bien DARD, 2012
Year 5	kg/ha	3800	5000	
Year 6-13	kg/ha	4365.0	6675	
Year 14-15	kg/ha	-10%	-10%	Assumption
Unit price:				
Output price, f.gate	000 VND/Kg	9.0	9	Son La Online; Dien Bien DARD, 2012
Seedling, pur.price	000 VND/ seedling	1.2	1.2	NCAE, 2009; Kon Tum PPC, 2015
Shad tree, pur.price	000 VND/ seedling	1.2	1.2	NCAE, 2009; Kon Tum PPC, 2015
Manure	000 VND/ton	500	500	NCAE, 2009; Kon Tum PPC, 2015
Org. fertiliser	000 VND/kg	2.152	2.152	FAO and NOMAFSI, 2014
Urea	000 VND/kg	11.4	11.8	FAO and NOMAFSI, 2014
Phosphate	000 VND/kg	2.3	2.3	FAO and NOMAFSI, 2014
Potassium	000 VND/kg	14.3	14.3	FAO and NOMAFSI, 2014
NPK	000 VND/kg	5.5	5.5	FAO and NOMAFSI, 2014
Pesticides (spray)	000 VND/kg or l	240	240.0	Field survey, 2014
Pesticides (soil app.)	000 VND/kg	23.0	23	Field survey, 2014
Manual labour	000 VND/person day	100	100	MOLISA & GSO, 2014
Pesticides (fr.yr 4)	000 VND/ha	1,689.0	1,716	FAO and NOMAFSI, 2014
MTERR_contr.	000 VND/ha		16,263	FAO and NOMAFSI, 2014
MTERR_main.	000 VND/ha		6,696	FAO and NOMAFSI, 2014

E.9. Conventional coffee enterprise budgets

Items	Unit	1	2	3	4	5	6 - 13	14	15	16**	17	18	19 - 29	30
Yield (cherries)	Kg	0	0	1,250	2,500	3,800	4,365	3,928	3,536	0	2,500	4,000	4,365	3,928
Plot size	ha	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1	1.0	1.0	1.0
Seedlings	nr	4,410	0	0	0	0	0	0	0	0	0	0	0	0
Shading tree	nr	200	0	0	0	0	0	0	0	0	0	0	0	0
Manure	ton	13	0	0	0	0	0	0	0	0	0	0	0	0
Org. fertiliser	kg				2,166	3,293	3,782	3,782	3,782	0	0	3,466	3,782	3,782
Urea	kg	200	400	220	192	292	335	335	335	400	220	307	335	335
Phosphate	kg	1,000	1,000	1,400						1,000	1,400			
Potassium	kg	150	150	170	89	135	155	155	155	150	170	142	155	155
NPK	kg				386	587	674	674	674	0	0	618	674	674
Pesticides (spray)	l	2	3	4						3	4			
Pesticides (soil ap.)	kg	15												
Land clearing	pers-day	10												
Land preparation	pers-day	97												
Planting	pers-day	55												
Weeding	pers-day	55	75	75	60	60	60	60	60	75	75	60	60	60
Fertilizer app.	pers-day	25	25	25	25	25	25	25	25	25	25	25	25	25
Pest control	pers-day	6	6	10	25	25	25	25	25	6	10	25	25	25
Pruning	pers-day		14	20	4	4	4	4	4	14	20	4	4	4
Other crop manag.	pers-day		45	45	44	44	44	44	44	45	45	44	44	44
Harv & posthar	pers-day				42	63	73	73	73			66	73	73
Financial Budget														
Total revenue	000 VND	0	0	11,250	22,500	34,200	39,285	35,356	31,820	0	22,500	36,000	39,285	35,356
Seedlings	000 VND	5,292			0	0	0	0	0			0	0	0
Shading tree	000 VND	240			0	0	0	0	0			0	0	0
Manure	000 VND	6,615			0	0	0	0	0			0	0	0
Org. fertiliser	000 VND				4,662	7,086	8,139	8,139	8,139			7,459	8,139	8,139
Urea	000 VND	2,280	4,560	2,508	2,187	3,325	3,819	3,819	3,819	4,560	2,508	3,500	3,819	3,819
Phosphate	000 VND	2,300	2,300	3,220						2,300	3,220			
Potassium	000 VND	2,138	2,138	2,423						2,138	2,423			
NPK	000 VND				2,110	3,207	3,683	3,683	3,683	0	0	3,375	3,683	3,683
Pesticides (spray)	000 VND	480	720	960										
Pesticides (soil ap.)	000 VND	345												
Fertilizers (l.sum)	000 VND													
Pesticides (fr.yr 4)	000 VND				1,689	1,689	1,689	1,689	1,689	720	960	1,689	1,689	1,689
Family labour	000 VND	24,800	16,500	17,500	19,908	22,069	23,008	23,008	23,008	16,500	17,500	22,401	23,008	23,008
Gross margin	000 VND	-19,690	-9,718	2,140	11,852	18,894	21,954	18,025	14,490	-9,718	13,390	19,977	21,954	18,025
	$	-940	-464	102	566	902	1,048	860	692	-464	639	954	1,048	860
Net margin	000 VND	-44,490	-26,218	-15,361	-8,056	-3,175	-1,054	-4,983	-8,518	-26,218	-4,111	-2,424	-1,054	-4,983
	$	-2,124	-1,251	-733	-385	-152	-50	-238	-407	-1,251	-196	-116	-50	-238
Returns fa. Lab.	000 VND/ day				60	86	95	78	63	-59	77	89	95	78
BCR					0.74	0.92	0.97	0.88	0.79	0.00	0.85	0.94	0.97	0.88

E.10. Mini-terracing coffee enterprise budgets

Items	Unit	1	2	3	4	5	6 - 15	16	17	18	19*	20	21 - 30
Yield (cherries)	kg	0	0	1,250	2,500	5,000	6,675	6,008	5,407	4,866	0	3,000	6,675
Plot size	ha	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1	1.0
Seedlings	nr	5,250	0	0	0	0	0	0	0	0	0	0	0
Shading tree	nr	200	0	0	0	0	0	0	0	0	0	0	0
Manure	ton	16	0	0	0	0	0	0	0	0	0	0	0
Org. fertiliser	kg				1,273	2,546	3,399	3,399	3,399	3,399	0	0	3,399
Urea	kg	200	400	378	96	193	257	257	257	257	400	378	257
Phosphate	kg	1,000	1,000	1,400							1,000	1,400	
Potassium	kg	150	150	170	0	0	0	0	0	0	150	170	0
NPK	kg				250	500	668	668	668	668	0	0	668
Pesticides (spray)	l	2	3	4							3	4	
Pesticides (soil ap.)	kg	15											
Land clearing	pers-day	10											
Land preparation	pers-day	105											
Planting	pers-day	95											
Weeding	pers-day	46	46	46	90	90	90	90	90	90	46	46	90
Fertilizer app.	pers-day				29	29	29	29	29	29	0	0	29
Pest control	pers-day				30	30	30	30	30	30	0	0	30
Pruning	pers-day				0	0	0	0	0	0	0	0	0
Other crop manag.	pers-day	45	45	45	32	32	32	32	32	32	45	45	32
Harv & posthar	pers-day				36	71	95	95	95	95			95
Financial Budget													
Total revenue	000 VND	0	0	11,250	22,500	45,000	60,075	54,068	48,661	43,795	0	27,000	60,075
Seedlings	000 VND	6,300			0	0	0	0	0	0			0
Shading tree	000 VND	240			0	0	0	0	0	0			0
Manure	000 VND	7,875			0	0	0	0	0	0			0
Org. fertiliser	000 VND				2,740	5,479	7,315	7,315	7,315	7,315			7,315
Urea	000 VND	2,354	4,707	4,449	1,133	2,265	3,024	3,024	3,024	3,024	4,707	4,449	3,024
Phosphate	000 VND	2,300	2,300	3,220							2,300	3,220	
Potassium	000 VND	2,138	2,138	2,423							2,138	2,423	
NPK	000 VND				1,372	2,744	3,663	3,663	3,663	3,663	0	0	3,663
Pesticides (spray)	000 VND	480	720	960							720	960	
Pesticides (soil ap.)	000 VND	345											
Fertilizers (l.sum)	000 VND												
Pesticides (fr. yr 4)	000 VND				1,716	1,716	1,716	1,716	1,716	1,716			1,716
MTERR_contr.	000 VND	16,263											
MTERR_main.	000 VND		6,696	6,696									
Family labour	000 VND	29,993	9,063	9,063	21,609	25,169	27,554	27,554	27,554	27,554	9,063	9,063	27,554
Gross margin	000 VND	-38,294	-16,561	-6,498	15,540	32,795	44,357	38,349	32,943	28,077	-16,561	15,948	44,357
	$	-1,828	-791	-310	742	1,565	2,117	1,831	1,572	1,340	-791	761	2,117
Net margin	000 VND	-68,287	-25,624	-15,561	-6,069	7,627	16,803	10,795	5,389	523	-25,624	6,885	16,803
	$	-3,260	-1,223	-743	-290	364	802	515	257	25	-1,223	329	802
Returns fa. Lab.	000 VND/day				72	130	161	139	120	102			161
BCR					0.79	1.20	1.39	1.25	1.12	1.01			1.39

APPENDIX F. ENTERPRISE BUDGETS FOR LIVESTOCK

F.1. Output prices and costs in livestock husbandry

Output	Unit	Cattle	Buffalo	Pig	Reference
Sales of adult for slaughtering	000 VND/live head	18,224	26,278		FAO and NOMAFSI, 2014
Sales heifers (meat, breed)	000 VND/live head	7,750	7,630		
Sales draft power- adult male	work days/ year	37.5	37.5		Adapted from Devendra and Thomas (2002)
Sales draft power - adult female	work days/ year	12.5	12.5		
Sales of draft pow. (net return)	000 VND/day	112	112		FAO and NOMAFSI, 2014
Finished pig for slaughtering	000 VND/live head			4,302.0	FAO and NOMAFSI, 2014
Weaners for patenting	000 VND/live head			534.2	Vo and Vu (2006)[1]
Pig sows for culling	000 VND/live head			4,302.0	Expert interview

Costs

Buy-in stock					
Calf [2]	000 VND/head	6,895	7,630		FAO and NOMAFSI, 2014
Adult	000 VND/head	18,224	26,278		
Weaners for fattening	000 VND/head			534.2	Vo and Vu (2006)[1]
Gilt (young sows)	000 VND/head			801.3	Lemke et al. (2008)
Husbandry costs					
Vaccines	000 VND/ head/year	19.4	16.7	33.8	
Medicines	000 VND/ head/year	40.7	141.7	37.30	
Veterinary services	000 VND/ head/year			49.7	FAO and NOMAFSI, 2014
Feed1 (own produced)	000 VND/ head/year	897.5	1,812.6	1271.7	
Feed2 (purchased)	000 VND/ head/year			1455.1	
Supplements (purchased)	000 VND/ head/year			540.1	
Pigs: sows and piglets					
Feed (purchased)	000 VND/sow/litter			3417.7	
Matting	000 VND/sow/litter			63.8	Vo and Vu (2006)[1]
Veterinary and medicines	000 VND/sow/litter			409.7	
Family labour	person day/head/year	17.7	21.0	12.8	FAO and NOMAFSI, 2014
	person day/litter			19.2	Assumption
	000 VND/person-day	100	100	100	MOLISA and GSO, 2014

Note: 1) Value converted to 2013 real value
2) Cattle: 6-8 months; Buffalo: 8-12 months

F.2. Cattle enterprise budgets

Year 1-10

Items	Unit	Present	1	2	3	4	5	6	7	8	9	10
Parameter												
Calving rate	%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Calves mortality	%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%
Heifers mortality	%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%
Adults mortality	%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%
Stock												
Calves	heads	1	1	1	1	2	2	2	2	2	3	2
Heifers	heads	0	1	2	2	2	1	1	1	2	2	2
Adult male (bulls)	heads	1	1	1	2	2	3	3	3	3	3	4
Adult female (cows)	heads	3	3	3	3	4	4	5	5	5	5	4
Total	heads	5	6	7	8	10	10	11	12	12	13	13
Off-take												
Heifers	heads	0	0	0	0	1	1	1	1	1	1	1
Adult male (ox)	heads	0	0	0	0	0	0	0	1	0	0	0
Adult female (cow)	heads	0	0	0	0	0	0	0	0	1	1	1
Financial budget												
Sales (adults)	000 VND	0	0	0	0	0	0	0	18,224	18,224	18,224	18,224
Sales (heifers)	000 VND	0	0	0	0	6,895	6,895	6,895	6,895	6,895	6,895	6,895
Draught power	000 VND	5,824	5,690	8,322	11,239	14,136	17,366	19,204	21,052	19,157	20,512	22,220
Sales (manure)	000 VND	0	0	0	0	0	0	0	0	0	0	0
Revenue	000 VND	5,824	5,690	8,322	11,239	21,031	24,261	26,099	46,171	44,276	45,631	47,339
Feed	000 VND	4,129	5,177	6,141	7,264	8,573	9,162	9,990	10,931	11,078	11,382	11,442
Vaccines	000 VND	89	112	133	157	185	198	216	236	239	246	247
Medicines	000 VND	187	235	278	329	389	415	453	496	502	516	519
Veterinary services	000 VND	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous	000 VND	291	285	416	562	1,052	1,213	1,305	2,309	2,214	2,282	2,367
Operating Costs	000 VND	4,696	5,808	6,968	8,312	10,199	10,989	11,964	13,971	14,033	14,426	14,575
Family labour	000 VND	8,142	10,210	12,110	14,325	16,907	18,069	19,702	21,557	21,847	22,448	22,566
Total costs	000 VND	12,838	16,018	19,078	22,637	27,106	29,058	31,667	35,529	35,880	36,874	37,141
Capital value	000 VND	67,063	74,307	92,092	112,266	133,792	151,142	164,699	179,165	178,058	179,865	181,352
Changes in inventory	000 VND	0	7,243	17,785	20,173	21,526	17,351	13,556	14,466	-1,107	1,807	1,487
Gross marg. (bef. fa. lab)	000 VND	1,128	7,125	19,139	23,101	32,358	30,623	27,691	46,666	29,135	33,012	34,250
	$	54	340	914	1,103	1,545	1,462	1,322	2,227	1,391	1,576	1,635
Net marg. (af. fa. lab.)	000 VND	-7,014	-3,085	7,029	8,776	15,451	12,554	7,989	25,108	7,289	10,565	11,684
	$	-335	-147	336	419	738	599	381	1,198	348	504	558
Returns to labor	000 VND/day	14	70	158	161	191	169	141	216	133	147	152
Benefit/Cost Ratio		0.45	0.81	1.37	1.39	1.57	1.43	1.25	1.71	1.20	1.29	1.31
Gross marg. (bef. fa. lab)	000 VND/head	245	1,235	2,797	2,854	3,388	3,000	2,488	3,832	2,361	2,603	2,686
Net marg. (af. fa. lab.)	000 VND/head	-1,525	-535	1,027	1,084	1,618	1,230	718	2,062	591	833	916
Captital value	000 VND/head	14,579	12,882	13,460	13,872	14,006	14,805	14,796	14,711	14,426	14,182	14,225

(continue next page)

Year 11-20 (continue)

Items	Unit	11	12	13	14	15	16	17	18	19	20
Parameter											
Calving rate	%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Calves mortality	%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%
Heifers mortality	%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%
Adults mortality	%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%
Stock											
Calves	heads	2	2	2	2	2	3	3	3	3	3
Heifers	heads	2	2	2	2	2	2	2	2	3	3
Adult male (bulls)	heads	4	5	4	4	4	3	3	3	3	4
Adult female (cows)	heads	4	4	4	5	5	6	6	6	7	6
Total	heads	13	12	13	13	13	14	14	15	15	16
Off-take											
Heifers	heads	1	0	0	1	1	1	1	1	1	1
Adult male (ox)	heads	0	1	1	1	1	1	0	1	0	1
Adult female (cow)	heads	1	0	0	0	0	0	1	0	1	0
Financial budget											
Sales (adults)	000 VND	18,224	18,224	18,224	18,224	18,224	18,224	18,224	18,224	18,224	18,224
Sales (heifers)	000 VND	6,895	0	0	6,895	6,895	6,895	6,895	6,895	6,895	6,895
Draught power	000 VND	24,337	26,041	24,379	24,129	23,890	22,215	20,798	22,896	22,719	25,912
Sales (manure)	000 VND	0	0	0	0	0	0	0	0	0	0
Revenue	000 VND	49,456	44,265	42,603	49,248	49,009	47,334	45,917	48,015	47,838	51,031
Feed	000 VND	11,288	10,972	11,375	11,953	11,930	12,229	12,706	13,362	13,814	14,534
Vaccines	000 VND	244	237	246	258	258	264	275	289	299	314
Medicines	000 VND	512	498	516	542	541	555	576	606	626	659
Veterinary services	000 VND	0	0	0	0	0	0	0	0	0	0
Miscellaneous	000 VND	2,473	2,213	2,130	2,462	2,450	2,367	2,296	2,401	2,392	2,552
Operating Costs	000 VND	14,516	13,920	14,267	15,216	15,180	15,414	15,852	16,657	17,131	18,059
Family labour	000 VND	22,261	21,638	22,433	23,574	23,529	24,117	25,057	26,351	27,243	28,664
Total costs	000 VND	36,777	35,558	36,700	38,790	38,708	39,531	40,910	43,008	44,373	46,723
Capital value	000 VND	182,984	181,838	184,054	193,200	197,632	198,598	201,853	209,256	217,355	229,702
Changes in inventory	000 VND	1,632	-1,146	2,216	9,146	4,432	966	3,255	7,403	8,099	12,348
Gross marg. (bef. fa. lab)	000 VND	36,572	29,200	30,552	43,178	38,261	32,885	33,320	38,761	38,806	45,320
	$	1,746	1,394	1,458	2,061	1,826	1,570	1,590	1,850	1,852	2,163
Net marg. (af. fa. lab.)	000 VND	14,312	7,562	8,119	19,604	14,733	8,768	8,263	12,410	11,563	16,656
	$	683	361	388	936	703	419	394	592	552	795
Returns to labor	000 VND/day	164	135	136	183	163	136	133	147	142	158
Benefit/Cost Ratio		1.39	1.21	1.22	1.51	1.38	1.22	1.20	1.29	1.26	1.36
Gross marg. (bef. fa. lab)	000 VND/head	2,908	2,389	2,411	3,242	2,878	2,414	2,354	2,604	2,521	2,799
Net marg. (af. fa. lab.)	000 VND/head	1,138	619	641	1,472	1,108	644	584	834	751	1,029
Captital value	000 VND/head	14,550	14,874	14,522	14,506	14,867	14,576	14,258	14,056	14,122	14,184

(continue next page)

Year 21-30 (continue)

Items	Unit	21	22	23	24	25	26	27	28	29	30
Parameter											
Calving rate	%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Calves mortality	%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%
Heifers mortality	%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%	4.6%
Adults mortality	%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%	2.3%
Stock											
Calves	heads	3	3	3	4	4	4	4	5	5	5
Heifers	heads	3	3	3	3	4	4	4	4	5	5
Adult male (bulls)	heads	4	5	5	6	5	7	7	7	8	9
Adult female (cows)	heads	7	7	8	8	8	9	10	11	11	11
Total	heads	17	18	19	20	21	23	24	26	29	31
Off-take											
Heifers	heads	1	1	1	1	1	1	1	1	1	1
Adult male (ox)	heads	0	1	0	1	0	1	1	0	0	1
Adult female (cow)	heads	1	0	1	0	1	0	0	1	1	0
Financial budget											
Sales (adults)	000 VND	18,224	18,224	18,224	18,224	18,224	18,224	18,224	18,224	18,224	18,224
Sales (heifers)	000 VND	6,895	6,895	6,895	6,895	6,895	6,895	6,895	6,895	6,895	6,895
Draught power	000 VND	26,007	29,436	29,928	33,839	34,868	39,388	41,115	43,634	49,138	55,498
Sales (manure)	000 VND	0	0	0	0	0	0	0	0	0	0
Revenue	000 VND	51,126	54,555	55,047	58,958	59,987	64,507	66,234	68,753	74,257	80,617
Feed	000 VND	15,145	16,045	16,848	17,967	19,023	20,429	21,813	23,595	25,835	28,095
Vaccines	000 VND	327	347	364	388	411	442	472	510	558	607
Medicines	000 VND	687	728	764	815	863	926	989	1,070	1,172	1,274
Veterinary services	000 VND	0	0	0	0	0	0	0	0	0	0
Miscellaneous	000 VND	2,556	2,728	2,752	2,948	2,999	3,225	3,312	3,438	3,713	4,031
Operating Costs	000 VND	18,716	19,847	20,729	22,118	23,296	25,023	26,586	28,612	31,278	34,008
Family labour	000 VND	29,868	31,643	33,228	35,434	37,515	40,289	43,019	46,532	50,950	55,408
Total costs	000 VND	48,584	51,490	53,957	57,552	60,811	65,312	69,604	75,145	82,228	89,415
Capital value	000 VND	240,138	254,833	268,375	286,719	304,385	327,421	350,450	379,613	412,927	450,000
Changes in inventory	000 VND	10,436	14,694	13,542	18,344	17,666	23,036	23,029	29,163	33,314	37,073
Gross marg. (bef. fa. lab)	000 VND	42,846	49,402	47,860	55,183	54,357	62,520	62,678	69,304	76,294	83,682
	$	2,045	2,358	2,284	2,634	2,595	2,984	2,992	3,308	3,642	3,994
Net marg. (af. fa. lab.)	000 VND	12,978	17,759	14,633	19,749	16,842	22,231	19,659	22,772	25,343	28,274
	$	619	848	698	943	804	1,061	938	1,087	1,210	1,350
Returns to labor	000 VND/day	143	156	144	156	145	155	146	149	150	151
Benefit/Cost Ratio		1.27	1.34	1.27	1.34	1.28	1.34	1.28	1.30	1.31	1.32
Gross marg. (bef. fa. lab)	000 VND/head	2,539	2,763	2,549	2,757	2,565	2,747	2,579	2,636	2,650	2,673
Net marg. (af. fa. lab.)	000 VND/head	769	993	779	987	795	977	809	866	880	903
Captital value	000 VND/head	14,231	14,255	14,296	14,322	14,361	14,384	14,419	14,440	14,345	14,375

(end of budget)

F.3. Buffalo enterprise budgets

Year 1-10

Items	Unit	Present	1	2	3	4	5	6	7	8	9	10
Parameter												
Calving rate	%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Calves mortality	%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%
Heifers mortality	%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%
Adults mortality	%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%
Stock												
Calves*	heads	1	1	1	1	1	1	1	1	1	1	1
Heifers	heads	0	1	1	1	1	1	1	1	1	2	2
Adult male	heads	0	0	1	1	1	2	2	2	3	3	4
Adult female	heads	2	2	2	3	3	3	4	4	4	5	5
Total	heads	4	4	5	6	6	7	8	9	10	11	12
Off-take												
Heifers	heads	0	0	0	0	0	0	0	0	0	0	0
Adult male	heads	0	0	0	0	0	0	0	0	0	0	1
Adult female	heads	0	0	0	0	0	0	0	0	0	0	0
Financial budget												
Sales (live animals)	000 VND	0	0	0	0	0	0	0	0	0	0	13,139
Sales (weaners)	000 VND	0	0	0	0	0	0	0	0	0	0	0
Draught power	000 VND	4,726	4,599	6,903	8,638	10,153	11,800	13,615	15,582	17,707	20,008	22,501
Sales (manure)	000 VND	0	0	0	0	0	0	0	0	0	0	0
Revenue	000 VND	4,726	4,599	6,903	8,638	10,153	11,800	13,615	15,582	17,707	20,008	35,640
Feed	000 VND	6,946	8,029	8,957	10,088	11,358	12,730	14,214	15,826	17,578	19,483	21,554
Vaccines	000 VND	64	74	83	93	105	117	131	146	162	179	199
Medicines	000 VND	543	628	700	789	888	995	1,111	1,237	1,374	1,523	1,685
Veterinary services	000 VND	0	0	0	0	0	0	0	0	0	0	0
Miscellaneous	000 VND	236	230	345	432	508	590	681	779	885	1,000	1,782
Operating Costs	000 VND	7,789	8,961	10,084	11,401	12,858	14,433	16,137	17,988	19,999	22,185	25,219
Family labour	000 VND	8,047	9,302	10,377	11,687	13,159	14,749	16,468	18,336	20,365	22,572	24,971
Total costs	000 VND	15,836	18,263	20,461	23,089	26,017	29,181	32,606	36,324	40,365	44,757	50,191
Capital value	000 VND	76,455	79,747	98,579	114,500	129,541	145,911	163,880	183,404	204,582	227,580	252,575
Changes in inventory	000 VND	0	3,292	18,832	15,921	15,041	16,369	17,970	19,524	21,178	22,998	24,995
Gross marg. (bef. fa. lab)	000 VND	-3,063	-1,069	15,651	13,158	12,336	13,737	15,447	17,117	18,885	20,820	35,416
	$	-146	-51	747	628	589	656	737	817	901	994	1,691
Net marg. (af. fa. lab.)	000 VND	-11,110	-10,372	5,274	1,470	-823	-1,012	-1,021	-1,218	-1,480	-1,751	10,445
	$	-530	-495	252	70	-39	-48	-49	-58	-71	-84	499
Returns to labour	000 VND/day	-38	-11	151	113	94	93	94	93	93	92	142
Benefit/Cost Ratio		0.30	0.43	1.26	1.06	0.97	0.97	0.97	0.97	0.96	0.96	1.21
Gross marg. (bef. fa. lab)	000 VND/head	-799.27	-241.43	3167.29	2364.22	1968.71	1955.94	1969.82	1960.46	1947.41	1937.08	2978.35
Net marg. (af. fa. lab.)	000 VND/head	-2,899	-2,341	1,067	264	-131	-144	-130	-140	-153	-163	878
Captital value	000 VND/head	19,952	18,003	19,950	20,574	20,674	20,776	20,898	21,005	21,096	21,173	21,241

(continue next page)

Year 11-20 (continue)

Items	Unit	11	12	13	14	15	16	17	18	19	20
Parameter											
Calving rate	%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Calves mortality	%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%
Heifers mortality	%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%
Adults mortality	%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%
Stock											
Calves*	heads	2	2	2	2	2	1	1	1	2	2
Heifers	heads	2	2	1	2	2	2	1	1	2	2
Adult male	heads	4	3	3	3	3	4	4	4	3	3
Adult female	heads	5	6	5	5	4	5	5	5	5	5
Total	heads	13	13	12	12	12	12	12	12	12	12
Off-take											
Heifers	heads	0	1	0	0	0	1	1	0	0	1
Adult male	heads	1	1	1	1	1	0	1	1	1	1
Adult female	heads	0	1	1	1	1	1	0	0	1	0
Financial budget											
Sales (live animals)	000 VND	26,278	39,417	39,417	39,417	26,278	13,139	13,139	26,278	39,417	26,278
Sales (weaners)	000 VND	0	7,630	0	0	0	3,815	3,815	0	0	7,630
Draught power	000 VND	23,106	21,898	21,754	20,109	20,247	21,301	24,068	24,103	21,783	21,146
Sales (manure)	000 VND	0	0	0	0	0	0	0	0	0	0
Revenue	000 VND	49,384	68,945	61,171	59,526	46,525	38,255	41,022	50,381	61,200	55,054
Feed	000 VND	22,901	23,566	21,778	21,637	21,041	21,132	21,319	21,594	22,081	21,812
Vaccines	000 VND	211	217	201	199	194	195	196	199	203	201
Medicines	000 VND	1,790	1,842	1,702	1,691	1,645	1,652	1,667	1,688	1,726	1,705
Veterinary services	000 VND	0	0	0	0	0	0	0	0	0	0
Miscellaneous	000 VND	2,469	3,447	3,059	2,976	2,326	1,913	2,051	2,519	3,060	2,753
Operating Costs	000 VND	27,372	29,073	26,740	26,504	25,206	24,891	25,233	26,000	27,071	26,471
Family labour	000 VND	26,533	27,303	25,231	25,068	24,377	24,482	24,699	25,017	25,582	25,271
Total costs	000 VND	53,904	56,376	51,971	51,572	49,582	49,373	49,933	51,017	52,653	51,742
Capital value	000 VND	266,615	270,254	256,428	239,682	233,040	240,180	254,486	260,415	256,101	245,581
Changes in inventory	000 VND	14,040	3,639	-13,826	-16,745	-6,643	7,140	14,306	5,928	-4,313	-10,520
Gross marg. (bef. fa. lab)	000 VND	36,051	43,511	20,605	16,276	14,677	20,504	30,095	30,309	29,816	18,063
	$	1,721	2,077	984	777	701	979	1,437	1,447	1,423	862
Net marg. (af. fa. lab.)	000 VND	9,519	16,208	-4,626	-8,792	-9,700	-3,978	5,395	5,292	4,233	-7,208
	$	454	774	-221	-420	-463	-190	258	253	202	-344
Returns to labour	000 VND/day	136	159	82	65	60	84	122	121	117	71
Benefit/Cost Ratio		1.18	1.29	0.91	0.83	0.80	0.92	1.11	1.10	1.08	0.86
Gross marg. (bef. fa. lab)	000 VND/head	2853.41	3346.67	1714.95	1363.49	1264.39	1758.80	2558.72	2544.22	2447.48	1501.05
Net marg. (af. fa. lab.)	000 VND/head	753	1,247	-385	-737	-836	-341	459	444	347	-599
Captital value	000 VND/head	21,102	20,787	21,343	20,079	20,076	20,602	21,637	21,860	21,023	20,408

(continue next page)

Year 21-30 (continue)

Items	Unit	21	22	23	24	25	26	27	28	29	30
Parameter											
Calving rate	%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Calves mortality	%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%
Heifers mortality	%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%	5.4%
Adults mortality	%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%	2.7%
Stock											
Calves*	heads	2	2	2	2	1	1	1	1	1	1
Heifers	heads	1	2	2	2	2	2	2	1	1	0
Adult male	heads	3	2	3	3	3	3	2	2	2	1
Adult female	heads	5	6	5	5	5	4	4	4	3	2
Total	heads	11	12	12	12	11	10	9	8	7	4
Off-take											
Heifers	heads	0	1	0	1	0	0	1	1	1	1
Adult male	heads	1	0	0	1	1	1	1	1	1	1
Adult female	heads	0	1	1	1	1	1	1	1	1	1
Financial budget											
Sales (live animals)	000 VND	26,278	26,278	26,278	39,417	52,556	52,556	39,417	39,417	52,556	52,556
Sales (weaners)	000 VND	0	3,815	0	3,815	0	0	7,630	3,815	7,630	7,630
Draught power	000 VND	20,303	17,935	19,554	20,847	19,624	16,775	14,337	12,835	10,637	6,459
Sales (manure)	000 VND	0	0	0	0	0	0	0	0	0	0
Revenue	000 VND	46,581	48,028	45,832	64,079	72,180	69,331	61,384	56,067	70,823	66,645
Feed	000 VND	20,335	21,068	21,016	21,581	19,962	18,479	16,720	13,821	12,000	7,952
Vaccines	000 VND	187	194	194	199	184	170	154	127	111	73
Medicines	000 VND	1,590	1,647	1,643	1,687	1,561	1,445	1,307	1,080	938	622
Veterinary services	000 VND	0	0	0	0	0	0	0	0	0	0
Miscellaneous	000 VND	2,329	2,401	2,292	3,204	3,609	3,467	3,069	2,803	3,541	3,332
Operating Costs	000 VND	24,441	25,311	25,144	26,671	25,315	23,560	21,250	17,833	16,589	11,979
Family labour	000 VND	23,559	24,409	24,348	25,003	23,127	21,409	19,371	16,013	13,902	9,213
Total costs	000 VND	48,000	49,720	49,492	51,674	48,442	44,969	40,620	33,846	30,492	21,192
Capital value	000 VND	242,722	238,777	239,190	240,306	229,722	204,104	180,065	162,147	134,680	89,456
Changes in inventory	000 VND	-2,859	-3,945	414	1,115	-10,584	-25,618	-24,039	-17,917	-27,467	-45,224
Gross marg. (bef. fa. lab)	000 VND	19,281	18,772	21,102	38,523	36,281	20,153	16,095	20,317	26,767	9,441
	$	920	896	1,007	1,839	1,732	962	768	970	1,278	451
Net marg. (af. fa. lab.)	000 VND	-4,277	-5,637	-3,246	13,520	13,154	-1,255	-3,276	4,305	12,865	229
	$	-204	-269	-155	645	628	-60	-156	205	614	11
Returns to labour	000 VND/day	82	77	87	154	157	94	83	127	193	102
Benefit/Cost Ratio		0.91	0.89	0.93	1.26	1.27	0.97	0.92	1.13	1.42	1.01
Gross marg. (bef. fa. lab)	000 VND/head	1718.72	1615.00	1820.05	3235.59	3294.47	1976.86	1744.85	2664.51	4043.27	2152.12
Net marg. (af. fa. lab.)	000 VND/head	-381	-485	-280	1,136	1,194	-123	-355	565	1,943	52
Captital value	000 VND/head	21,636	20,543	20,630	20,183	20,860	20,021	19,521	21,265	20,344	20,391

(end of budget)

F.4. Pig enterprise budgets

Items	Unit	Year 1	Year 2 -6; 8-12; 14-18; 20-24; 26-30	Year 7, 13, 19, 25
Parameter				
Mortality of piglets[1]	%	20%	20%	20%
Mortality of pigs finishing[2]	%	15.3%	15.3%	15.3%
Litter per sow per year[3]	litter	1.9	1.9	1.9
Piglets born live per litter[4]	heads	10.5	10.5	10.5
Litter fattened/ sold out as weaners[5]	%	50%	50%	50%
Piglets	heads	0	16	16
Pigs finishing	heads	0	7	7
Sows	heads	0	1	0
Gilt (young sow for start stocking or replacement)	heads	1	0	1
Total	heads	1	9	8
Sows (selling as a cull)	heads	0	0	1
Piglets selling as weaners	heads	0	8	8
Pigs for slaughtering	heads	0	7	7
Total	heads	0	15	16
Financial budget (VND)				
Sales of live fis. pigs	000 VND	0	29,074	29,074
Sales of live weaners	000 VND	0	4,263	4,263
Sales of culled sows	000 VND	0	0	4,302
Revenue	000 VND	0	33,337	37,639
Gilt purchasing	000 VND	801	0	801
Feed	000 VND	2,727	24,922	21,155
Livestock health care	000 VND	121	1,595	937
Matting costs (art.)	000 VND	0	121	0
Miscellaneous	000 VND	0	1,667	1,882
Operating Costs	000 VND	2,848	28,305	23,974
Hired labor	000 VND	0	0	0
Family labor	000 VND	1,278	13,493	9,915
Total costs	000 VND	4,126	41,798	33,889
Gross marg. (bef.fa.lab)	000 VND	-2,848	5,032	13,665
	$	-136	240	652
Net marg. (af.fa.lab.)	000 VND	-4,126	-8,462	3,749
	$	-197	-404	179
Returns to labor	000 VND/day	-223	44	134
Benefit/Cost Ratio		0.00	0.80	1.11
Gross marg. (bef.fa.lab)	000 VND/head	920.21		
Net marg. (af.fa.lab.)	000 VND/head	-357.79		

Source: 1) Herold et al., 2010; 2) VARHS 10-14; 3) Phung et al. (2008); 4) Phung et al. (2008) and Vo & Vu (2006); and 5) Lemke et al. (2008).

APPENDIX G. REPRESENTATIVE FARMS

G.1. Provincial households, land use type, crop and livestock in 2011

Province	Total of household	Agricultural household	Agricultural land by province and type of land use (000 ha)						Cultivated area (000 ha)				Livestock (000 head)		
			Total	Annual cropland	Annual cropland: rice	Perennial cropland	Forest land	Aqua-culture	Upland rice *	Maize	Tea	Coffee	Cattle	Buffalo	Pig
National total	15,343,852	9,534,670	26,226.41	6,437.59	4,120.16	3,688.51	15,366.48	689.81	130.0	1,121.3	128.2	623.1	5,436.6	2,712.0	27,056.0
NMR	2,363,934	1,889,658	7,264.14	1,197.73	529.28	372.95	5,662.46	29.75	81.5	465.7	91.6	11.0	924.7	1,506.2	6,424.9
Hà Giang	127,363	119,581	684.19	123.02	30.49	29.64	530.35	1.14	4.3	49.9	19.4		103.0	156.3	461.0
Cao Bằng	89,801	83,497	629.36	89.94	34.24	4.64	534.32	0.44	3.4	39.0	0.2		122.6	102.1	354.1
Bắc Kạn	59,363	52,287	413.71	31.25	18.52	5.28	376.13	1.04	2.5	16.9	2.6		22.4	60.8	183.5
Tuyên Quang	158,733	131,002	531.95	48.72	26.57	33.94	447.12	1.94	5.2	16.5	8.1		20.9	116.9	427.5
Lào Cai	103,252	88,074	413.81	64.60	23.63	19.35	327.76	2.05	3.5	32.7	4.1		17.2	123.6	422.5
Yên Bái	145,824	122,098	584.25	64.74	27.46	43.14	474.74	1.57	4.7	24.9	11.2		20.5	102.3	426.8
Thái Nguyên	223,755	172,515	293.38	64.85	48.03	44.43	179.81	4.19	8.1	18.6	18.6		30.8	73.9	516.6
Lạng Sơn	137,758	120,373	667.15	75.75	41.98	30.95	559.17	1.18	5.7	20.9	0.9		38.0	132.4	333.2
Bắc Giang	374,008	264,573	273.86	78.67	71.63	48.59	140.75	5.66	12.8	10.8	0.5		139.1	74.7	1,168.2
Quảng Ninh	139,108	82,352	460.12	35.66	28.53	15.23	388.4	20.81	5.0	6.3	1.2		21.7	56.6	330.8
Phú Thọ	292,531	200,471	282.16	57.09	45.53	41.67	178.34	4.99	7.9	21.4	15.9		100.1	77.3	658.7
Điện Biên	86,069	78,667	758.05	143.38	60.82	11.17	602.48	0.97	5.4	29.8	0.5	3.7	40.4	113.4	289.3
Lai Châu	62,270	57,425	490.94	75.94	33.25	13.18	401.24	0.54	3.3	20.0	2.8		14.9	96.0	203.9
Sơn La	201,985	185,786	888.41	226.01	37.27	35.43	624.38	2.45	5.0	127.5	3.3	7.2	188.0	166.1	544.3
Hoà Bình	162,114	130,956	352.92	53.77	29.86	11.54	285.87	1.59	4.6	36.8	2.2	0.1	66.8	110.4	435.3

Source: GSO (2011)

G.2. Average of cropland, crop area and livestock head per household

Province	Total cropland	Cultivated area (ha/hh)				Livestock (head/hh)		
		Upland rice	Maize	Tea	Coffee	Cattle	Buffalo	Pig
Country	1.06	0.01	0.12	0.01	0.07	0.57	0.28	2.84
NMR	0.83	0.04	0.25	0.05	0.01	0.49	0.80	3.40
Hà Giang	1.28	0.04	0.42	0.16		0.86	1.31	3.86
Cao Bằng	1.13	0.04	0.47	0.00		1.47	1.22	4.24
Bắc Kạn	0.70	0.05	0.32	0.05		0.43	1.16	3.51
Tuyên Quang	0.63	0.04	0.13	0.06		0.16	0.89	3.26
Lào Cai	0.95	0.04	0.37	0.05		0.20	1.40	4.80
Yên Bái	0.88	0.04	0.20	0.09		0.17	0.84	3.50
Thái Nguyên	0.63	0.05	0.11	0.11		0.18	0.43	2.99
Lạng Sơn	0.89	0.05	0.17	0.01		0.32	1.10	2.77
Bắc Giang	0.48	0.05	0.04	0.00		0.53	0.28	4.42
Quảng Ninh	0.62	0.06	0.08	0.01		0.26	0.69	4.02
Phú Thọ	0.49	0.04	0.11	0.08		0.50	0.39	3.29
Điện Biên	1.96	0.07	0.38	0.01	0.05	0.51	1.44	3.68
Lai Châu	1.55	0.06	0.35	0.05		0.26	1.67	3.55

Sơn La	1.41	0.03	0.69	0.02	0.04	1.01	0.89	2.93
Hoà Bình	0.50	0.04	0.28	0.02	0.00	0.51	0.84	3.32

Source: GSO (2011)

G.3. Detail of simulating net income by representative farms

Scenario 1	Total	Upland rice	Maize	Tea	Coffee	Cattle	Buffalo	Pig
Farm 1	-90.7	-51.0	2.0		0.0	8.5	5.5	-55.7
Farm 2	-85.2	-54.5	5.2		-1.9	18.7	7.2	-59.9
Farm 3	-94.7	-64.3	7.1		-2.4	23.0	10.5	-68.6
Scenario 2								
Farm 1	-88.2	-51.0	2.0	2.5	0.0	8.5	5.5	-55.7
Farm 2	-69.2	-54.5	5.2	16.0	-1.9	18.7	7.2	-59.9
Farm 3	-67.3	-64.3	7.1	27.4	-2.4	23.0	10.5	-68.6
Scenario 3								
Farm 1	-86.3	-51.0	2.0	4.4	0.0	8.5	5.5	-55.7
Farm 2	-57.2	-54.5	5.2	28.0	-1.9	18.7	7.2	-59.9
Farm 3	-46.8	-64.3	7.1	48.0	-2.4	23.0	10.5	-68.6
Scenario 4								
Farm 1	-73.6	-51.0	14.3	4.4	0.4	8.5	5.5	-55.7
Farm 2	7.8	-54.5	37.2	28.0	31.1	18.7	7.2	-59.9
Farm 3	36.6	-64.3	50.2	48.0	37.8	23.0	10.5	-68.6

Source: Own elaborations

G.4. Detail of simulating family labor by representative farms

Scenario 1	Total	Upland rice	Maize	Tea	Coffee	Cattle	Buffalo	Pig
Farm 1	92.6	13.6	19.3		0.1	3.5	14.4	41.7
Farm 2	144.8	14.5	50.3		8.8	7.6	18.8	44.9
Farm 3	183.7	17.2	67.8		10.7	9.3	27.4	51.3
Scenario 2								
Farm 1	94.1	13.6	19.3	1.5	0.1	3.5	14.4	41.7
Farm 2	154.5	14.5	50.3	9.6	8.8	7.6	18.8	44.9
Farm 3	200.2	17.2	67.8	16.5	10.7	9.3	27.4	51.3
Scenario 3								
Farm 1	94.5	13.6	19.3	1.8	0.1	3.5	14.4	41.7
Farm 2	156.5	14.5	50.3	11.7	8.8	7.6	18.8	44.9
Farm 3	203.7	17.2	67.8	20.0	10.7	9.3	27.4	51.3
Scenario 4								
Farm 1	90.8	13.6	15.6	1.8	0.1	3.5	14.4	41.7
Farm 2	148.9	14.5	40.7	11.7	10.7	7.6	18.8	44.9
Farm 3	193.2	17.2	54.9	20.0	13.0	9.3	27.4	51.3

Source: Own elaborations

APPENDIX H. PARTIAL CARBON FOOTPRINT

H.1. Shan tea stands by tree diameter and commune in Lao Cai Province

District and commune	Total (tree)	Diameter class (cm)					
		< 10	11-20	21-30	31-40	41-50	> 51
Prov. total	*846,160*	*204,921*	*466,787*	*116,270*	*38,852*	*17,210*	*2,120*
Si Ma Cai Dist.	*129,260*	*35,670*	*59,040*	*26,800*	*6,430*	*1,250*	*70*
Lung Sui	12,460	3,100	6,050	2,100	1,180	30	
Quan Than San	52,000	15,500	25,500	7,690	2,740	550	20
Can Ho	1,490	430	800	230	30		
Man Than	7,930	2,650	3,450	1,540	270	20	
Sin Cheng	47,420	12,200	20,020	13,470	1,460	270	
Nan Sin	5,000	970	1,900	1,020	680	380	50
Thao Chu Phin	2,960	820	1,320	750	70		
Bac Ha Dist.	*408,510*	*96,090*	*255,488*	*36,520*	*12,442*	*7,370*	*600*
Hoang Thu Pho	24,710	6,600	9,080	4,830	2,190	1,890	120
Ta Van Chu	6,820	1,200	4,030	1,170	390	30	
Ban Pho	1,640	470	810	320	40		
Ban Lien	368,550	85,400	238,528	28,960	9,762	5,420	480
Ta Cu Ty	6,790	2,420	3,040	1,240	60	30	
Muong Khuong Dist.	*159,690*	*30,680*	*79,630*	*30,470*	*10,990*	*6,630*	*1,290*
Nam Chay	3,100	760	2,090	210	40		
Thanh Binh	2,650	870	1,550	230			
Cao Son	8,350	2,200	5,260	690	140	60	
La Pan Tan	16,390	4,500	8,720	2,560	580	30	
Ta Thang	129,200	22,350	62,010	26,780	10,230	6,540	1,290
Bat Xat Dict.	*99,050*	*31,127*	*42,883*	*17,810*	*5,660*	*1,480*	*90*
A Mu Sung	73,200	24,350	30,290	13,780	3,720	970	90
Nam Chac	2,320	630	1,390	240	60		
Y Ty	2,780	765	1,785	220	10		
Den Sang	17,880	4,563	7,577	3,360	1,870	510	
Sang Ma Sao	1,900	543	1,207	150			
Den Thang	970	276	634	60			
Sa Pa Dist.	*49,650*	*11,354*	*29,746*	*4,670*	*3,330*	*480*	*70*
Nam Cang	3,250	890	2,250	110			
Ban Khoang	4,100	1,240	2,210	650			
Ta Giang Phinh	25,700	4,567	14,793	2,830	2,960	480	70
Trung Chai	4,650	985	3,335	330			
Ta Phin	3,150	1,260	1,740	150			
Sa Pa	2,050	450	1,520	80			
San Sa Ho	4,640	1,220	2,600	450	370		
Ban Ho	2,110	742	1,298	70			

Source: Lao Cai DARD (2013)

H.2. Inventory data in 4 production systems

H.2.1. Conventional tea production (Yen Bai, Son La and Dien Bien)

Inventory data	Unit	Value	Elaboration/ source
Pre-farm:			
Urea	kg/ha	465	FAO and NOMAFSI, 2014
NPK 5:10:3	kg/ha	575	FAO and NOMAFSI, 2014
N in NPK	kg/ha	28.75	FAO and NOMAFSI, 2014
P2O5 in NPK	kg/ha	57.5	FAO and NOMAFSI, 2014
K2O in NPK	kg/ha	17.25	FAO and NOMAFSI, 2014
Pesticides, fungicides, herbicides	kg/ha	12.96	FAO and NOMAFSI, 2014 and Field survey 2014
Gasoline	L/ha	18.63	
Diesel oil	L/ha		
On-farm:			
N-fertilizer application	kg/ha	242.65	
Gasoline for transport		13.6	
Distance (one way)	km	2.5	Assumption
Fuel consumption	L/100 km	2.5	Motorcycle
Load per motorcycle	kg	70	Assumption
Gasoline for pruning	L/ha	5	0.5 litter for 1000 m2
Yield output	ton/ha	7.6	

H.2.2. Mini-terracing tea production (Yen Bai, Son La and Dien Bien)

Inventory data	Unit	Value	Elaboration/ source
Pre-farm:			
Urea	kg/ha	321	FAO and NOMAFSI, 2014
NPK 5:10:3	kg/ha	616	FAO and NOMAFSI, 2014
N in NPK	kg/ha	30.8	FAO and NOMAFSI, 2014
P2O5 in NPK	kg/ha	61.6	FAO and NOMAFSI, 2014
K2O in NPK	kg/ha	18.48	FAO and NOMAFSI, 2014
Pesticides, fungicides, herbicides	kg/ha	15.47	FAO and NOMAFSI, 2014 and Field survey 2014
Gasoline	L/ha	21.27	
Diesel oil	L/ha		
On-farm:			
N-fertilizer application	kg/ha	178.46	
Gasoline for transport		16.3	
Distance (one way)	km	2.5	Assumption
Fuel consumption	L/100 km	2.5	Motorcycle
Load per motorcycle	kg	70	Assumption
Gasoline for pruning	L/ha	5	0.5 litter for 1000 m2
Yield output	ton/ha	9.1	

H.2.3. Natural Organic Shan tea (Suoi Bu Commune, Van Chan - Yen Bai)

Inventory data	Unit	Value	Elaboration/ source
Pre-farm:			
Gasoline	L/ha	5.10	Value taken from on-farm
Diesel oil	L/ha		
On-farm:			

Gasoline for transportation fresh tea to processor		5.10	Farmer do own transportation, 1/2 mass production by motorcycle and 1/2 mass production by truck
Suoi Bu Commune:		2.25	
Distance (one way)	km	2.5	Interviews with processor and observation
Fuel consumption	L/100 km	2.5	Motorcycle in upland road conditions
Load per motocycle	kg	75	Interviews with processor and observation
Yield per ha	ton/ha	1.35	Focus group and farmer interviews
Other communes:		2.85	
Distance (one way)	km	22.5	Interviews with processor and observation
Fuel (diesel) consumption	L/100 km	7.5	Interviews with processor and observation
Load per light truck (6 wheel, 1.4 tons)	ton	1.2	Interviews with processor and observation
Yield output	ton/ha	1.35	Focus group and farmer interviews

H.2.4. Natural Organic Shan tea (Tien Nguyen, Quang Binh - Ha Giang)

Inventory data	Unit	Value	Elaboration/ source
Pre-farm:			
Gasoline	L/ha	4.82	
Diesel oil	L/ha		
On-farm:			
Gasoline for transportation fresh tea to processor	L/ha	4.82	Producers do transportation
Distance (one way)	km	4.5	Field data, averaged
Fuel consumption	L/100 km	2.5	Interviewing farmer, technical staff
Load per motocycle	kg	70	Interviewing farmer
Yield output	ton/ha	1.5	Focus group and farmer interviews

H.3. Averaged of inventory data on emission sources used in CFP study

Emission source	Unit	Conv.	MTERR	Organic
Pre-farm:				
Urea	kg/ha	465	321	
NPK 5:10:3	kg/ha	575	616	
N in NPK	kg/ha	28.75	30.8	
P2O5 in NPK	kg/ha	57.5	61.6	
K2O in NPK	kg/ha	17.3	18.5	
Pesticides, fungicides, herbicides	kg/ha	13.0	15.5	
Gasoline	L/ha	18.6	21.3	5.0
On-farm:				
N-fertilizer application	kg N/ha	242.7	178.5	
Gasoline for transportation	L/ha	13.6	16.3	5.0
Gasoline for pruning	L/ha	5	5	

Conv. = Conventional tea, various cultivars, age unspecified, coefficients averaged from Son La, Dien Bien & Yen Bai

MTERR = Mini-terracing tea, various cultivars, age unspecified, coefficients avearged from Son La, Dien Bien & Yen Bai

Organic = Natural Organic Shan in Yen Bai and Ha Giang (ancient, mixed ages)