DISSERTATION

AN INTEGRATED ECO-SOCIO-ECONOMIC ANALYSIS OF FOREST TRANSITION AND FOREST RESTORATION IN VIETNAM

Submitted by

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ABSTRACT

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IN VIETNAM

Forests provide numerous benefits to human well-being, so changes in forest cover have large societal impacts from local to global scales. Several studies in Vietnam and elsewhere have found single solutions for increasing forest cover. However, a comprehensive solution for harnessing forest restoration to satisfy growing demands for sustainable global development that improves rural community livelihood, enhances biodiversity and environmental services, and mitigates climate change is lacking. This dissertation focuses on obtaining a deeper understanding of forest transition, forest restoration, and their proximate drivers as well as trade-offs of land use in upland forests in Vietnam.

This dissertation is a collection of four independent studies. The first study quantified the drivers of deforestation and forest degradation at a national scale in Vietnam. Results show that around 1.77 and 0.65 million hectares of forests were lost or degraded, respectively, between 2000 and 2010. Deforestation and forest degradation declined in Vietnam between 2000 and 2010, but these processes remain significant. The extent and magnitude of deforestation and degradation vary across provinces and were most notable in the north central, northeast, central highland, and northwest areas of the nation. Poverty, initial forest cover, governance, and population growth were the top drivers of deforestation and degradation.

The second study investigated the extent of forest restoration and its proximate drivers at the local-communal scale in Vietnam's Dien Bien Province. Geographic information system (GIS) tools, a structural regression model based on forest cover maps, and a field survey were employed while numerous socio-economic variables that were potentially associated with forest restoration were examined. I found that around 118,000 hectares of forests were restored between 1990 and 2010. Restored forest comprised the largest share (above 84%) of total forest gain and this share increased from 1990-2000 to 2000-2010. Expansion of restored forest was mainly driven by the presence of migration, lower population density, higher income, and the implementation of forestry policies.

The third study explored the willingness of urban households to support forest restoration in Vietnam. I randomly surveyed over 200 households in the capital city Hanoi and a maximum likelihood estimator model was used to obtain the parameters of a model to quantify willingness-to-pay (WTP) for a program of forest restoration. Over forty percent of the households surveyed were willing to pay for forest restoration. As well as quantified determinants of WTP, my findings suggest that either improving households' income and educational level or focusing on females in the family may represent untapped sources of restoration funding among urban households.

Finally, in a fourth study, the potentials and challenges of climate change mitigation programs in the north central region of Vietnam demonstrate possible scenarios associated with many levels of uncertainty. The role of plantation forests in total household income was quantified, trade-offs between shifting cultivation and plantation forests were analyzed and the factor groups that constrain plantation forest expansion were highlighted. My empirical results offer several important policy implications, not only for forest restoration practices as part of forest-based climate change mitigation programs but also for sustainable mountainous rural livelihood development in Vietnam and beyond.

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DEDICATION

To my parents, wife, and sons. They instilled in me the virtues of patience, industriousness, and grit in striving to achieve my goals.

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Chapter 1- GENERAL INTRODUCTION

The planet we live on is in one of its most sensitive states ever. Earth temperatures have warmed by almost 0.6 degrees Celsius over the past three decades and the warming will likely surpass 2 degrees Celsius by the end of the century (Hansen et al., 2006; IPCC, 2007; WB, 2010). The World Bank has reported that climate change will be one of the greatest challenges for humans in the 21st century (WB, 2010). Over the past decade, the international community and scientists have spent a great amount of time and effort seeking solutions to combat this growing challenge (Damtoft et al., 2008; Hardy, 2003; IPCC, 2014a, 2014b). More than 15,000 scientists from 184 countries have recently signed a rescue call to protect the earth with a sharp warning that our planet's current state of climate change will not be reversed without appropriate timely interference (Ripple et al., 2017).

The urgency of finding resolutions in response to this pressing threat has led to a number of possible solutions, and one is to use forests to mitigate climate change (Canadell and Raupach, 2008; Griscom et al., 2017; IPCC, 2014a). Forests have long been known as a living resource for mankind (food, medicine, shelter, fuel, etc.), and thanks to its capacity to absorb CO_2 in the atmosphere through photosynthesis under sun light, forests could help combat climate change (Canadell and Raupach, 2008; Gorte, 2009; Kimmins, 2004). The world's forests offer the potential for offsetting emissions by up to 30 percent, while a reforestation strategy could offer one of the strongest natural solutions to climate change (Canadell and Raupach, 2008; Griscom et al., 2017). Improved forests thus would have large societal impacts from the local to the global scale.

The term “forest transition” was introduced more than two decades ago, and it has recently become an even more important term in the context of climate change. This term refers to the phenomenon of changing from deforestation to reforestation (Mather, 1992b; Meyfroidt and Lambin, 2011b). Forest transition offers policy implications for forest management in many countries around the world. A better understanding of the processes of forest expansion and forest transition in developing countries that have achieved forest restoration could help accelerate forest transition in other countries.

Vietnam’s forests have undergone a forest transition process over the past two decades (Hosonuma et al., 2012; Meyfroidt and Lambin, 2008b). In the broad view, this transition in Vietnam was driven by scarcity and economics, but, it is the result of a series of macro policies (economic and political reform under “DOI MOI” in 1986, land reform under Land Law1993, etc.) and many years of persistence in comprehensive forestry-rural development policies (Forest Development and Protection Law 2004; Forestland Allocation Policy; Five Million Hectares of Reforestation Program 1998-2010; National Targeted Program on Poverty Reduction and Employment, etc.). Despite the successes achieved in the past, the requirements for expanding and harnessing forests to meet the growing need for livelihood improvement, biodiversity conservation, and climate change mitigation in the coming years is high and requires a constantly improving policy system. Therefore, comprehensive research on forest transition, forest restoration, and land use options for climate change mitigation programs are needed to provide the scientific community, policy-makers, and the public with information to make useful recommendations in Vietnam and beyond.

1.1. Research objectives

This dissertation contains four main chapters, consisting of four independently designed studies. The general objective of these studies was to improve the understanding of forest transition and forest restoration in Vietnam. Specific objectives include:

(a) to quantify the extent of deforestation and forest degradation at a national scale in Vietnam; statistically test changes in deforestation and forest degradation from 2000 to 2010; and develop a regression tree model and a structural model to quantify the proximate drivers influencing the changes in deforestation and forest degradation.

(b) to determine the extent of restored forests at the local-communal scale in Dien Bien Province; statistically test the changes in forest restoration from1990 to 2010; and develop a structural model to quantify the proximate drivers influencing changes in forest restoration.

(c) to estimate the willingness of urban citizens in Hanoi to pay for forest restoration programs; and to determine factors influencing this willingness to pay.

(d) to measure the contribution of plantation forests to total household income; use a total economic value approach and a cost-benefit analysis tool to measure the total benefit of shifting cultivation and plantations under possible scenarios associated with many levels of uncertainty.

1.2. Dissertation structure

The dissertation is organized in six chapters, including this introduction and conclusions in the final chapter. The four primary chapters corresponding to the four objectives listed above have been or will be submitted for publication.

Chapter 2 quantifies the drivers of deforestation and forest degradation at a national scale in Vietnam. Deforestation and forest degradation between 2000 and 2010 were determined by a forest distribution map. The trend in deforestation and forest degradation from 2000 to 2010 was tested. The extent and magnitude of deforestation and degradation across provinces and regions (north central, northeast, central highland, and northwest) was quantified. Numerous potential factors influencing deforestation and forest degradation were examined via a regression tree model and a structural model.

Chapter 3 investigates the extent of a restored forest and its proximate drivers at the local-communal scale in Dien Bien Province. Geographic information system (GIS) tools were used to extract restored forest data and a structural regression model was used to quantify many socio-economic variables (i.e., migration, population density, income, forestry policies, etc.) that are potentially associated with forest restoration.

Chapter 4 explores the willingness of urban households to support forest restoration in Vietnam. Using a contingent valuation method (CVM), a payment card response format was used to elicit respondents' willingness to pay for forest restoration. A maximum likelihood estimator model was used to obtain the parameters of my model and quantify willingness to pay (WTP) for a program of forest restoration. Additionally, the determinants of WTP were quantified.

Chapter 5 assesses the potentials and challenges of climate change mitigation programs in north central Vietnam through three key components. The first was the economic role of plantation forests in household livelihood. The second involved trade-offs between shifting cultivation and plantation forests under cases associated with different uncertainties. Both absolute and relative advantage of land use options were considered and analyzed. The final component includes the factor groups that hamper forest planting practices at the household level.

1.3. Potential contribution of the study

This is one of the first comprehensive studies of deforestation, forest degradation, forest restoration, willingness to pay for forest restoration, and climate change mitigation programs associated with land use in the upland forests of Vietnam. The goal of the study was to extend and improve our understanding of forest transition and forest restoration with key potential contributions to scientific theory and practical applications, as follows.

First, the study provides applications for designing appropriate policies not only for Vietnam but for many poor and developing countries, where forest transition has just begun, to accelerate forest transition and foster synergies with livelihood improvements. The relation between forest conservation and livelihood improvement is generally marked by many trade-offs, making it complicated to achieve both goals together. Observations from my study area could demonstrate that it is possible to design policies that foster synergies between these two goals, at least to some extent, by testing the occurrence of forest transition that co-occurs with significant achievements in economic growth and poverty reduction.

Second, the study provides applications for designing strategies for sustainable rural development that embrace the goals of conserving and restoring forests, and improving rural livelihood, food security, and rural environments through national and sub-national policies and programs. Furthermore, it is notable that forestland reform is hypothesized to be a powerful part of a portfolio of policies since it could facilitate sustainable rural development in many dimensions such as land tenure, equity, and equal access to land resources.

Third, a society's willingness to pay for forest restoration would be paramount not only because it reflects citizens' perception and participation in forest restoration, but it could provide the financial support that would secure long-term success in forest restoration projects. This study could provide policy implications for improved access to untapped sources of forest restoration funding among urban households.

Fourth, this study provides information for designing appropriate policies for climate change mitigation programs while including farmers' demands for food security and income in the portfolio of policies. This is because I considered the contribution of forests to farmers' livelihood to be trade-offs between shifting cultivation and forest plantations.

Finally, this study provides practical applications regarding appropriate model formulation to handle the complex interaction of the processes of forest transition and forest restoration within land use science. This is because I combined a regression tree model and a structural model with cross-sectional data to quantify drivers of deforestation and forest degradation, while I used a structural model with a unique panel dataset to quantify drivers of forest restoration.

Chapter 2 - DRIVERS OF DEFORESTATION AND FOREST DEGRADATION IN VIETNAM: AN EXPLORATORY ANALYSIS AT THE NATIONAL LEVEL

Summary

Climate change is a pressing global issue and it negatively affects many developing countries, including Vietnam. To help Vietnam effectively respond to this pressing challenge, the country has recently introduced a major program for reducing carbon emissions arising from deforestation and forest degradation, fostering conservation, managing forests sustainably, and enhancing forest carbon stocks (REDD+). REDD+ aims to reduce carbon emissions by preserving forest carbon stocks, managing forests sustainably, and improving forest carbon stocks through forest restoration. Current policies in Vietnam provide a sound platform for the development of REDD+, and REDD+ can potentially greatly contribute to the reduction of deforestation and forest degradation. However, these policies and the REDD+ program are hindered by limited understanding of the extent of deforestation and forest degradation and their underlying causes. This study employed geographic information system (GIS) tools, a structural regression model (structural model), and a regression tree method to quantify the extent as well as the approximate causes of deforestation and forest degradation in Vietnam. Results show that around 1.77 and 0.65 million hectares of forests were lost and degraded, respectively, between 2000 and 2010. Deforestation and forest degradation were most notable in the north central, northeast, central highland, and northwest areas of the nation. There were several underlying indicators of deforestation and forest degradation including initial forest cover, per capita income, agricultural production, governance, population growth, food, and poverty. Our results illustrate several important policy implications for forest restoration and the REDD+ program in Vietnam: Vietnam

should focus most strongly on reducing poverty, preserving existing forests, improving provincial-level governance, and controlling population growth.

2.1. INTRODUCTION

Land use and land cover change (LULCC), mainly deforestation and forest degradation, are responsible for 17-25% of annual anthropogenic greenhouse gas emissions that are a principal factor in global warming (Bernstein et al., 2008; Le Quéré et al., 2015). Although deforestation and forest degradation have declined, they are still serious in scope and quantity, especially in developing countries (Calle et al., 2016; Hansen et al., 2013; Köthke et al., 2013). Understanding drivers of deforestation and forest degradation is fundamental to and necessary for the development of policies and measures that allow humans to modify current trends in forest activity toward a more climate- and biodiversity-friendly outcome (Hosonuma et al., 2012; Kissinger et al., 2012).

International bodies have developed various policies for reducing carbon emissions related to deforestation and forest degradation. Many challenges remain for implementing programs to reduce forest degradation and deforestation, particularly monitoring projects and improving developing countries' capacity for ensuring compliance (Hosonuma et al., 2012; Kissinger et al., 2012; Pham et al., 2012). Parties to the United Nations Framework Convention on Climate Change (UNFCCC) have developed a mechanism for reducing emissions resulting from deforestation and forest degradation. The UNFCCC has encouraged developing countries to identify drivers of land use change, including deforestation and forest degradation (Hosonuma et al., 2012).

Vietnam has reputation for tropical forest ecosystems with high diversity and uniqueness. Vietnam's forests have undergone a transition from net deforestation to net reforestation since the 1990s (Meyfroidt and Lambin, 2008a). Although forest cover has increased in Vietnam, deforestation and forest degradation continues (JICA, 2012). In the beginning years of the 21st century, Vietnam was one of the top nations for gross tree cover loss (Hansen et al., 2013). How to help control this emerging issue and contribute to climate change mitigation has been a central question for Vietnam recently, motivating this study to determine why forest loss and forest degradation occur and to better understand patterns and intensity of deforestation and forest degradation in Vietnam during the past decade.

In an effort to halt deforestation and forest degradation, Vietnam is participating in the REDD+ (Reducing Emissions from Deforestation and Forest Degradation project, fostering conservation, sustainably managing forests, and improving forest carbon stocks) (Pham et al., 2012). Although current policies in Vietnam have provided a sound platform from which REDD+ can develop, and REDD+ can potentially contribute significantly to initiatives battling deforestation and forest degradation, current policies are incomplete. This is due to lack of information on the extent of forest loss and forest degradation and their drivers on a national scale. Current information on this topic in Vietnam comes mainly from research that was derived from small-scale (e.g., village, commune) (Khang and Bao, 2015; Meyfroidt, 2013; Muller and Zeller, 2002) and annual forest development reports (FSSP, 2014, 2015) that were not adequate to assist in policy formation. In many cases, the current policy is either out of date or incomplete to some degree since the input for policy formulation lacks updated and large-scale (i.e., province-level) information.

In this study, our goal was to overcome those shortcomings by determining the extent of forest loss and forest degradation and their approximate drivers based on cross-province data gathered between 2000 and 2010. To clarify to what extent drivers influence forest loss and forest degradation, we tested some key variables—income, population, poverty, food security, and governance—in a structural model and a regression tree model. We employed an interdisciplinary method that combines GIS tools and econometrics to compute and analyze a newly updated province-scale database.

2.2. METHODS

2.2.1. Conceptual framework

2.2.1.1. Forests

Forests are a central part of terrestrial ecosystems and have been the subject of interest for scholars and scientists around the world. There have been around 1,500 definitions of the term *forest* on many levels, including at the local, state, provincial, national, and international scale (Lund, 2014). Generally, definitions of *forest* are made to fit specific purposes, based on views, concepts, and priorities (Chazdon et al., 2016). In Vietnam, *forest* has been clearly defined and used officially in forest protection and development law for several years. In this study, we adopted the definition presented in Vietnamese Circular Number 34/2009/TT-BNNPTNT. *Forest is an ecological system which mainly consists of long term wood trees, coco species with a height of 5.0 m or more (excluding new plantation forest and mangrove forest), and bamboo species that can provide timber, non-timber forest products, and direct or indirect value such as biodiversity and landscape conservation*. Areas considered to be forests include newly planted forests with woody trees, regenerating forests after harvesting, plantation forests with an average tree height of more than 1.5 m for slow-growing species and more than 3.0 m for fast-growing species with a density of 1,000 trees per hectare or more. Canopy cover of the main tree species of the forest is 10 percent or more. The forest has a minimum block area of 0.5 ha. In the case of trees strips, a minimum width is 20 m and there must be at least 3 rows of trees in a strip. In addition to the term “forest” in legal documents, it is important to define the forest classification system that was developed for forest inventory by the Forest Inventory Planning Institute (FIPI) in 2008. There are 17 land use types in the forest classification system. They are classified into forest vegetation group and non-forest vegetation group. The forest vegetation group includes 12 forest vegetation types such as evergreen forest (rich, medium, poor), rehabilitated forest, deciduous forest, bamboo, mixed bamboo, coniferous forest, mixed evergreen and deciduous, mangrove forest, limestone forest, and plantation forest. The non-forest vegetation group consists of five non-forest land use types: limestone, bare land, water body, residential, and other land (JICA, 2012).

2.2.1.2. Deforestation and forest degradation

Deforestation is a well-defined term that has been widely used for some years. Hosonuma et al., (2012) referred to deforestation as the removal of trees and the conversion from forest vegetation into non-forest vegetation and other land uses such as agriculture, mining, etc. Remarkably, Lund (2014) compiled more than 250 definitions of deforestation and classified them as a change in land cover, a change in land use, or both. He concluded his study by defining deforestation as “the act or process of changing forest land to non-forest land”. In this study, we used the definition proposed by FAO (2010): *Deforestation is the transformation from forested land to non-forested land during a certain time*.

Forest degradation is more difficult to define, as it may refer to several dimensions in terms of state and process that are difficult to observe and quantify. Various definitions of forest degradation have recently been proposed (FAO, 2011; IPCC, 2003a; ITTO, 2002; Putz and Redford, 2010; Thompson et al., 2013). Thompson et al. (2013) proposed five criteria with which to assess the degree of forest degradation such as productive functions, biodiversity, unusual disturbances, protective functions, and carbon storage. In this study, we define forest degradation as a decline in forest production capacity that is indicated by several measures including (i) forest quality (i.e., reduced tree density), (ii) carbon stock (i.e., reduced carbon stocks), and (iii) type of forest vegetation (i.e., evergreen forest turns into bamboo).

2.2.1.3. Theoretical model of deforestation and forest degradation

There are many models of drivers of deforestation in the literature. In this study, we adapted the widely-used framework for tropical forest deforestation proposed by Kaimowitz and Angelsen (1998). This framework is built on three levels of drivers that are associated with deforestation and forest degradation. The first level is agents of deforestation and forest degradation (i.e. small farmers, ranchers, plantations, loggers, etc.). The decision parameters and agent characteristics belongs to the second level while the last level is those factors that can be considered the underlying drivers of deforestation and forest degradation such as the broader economic, political, cultural, demographic, and technological forces, which determine the agents' characteristics and decision parameters).

To build a general model of deforestation and forest degradation in Vietnam, we employed a literature review-based approach. We first reviewed numerous relevant publications on deforestation and forest degradation and their models, and we then narrowed down to several publications that are closely associated with Vietnam. There are many factors reported to influence forest loss and forest degradation; we ultimately selected seven groups of factors that can affect forest loss and forest degradation in Vietnam. Those groups include agricultural production, income, poverty, population, forest capital, food, and province-scale governance. The following is our justification for selecting these factors.

As in many developing countries, the expansion of agricultural land is a principal driver of deforestation and forest degradation, driven by continuous increase in demand for agricultural products. Up to now, the majority of agricultural land has been transformed from previous forestland (DeFries et al., 2010; Kissinger et al., 2012; Meyfroidt et al., 2013). Agricultural expansion occurs for both subsistence-oriented production, such as through shifting cultivation, as well as for commercial agriculture destined both for domestic and international markets. Therefore, agricultural production is assumed to play an important role in promoting deforestation and forest degradation in Vietnam.

The causal relationship between income and deforestation has been documented in several studies (Kaimowitz and Angelsen, 1998). As income grows, investment in forests increases as well. As a result, newly planted forests can compensate for forest loss (Bhattarai and Hammig, 2001). In Vietnam, where per capita income is increasing, and current programs of eradicating hunger and alleviating poverty are still in progress, income was included in our deforestation and forest degradation model.

Population is a underlying driver of deforestation (Chakravarty et al., 2012; DeFries et al., 2010; Kaimowitz and Angelsen, 1998; Kissinger et al., 2012). This is understandable; population growth increases the demand for natural resources extraction, including forests. Further, in-migration often occurs in the mountainous areas where forest loss often takes place at the highest level. This was often seen in Vietnam. Hence, population density is a variable in our model.

Income and poverty are relatively closely correlated. Although the relation between income and forest cover is often more ambiguous and complex (Barbier et al., 2017; Chowdhury and Moran, 2012), in some cases, higher income may provide a stronger incentive to afforest (Kaimowitz and Angelsen, 1998) while in other cases, a higher poverty rate promotes the scope and rate of deforestation (Chakravarty et al., 2012). Vietnam has achieved considerable improvement in poverty reduction but the current poverty rate is still high (WB, 2012). Therefore, we took poverty into account in our model of deforestation and forest degradation in Vietnam.

Forest resources can be described through a spatial scale (i.e., forest distribution), quantity (i.e., forest cover rate), and quality (i.e., biomass or carbon stock). Forests are also associated with ecological-socioeconomic factors such as soil quality, climate conditions, and management factors. To some extent forest distribution or the scale of forest stock can be a factor that considerably affects deforestation (i.e., a larger area of forest or rich forest might be at greater risk of illegal logging from local and outside people). In contrast, smaller or more degraded forest resources can induce a stronger protection of the remaining forests or actions to replenish them (Barbier et al., 2017; Hyde et al., 1996; Meyfroidt, 2013). Therefore, forest resource can be regarded as an implicit variable of the model of deforestation and forest degradation in Vietnam.

Food as a variable refers to the outcome of agricultural cultivation activities associated with agricultural expansion and intensification that can affect deforestation (Meyfroidt et al., 2013; Shriar, 2002). Food security has been an important issue in the 21st century not only for poor countries but for developing countries, and Vietnam is no exception (Godfray et al., 2010). Thus, we assume that production of cereal crops might be a strong variable with its positive effect on the model of deforestation and forest degradation in Vietnam.

Finally, we considered province-level governance (PLG) in developing our model. It has been widely acknowledged that poor governance is closely linked to corruption that assists illegal forest practices. Illegal forestry activities can be carried out in the form of illegal contracts (i.e. illegal sale of harvesting permits, etc.) between private enterprises and forestry officials (Bofin et al., 2011; Chakravarty et al., 2012; Ernst et al., 2013; Pham et al., 2012). In addition, a stronger "general" governance that encourages business could increase deforestation, while a stronger more specific environmental governance could decrease deforestation (Ceddia et al., 2014). In Vietnam, the government created the composite provincial competitiveness index (PCI) in 2005 to assess and rank the quality of economic governance of provincial authorities to create a favorable business environment for development of the private sector. PCI was formed from 10 different indicators, including entry cost, land access and tenure, transparency, time costs, informal charges, policy bias, proactivity, business support, labor training, legal institutions (VCCI, 2010). Hence, a higher value of PCI could mean stronger province-level governance and therefore less corruption and illegal activities that could affect deforestation and forest degradation in Vietnam, and a better enforcement of measures such as land use planning and policies. Thus, we propose adding PLG to our model. From this discussion, a general model of deforestation and forest degradation is formed as below:

$$\mathrm{DF}_{it}|\mathrm{FD}_{it}|\mathrm{DFD}_{it} = f(\mathrm{AG}_{it}, \mathrm{IN}_{it}, \mathrm{POP}_{it}, \mathrm{PO}_{it}, \mathrm{FD}_{it}, \mathrm{FOR}_{it}, \mathrm{GO}_{it}) \qquad (1)$$

where DF_{it}, FD_{it}, and DFD_{it} are per capita area of deforestation, forest degradation, and total deforestation and forest degradation, respectively. AG_{it} is agricultural production, IN_{it} refers to income, POP_{it} refers to population, PO_{it} denotes poverty, FOR_{it} is initial forests capital, FD_{it} represents food, and GO_{it} denotes governance.

2.2.1.4. A more integrated system of deforestation and forest degradation

As presented above, deforestation and forest degradation can be shaped by seven factors, but in practice, the underlying drivers are complex interactions among social, economic, political, cultural and technological processes that shape the proximate drivers to cause deforestation or forest degradation (Kissinger et al., 2012). To disentangle the complex interactions of the drivers of forest loss and forest degradation, we employed the approach presented by Yin and Xiang (2010) to build up the structural model of drivers of deforestation and forest degradation. However, in addition to components of deforestation and forest degradation (Section 2.1.3), our new integrated model (structural model) adds four components: poverty, income, agriculture, and food. The following is our justification for building up the more integrated model for each these factors.

It is widely acknowledged that poverty can be attributed to different processes and multifaced forces (Philip and Rayhan, 2004). While there is little debate that poverty is inherently linked to income level, poverty can also be associated with locations where land is limited, a lack of skilled labor, and/or relatively undeveloped infrastructure (CIE, 2002; Philip and Rayhan, 2004). Thus, income, available land, labor, and infrastructure are included in our model of poverty.

Income can also be strongly linked to agricultural production value (AG). This is understandable in Vietnam where up to 70% of the population works and lives in rural areas where agriculture production is a main household income (Duong and Izumida, 2002; VUSTA, 2011). Furthermore, income may also be associated with rural to urban migration (MI) as farmers seek better employment and income (Coxhead et al., 2015; Nguyen et al., 2015). It is this migration that can drive change in labor forces (quantity and quality) and employment across a nation. Thus, we take agricultural production value (AG), food production (FO), migration (MI), human resource (HU) into consideration in the model of income (IN).

Agriculture has played a very important role in the economic growth of Vietnam (Dollar, 1994; Duong and Izumida, 2002) even though its share has decreased recently due to the growing role of the industry and service in total national economy (GSO, 2010b, 2015). Agricultural production depends on available land, labor, financial capital, as well as science and technology. Generally speaking, agricultural land is characterized by area while labor is mainly judged by skill of the workforce. Contributions from the science and technology to agricultural production in Vietnam are mediated by agriculture extension services that help farmers improve productivity. Infrastructure is also an important factor influencing agricultural production since it can impact access to information and technology for improving production efficiency. Vietnam has undergone a transition in forests, which is significantly attributed to increased plantation forest area (Meyfroidt and Lambin, 2008a). This forest expansion could imply that higher investment in plantations has been made and that higher value from harvested plantation forests can be achieved, suggesting that plantation forests could contribute to total agricultural production value. Thus, available land, labor, agricultural extension service, infrastructure, and plantation forests are included in our model of agriculture.

Being one output of agricultural production, mathematically, food is a function of land capital, human resource, and agriculture extension service. Additionally, migration could also an underlying driver of food production, so it is also included in the model of food.

Therefore, we propose a more integrated approach (structural model) for modelling deforestation and forest degradation as:

$$\mathrm{DF}_{it}|\mathrm{FD}_{it}|\mathrm{DFD}_{it} = f(\mathrm{AG}_{it}, \mathrm{IN}_{it}, \mathrm{POP}_{it}, \mathrm{PO}_{it}, \mathrm{FD}_{it}, \mathrm{FOR}_{it}, \mathrm{GO}_{it}) \quad (2)$$
$$\mathrm{PO}_{it} = f(\mathrm{IN}_{it},\ \mathrm{LA}_{it}, \mathrm{HU}_{it}, \mathrm{IF}_{it}) \quad (3)$$
$$\mathrm{IN}_{it} = f(\mathrm{MI}_{it}, \mathrm{HU}_{it}, \mathrm{FD}_{it}, \mathrm{AG}_{it}) \quad (4)$$
$$\mathrm{AG}_{it} = f(\mathrm{LA}_{it}, \mathrm{PF}_{it}, \mathrm{KN}_{it}, \mathrm{HU}_{it}, \mathrm{IF}_{it}) \quad (5)$$
$$\mathrm{FD}_{it} = f(\mathrm{LA}_{it}, \mathrm{HU}_{it}, \mathrm{MI}_{it}, \mathrm{KN}_{it}) \quad (6)$$

where $\mathrm{DF}_{it}, \mathrm{FD}_{it}, \mathrm{DFD}_{it}$, PO_{it}, IN_{it}, AG_{it}, FD_{it} are endogenous variables while $\mathrm{LA}_{it}, \mathrm{HU}_{it}, \mathrm{IF}_{it}$, MI_{it}, FD_{it}, PF_{it}, KN_{it} are exogeneous variables. DF_{it}, FD_{it}, and DFD_{it} are per capita area of deforestation, forest degradation, and total deforestation and forest degradation, respectively. AG_{it} is agricultural production, IN_{it} refers to income, POP_{it} refers to population, PO_{it} denotes poverty, FOR_{it} is initial forests capital, FD_{it} represents food, GO_{it} denotes governance, LA_{it} denotes land, HU_{it} is human resource, IF_{it} is infrastructure, MI_{it} is migration, PF_{it} is plantation forests, and KN_{it} denotes agriculture extension service.

2.2.2. Regression models

Appropriate estimation methods and identification are two critical concerns in our empirical analysis. We first considered ordinary least square (OLS) regression since it has been shown to be a well-known model for exploring explanatory relationships between dependent and independent variables. However, this model is only used effectively if certain assumptions or conditions are satisfied (Stock and Watson, 2003).

We then used many steps to arrive at the best model or final model. We began by including all potential variables (Table 2.1) of seven factor groups in the full regression model. The raw data were first checked before coding. We examined possible correlations among variables, and combined them through a multiple linear regression. After eliminating variables that were highly correlated, we used STATA v11 (Stata Corp LP, College Station, TX, USA) to examine model specification. We then formally tested for collinearity using variance inflation factors (VIF) and for heteroscedasticity using the Breusch-Pagan test. Next, we used a stepwise method on SPSS v22 (IBM Corp. Armonk, NY, USA) and an R software package (https://cran.r-project.org) to arrive at the final model, which retains only the statistically significant variables in the model. Finally, we employed STATA v11 to re-examine the reliability and validity of the final model (an excluded model) using the Shapiro-Wilk-Test for normality ($P > 0.1$).

Spatial correlation is an important aspect for regression model formulation since its presence could give rise to bias and inefficiency in OLS estimates (Meyfroidt and Lambin, 2008a). In this study, spatial correlation might be a potentially significant determinant influencing the spatial data-based model (Anselin and Rey, 2014) so we carried out the test of spatial autocorrelation using the Lagrange Multiplier (lag) and Lagrange Multiplier (error) with the support of ARCGIS software and of GEODA v1.6 (http://geodacenter.github.io) (Meyfroidt and

Lambin, 2008b). No spatial autocorrelation was found to exist. We don't know exactly why there is no spatial autocorrelation, but that in any case one should not necessarily lead one to expect spatial autocorrelation to be there.

The OLS model could be susceptible to endogeneity if at least one explanatory variable is correlated with error term of the model, which would render the OLS prediction biased or inconsistent (Stock and Watson, 2003; Yin and Xiang, 2010). To assess this possibility, we repeatedly ran tests for potential variables to determine endogenous and exogenous variables in the model with the support of STATA v11. Specifically, we carefully designed and ran four diagnostic tests, including an endogeneity test, an under-identification test, a weak identification test, and an over-identification test (Shi et al., 2017). It turned out endogeneity occurred in at least one of the explannatory variables (i.e., poverty, income) in the model of deforestation and forest degradation.

Based on the findings of Yin and Xiang (2010) and on the theoretical model presented above, we used simultaneous equations and ran a 3-stage least square (3SLS) model to overcome this endogeneity. This structural model was comprised of five interative components: forest loss and forest degradation, poverty, income, agricultural production, and food. All variables included in our empirical regression models of deforestation and forest degradation in Vietnam between 2000 and 2010 are shown in Figure 2.1.

Variables candidate

POPDEN1 | **POPDEN2**
AGGDP1 | **AGGDP2**
FODCAP1 | **FODCAP2**
INCOME1 | **INCOME2**
POVERTY1 | **POPVERTY2**
CPI1 | **CPI2**
FODLAND1 | **FODLAND2**
AGLAND | FLAND
PFOREST | **COMKN06**
VILKNL | **LITER**
MIGRAT | ALATRAIN06
LATRAIN | **JOBRATIO06**
AGRLAB06 | **POSNET06**
FCOVER | PRINET06

(1)
$$\ln(DF_i|FD_i|DFD_i) = \alpha + \gamma_1 CPI2_i + \gamma_2 POVERTY2 + \gamma_3 INCOME2_i + \gamma_4 FODCAP2_i + \gamma_5 POPDEN2_i + \gamma_6 AGGDP2_i + \gamma_7 FCOVER2_i + \varepsilon_i$$

(2)
$$POVERTY2_i = \alpha + \gamma_1 FODLAND1_i + \gamma_2 INCOME2_i + \gamma_3 JOBRAT06_i + \gamma_4 LITERAT_i + \gamma_5 POSNET_i + \varepsilon_i$$

(3)
$$INCOME2_i = \alpha + \gamma_1 MIGRAT_i + \gamma_2 LITERAT_i + \gamma_3 LATRAIN_i + \gamma_4 \ln AVFODCAP_i + \gamma_5 AGGDP2_i + \varepsilon_i$$

(4)
$$AGGDP2_i = \alpha + \gamma_1 FODLAND1_i + \gamma_2 FODLAND2_i + \gamma_3 PFOREST_i + \gamma_4 COMKN06_i + \gamma_5 LATRAIN_i + \gamma_6 JOBRAT_i + \gamma_7 POSNET_i + \varepsilon_i$$

(5)
$$FODCAP2_i = \alpha + \gamma_1 FODLAND1_i + \gamma_2 FODLAND2_i + \gamma_3 LATRAIN_i + \gamma_4 MIGRAT_i + \gamma_5 COMKN06_i + \varepsilon_i$$

Figure 2.1. Empirical simultaneous equations of deforestation and forest degradation in Vietnam. A total of 29 candidate variables were used for establishing the empirical models (see the details in Table 2.1). After eliminating unsuitable variables, seventeen significant variables remained in the models. DE_i, FD_i, and DFD_i present the dependent variables of model (1), POVERTY2, INCOME2, AGGDP2, FODCAP2 are the dependent variables of model (2), (3), (4), (5), respectively. α is a constant, γ_{1-7} are coefficient corresponding to different independent variables of the models, ε_i is an error term.

Table 2.1. Definition and descriptive statistics for potential variables in the integrated system of deforestation and forest degradation in Vietnam between 2000 and 2010

Variables used in the regression models		Mean	Std. Dev.	Min	Max
Forest resources condition factor					
FCOVER	Forest cover rate (%)	33.31	17.39	1.60	65.70
PFOREST	Percentage of plantation forests relative to total area by province (%)	7.44	5.06	0.53	20.62
Income factor					
INCOM1	Per capita income by province in 2002 (1,000s VND $person^{-1}$ $month^{-1}$)	297.67	86.60	173.10	510.40
INCOM2	Change in per capita income by province in 2002-2010 (%)	282.61	50.17	191.62	435.00
Agricultural production factor					
AGGDP1	Agricultural sector's production value in 2000 (1,000s VND $person^{-1}$ $month^{-1}$)	134.38	90.11	22.92	328.51
AGGDP2	The change in agricultural sector's production value in 2000-2010 (%)	414.70	244.27	1.00	1,289.60
Population density factor					
POPDEN1	Population density (people km^{-1})	233.78	175.39	34.10	805.10
POPDEN2	Change in population density in 2000-2010 by province (%)	12.48	17.89	-4.92	107.89
Poverty factor					
POVERTY1	Poverty rate in 2006	20.41	10.62	0.50	42.90
POVERTY2	Average poverty rate in 2006-2010 by province (%)	19.77	11.18	.50	54.00
Food factor					
FODCAP1	Production of cereals per capita by province in 2000 (kg $person^{-1}$)	392.00	323.38	66.00	1,498.90
FODCAP2	Change in production of cereals per capita by province in 2000-2010 (%)	26.86	34.87	-73.47	151.22
AVFODCAP	Average of production of cereals per capita by province in 2000-2010 (kg $person^{-1}$)	436.81	347.48	57.84	1743.84
Provincial governance factor					
PCI1	Competitive province index in 2006 (points in 100 point-scale)	52.52	7.94	36.76	76.23
PCI2	Competitive province index, on average, in period 2006-2010 (points in 100 point-scale)	55.62	6.62	45.13	73.25

Land factor group					
FODLAND1	Percentage of production area for cereals relative to total area by province in 2000 (%)	26.04	28.93	3.15	100
FODLAND2	Change in production area for cereals by province in 2000-2010 (%)	3.87	26.86	-59.54	90.44
AGLAND	Percentage of agricultural land relative to total area by province (%)	34.80	20.51	5.30	77.00
FLAND	Percentage of forest land relative to total area by province (%)	43.71	24.07	1.30	85.10
Agricultural extension service factor					
COMKN06	Percentage of commune having agricultural extension staff in 2006 by province (%)	72.48	28.61	0.00	100.00
VILKNL06	Percentage of village having agricultural extension staff in 2006 by province (%)	22.47	25.21	0.00	98.94
Human resource factor group					
LITER	Literacy rate of population aged 15 and over in 2006-2010 by province (%)	91.05	7.39	61.03	97.30
MIGRAT	Ratio net of migration to out-migration in 2005-2010 (‰) by province	-1.71	8.02	-10.16	45.78
ALATRAIN06	Percentage of the labor force in rural in 2006 having training (%)	12.59	4.76	5.63	32.40
LATRAIN	Percentage of the labor force having training by province (%)	7.62	3.03	2.60	16.60
JOBRATIO06	Ratio of the labor force of agriculture to non-agriculture in 2006 by province	5.03	4.23	0.67	20.68
AGRLAB06	Percentage of labor force in agriculture in 2006 by province (%)	75.42	13.67	38.92	95.35
Infrastructure factor group					
POSNET06	Percentage of communes having a post-office connected to the internet by province (%)	24.82	21.77	1.32	86.49
PRINET06	Percentage of communes having private internet service by province (%)	29.93	18.49	2.47	83.02

Note: $1 roughly equal 22.7 thousand VND (Vietnamese Dong) as of October 13, 2017.

2.2.3. Classification and regression trees model

We used a structural model to derive the explanatory relationship between deforestation and forest degradation and their drivers. However, some variables of this model were not normally distributed (P <0.01) (Supplementary Table S2.2), which may reduce the quality of the model to some degree. To overcome this concern, we followed the approach presented in the study of DeFries et al. (2010) by using classification and regression trees (CART model) to test robustness of results from the structural model. The rationale for employing this CART model is that it can build trees for predicting continuous (regression) and categorical predictor (classification) variables. The simple interpretation of the results and a nonparametric and nonlinear approach are two of the biggest advantages of the CART model (DeFries et al., 2010; Reich, 2008). We selected the same variables that were significant in the structural model for the regression tree.

2.2.4. Data

Vietnam consists of 63 provinces. The province is the largest administrative unit in Vietnam, followed by the district and commune units. On average, each province has 5.2 thousand km^2. Nghe An is the largest province, with approximately 16.4 thousand km^2, while Bac Ninh is the smallest province, with almost 820 km^2. In this study, we selected the province as the study unit. The administrative management system at the provincial level is relatively complete and systematic and it allow us access to robust data.

Forests are mostly distributed in the northeast, northwest, north central, south central, and central highland regions. Those provinces that have areas of deforestation and forest degradation that are too small or zero were eliminated due to the outlier effect. In addition, those provinces that have incomplete data (i.e., Dien Bien province was established in 2003 and this province lacks forest data for the period 2000-2003) were also excluded. Ultimately, data from 46 provinces were selected for an analysis of forest loss and forest degradation (Supplementary Table S2.1).

Based on our study's objectives and conceptual framework, we obtained socioeconomic and forest data from governmental offices such as the Ministry of Agricultural and Rural Development (MARD), the Ministry of Natural Resources and Environment (MONRE), and the General Statistics Office of Vietnam (GSO). Socioeconomics data collection is conducted and published annually, while forest data inventory is carried out during five-year cycles. 10-years is a common length of time for many studies in similar topic (Meyfroidt and Lambin, 2008a; Viña et al., 2016). For the Vietnam context that it takes one to three years to complete a national forest inventory, so the decadal period represents an appropriate interval and is a long enough period in which to analyze changes in a forest and the drivers of those changes, at least in the short term.

Data on population density, cereal-cultivating land, plantation forests, agricultural production value, and food output were available from 2000 to 2010. Data on agricultural extension services, labor force in agriculture, available post office at commune level, availability of private internet service at commune were available in 2006. Data on income were available from 2002 to 2010 while data on poverty and population literacy were available from 2006 to 2010. Data from the Provincial Competitiveness Index (PCI) were also available from Vietnam Chamber of Commerce and Industry (VCCI) (http://pcivietnam.org) (Table 2.1).

For forest data, we used forest distribution maps from between 2000 and 2010 as input for deriving forest loss and forest degradation. These data were then included in the regression model as dependent variables, calculated as changes in the different forest variable per capita (ha person^{-1}). There are two main reasons for choosing forest loss and forest degradation area per capita instead of percent of area of forest loss and forest degradation per area of the province. First, the percentage of forest loss area per province area has been studied by many authors (Cochard et al., 2016; Khang and Bao, 2015; Meyfroidt and Lambin, 2008a) but the province area differs significantly across the country (Supplementary Table S2.1). Hence, numeric values of "%" do not reflect the full status of the extent of forest change in many provinces. Secondly, it has been widely acknowledged that population is inherently a principal underlying reason for deforestation, but that the relation between population and forest is strongly moderated by multiple factors including socioeconomic and policy factors. Thus, the evolution of deforestation area per capita measures how the pressure from population on forest changes over time due to policies, income, and other factors. However, before having forest distribution maps available for our analysis, we used information from the preparation of forest distribution maps that includes compilation of existing data, identification of gaps, visual interpretation for filling gaps, securing classification consistency, and verification by a third party. We then moved to the step of verification of forest distribution maps. The forest distribution maps from 2000 to 2010 were based on three kinds of forest classification systems: Decision 84, approved in 1984; Cycle-4, which denotes the time between 2005 and 2010, developed in 2008; and Circular 34, approved in 2009. Modification of the maps from 2000 to 2005 in 2011 follows the newest indicator of Cycle-4 based on Circular 34. Because different indicators were used for Decision 84, Cycle-4, and Circular 34 in each time series, the accuracy of the maps was inconsistent. For this reason, a land classification system (LCS) with 17 land use types (LUT) was developed in 2010 to harmonize the three classification systems to create land distribution maps with time consistency among three-time series (2000 and 2010), with the cooperation of the Nordic Agency for Development and Ecology (NORDECO) project and Forest Inventory and Planning Institute (FIPI). Detailed methods are presented in the final report of JICA (2012).

To measure the magnitude of deforestation and forest degradation, ARCGIS v10.2 (ESRI, CA, USA) was employed. We followed the method in JICA (2012) to generate data of deforestation and forest degradation. A map of land use change was created by overlapping two GIS map layers of state of land use in 2000 and 2010. Specifically, each GIS map layer contains 17 kinds of codes corresponding to 17 kinds of land use type. We extracted the forested land by specifying query condition (i.e., Ftype2000: code 1 to 12) in the attribute table of the composite maps. On the same composite map, we extracted non-forest area by specifying query condition (Ftype2010: code 13 to 17). Finally, we used the "intersect" and "dissolve" commands in ARCGIS v10.2 to generate data and a map of deforestation. Similarly, we applied query condition for forest degradation to extract data and a map of forest degradation. After deriving data on deforestation and forest degradation, we employed a non-parametric test to understand the trend in forest loss and forest degradation between 2000-2005 and 2005-2010.

2.3. RESULTS AND DISCUSSIONS

2.3.1. Forest loss and forest degradation

The total area of forest loss and forest degradation in the period 2000-2010 was always smaller than that of the sum of the 2000-2005 and 2005-2010 periods (Table 2.2). This is because some of the deforested area from the first period regrew in the second period. The total area of forest loss and forest degradation was almost 2.4 million ha, accounting for 7.4% of the total land area and 20.1% of the total forest area at the beginning year of the same period of time in the study. The total areas of forest loss and forest degradation were 1.76 million ha and 0.65 million ha, respectively.

Table 2.2. The extent of deforestation and forest degradation by periods in Vietnam in 2000-2010

Period	Unit	Forest loss (DF)		Forest degradation (FD)		Total area of forest loss and forest degradation (DFD)	
		Sampling (n=46)	Nationwide (n=63)	Sampling (n=35)	Nationwide (n=63)	Sampling (n=46)	Nationwide (n=63)
2000-2005	Ha	1,392,674	1,529,931	450,477	460,201	1,837,554	1,990,131
	%	4.86	4.64	1.55	1.4	6.42	6.04
	%	12.40	12.73	3.96	3.83	16.36	16.55
2005-2010	Ha	1,074,772	1,171,165	269,069	269,629	1,335,261	1,440,794
	%	3.74	3.55	0.91	0.82	4.65	4.36
	%	8.60	8.79	2.09	2.02	10.69	10.81
2000-2010	Ha	1,563,974	1,768,171	636,888	652,682	2,200,862	2,420,853
	%	5.46	5.36	2.22	1.98	7.68	7.35
	%	13.92	14.70	5.67	5.43	19.59	20.13

Note: Each period includes three rows. The first row is the area (ha) of forest loss, forest degradation, and total forest loss and forest degradation for 2000-2010. The second row is percent of forest loss, forest degradation, and total area of forest loss and forest degradation for 2000-2010 relative to the total natural area in 2000. The third row is percent of forest loss, forest degradation, and total area of forest loss and forest degradation for 2000-2010 to total area of forest in 2000.

Forests resources are distributed unevenly across Vietnam; deforestation and forest degradation occurred in eight ecoregions (Supplementary Figure S2.1). The north central region exhibited the largest area of deforestation and forest degradation with a total area of 571,000 ha, accounting for 11% of nationwide natural land, followed by the northeast. The central highland is an area of intensive forestry and was ranked the third largest area of deforestation and forest degradation, with 8.4% of the total natural area. The northwest and south-central areas hold fourth and fifth place with 8% and 7.9% of total natural area, respectively. The intensity level of deforestation and forest degradation was reflected throughout the entire area in the rate of forest loss and degradation but also through per capita area of forest loss and degradation. In a two-dimensional graph of the rate of deforestation and forest degradation versus per capita area of deforestation and forest degradation, the provinces of Binh Phuoc (south central), Quang Tri (north central), and Lao Cai (northwest) show the highest levels of intensity of deforestation and forest degradation (Figure 2.2-2.4). For a two-dimensional graph of the area of deforestation in 2000-

2005 versus 2005-2010, the provinces of Son La (northwest) and Nghe An (north central) had the highest levels of deforestation and forest degradation. This finding is important because it confirms that deforestation and forest degradation took place in the north central, south central, and northwest regions, where the poverty rate was extremely high (Cochard et al., 2016). The relationship between poverty and deforestation is examined in the next section of this study.

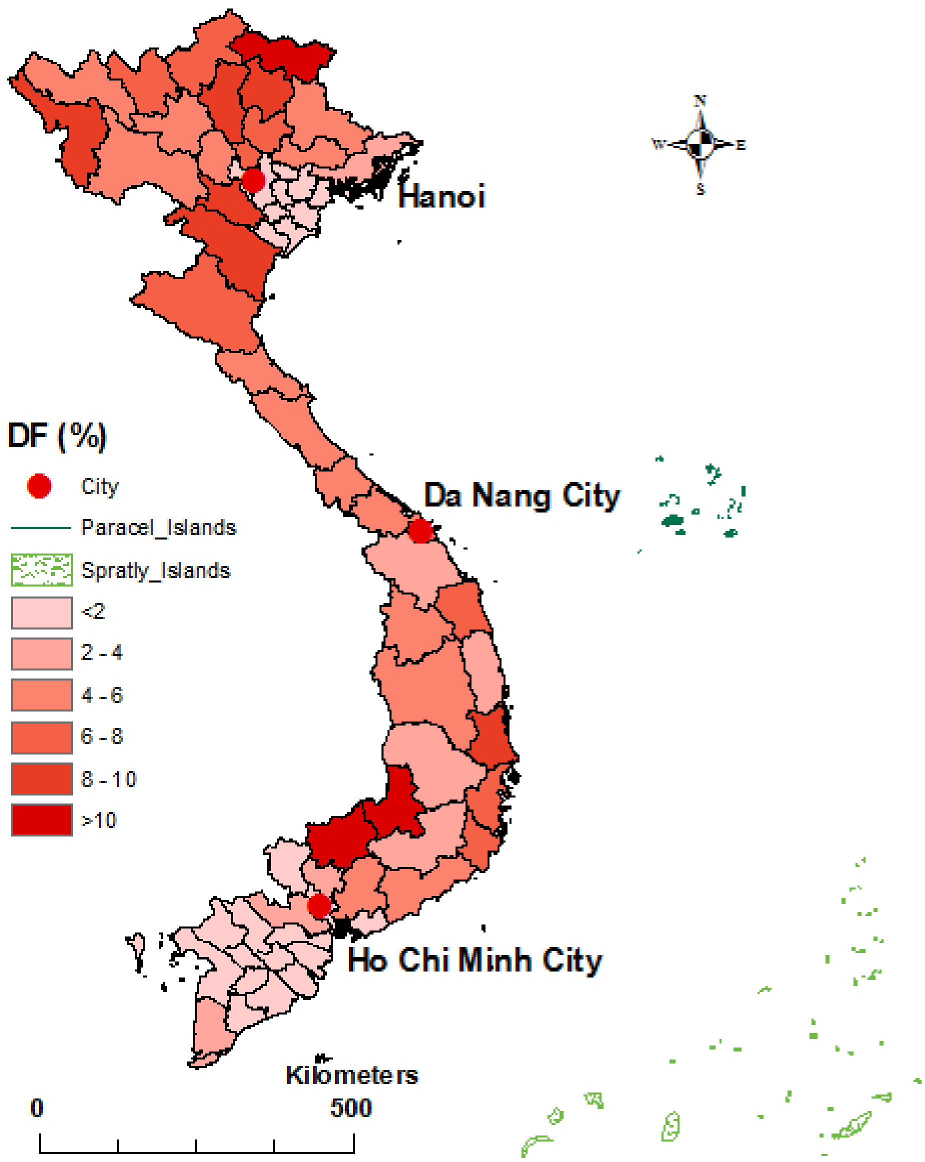


Figure 2.2. Map of deforestation (DF) by province in Vietnam between 2000 and 2010

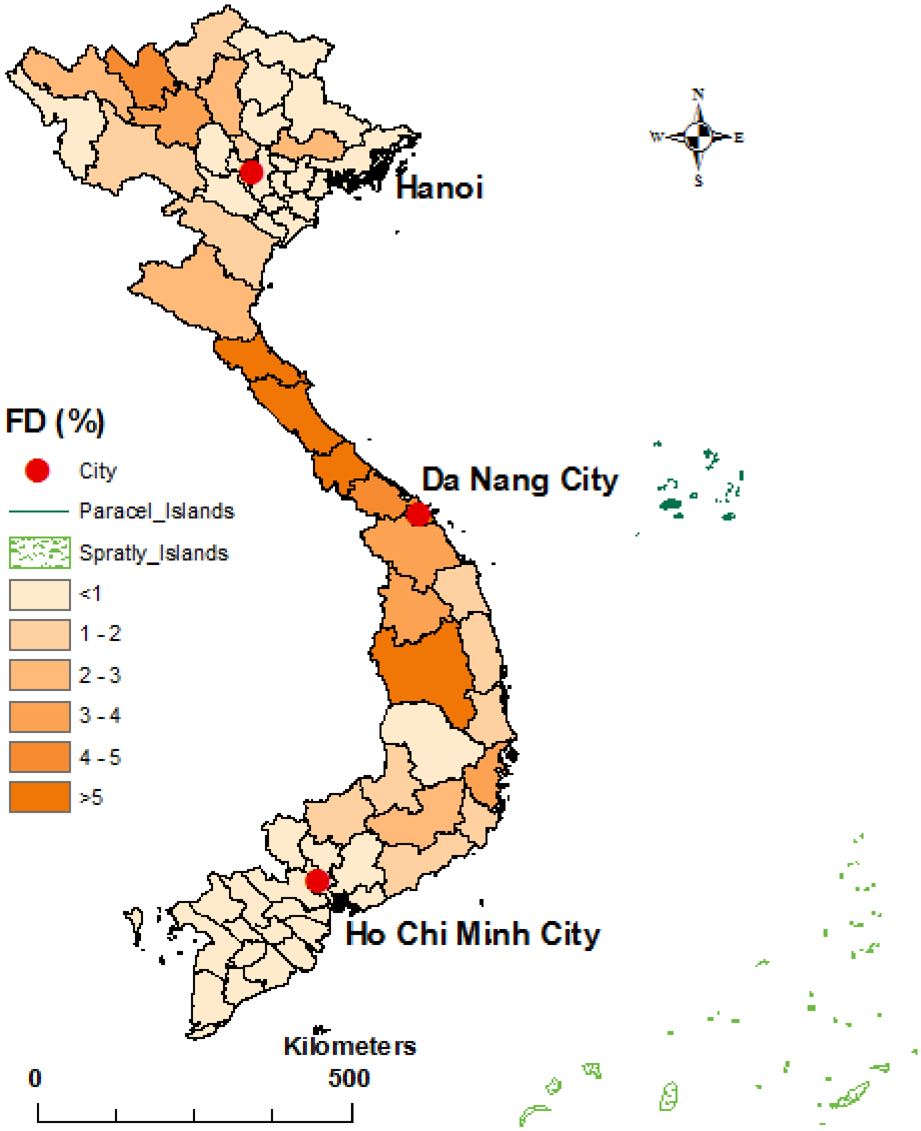


Figure 2.3. Map of forest degradation (FD) by province in Vietnam between 2000 and 2010

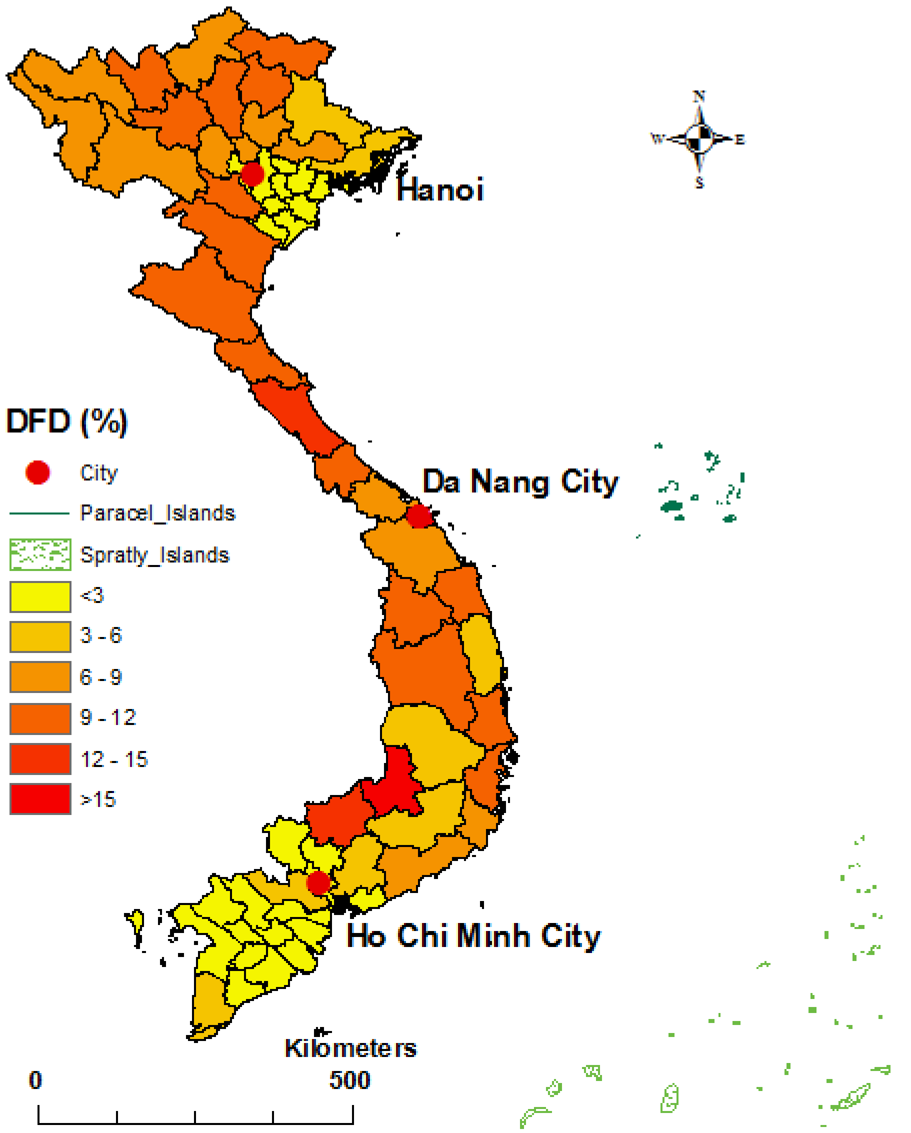


Figure 2.4. Map of deforestation and forest degradation (DFD) by province in Vietnam between 2000 and 2010.

In terms of deforestation and forest degradation by types of forest; there are 12 types of forests within the national forest inventory. They are evergreen (rich, medium, poor), rehabilitated forest, deciduous, bamboo, mixed bamboo, mixed evergreen, mangrove, deciduous, limestone forest, and plantation. Deforestation mostly occurred in bamboo, plantation, and rehabilitated forests, while forest degradation mostly took place in evergreen forests (rich and medium) (Supplementary Figure S2.2). Total forest loss and forest degradation was most frequently seen in the four top types of forests: rich evergreen, bamboo, medium evergreen, and plantation forests (in decreasing order of importance).

The change in deforestation and forest degradation by time was examined. During 2000-2005 and 2005-2010, the P-value of the non-parametric test is less than 0.001 (Supplementary Table S2.3) in the models of deforestation and forest degradation, indicating that forest loss and forest degradation differ. Recall that forest was lost and degraded in 2000-2005 and in 2005-2010 are almost 1.4 and 1 million hectares, respectively. Therefore, it can be concluded that deforestation and forest degradation declined between 2000-2005 and 2005-2010. This finding is reasonable and is strongly consistent with the forest transition that Vietnam has undergone since the 1990s (Hosonuma et al., 2012; Meyfroidt and Lambin, 2008b). This status of forest loss in Vietnam strongly supports the finding of Hansen et al. (2013) with regards to the deforestation trend in the world in the period from 2000 to the present, although other studies report an acceleration of deforestation over the 2000s (Cochard et al., 2016).

Regarding elevation and forest cover, both are positively and significantly correlated with deforestation and forest degradation (i.e., correlation is significant at the 0.1 and 0.01 level (2-tailed)). This means that areas of forest loss and degraded forest were larger in the provinces that have larger areas of forests and are at higher elevations. In other words, biophysical conditions are positively associated with forest loss and degraded forests.

2.3.2. Estimated regression model of deforestation and forest degradation

2.3.2.1. Results of the structural model

The structural model was employed to identify the approximate drivers of deforestation and forest degradation. There are five modes (1-5) presented in Table 2.3-2.5, but the main interest is model 1 highlighted in bold with its dependent variables of area of forest loss, forest degradation, and sum of forest loss and forest degradation per capita. Because endogeneity occurred for at least one explanatory variable in model of deforestation and forest degradation, we used results of 3SLS estimation for empirical analysis. The *P*-value is a measure of evidence against the hypothesis that the regression coefficient is zero, so the *P*-value of was less than 0.05 (Table 2.3-2.5) in all five models indicating that these models are statistically significant in explaining variation in the dependent variable. The differences in the full model and the restricted model lie on the presence or absence of INCOME2 and FODCAP2 variables. The value of R^2 of the full model was always smaller than that in restricted model (Table 2.3-2.5) implying that the restricted model was better than the full model, so results of the restricted model are used for discussion.

Table 2.3. Estimated results of the structural model of deforestation

Variables	**Full model**					**Restricted model**				
	Deforestation	Poverty	Income	Agricultural production	Food security	**Deforestation**	Poverty	Income	Agricultural production	Food security
	(1)	(2)	(3)	(4)	(5)	**(1)**	(2)	(3)	(4)	(5)
PCI2	**-0.040(2.01)****					**-0.040(2.08)****				
POVERTY2	**0.056(3.22)*****					**0.047(3.62)*****				
INCOME2	**0.008(1.64)**	-0.117(4.47)***					-0.133(4.50)***			
FODCAP2	**0.002(0.70)**									
POPDEN2	**0.003(0.34)**					**0.012(1.92)***				
AGGDP2	**0.001(1.11)**		0.065(2.03)**			**0.001(1.74)***		0.061(1.96)**		
FCOVER	**0.032(3.92)****					**0.038(5.45)*****				
AVFODCAP (ln)			-17.065(1.54)					-19.720(1.79)*		
FODLAND1		-0.079(2.44)**		-2.498(2.39)**	0.015(8.93)***		-0.091(2.62)***		-2.418(2.28)**	0.015(8.94)***
FODLAND2				1.381(1.39)	0.008(4.69)***				1.485(1.56)	0.008(4.73)***
PFOREST				19.514(3.39)***					19.678(3.41)***	
MIGRAT			2.396(3.05)***		-0.021(3.39)***			2.124(2.75)***		-0.020(3.33)***
LITER		-0.129(0.63)	2.017(2.69)***				-0.043(0.20)	2.099(2.79)***		
LATRAIN			-0.677(0.50)	10.010(1.68)*	-0.032(3.18)***			-0.605(0.46)	10.395(1.73)*	-0.033(3.27)***
JOBRAT06		1.242(3.64)***		18.090(2.44)**			1.298(3.64)***		17.213(2.33)**	
POSNET06		-0.151(3.93)***		3.560(2.39)**			-0.152(3.85)***		3.290(2.27)**	
COMKN06				1.971(2.07)**	0.002(1.45)				1.944(2.03)**	0.002(1.55)
Constant	**2.616(1.34)**	64.122(3.43)***	184.458(1.79)*	-119.045(0.88)	5.639(28.76)***	**4.736(3.71)*****	60.832(3.11)***	192.680(1.87)*	-114.513(0.85)	5.640(28.61)***
Observations	**46**	46	46	46	46	**46**	46	46	46	46
R square	**0.5931**	0.6470	0.5002	0.5007	0.8126	**0.7141**	0.5958	0.4973	0.5003	0.8127
P-value	**<0.001**	<0.001	<0.001	<0.001	<0.001	**<0.001**	<0.001	<0.001	<0.001	<0.001

Note: Absolute value of z statistics in parentheses * significant at 10%; ** significant at 5%; *** significant at 1%. Robust t statistics in parentheses; Bold text indicates that the model is a subject to main interest since its dependent variable is deforestation. P is probability of the model. Variables of INCOME2, FODCAP2 are excluded in the restricted model; Units in Table 2.1.

Table 2.4. Estimated results of the structural model of forest degradation

Variables	**Full model**					**Restricted model**				
	Forest degradation	Poverty	Income	Agricultural production	Food	**Forest degradation**	Poverty	Income	Agricultural production	Food
	(1)	(2)	(3)	(4)	(5)	**(1)**	(2)	(3)	(4)	(5)
PCI2	**0.042(1.48)**					**0.062(2.34)****				
POVERTY2	**0.078(3.00)*****					**0.100(5.86)*****				
INCOME2	**-0.010(1.44)**	-0.152(4.84)***					-0.149(4.70)***			
FODCAP2	**-0.008(1.36)**									
POPDEN2	**0.028(1.64)**					**0.010(0.70)**				
AGGDP2	**-0.002(2.29)****		0.094(3.14)***			**-0.004(4.00)*****		0.110(3.47)***		
FCOVER	**0.042(3.16)*****					**0.041(3.18)*****				
AVFODCAP (ln)			-4.579(0.27)					-15.390(0.82)		
FODLAND1		0.050(0.62)		3.072(1.16)	0.014(3.12)***		0.041(0.50)		4.194(1.71)*	0.012(2.88)***
FODLAND2				2.018(1.56)	0.008(3.81)***				2.283(1.92)*	0.007(3.65)***
PFOREST				18.803(2.99)***					17.316(2.90)***	
MIGRAT			5.766(2.64)***		-0.036(2.07)**			5.628(2.60)***		-0.037(2.12)**
LITER		0.420(1.71)*	3.180(3.84)***				0.476(1.92)*	3.292(3.97)***		
LATRAIN			-2.500(1.48)	18.281(2.76)***	-0.031(2.43)**			-3.204(1.84)*	17.454(2.77)***	-0.028(2.20)**
JOBRAT06		2.246(5.29)***		27.565(3.53)***			2.338(5.45)***		27.086(3.56)***	
POSNET06		-0.093(1.83)*		4.728(2.44)**			-0.095(1.86)*		4.281(2.34)**	
COMKN06				2.054(1.79)*	0.001(0.67)				1.940(1.78)*	0.001(0.76)
Constant	**35**	35	35	35	35	**35**	35	35	35	35
Observations	**2.798(0.91)**	16.821(0.77)	31.717(0.24)	-388.783(2.22)**	5.690(20.66)***	**-1.047(0.56)**	10.359(0.47)	84.785(0.62)	-364.533(2.14)**	5.668(20.69)***
R square	**0.4451**	0.6139	0.3918	0.4144	0.5420	**0.3810**	0.6196	0.3854	0.4151	0.5473
P-value	**<0.001**	<0.001	<0.001	<0.001	<0.001	**<0.001**	<0.001	<0.001	<0.001	<0.001

Note: Absolute value of z statistics in parentheses * significant at 10%; ** significant at 5%; *** significant at 1%. Robust t statistics in parentheses; Bold text indicates that the model is a subject to main interest since its dependent variable is forest degradation. Variables of INCOME2, FODCAP2 are excluded in the restricted model; Units in Table 2.1.

Table 2.5. Estimated results of the structural model of total deforestation and forest degradation

Variables	**Full model**					**Restricted model**				
	Deforestation and forest degradation	Poverty	Income	Agricultural Production	Food	**Deforestation and forest degradation**	Poverty	Income	Agricultural Production	Food
	(1)	(2)	(3)	(4)	(5)	**(1)**	(2)	(3)	(4)	(5)
PCI2	**-0.028(1.42)**					**-0.027(1.42)**				
POVERTY2	**0.058(3.53)*** **					**0.053(4.23)*** **				
INCOME2	**0.005(1.05)**	-0.117(4.44)***					-0.133(4.50)***			
FODCAP2	**0.001(0.41)**									
POPDEN2	**0.002(0.19)**					**0.007(1.19)**				
AGGDP2	**0.001(0.98)**		0.064(1.99)**			**0.001(1.39)**		0.060(1.93)*		
FCOVER	**0.047(5.85)*** **					**0.050(7.37)*** **				
AVFODCAP (ln)			-15.911(1.41)					-19.153(1.73)*		
FODLAND1		-0.079(2.40)**		-2.416(2.26)**	0.015(8.88)***		-0.092(2.63)***		-2.389(2.22)**	0.015 (8.92)***
FODLAND2				1.419(1.42)	0.008(4.69)***				1.450(1.49)	0.008 (4.74)***
PFOREST				19.354(3.30)***					19.594(3.34)***	
MIGRAT			2.458(3.10)***		-0.021(3.45)***			2.159(2.80)***		-0.021 (3.41)***
LITER		-0.135(0.66)	2.000(2.65)***				-0.068(0.31)	2.041(2.70)***		
LATRAIN			-0.513(0.37)	10.868(1.78)*	-0.033(3.25)***			-0.532(0.41)	11.031(1.81)*	-0.033 (3.30)***
JOBRAT06		1.235(3.58)***		18.748(2.50)**			1.269(3.54)***		18.266(2.45)**	
POSNET06		-0.152(3.91)***		3.579(2.37)**			-0.150(3.79)***		3.468(2.35)**	
COMKN06				1.877(1.93)*	0.002(1.45)				1.858(1.91)*	0.002 (1.53)
Constant	**2.608(1.37)**	64.611(3.42)***	177.615(1.70)*	-127.902(0.93)	5.651(28.88)***	**3.877(3.07)*** **	63.283(3.22)***	194.204(1.88)*	-125.977(0.92)	5.648 (28.80)***
Observations	**46**	46	46	46	46	**46**	46	46	46	46
R square	**0.7349**	0.6484	0.4985	0.5022	0.8125	**0.7769**	0.5953	0.4963	0.5016	0.8125
P value	**<0.001**	<0.001	<0.001	<0.001	<0.001	**<0.001**	<0.001	<0.001	<0.001	<0.001

Note: Absolute value of z statistics in parentheses * significant at 10%; ** significant at 5%; *** significant at 1%. Robust t statistics in parentheses; Bold text indicates that the model is a subject to main interest since its dependent variable is total deforestation and forest degradation. Variables of INCOME2, FODCAP2 are excluded in the restricted model; Units in Table 2.1.

Regarding the relationship between natural conditions and forest loss and forest degradation, the forest cover variable had a statistically significant and positive correlation with per capita area of forest loss and forest degradation. When forest cover increases by 1%, per capita area of deforestation increases by around 3.8% (Table 2.3) and forest degradation increases by 4.1% (Table 2.4). If poverty rate increases, then deforestation and forest degradation increased as well. As presented in Table 2.3-2.5, for model 2, poverty is strongly associated with income (INCOME2), land (FODLAND1) and literacy (LITER). Model 3 illustrated that income is positively correlated with agricultural production value (AGGDP2), literacy (LITER), and migration (MIGRAT). In model 4, agricultural production heavily depends on the skill of labor (LATRAIN), infrastructure (POSNET) and agricultural extension service (COMKN06). Finally, model 5 suggested that food increase is strongly determined by land area (FODLAND1, FODLAND2). Therefore, it can be concluded that higher income and lower poverty could lead to decrease in forest loss and degradation. Reductions in forest loss and degradation could be achieved through improving and managing the quality of labor force, literacy, agricultural extension service at the commune level, communal internet service, and migration. These findings verify the hypothesis that rural livelihood improvement contributes to a reduction in deforestation and forest degradation in Vietnam. Our findings strongly agrees with that obtained by Bhattarai and Hammig, (2001) but contrasts with Culas, (2007). Our findings are important because the program of eradicating hunger and alleviating poverty is still in progress in Vietnam.

Another factor that significantly influenced forest loss and forest degradation was the change in population density from 2000 through 2010. A variable POPDEN2 was positively and significantly related to both models of deforestation and forest degradation. If the population density by province increases by 1%, then the per capita areas of forest loss and forest degradation increased by 1.2% (Table 2.3) and 1% (Table 2.4), respectively. This is understandable because a growing population causes higher pressures on natural resources to satisfy daily demand and income generation. This finding is consistent with Kaimowitz and Angelsen, (1998); Ernst et al., (2013). This finding is important because it firmly supports current policies on population and migration management, which has recently been a principal cause of conflict regarding forestland in Vietnam.

Agricultural production is responsible for deforestation, but agricultural intensification as a driver of forest loss and forest degradation has not been tested in Vietnam with province-level data. The AGGDP2 variable represents the change in agricultural production value by province. AGGDP2 is statistically significant in the model of forest degradation; its negative coefficient indicates that agricultural production negatively impacts forest degradation. This result contrasts with DeFries et al., (2010); Hosonuma et al., (2012); Pham et al., (2012) but supports Tachibana et al., (2001). The underlying reason for the finding may be complex, but it could be that effective assistance from a strong agricultural extension system makes agricultural intensification more significant in reducing agricultural production's dependence on agricultural land. This leads to less pressure on forest and forestland in mountainous provinces. This finding is very meaningful because it supports policies of strengthening investment in science and technology for agriculture and improving the agricultural extension system in rural areas.

The final factor that significantly influences forest loss and forest degradation is the province competitiveness index (PCI2). This factor reflects province-level comprehensive governance, including the ability to formulate and implement public policy. PCI2 has a statistically significant and negative coefficient with per capita area of forest loss only. If PCI2 increases by 1-point (on a 100-point scale), per capita area of forest loss decreases by 4% (Table 5.3). This is understandable because stronger governance means less corruption and more protection of natural resources (forests, water, land, etc.) through more appropriate design and implementation of policies. This negative effect of deforestation and forest degradation is consistent with the argument of McElwee, (2004); Pham et al., (2012); Ernst et al., (2013), yet it contrasts with the conclusion that a stronger “general” governance which encourages business can increase forest loss of (Ceddia et al., 2014). Thus, this finding is important because, since the program of reforming administrative procedures in public offices is still in progress, there is room to help reduce deforestation by continuing to reform the province-level offices. To do that, the priority works could concentrate on improving transparency, reducing time cost, enhancing land access and tenure, improving policy bias, and strengthening legal institutions (VCCI, 2016).

2.3.2.2. Results of the regression tree model

The regression tree was expected to test the robustness of results from the structural model. Generally, results from the regression tree were consistent with that of the structural model (i.e. most of the statistically significant variables in the structural model were also significant in the regression tree model).

In the model of deforestation, the POVERTY2 variable was the first split in the regression tree, meaning that it is the most powerful discriminator between provinces with relatively high and low per capita forest loss. The highest per capita deforestation occurs in those provinces with a relatively high poverty rate (in the first right node in the tree), while the lowest per capita forest loss occured in those provinces with a lower poverty rate (<28.95%) and low forest cover (<29.39%). After POVERTY2, the most powerful discriminators in the regression tree were FCOVER, AGGDP2, and INCOME2. These findings are highly consistent with the results in the structural (3SLS) model in terms of the magnitude of different drivers associated with deforestation in Vietnam between 2000 and 2010 (see the details in Figure 2.5).

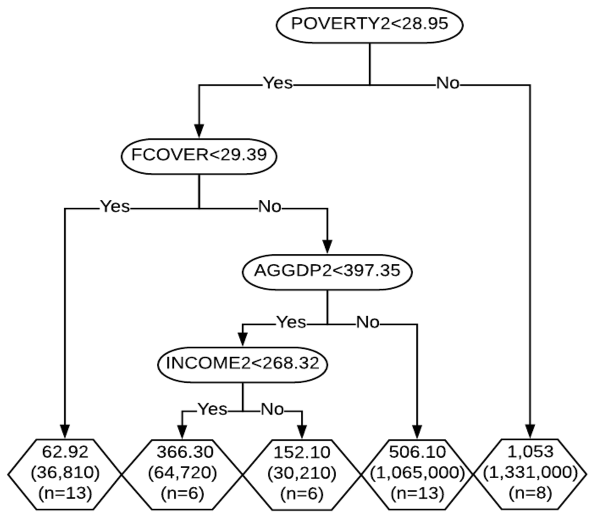


Figure 2.5. Regression tree of deforestation derived from forest cover, demographics, economic, and governance variables for Vietnam provinces in the study. The hexagons are terminal nodes with mean forest loss (ha per capita) and deviance, which measures the heterogeneity (e.g. misclassification, variability) at each node, in parentheses. OVERTY2 is the average poverty rate for 2006-2010; FCOVER is the percentage of forest cover in 2000; AGGDP2 is the percentage of change in agricultural production value between 2000 and 2010; INCOME2 is the percentage of change in per capita income per month between 2000 and 2010.

The regression tree of forest degradation had three significant variables (POVERTY2, FCOVER and POPDEN2) and was similar to the structural model, which had four significant variables (POVERTY2, FCOVER, POPDEN2, and PCI2). In both models, the first variable has higher significance than the second and the third. The highest per capita forest degradation took place in those provinces with relatively high poverty rate (the first right node and the second left node in the tree). The lowest per capita forest degradation occurred in those provinces with relatively low poverty rate (the first left node in the tree) and low forest resources (the second left node in the tree) (Figure 2.6).

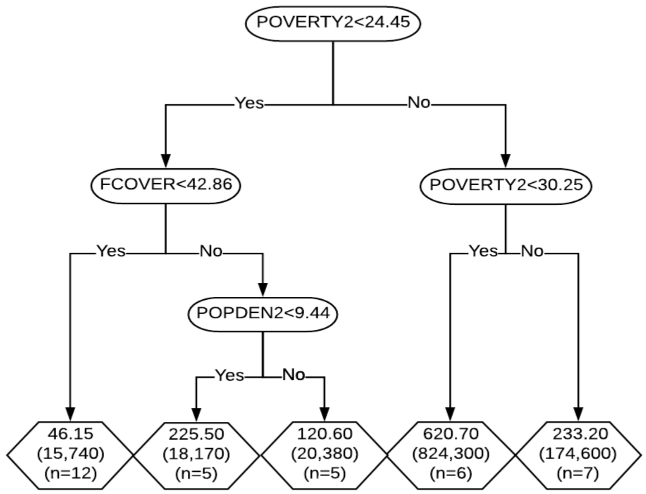


Figure 2.6. Regression tree on forest degradation derived from forest cover, demographics, and economic variables for the provinces in the study. The hexagons are terminal nodes with mean degraded forest (ha per capita) and deviance in parentheses. POVERTY2: the average poverty rate for 2006-2010; FCOVER: the percentage of forest cover in 2000; POPDEN2: the percentage of the change in population density for 2000-2010.

For the regression tree of deforestation and forest degradation, the variables of POVERTY2, FCOVER, PCI2 and POPDEN2 are powerful discriminators. The highest per capita area of forest loss and forest degradation was extremely high in those provinces with relatively high poverty rate (the first right node in the tree) and high FCOVER (the second right node in the tree), while the lowest per capita forest loss and forest degradation occurred in those provinces with relatively low poverty rate (the first left node in the tree) and lower forest cover (the second left node in the tree) (Figure 2.7). In summary, these findings confirm the results of the structural regression test. As expected, poverty, forest resources, population density, agricultural production, and province-level governance (PCI) were the most crucial factors affecting deforestation and forest degradation in Vietnam between 2000 and 2010.

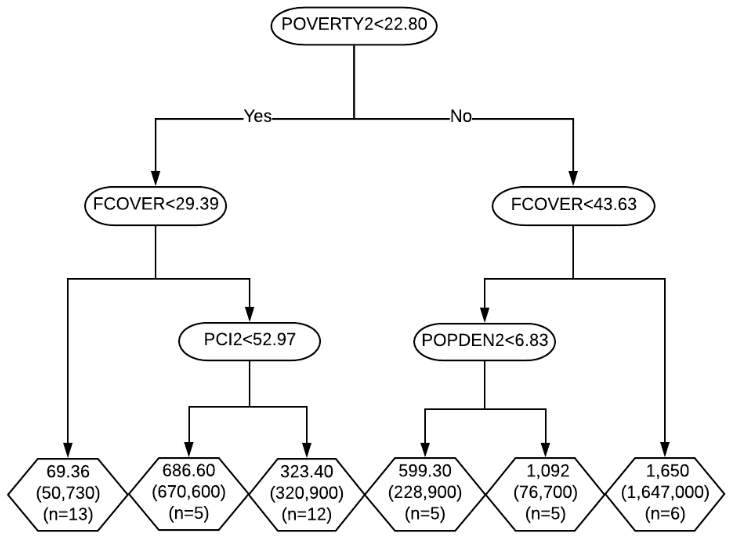


Figure 2.7. Regression tree derived from forest cover, economic, and governance variables for provinces in the study. The hexagons are terminal nodes with mean forest loss and forest degradation (ha) and deviance in parentheses. POVERTY2: the average poverty rate for 2006-2010; FCOVER: the percentage of forest cover in 2000; PCI2: average points of 100-point scale for 2006-2010; POPDEN2: the percentage of the change in population density for 2000-2010.

2.4. CONCLUSIONS

This study attempted to quantify the magnitude of forest loss and forest degradation and their drivers in Vietnam from 2000 to 2010. We used a provincial-scale data set and employed a comprehensive approach derived from a variety of disciplines, including forest ecology, remote sensing, GIS, and econometrics. Based on our analyses, we draw the following important conclusions and policy implications regarding tropical forest management.

Generally, as projected, forest loss and forest degradation have decreased from 2000 to 2010 even though they were still taking place at a high intensity with a large scope. This finding strongly supports the conclusion of Hansen et al., (2013); Sloan and Sayer, (2015); Calle et al., (2016) as well as the theory of forest transition in Vietnam in Meyfroidt and Lambin, (2008b); Hosonuma et al., (2012). Forests are unevenly distributed across Vietnam, as are forest loss and forest degradation. Forest loss and forest degradation are strongly linked to elevation and forest stock at the start of the study period (the year of 2000). A total of almost 2.4 million ha of forest were either being lost or becoming degraded, which accounts for around 21.4% and 17% of total forest area in 1990 and 2010, respectively. The largest area of deforestation and forest degradation was found in the north-central region, followed by the northeast, central highland, northwest, and south-central regions. The three provinces with the highest rates of deforestation and forest degradation are Binh Phuoc, Quang Tri, and Lao Cai. Those provinces belong to the regions of south central, north central, and northwest, respectively. Son La and Nghe An are the two provinces that exhibit the most deforestation and forest degradation. Bamboo, plantation forests, and rehabilitation forests are most subject to deforestation, while evergreen forests had the most forest degradation. Deforested areas were often those that had richness in biodiversity and forest biomass in previous time periods (Phung et al., 2006; Rebecca et al., 2013). Thus, deforested areas should be high priority areas for controlling deforestation and forest degradation for the sake of future biodiversity and environmental service protection in Vietnam.

We employed a structural model and a CART model to quantifying the drivers of deforestation and forest degradation. We found that poverty and initial forest stock serve as two leading approximate drivers of deforestation and forest degradation. In contrast to the finding of Ceddia et al., (2014), our study indicated that "stronger" province-scale governance might help decrease deforestation and forest degradation. Along with poverty, forest condition in 2000, agricultural production, and population growth, we found that province-scale governance was an important factor influencing forest degradation and deforestation. Our study indicates that improved province-scale governance could lead to lower forest loss and forest degradation. These findings are consistent with the conclusions of Hyde et al., (1996); Kaimowitz and Angelsen, (1998); DeFries et al., (2010); Bofin et al., (2011); Chakravarty et al., (2012); Kissinger et al., (2012); Pham et al., (2012); Ernst et al., (2013); Meyfroidt, (2013); Khang and Bao, (2015) and Barbier et al., (2017).

Our findings have several policy implications. The first is that the combination of the structural model and the CART model have proved to be effective and reliable tools for determining the drivers of deforestation and forest degradation in Vietnam. Our recommendation is that this method might be an appropriate tool for exploring similar topics with regional-scale data in other developing countries. The second implication is that current Vietnamese policies regarding poverty alleviation, forest conservation, economic development, provincial governance, and population have been on the right track but may not be strong enough. Therefore, these policies need to be maintained and strengthened particularly in the literacy of the population, the skill of the labor force, migration, agricultural extension service and internet infrastructure at the commune level. Further, forest restoration is a central aspect of sustainable forest ecosystem management. The objective of forest restoration is to assist the recovery of forest ecosystems that have been either degraded or destroyed (SER, 2004; Stanturf, 2005). The extent of forest loss and forest degradation is significant in Vietnam for 2000-2010 so we firmly suggest that forest restoration should be top priority actions, especially for those forests that are seriously exposed to deforestation and forest degradation in terms of forest types, locations, regions, and provinces.

Vietnam's story of deforestation and forest degradation and their drivers is very noteworthy, particularly for developing countries where tropical forests dominate. Although reducing poverty, preserving existing forests, improving provincial-level governance, and controlling populations are the four top priority actions that policy-makers should focus on, our critical recommendation is that no single solution can effectively reduce deforestation and forest degradation unless policy-makers resolve many issues and subjects simultaneously though enactment of comprehensive policies.

This study has some limitations. The ten years' time period is sufficient to observe the influence of many socioeconomic and policy factors, but may be insufficient to capture some of the long-term trends and drivers of forest cover change. The satellite-derived forest data set contains a certain inaccuracy rate (JICA, 2012; Putz and Redford, 2010) as well as socioeconomic data that have been criticized for inferior quality (Meyfroidt and Lambin, 2008a). Data on poverty from different sources, for example, was inconsistent (Nguyen et al., 2009), while the poverty standard has changed over time (GSO, 2010a). Another limitation is that the terms "forest loss" and "deforestation" are not identical in some cases but have been used interchangeably. The satellite-derived forest data provides estimates of forest loss rather than deforestation, and may be capturing plantation harvest, reclaiming of secondary regrowth, or forest loss from wildfires in some locations rather than clearing of primary forest (DeFries et al., 2010). The accuracy of the data on forest degradation is limited because forest degradation is difficult to measure using remote sensing at a regional scale (Davidar et al., 2010; Putz and Redford, 2010). Additionally, forest degradation is relatively different from deforestation (Hosonuma et al., 2012; Morales-Barquero et al., 2015) but in our study the deforestation model and the forest degradation model had the same types of drivers. Among five significant factors (poverty, initial forests, agricultural production, population density, and provincial-scale governance) of the model of deforestation, only four of them are the significant drivers of forest degradation. Thus, the quality of the forest degradation model is limited to some extent. Further, temporal correlation was not taken into consideration in this study might be also other limitation.

Finally, distinguishing between correlation and causality or determining the direction of causality is a central concern of this study. It has been widely acknowledged that the larger the scale of data used in a regression model, the less the causal relationship derived. Province-scale data are neither on a global nor a local scale. We cannot infer strong causal relationships based on the association between forest loss and the independent variables defined here. As the degrees of freedom were limited, we had to restrict the number of variables to test. The effects of biophysical variables such as elevation on deforestation has been explored in many studies over multiple contexts, including in Vietnam; therefore, we concentrated our study on a set of socioeconomic variables that can be influenced by policies and have been less often tested. A more in-depth exploration of the causal mechanisms (Meyfroidt, 2016) that link the identified drivers, i.e. provincial governance, initial forest cover, and income and population to changes in forest cover remains to be done.

In summary, our study presents updated information on the extent and magnitude of deforestation and forest degradation in Vietnam that is inherently difficult to define and measure. We have combined a structural model and regression tree model to determine the approximate drivers of forest loss and forest degradation. The combination of these two models proved to be an effective and reliable tool for determining the causes of deforestation and forest degradation using provincial-scale data. We have also proposed and included the provincial competitiveness index (PCI) as an approximate driver of forest loss and forest degradation. This approach could provide insights for future policy to improve forest management. Our analyses and key findings as well as acknowledgement of the limitations of our study could help others improve future studies. We hope that our findings can contribute to a better understanding of deforestation and forest degradation in Vietnam and lead policy-makers to reduce deforestation and forest degradation in other tropical countries. Unfortunately, no matter how much effort is made to manage deforestation and forest degradation, these processes continue to happen, though they happen in many ways, dimensions, and scales, with patterns varying from place to place and changing over time. Thus, better understanding of deforestation and forest degradation and their approximate drivers is important and needed currently and for the future to help control and manage forests effectively and sustainably. This topic merits further research that focuses on the concept, data, and models of deforestation and forest degradation.

Chapter 3 - SOCIO-ECONOMIC DRIVING FORCES OF FOREST RESTORATION IN UPLAND NORTHWEST VIETNAM: AN EXPLORATORY ANALYSIS AT A LOCAL-COMMUNAL SCALE

Summary

Vietnam's forests have undergone major transformations since the 1990s, including a transition from net forest loss to net expansion. Plantation forests and restored forests have seemingly greatly contributed to this transition. Under the growing effects of climate change, it is important to understand the socio-economic drivers of Vietnam's forest restoration to expand tropical forest restoration in other regions. In light of forest transition theory, we used geographic information system (GIS) tools, a structural regression model based on official Government of Vietnam forest cover maps, and field surveys to quantify the extent of forest restoration and its drivers at the local, commune, scale, in Dien Bien province, Vietnam. Results showed that around 118,000 hectares of forests were restored between 1990 and 2010. Restored forest comprised the largest share (above 84%) of total forest gain and this share increased from 1990-2000 to 2000-2010. Forest restoration was highly associated with biophysical and accessibility conditions (elevation, road density). Expansion of restored forest was mainly driven by the presence of migration, lower population density, higher income, and the implementation of forestry policies. The empirical results have policy implications for forest restoration practices as part of forest-based climate change mitigation programs as well as for sustainable mountainous rural livelihood development in Vietnam and beyond.

3.1. INTRODUCTION

Forests offer numerous benefits to human well-being (Chhatre and Agrawal, 2009; Griscom et al., 2017; Hogarth et al., 2013), so changes in forest cover have large societal impacts from the local to the global scale. Increase in forest area could improve rural community livelihood, enhance biodiversity and environmental services as well as mitigate the effects of climate change Accordingly, seeking solutions to expand forest resource, including forest cover and harness its utility is of great interest for policy makers and scientific communities (Canadell and Raupach, 2008; Chhatre and Agrawal, 2009; Kanninen et al., 2010; Martin and Watson, 2016; Miles and Kapos, 2008; Pirard, 2012; Sunderlin et al., 2005).

Several countries have experienced what has been called a forest transition, i.e. deforestation followed by a shift to increasing net forest cover (Grainger, 1995; Mather, 1992b; Meyfroidt and Lambin, 2011a). While most of developed countries' forests have completed the forest transition stage, forests in many developing nations like Indonesia and Lao are still undergoing the pre-phrase or early phrase of forest transition (Hosonuma et al., 2012). This implies that large areas of global forests could be lost in the coming years. A better understanding of successful stories about forest restoration in developing countries is the key to accelerate forest transitions in other countries with similar development conditions.

Vietnam's forests have undergone a forest transition over the past decades (Meyfroidt and Lambin, 2008b). The country's net forest cover has increased significantly from 28.7% in 1990 to 40.8% in 2015 (De and Trieu, 2006; MARD, 2016b). In addition, about 160,000 hectares of forest cover is being restored or newly added annually. This expansion of forest cover has been attributed to expansion or regeneration of both natural forests and plantation forests (Lambini and Nguyen, 2014; Meyfroidt and Lambin, 2008a). Understanding the driving forces of forest cover changes is important for Vietnam and the neighboring countries to improve forest policies for better multi-functional forest management.

Vietnam's forest transformation has been intensively studied by many Vietnamese and international scientists (Clement et al., 2009; Cochard et al., 2016; De, 2010; Khuc et al., 2018; Lang, 2001; McElwee, 2009; Meyfroidt and Lambin, 2008a, 2008b; Meyfroidt et al., 2013; Nguyen et al., 2014; Stibig et al., 2014). These studies clarified the overall picture of forest change (e.g., forest loss, forest degradation, and forest gain) and approximated its drivers. However, they did not fully examine the effects of the complex interactions among many social, economic, political, cultural and technological drivers on forest change. Furthermore, Vietnam's forest restoration, a key factor contributing to national forest cover increase, has not been thoroughly investigated especially at the subnational, local scale such as the village and commune (De and Trieu, 2006; JICA, 2012; Meyfroidt and Lambin, 2008a).

Our study aimed to explore the patterns of forest restoration and quantify its proximate drivers in Dien Bien province, an upland region in the Northwest of Vietnam, at a communal level. We used GIS tools, a structural regression model based on a unique panel dataset to answer two key research questions: (i) where and how much forests have been restored in Dien Bien? and (ii) what are the proximate driving forces of the restoration? We hypothesized that forest restoration increased and contributed to the observed forest gain at the local-commune scale from 1990 to 2010 and that rural livelihood improvement contributed to forest restoration, which in turn helped increase forest cover. We also hypothesized that ethnicity and food security could influence forest restoration and that higher population density and migration could shrink restored forests while forestland allocation policy was expected to help facilitate and increase forest restoration in the upland area of Vietnam. Our study contributes to literature on land use change and forest transition theory in several ways: (i) it extends the understanding of the spatial pattern of forest cover change and its driving forces at the subnational scale; (ii) it is based on a panel data approach, which offers information on the temporal course of forest restoration with less multicollinearity and increased degrees of freedom relative to cross-sectional or time series data; (iii) it is based on a structural model, which helps handle not only the complex interactions among social, ecological and economic process that influence forest restoration, but also addresses endogeneity issues.

3.2. METHODS

3.2.1. Conceptual framework

3.2.1.1. Forest transition

Forest transition has become a central theme of land use science within the international scientific community over the past two decades. The term “forest transition” was first introduced by geographer Alexander Mather in 1992 (Grainger, 1995; Mather, 1992a; Yeo and Huang, 2013) and then was developed by many scientists, becoming a fundamental theory in land system science (Barbier et al., 2010; Kull, 2017; Meyfroidt and Lambin, 2008b, 2011a; Rudel et al., 2010; Southworth et al., 2012). This term refers to the shift from decreasing forest cover (deforestation) to increasing (reforestation and afforestation) net forest cover (Hosonuma et al., 2012). This phenomenon has occurred in several developed and developing countries (Mather and Needle, 1998; Meyfroidt and Lambin, 2011a). Forest transition can be analyzed in three phases with distinct land use change (Barbier et al., 2010). In the early development phase, total primary forest decreases while agricultural land increases. In the second phase, both primary forest and agricultural land stay constant. In the final phase, total forest cover increases while agricultural land decreases. Some developing countries have passed the forest transition turning point (i.e., China, Thailand, Vietnam, etc.) (De, 2010; Hosonuma et al., 2012). According to Rudel et al. (2005) and Meyfroidt & Lambin, (2011) forest transitions can be driven by two major forces: economic development and forest scarcity. The first is linked to three mutually reinforcing processes: (a) industrialization and the growth of a service economy that attracts a labor force to cities from rural areas, (b) agricultural intensification that improves food security in the regions of a country most suitable for agriculture, and (c) market networks that push depopulation and agricultural decline into the least suitable regions for agriculture. The second force involves agricultural expansion or wood extraction that results in a scarcity of forest products and decreases the capacity of forests to supply ecosystem goods and services. Increasing demand for wood products resulting from economic growth may intensify this scarcity. With rising forest product prices (timberwood, firewood, etc.), as well as rising valuation of the ecosystem services provided by forests, landowners are encouraged to engage in tree-planting and more intensive forest protection.

Expansion of forest cover in Vietnam has resulted from plantation forests and regenerating natural forests; the latter was achieved through forest restoration and forest rehabilitation (Table 3.1). Theoretically, forest restoration is understood as a process of assisting in the recovery of a degraded, damaged, destroyed forest ecosystem (SER, 2004; Stanturf, 2005). Unlike "forest restoration", which refers to the process of supporting the development of forest ecosystems to improve their structure and function or to improve species diversity, vegetation structure, and ecosystem processes (Ruiz-Jaen and Mitchell Aide, 2005), "forest rehabilitation" is a process of repairing damaged forest ecosystem function, with the goal of raising productivity for some beneficial use (Mansourian, 2005; SER, 2004). In Vietnam, to restore degraded or damaged forests (i.e., areas classified by the government as special-use forest and protection forest) in upland areas, strategies of restoration and rehabilitation have been used for several decades (De and Trieu, 2006; McElwee, 2009). Forest transition is, thus, strongly linked to and depends upon deliberate efforts of forest restoration and forest rehabilitation.

Table 3.1. Forest change in Vietnam between 1943-2010 (Lambini & Nguyen, 2014; Meyfroidt & Lambin, 2008a).

Year	Forest area (1,000 ha)			Forest cover (%)	Forest area per capita (ha)	Average annual change	
	Natural forest	Plantation	Total			Area (1,000 ha)	%
1943	14,300	0	14300	43.0	0.70		
1976	11,077	92	11,169	33.8	0.22	-94.88	-0.66
1980	10,186	422	10,608	32.1	0.19	-140.25	-1.26
1985	9,038	584	9,892	30.1	0.16	-143.20	-1.35
1990	8,430	745	9,175	27.8	0.14	-143.40	-1.45
1995	8,252	1,050	9,302	28.2	0.12	25.40	0.28
2000	9,444	1,471	10,915	33.2	0.14	322.60	3.47
2005	10,283	2,334	12,617	36.4	0.15	340.40	3.12
2010	10,305	3,083	13,388	39.5	0.15	154.20	1.22

In this study, we used the widely accepted term “forest restoration” and not “forest rehabilitation” for the following reasons. First, as we are using it here, forest restoration is an overarching term that includes the act of forest rehabilitation. In practice, it is difficult to divorce forest rehabilitation from the process of forest restoration and the overall goal of restoring a forest. As an example, one can consider the situation of areas in Vietnam officially classified as ‘protected forest’. In these areas one could do both protecting and planting to restore the forest ecosystem and enhance the forest’s productivity, thus “forest restoration” and “forest rehabilitation” in this case would be intertwined. A second reason for using the term ‘forest restoration’ in this study is that the term is an increasingly used in discussing both the theory and practice of forest landscape restoration and restoration ecology (Ghazoul and Chazdon, 2017; Maginnis et al., 2012; Mansourian, 2005; Stanturf et al., 2012). Additionally, the final aim of the actions undertaken through forest rehabilitation within the forest restoration process is a restored forest and using the term ‘forest restoration’ best captures this aim.

3.2.1.2. Theoretical structural model of forest restoration

We developed a theoretical model of forest restoration that contains key categories of factors that could explain changes in forests in the study area. We adapted the framework for forest restoration presented by De & Trieu (2006), which identifies several categories of factors that influence the outcome of forest restoration at a national scale. The first category is policies and legislation, which range from command and control policies to enabling instruments like credit facilities, and incentives like payments for planting, and environmental services. The second one is players, actors, and arrangements, which covers the organization, capacity, competition aspects, adoption of forest restoration by relevant players, or sustainability of arrangements. The third factor is funding (i.e., amounts of funds invested in forest restoration programs). The fourth is the objectives of restoration, which spans linkage between objectives and causes of degradation, the processes of determining objectives, and compatibility and competition between objectives. The fifth is economic factors including demands, dynamics of markets, and evolving wood industries. The sixth factor is technology, which is associated with availability and dissemination of available technologies. The last group is composed of educational extension services, technical assistance, and training.

To establish a general model of forest restoration in Vietnam at a local scale, we combined a literature review-based approach and empirically driven context-based approach. We first reviewed numerous relevant publications on restoration and its factors, and we then narrowed the review down to several publications that are closely associated with Vietnam. Many factors influence forest restoration; we ultimately proposed five factors or groups of factors that can affect forest restoration in Dien Bien province. Those groups include biophysical and accessibility factors, socioeconomic factors, food security, population, and forest policy. Forest restoration is, in practice, driven by several underlying drivers that are complex interactions among social, economic, political, cultural, and technological processes (De and Trieu, 2006; Kull, 2017), so we employed the structural model-based approach presented by Yin and Xiang (2010) to unravel the complex interactions of the drivers of forest restoration to build our model. Our structural model included three interactive components: area of restored forest, income, and food availability. The following is our justification for selecting these factors for use in the equation of restored forest, income, and food, respectively.

We first considered biophysical and accessibility factors, which have been reported as constituting important variables in models of reforestation, forest recovery, or forest change (Call et al., 2017; Cochard et al., 2016; Meyfroidt and Lambin, 2008a; Viña et al., 2016). Taking the distance variable as an example, we assumed that forest restoration would be larger at places farthest from urban areas. We next considered socioeconomics factors. These include several key variables that were seen in models of forest change or similar studies (Call et al., 2017; Cochard et al., 2016; Meyfroidt and Lambin, 2008a; Rudel et al., 2016). In this factor group, population and income might be the most important variables. The basic assumption is that population and economic growth are closely linked to increasing demand for forest products. This could expose forests to higher risk of harvest rather than protection, which could influence restoration of forests. In addition, there are many groups of ethnic minorities in the study area, which have different practices in terms of land use and use of forest products. In Vietnam, success in early forest restoration has been acknowledged by the international community (De, 2010) and could be related to national forestry policy (i.e., forest land allocation policy) (Cochard et al., 2016; De and Trieu, 2006). Thus, national forestry policy could be an important factor in the model of forest restoration.

While it needs to be recognized that Vietnam, like all other countries in Southeast Asia, is a rapidly urbanizing country, historically Vietnam has been a country where most of the population works and lives in rural areas and where agriculture production is a main source of household income (Pham and Izumida, 2002; VUSTA, 2011). Land is an input of agricultural production, so it could significantly influence both food production and income. Human resources are another important factor in household livelihood. Dien Bien Province, the location of the case study in this article, has a well-known upland area where an industrial tree development program was introduced in 2008, so this program could be a factor influencing people's income in that region. When forests are restored, people can benefit from the income from the forest in several ways. Some will get revenue from salaries from the government in the role of protecting the forest; some will get revenue by selling timber and non-timber forest products. Thus, we include land capital, human resources, and forest production in our model of income while taking land and human resources into consideration in the model of food production.

Based on the above reasoning, area of restored forest, income, and food availability were analyzed within a framework of factors including biophysical, accessibility, socioeconomic, food security, population, national forestry policy, land capital, and human capital factors. Thus, a theoretical structural model of forest restoration (FR) follows:

$$\mathrm{FR_{it}} = \mathrm{f(BI_{it}, AC_{it}, SO_{it}, IN_{it}, FD_{it}, POP_{it}, FP_{it})} \qquad (1)$$
$$\mathrm{IN_{it}} = \mathrm{f(LA_{it}, HU_{it}, FP_{it}, FR_{it})} \qquad (2)$$
$$\mathrm{FD_{it}} = \mathrm{f(LA_{it}, HU_{it})} \qquad (3)$$

$\mathrm{FR_{it}}, \mathrm{IN_{it}}$, and $\mathrm{FD_{it}}$ are endogenous variables while $\mathrm{BI_{it}}, \mathrm{SO_{it}}, \mathrm{POP_{it}}$, $\mathrm{FP_{it}}$, $\mathrm{LA_{it}}$, and $\mathrm{HU_{it}}$ are exogenous variables. $\mathrm{FR_{it}}$ is the per capita area of restored forests or percentage of restored forests, $\mathrm{BI_{it}}$ is biophysical factors, $\mathrm{AC_{it}}$ denotes accessibility factors,

$\mathrm{SO_{it}}$ refers to social factors, $\mathrm{IN_{it}}$ is income, $\mathrm{FD_{it}}$ denotes food, $\mathrm{POP_{it}}$ refers to population, $\mathrm{FD_{it}}$ represents food, $\mathrm{LA_{it}}$ denotes land, $\mathrm{HU_{it}}$ is human resources, and $\mathrm{FP_{it}}$ is forest policy.

3.2.2. Study design

3.2.2.1. Study region

Dien Bien is a mountainous province in the northwest region of Vietnam. Around 86% of the population is composed of ethnic minorities (mostly Thai and Hmong). Formal education is limited and only 55% of the population is literate. Livelihoods in Dien Bien depend mainly on shifting cultivation, livestock, forest-planting, and forest protection; however, income level remains low (JOFCA, 2012). The GDP per capita is 14.7 million Vietnamese Dong (M.VND), 700 USD in 2013, and the average percentage of households that have enough food is 67.63%. Dien Bien province has a high potential for forest development and livelihood improvement because of its large area of forestland and unused land (La, 2014, 2015; Tran, 2012), although land which is officially categorized as unused is often actually fallow land in shifting cultivation systems with various stages of bush and small to medium size trees growing on it (Leisz, 2009; Leisz and Rasmussen, 2012; Nikolic et al., 2008). There are 602,566 ha of forestland and 176,097 ha of land classified as unused, accounting for 63.01% and 18.41% of total land area in the province, respectively. A forestry land allocation policy was implemented beginning in the 1990s (To & Tran 2014; Nguyen, et al., 2008). As of 2009, the communes had allocated on average 5,904 hectares to households for long-term forestry uses. Many national comprehensive forest development programs have been implemented in Dien Bien (Table S3.1). Since the 2000s, an industrial tree (Rubber) development program has been introduced and 45% of the communes in the province took part in this program. Rubber plantation establishment is a key social-economic development strategy of Dien Bien province, as well as rubber development in the North-West policy of Vietnam Rubber Corporation (Dao, 2015). Tree cover increases due to rubber plantations occurred mostly in 2008, and rubber trees are growing and developing since then. Land availability for rubber plantations is mostly from unused land or from degraded forest (Tran, 2012). The social and ecological conditions found in Dien Bien province are representative of the northern mountain region, for this reason we selected Dien Bien province as the location for this study (Figure 3.1).

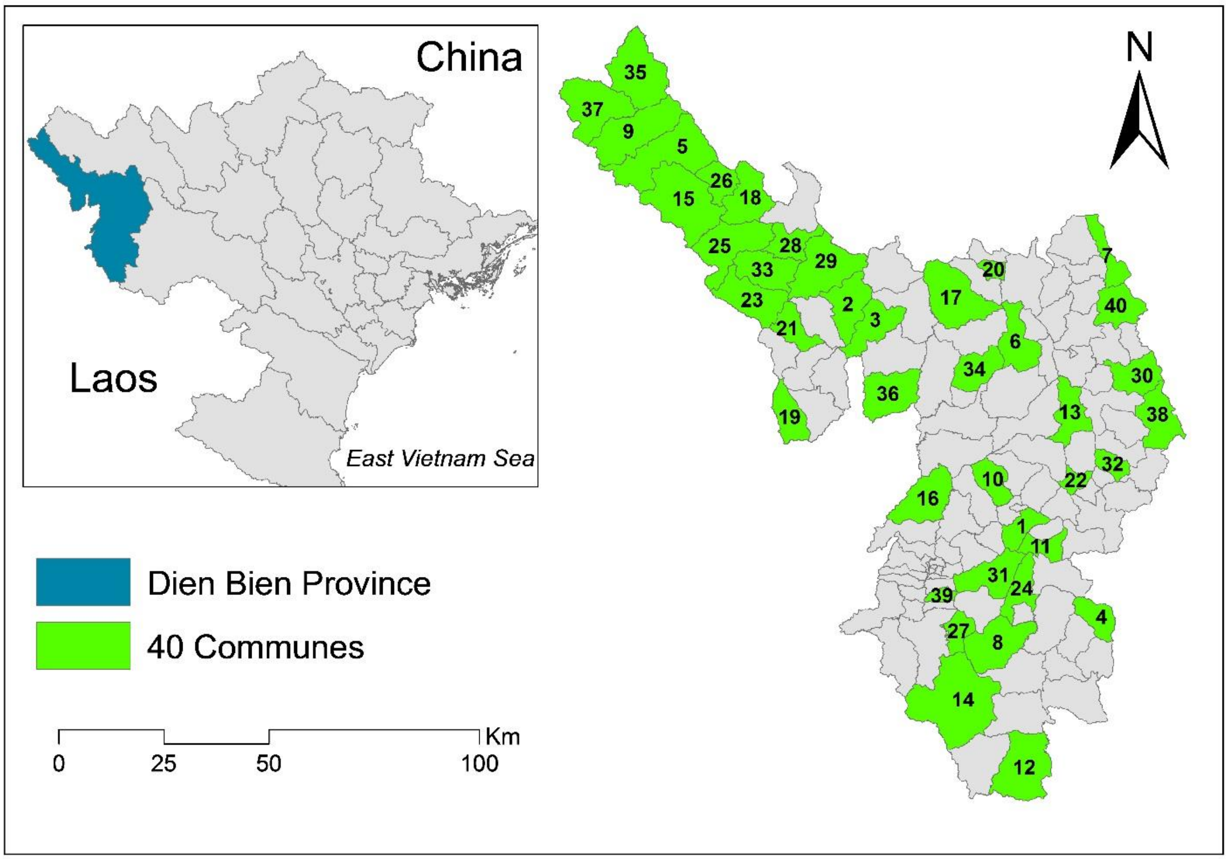


Figure 3.1. Map of study region (Northwest area) and study sites (40 mountainous communes) in Dien Bien province, Vietnam.

3.2.2.2. Study site

Dien Bien consists of 116 communes (GSO, 2015). The commune is the smallest administrative unit in Vietnam. We selected the commune as the study unit to explore the drivers of forest restoration at the local scale. To determine the communes that best represent Dien Bien's typical socioeconomic and ecological conditions, the study team consulted with foresters and managers from the Department of Agriculture and Rural Development (DARD), the Department of Forestry (DoF), and the Department of Forest Protection (DoFP) in Dien Bien. Ultimately, 40 communes were selected for an analysis of forest restoration (Figure 3.1, Table S3.2).

The targeted communes cover 539,700 ha, accounting for 56.49% of land area and comprising 63.18% of the province's forest cover—Vietnamese law distinguishes between "forestry land," land designated for forestry uses, and "forest land," land under forest cover. Each commune had an average area of 12,309 hectares; the Muong Toong commune had the largest area with 23,093 hectares, and the Thanh An commune had the smallest area with 2,013 hectares. The population density for the entire study site was 44 people km^{-2}, with the Si Pa Phin commune having the lowest density, 15 people km^{-2}, and the Phinh Sang commune having the highest density, 113 people km^{-2}. In recent years, the population has changed significantly. Some 40% of the communes have experienced migration. On average, each commune consumes 124 Mg of wood and 200 Mg of firewood per year. The infrastructure has significantly improved in recent years but remains in poor condition. Additionally, the communes contain areas that have seen increases and decreases in forest cover, representing reforestation and deforestation. The communes are involved in a payment for environmental services (PES) project and have areas that are planned to be managed as forest protection areas.

3.2.2.3. Empirical regression model

Given a theoretical structural model in section 2.a.(ii), we followed the integrative approach of (Yin and Xiang, 2010) and Khuc et al., (2018) to develop an empirical structural model for forest restoration. In this section, we specify the variables that are included in our empirical structural model. Our proxies for biophysical factors and accessibility are elevation and road density, respectively. Our proxies for social factors are population density, migration, and ethnic minority. For economic factors, the variables of income, cash capacity, forest-based income, and industrial tree development program are used. For food security, we use the variable of food capacity. For population factor, we use the variable of population density. Our proxies for natural capital and human capital are paddy rice land and literacy, respectively. For forestry policy, we use forestland allocated by the district-level authority to households. Finally, our proxy for forest restoration is restored forest area. Details, including units for each of these variables, are provided in Table 3.2. We then used 3-stage least square (3SLS) estimator to estimate socio-economic variables that associated with changes in restored forests. A structural model with 3SLS-based estimation not only can handle endogeneity, which causes bias and inconsistency, but can disentangle the complex interactions of drivers of forest restoration. We also considered spatial autocorrelation, which might be a potentially significant factor influencing the spatial data-based model (Anselin et al., 2006; Anselin and Rey, 2014), so we ran a test of spatial autocorrelation using Lagrange Multiplier (lag) and Lagrange Multiplier (error) with the support of ARCGIS software and of GEODA v1.6 (http://geodacenter.github.io). No spatial autocorrelation was found to exist, so the structural model was ultimately chosen. Ultimately, an empirical structural model was developed, and it comprised of three interactive components: forest restoration, income, and food (Figure 3.2).

Variables candidate

MIGRAT
FOODCAP
INCOM
POPDEN
RESTO
ITP
ROADEN
ELEV
DIST
ETHNIC
LITERAT
PADRICE
FINCOM
REDBOK
FCOVER

(1)

$$\mathrm{lnRESTO}_{it} = \alpha + \gamma_1 \mathrm{MIGRAT}_{it} + \gamma_2 \mathrm{FOODCAP}_{it} + \gamma_3 \mathrm{INCOM}_{it} + \gamma_4 \mathrm{POPDEN}_{it} + \gamma_5 \mathrm{ETHNIC}_{it} + \gamma_6 \mathrm{REDBOK}_{it} + \varepsilon_{it}$$

(2)

$$\ln \mathrm{INCOME}_{it} = \alpha + \gamma_1 \mathrm{REHAB}_{it} + \gamma_2 \mathrm{ITP}_{it} + \gamma_3 \mathrm{LITER}_{it} + \gamma_4 \mathrm{PADRICE}_{it} + \varepsilon_{it}$$

(3)

$$\mathrm{FOODCAP}_{it} = \alpha + \gamma_1 \mathrm{PADRICE}_{it} + \gamma_2 \mathrm{LITERAT}_{it} + \varepsilon_{it}$$

Figure. 3.2. Empirical structural model (simultaneous equations) of forest restoration in Dien Bien. A total of 15 candidate variables were used for establishing the empirical models (Table 2). After eliminating unsuitable variables, ten significant variables remained in the models. RESTO_{it}, INCOM_{it}, and $\mathrm{FOODCAP}_{it}$ present the dependent variables of model (1), (2), (3), respectively; α is a constant; γ_{1-7} are coefficients corresponding to different independent variables of the models; ε_i is an error term. Bold font indicates variables ultimately selected for final empirical structural model

Table 3.2. Definition and descriptive statistics for potential variables in the integrated system of forest restoration in Dien Bien in 1990 -2010. Units of analyses are the 40 communes in Dien Bien province.

Variables used in the regression models		1990-2000		2000-2010	
		Mean	SD	Mean	SD
RESTO1	Percentage of restored forests relative to each commune area (%)	11.67	9.96	16.15	6.60
RESTO2	Per capita area of restored forest (m^2)	8,701.35	13,771.86	4,468.70	2,509.62
ELEV	Average elevation (m)	814.38	231.99	14.38	231.99
ROADEN	Road density (km km^{-2})	0.26	0.23	0.26	0.23
DIST	Distance from commune centroid to province center (km)	61.79	34.54	61.79	34.54
FCOVER	Initial forest cover in 1990 (%)	22.40	17.47	30.26	18.83
INCOM	Per capita income (million VND)	9.59	2.41	17.40	2.05
FINCOM	Average percentage of forest-based revenue relative to total household income at a commune (%)	18.85	6.75	13.45	3.70
ETHNIC	Percentage of minority ethnic in selected commune (%)	85.63	7.16	86.15	6.77
POPDEN	Population density (people km-2)	31.57	34.47	44.35	24.91
PADRICE	Percentage of paddy rice land of agricultural land (%).	5.24	7.81	10.05	7.95
FOODCAP	Average percentage of households having enough food within a year (%)	42.25	18.50	67.63	10.31
LITER	Percentage of ethnic minority (%)	46.88	8.75	55.43	8.78
MIGRAT	Dummy variable (the presence of migration takes 1; otherwise is 0)	0.63	0.49	0.40	0.50
Forestry policy and production					
REDBOOK	Percentage of allocated forestland (%)	-	-	43.96	28.38
ITP	Dummy variable (the presence of industrial tree development program takes 1; otherwise takes 0)	0.13	0.33	0.45	0.50

Note: $1 USD roughly equaled 22.7 thousand VND (Vietnamese Dong) on October 13, 2017. Sources of original data: Ministry of Agriculture and Rural Development (MARD), Ministry of Natural Resource and Environment, (MONRE), La (2015) and Tran (2012).

3.2.3. Data

Based on our study's objectives and conceptual framework, there were three main groups of data required: biophysical, accessibility, forest, and socioeconomic data during the period 1990-2010. Biophysical and accessibility data were obtained from the Ministry of Natural Resource and Environment (MONRE), and forest data was collected from the Ministry of Agriculture and Rural Development (MARD). For forest data, we employed the approach presented in Khuc, et al. (2018) to use a forest distribution map, which was made by MARD and the Japanese International Cooperation Agency (JICA). Forest data came from a 5-year cycle national forest inventory program, which was implemented by the Forest Inventory and Planning Institute (FIPI). JICA and FIPI then constructed forest distribution maps for 1990, 2000, and 2010, which are based on a forest classification system with 17 categories (i.e., "restored forest" has a code 4) (JICA, 2012) (Table S3.3). The maps are made through a visual interpretation of relevant satellite images (Landsat TM, ASTER, ALOS, and SPOT) and ground truthing. It should be noted that the forest classification system of FIPI uses the definition of "restored forest" found in Vietnamese Circular Number 34/2009/TT-BNNPTNT, which defines "restored forest" as forest that has been restored from a degraded or destroyed secondary forest that was caused by wildfire, deforestation or shifting cultivation. The forest distribution maps were officially checked for consistency in interpretation by two parties when they were made and it was found that the classification consistency is 89% between the two parties (JICA, 2012). In order to have an objective accuracy assessment of the forest distribution map we exported a random sample of 50 polygons classified on the 2010 map as rehabilitation forest from the 40 communes this study focuses on, and compared the polygons to the 2010 image in Google Earth (which in some cases is high resolution data sourced from Digital Globe and in other cases is Landsat data) and also to following year images if the data was available. We assessed if the land-cover observed in the Google Earth image for 2010 could fit within the definition of restored forest as per Circular Number 34/2009/TT-BNNPTNT. The results of our interpretation suggest that 29 fit the category, five do not, and 16 might fit this category, but further ground-based investigation is needed. Most of the 29 that fit the category appear to be tree cover associated with shifting cultivation or degraded areas of forest. The 16 questionable polygons appear to have either active agriculture plots with some scattered trees or are areas of older tree cover that may be more accurately classified as another forest cover type.

For communal-scale socioeconomic data, we used data collected in 2012-2013 by a team from the Vietnam National University of Forestry (the data is also found in La (2015)). That survey included a total of 40 communes in seven districts of Dien Bien province (Figure 3.3)[3]. Data was collected through individual and group interviews. To improve the data quality (and minimize bias), the study team controlled three key components: interviewers (i.e., researcher, lecturer), respondents (i.e., local commune staff, farmer), and organizing (i.e., pre-survey, final survey). For interviewers, a questionnaire was designed and tested on a focus group, then revised as necessary. In addition, a face-to-face short training in interviewing techniques was provided to the interviewer. This preparation aimed to ensure that both the quality of interviewer and the questionnaire was sufficient before going to the field. A pre-survey and final survey were organized and conducted. After the pre-survey, the questionnaire was revised one time more. Two groups of respondents were interviewed: In each commune one group was comprised of the commune staff and the other group consisted of local households. Commune staff were interviewed about general background information, while local households were interviewed regarding specific household practices. Only respondents who had lived in the commune for a long time (i.e., 20 years or more) were interviewed. The interviews collected data on: commune-scale socioeconomic status (i.e., name, year of establishment; population, migration; ethnic minorities; and general); households' income (i.e., revenue from upland cultivation, paddy cultivation, livestock grazing, and other income) at the time of the interview; agricultural practices (i.e., area of land use types and the changes of land use purpose, upland cultivation; paddy rice cultivation; other crops), forestry practices (i.e., plantation, natural forest, restored forest); supporting policies of the state (i.e., economics, infrastructure development, agro-forestry development, resettlement programs, forest land allocation program, other forest plantation programs, and their effectiveness).

The socio-economic data collected was organized in a panel format (panel data), which contain observations of multiple dimensions obtained over two-time periods for the same commune, similar to the forest map data. We used forest distribution maps as input for deriving the area of restored forest for the two periods 1990-2000 and 2000-2010. These data were then included in the regression model as dependent variables. We set up both per capita area of restored forests and percentage of restored forests relative to the commune area as dependent variables for two main reasons. First, the percentage of restored forest area per province area has been studied by many authors (Cochard et al., 2016; La and Tran, 2015; Meyfroidt and Lambin, 2008a). Secondly, it has been widely acknowledged that population is inherently a principal underlying reason for deforestation, but that the relation between population and forest cover is strongly moderated by multiple factors, including socioeconomic and policy factors. Thus, the evolution of forest restoration area per capita measures how the pressure from population affects forest restoration over time due to policies, income, and other factors. We used this data because it reflects forest change corresponding to forest-protection and management efforts of many stakeholders such as government, forest enterprise, farmers, etc. To understand the relationship between forest restoration relative to other important metrics, we considered and measured plantation forest, forest area gain, and forest area loss across the same time scale.

Measurement of those metrics required several procedures, including preparation for forest distribution maps in Dien Bien. However, we simplified this step by making use of a processed map of cross-provincial data from the study of Khuc et al., (2018). We used this forest distribution map for our analysis because was the best available forest data in Vietnam, which was constructed and validated at the national scale with a relatively high overall accuracy (JICA, 2012). Forest distribution maps from 1990 to 2010 contain a land classification system (LCS) of a total of 13 land use types (LUTs). Restored forest was the forest that was restored from deforested areas; forest gain refers to the area that changes from non-forest to forest; forest loss is the area that changes from forested to non-forest area, between two-time periods. We next followed the method in JICA (2012) and Khuc et al., (2018) to generate data on area of restored forest, plantation forest, forest gain, and forest loss in selected communes.

To measure the magnitude of those metrics, we used ARCGIS v10.2 (ESRI, CA, USA). Each GIS map layer contained 13 land use codes[5], which were 1 to 4, 6 to 7, and 11 to 17 corresponding to 13 LUTs: rich evergreen forest, medium evergreen forest, poor evergreen forest, restored forest, bamboo forest, mixed bamboo forest, limestone forest, plantation forest, limestone, bare land, water body, residential, and other land, respectively. We created both non-forest and forest maps by specifying query conditions at the initial time. We then created a map of restored forest, plantation forest, and forested area category by specifying query conditions in the later time. Finally, we employed "intersect" and "dissolve" commands in ArcGIS v10.2 to create data and a map of restored forest, plantation forest, forest loss, and forest gain. Because some of the derived data (restored forest, plantation forest, forest gain, deforestation) were not normally distributed (Shapiro-Wilk normality test) (Table S3.5), we employed a non-parametric test (Wilcoxon signed rank test) to understand forest restoration's trend and its relation to other metrics between 1990 and 2010.

3.3. RESULTS

3.3.1. Forest change and forest restoration in Dien Bien

One goal of this study was to explain the extent of forest restoration in Dien Bien. Generally speaking, in 1990, medium evergreen forests comprised the largest share of Dien Bien's forest area, followed by poor evergreen forests, mixed bamboo forests, and restored forests. However, in 2010, restored forests comprised the largest area, followed by mixed bamboo forests and medium and poor evergreen forests. The expansion of restored forests alone is very impressive. That forest type increased from 21,000 hectares in 1990 to 101,000 hectares in 2000 and 161,000 hectares in 2010 (Figure 3.1).

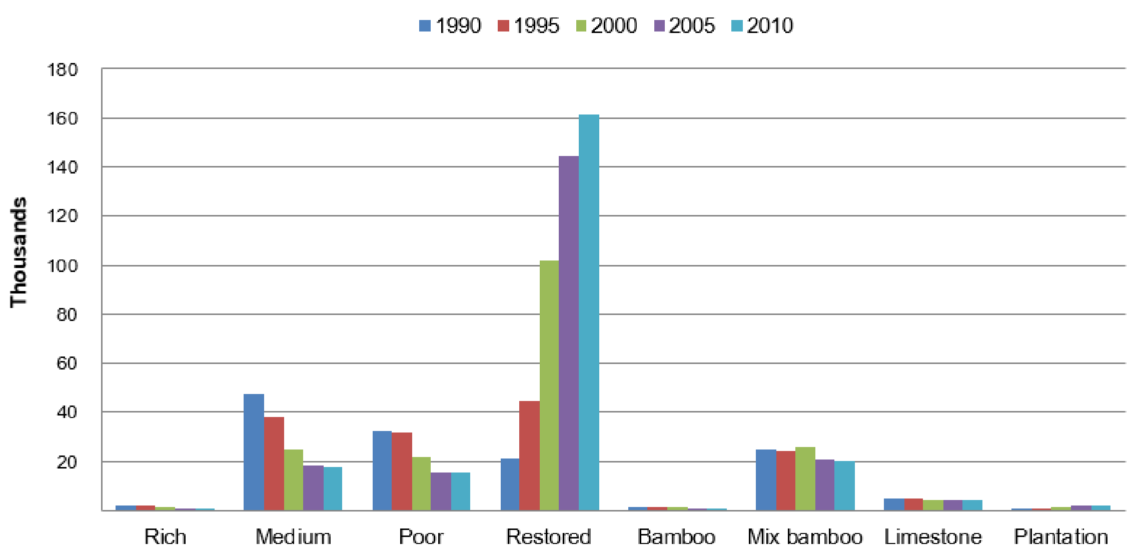


Figure 3.1. Change in forest area within various forest types in Dien Bien province, Vietnam between 1990 and 2010. Note: Forest types include: Rich (rich evergreen forest), Medium (medium evergreen forest), Poor (poor evergreen forest), Rehab (restored forest), Bamboo, Mix. Bamboo (mixed bamboo forest), Limestone (limestone forest), and Plantation (plantation forest).

The share of restored forests relative to total forest area is large (84%), while that of plantation forest is relatively small (<7%). The trend of forest restoration across the time period is notable for 1990-2010. Restored forest area increased significantly between 1990-2000 and 2000-2010[4]; plantation forest showed an opposite trend for the same time scale. Further, the sum of area of restored forest and plantation forest comprises almost the same area of the total forest gain of Dien Bien and of the communes in the study (>90%). The other six types of forest (rich evergreen forest, medium evergreen forest, poor evergreen forest, bamboo forest, mixed bamboo forest, limestone forest) contribute the remainder of total forest gain (Table 3.3, Figure S3.1).

Table 3.3. The extent of restored and plantation forests by different periods in Dien Bien province, Vietnam between 1990 and 2010.

Period	Unit	Restored forest (RF)		Plantation forest (PF)		Total area of restored forest and plantation forest (RFP)	
		Sampling (n=40)	Province (n=124)	Sampling (n=40)	Province (n=124)	Sampling (n=40)	Province (n=124)
1990-2000	Ha	69,054	100,117	1,432	8,361	70,486	108,478
	%	84.17	82.47	6.11	6.89	90.28	89.36
	%	12.62	10.47	0.37	0.87	12.99	11.34
2000-2010	Ha	90,106	161,240	1,311	7,121	91,417	168,361
	%	96.37	94.29	1.82	4.16	98.19	98.45
	%	16.15	16.87	0.33	0.74	16.48	17.61
1990-2010	Ha	118,753	203,923	1,785	9,843	120,538	213,766
	%	92.72	90.60	1.67	4.37	94.39	94.97
	%	20.94	21.33	0.41	1.03	21.35	22.36

Note: Each period includes three rows. The first row is the area (ha) of forest. The second row is percentage of forest relative to the total area of forest gain. The third row is percentage of forest relative to total area.

The relationship between restored forests in the study sites and biophysical variables is a notable feature. Restored forests display different patterns of forest cover change across the study period (Table 3.4) with regards to the different biophysical variables found across the landscape. Restored forest occurred mainly in communes that had a larger area of forestland and were farther from the province center. Meanwhile, proximity to the province capital was statistically correlated with restored forests, but a higher road density was associated with fewer restored forests (Figure S3.2).

Table 3.4. Correlations between restored forest area and biophysical variables in Dien Bien province, Vietnam between 1990 and 2010.

Variables	Initial restored forest (ha)			Restored forest by periods (ha)		
	1990	2000	2010	1990-2000	2000-2010	1990-2010
Elevation[a]	0.377**	0.375**	0.042**	0.186	0.125	0.198
Distance[b]	0.382**	0.584***	0.419***	0.447***	0.146	0.278*
Road density[a]	-0.104	-0.449***	-0.496***	-0.555***	-0.563***	-0.532***
Forestland[a] area	0.298*	0.850***	0.861***	0.790***	0.717***	0.778***

Note: [a, b] are Spearman and Pearson correlation, respectively; ***, **, * Correlation is significant at the 0.1, 0.05, 0.01 level (2-tailed).

3.3.2. Estimated model of forest restoration in the study area

A structural model with panel data was employed to quantify the proximate driving forces of forest restoration at the communal scale. We developed three sub-models (1-3) in each full and restricted model, but the main interest is model 1, because the dependent variables are per capita area of restored forest (Table 3.5) and percentage of restored forests relative to each commune area (Table 3.6). Because of potential endogeneity for at least one explanatory variable in the model of restored forest area, we used results of the 3SLS estimation for empirical analysis. The P-value was less than 0.05 in all three models, indicating that these models were statistically significant in explaining variation in the dependent variable. The differences between the full model and the restricted model is in the presence or absence of allocated forestland and ethnicity variables. The value of R^2 of the full model was always smaller than that in the restricted model (Table 3.5-3.6), implying that the restricted model was better than the full model, so the results of the restricted model are largely used in our discussion.

Table 3.5. Estimated results from a structural model of the per capital area of restored forest in Dien Bien province, Vietnam.

Variables	Full model			Restricted model		
	Restored forest (ln)	Income	Food capacity	Restored forest (ln)	Income	Food capacity
	(1)	(2)	(3)	(1)	(2)	(3)
Restored forest		0.181(6.32)***			0.201(6.93)***	
Income	0.297 (2.42)**			0.251 (3.97)***		
Food capacity	-0.038 (1.65)*			-0.036 (2.21)**		
Migration	0.658 (2.21)**			0.631(3.32)***		
Population density	-0.015 (3.83)***			-0.016 (5.05)***		
Ethnicity	0.016 (0.95)					
Allocated forestland	-0.007(0.86)					
Industrial tree program		0.898 (1.89)*			1.031(2.03)**	
Literacy		0.207 (5.41)***	0.620 (3.15)***		0.184 (4.85)***	0.537 (2.71)***
Paddy rice land		0.134 (2.78)***	1.166 (4.97)***		0.153 (3.18)***	1.223 (5.20)***
Constant	5.301(2.61)***	-0.926 (0.49)	14.296 (1.54)	7.104 (14.07)***	-0.201 (0.11)	18.121 (1.95)*
N	80	80	80	80	80	80
R^2	0.2283	0.5551	0.4979	0.2621	0.5485	0.4981
Chi2	45.94	109.24	81.39	67.68	112.93	78.58
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Note: Estimated results of the structural model with the 3-stages least square (3SLS) estimation of restored forests. Each full and restricted model includes three sub-models (1-3). Dependent variable of model 1, 2, 3 are the per capital area of restored forest (m^2 $person^{-1}$), per capita income (million VND), average percentage of households having enough food within a year (%), respectively. Ethnicity and allocated forestland variable were excluded in restricted model. Absolute value of z statistics in parentheses. *, **, *** represent significance at 10%, 5%, 1%, respectively.

Table 3.6. Estimated results of a structural model of the percentage of restored forest relative to the total area in Dien Bien province, Vietnam.

Variables	Full model			Restricted model		
	Restored forest	Income (ln)	Food capacity	Restored forest	Income (ln)	Food capacity
	(1)	(2)	(3)	(1)	(2)	(3)
Restored forest		0.019(1.94)*			0.000(0.03)	
Income (ln)	-0.995(0.08)			14.025(1.72)*		
Food capacity	-0.058(0.34)			-0.153(1.00)		
Migration	1.898(0.77)			6.937(3.27)***		
Population density	-0.017(0.68)			-0.014(0.40)		
Allocated forestland	0.132(1.91)*					
Industrial tree program		0.108(1.80)*			0.100(1.24)	
Literacy		0.020(4.16)***	0.559(2.83)***		0.021(3.82)***	0.559(2.83)***
Paddy rice land		0.009(1.46)	1.206(5.13)***		0.006(0.87)	1.206(5.13)***
Constant	16.398(0.65)	1.156(4.74)***	17.117(1.84)*	-16.197(1.09)	1.391(4.96)***	17.121(1.84)*
N	80	80	80	80	80	80
R^2	0.1209	0.4193	0.4983	0.1988	0.3552	0.4983
Chi2	20.41	47.79	79.10	13.66	35.69	79.14
P-value	0.0010	<0.0001	<0.0001	0.0085	<0.0001	<0.0001

Note: Estimated results of the structural model with the 3 stages least square (3SLS) estimation of restored forests. Each full and restricted model includes three sub-models (1-3). Dependent variable of model 1, 2, 3 are the percentage of restored forest relative to the total area (%), per capita income (million VND), average percentage of households having enough food within a year (%), respectively. Allocated forestland variable was excluded in restricted model. Absolute value of z statistics in parentheses. *, **, *** represent significance at 10%, 5%, 1%, respectively.

We hypothesized that rural livelihood improvement contributes to forest restoration, which in turn helps increase forest cover in the upland area of Vietnam. As expected, using model 1, the income variable had a statistically significant and positive correlation with per capita area of restored forest. Similarly, the income variable had a statistically significant and positive correlation with percentage of restored forest relative to commune area. When per capita income increased by 1 million VND, per capita restored forest area increased by around 25.1% (Table 3.3) and restored forest area at the commune scale increased by 1.14% (Table 3.4). This finding indicates that if economic conditions were improved, then restored forest area might increase as well. This is consistent with the Environmental Kuznets Curve (EKC), which refers to the proportional relationship between growing income and environmental improvement (Culas, 2007; Stern et al., 1996).

As hypothesized, population influenced restored forest area. Population density was negatively and significantly related to restored forest area. An increase in population density triggered a decrease in per capita areas of restored forest (Table 3.5) and percentage of restored forest (Table 3.6). This is expected as a growing population is likely to cause higher pressure on restored forests to satisfy growing demand. This finding is consistent with Kaimowitz and Angelsen (1998) and Ernst et al. (2013). For the opposite case, migration from the communes was positively and significantly related to restored forest area. This means that if migration appears in the studied communes, then the per capita areas of restored forest increases (Table 3.5). This is because even though some households migrated from other locals, they still received allocated forestland for forest protection and management activities to make a living and stabilize their livelihood. It is their forest practices that might contribute to additional expansion of restored forest to some extent.

Another factor related to forest restoration was forest land allocation (FLA) policy. The variable allocated forestland was positively and significantly correlated to restored forest area (Table 3.6). If allocated forest land increased by 1%, then restored forests increased by almost 0.13%. This evidence indicates that FLA could be a driving force for expansion of forest restoration or have a positive impact on forest development. This is highly consistent with several other studies (Castella et al., 2006; Meyfroidt and Lambin, 2008a; Nguyen et al., 2010; Nguyen et al., 2014). This finding is important since it could support the ongoing forest land allocation policy even though FLA has been assessed to have little impact on forest development and livelihood improvement in some upland areas (Clement et al., 2009; Sikor, 2001).

In model 2, the results for income are mostly as expected. Industrial tree development program, paddy rice land, literacy, and restored forests all had significant positive effects on income. Per capita income increased by the most, 1 million VND and 0.2 million VND, with the presence of industrial tree development and a per capita restored forest increase of 1 hectare, respectively (Table 3.5). Similarly, per capita income increased the most, by 1.5 million VND and 0.24 million VND, with the presence of industrial tree development and a literacy rate increase of 1%, respectively (Table 3.6). These results indicate that plantation forests play a crucial role in increasing income at the communal-scale. Further, the expansion of restored forests and higher level of education could help improve income in the study region.

In model 3, all variables in the food equation had the expected effects; available land and literacy level had significant positive effects on food capacity. Food capacity increased by around 1.2% and almost 0.5%, when the paddy rice land and literacy rate increased by 1%, respectively (Table 3.5-3.6). These findings are valuable since they support the current policies on developing livelihood, improving food security, and reducing poverty in mountainous areas of Vietnam.

3.4. CONCLUSIONS & POLICY IMPLICATIONS

This study extends the forest transition framework to determine the extent of forest restoration and its proximate drivers in Dien Bien province, from 1990 to 2010. We used a unique commune-scale panel dataset and employed a comprehensive approach derived from a variety of disciplines. Based on our analyses, we can make the following conclusions and policy implications regarding tropical forest management and sustainable rural livelihood development in the upland area of Vietnam, which may have wider applicability.

Forest cover increased considerably between 1990 and 2010 in the communes we studied, but surprisingly, the forest gain was largely due to restored forest rather than plantations. This finding indicates that forest transformation in some upland communes was mainly affected by forest restoration, not by forest plantations. What is more important is that the finding represents a positive impact or effect of the national forest-development programs (the 327, 661 programs), which were implemented in the upland in the past two decades (McElwee, 2016a) and changing livelihood systems which have improved livelihoods, and specifically household income. Further, the small contribution to forest gain from plantation forests implies that the Vietnamese government has a potential but also a challenge to expand upland plantation forests and their economic value through afforestation in the future.

The relationship between human-induced disturbances and forest restoration was examined in this study. Higher population density could lead to decreases in forest restoration while the presence of migration could result in increased forest restoration. From a socio-economic perspective, we would argue that population could be a central factor influencing forest restoration. Higher population could lead to higher pressure on natural resources like forests, but also could represent a workforce available in forest practices. However, no matter the reason, the influence of human-induced disturbances on restored forests is significant, so managing population as well as migration to prevent deforestation (Khuc et al., 2018) and accelerate forest restoration is paramount.

It is noteworthy that the proportional relationship between livelihood improvement and forest restoration expansion was confirmed in our communal scale study. Our reasoning is that the occurrence of “upland rural transformation”(Turner, 2012a, 2012b) is striking, which has altered and diversified rural livelihood strategies. Upland communities have diversifying opportunities to make a living (Turner, 2012a, 2012b), so they have gradually reduced their reliance on forests, which ultimately helps reduce human-induced disturbances and stimulate forest restoration. In light of EKC theory, our results suggest that policies aimed at socio-economic development may have positive impact on forest cover too if they actually improve income and livelihoods when accompanied by appropriate land use and land tenure policies. Changes in land use paradigms through agricultural intensification have been shown to effectively contribute to reforestation (Meyfroidt and Lambin, 2008a). The industrial trees program appears to have a positive impact on average income at the commune level, but may also lead to negative long-term impacts on the sustainability of rural livelihoods (Dao, 2015). This suggests that current government programs aimed at poverty alleviation (such as the “New Rural” program) may be effective, but the extension of the industrial tree plantation program requires adjustments.

Vietnam’s FLA policy has played an important role in expanding and accelerating forest cover over the past two decades (De and Trieu, 2006; Meyfroidt and Lambin, 2008a; To and Tran, 2014). Land privatization and equitable opportunities for capital access were central points of this policy, which supports local peoples’ active involvement in forest restoration and afforestation (Nguyen, 2012; Nguyen et al., 2010; Nguyen et al., 2014). FLA helps accelerate the devolution of ownership to farmers or other stakeholders, although its impact on natural forest restoration has been questioned (Sikor, 2001; Tran and Sikor, 2006). In our study, the high correlation of FLA and increased restored forest suggests that the FLA policy has had an impact on forest restoration. Continuing the implementation of FLA in creative and efficient ways could bring further benefits. Accordingly, resolving existing shortcomings of FLA policy should be a top priority, including giving clear and systematic instructions about FLA, improving the speed of implementation of FLA, defining clear boundaries of forestland in the field, and supporting policy mechanisms following FLA (Nguyen et al., 2008; To and Tran, 2014).

The findings of our study could offer key policy implications not only for Vietnam, but for countries in similar contexts, particularly for nations that have not experienced a forest transition. Forest restoration is a main source of forest gain locally and it could ultimately greatly contribute to the acceleration of forest transition in Vietnam as a whole. The relation between forest conservation and livelihoods improvement is generally marked by many trade-offs, making it complicated to achieve both goals together (Sunderlin et al., 2005; Wunder, 2001). In contrast, observing that in our study area, forest transition co-occurs with significant achievements in economic growth and poverty reduction (Anwar and Nguyen, 2011; Dollar et al., 1998; Jenkins, 2004) suggests that it is possible to design policies that foster synergies between these two goals, at least to some extent.

The lessons from Vietnam could be relevant for many other poor and developing countries (Cambodia, Indonesia, Nepal, Tanzania, etc.), where forest transition has just begun (Hosonuma et al., 2012; Kauppi et al., 2006), to accelerate the forest transition and foster synergies with livelihoods improvements. Nevertheless, strategies for sustainable rural development need to be rooted in local contexts and it is important to assert that no single solution will be successful in all contexts. The goals of conserving and restoring forest, improving rural livelihoods, food security, and rural environment need to be balanced through national and subnational policies and programs. Yet, an important policy implication is that forestland reform can be a powerful part of the portfolio of policies, since it could facilitate sustainable rural development in many dimensions such as land tenure, equity, and equal access to land resources (Nguyen et al., 2010; To and Tran, 2014).

Although this study was completed with attention to detail, it has some limitations. The first drawback concerns the inferior quality of some datasets. Classifying "forest restoration" or "forest rehabilitation" is based on the change seen in the FIPI forest cover maps. Each map is made from data for a single year and the maps are produced at ten-year intervals. It is very possible that some of the area classified as "restored forest" is actually area that has had trees regrow on it after being cleared for shifting cultivation and then left fallow. If this area is not cleared anymore for shifting cultivation, then passive restoration may occur (Ghazoul & Chazdon, 2017) and the forest will continue to restore but alternatively, the area may be cleared again for future years. These data therefore do not allow us to make conclusions about long-term outcomes in terms of forest restoration. The satellite-derived forest restoration data set, derived from the FIPI forest cover maps, also contain a certain inaccuracy rate (JICA, 2012; Putz and Redford, 2010), and there may have been error in the socioeconomic data due to potential bias of respondents, who might have found it hard to answer questions on communal-scale socioeconomic information or relevant events that occurred several years before the survey. Another limitation is the small sample size. The northwest region of Vietnam has four provinces (Dien Bien, Lai Chau, Son La, Hoa Binh) with nearly 600 communes (GSO, 2015), so a study of 40 communes might limit generalizations of the model of forest restoration. Furthermore, as the degrees of freedom were limited due to sample size, we had to restrict the number of variables to test. This could limit the understanding of some other variables that could influence forest restoration.

Finally, discerning between correlation and causality or determining the direction of causality is a limitation of this study. Data at smaller scales can facilitate the characterization of causal relationships. Communal-scale data could be, in this study, classified as fine scale (looking at a small area); however, we cannot infer strong causal relationships based on the association between restored forest and the explanatory variables included in the structural model. The effects of biophysical and access variables such as elevation, road density, distance between the targeted communes and large cities have been explored in many studies in multiple contexts; hence, we concentrated our study on a set of socioeconomic variables that can be influenced by policy-based intervention, which have been less often tested. A more in-depth exploration of causal mechanisms that link factors we identified in our study (population, income, food, forest policy) remains to be done.

In closing, our study presents updated information on the extent and magnitude of forest restoration in 40 upland communes in Dien Bien Province, Vietnam. We employed a structural model and panel dataset to determine the proximate drivers of forest restoration. This model proved to be a relatively strong and reliable tool for determining proximate drivers of forest restoration, at the communal scale, under a wider, more complex lens. Our analyses and key findings, as well as acknowledgement of the limitations of our study, could help others improve future studies. We hope that our findings will contribute to a better understanding of local-scale models for forest restoration in Vietnam, which could ultimately help accelerate forest restoration and improve sustainable upland rural livelihood in Vietnam or in other parts of the world.

Chapter 4 - ESTIMATING URBAN HOUSEHOLDS' WILLINGNESS-TO-PAY FOR UPLAND FOREST RESTORATION IN VIETNAM

Summary

Increased urbanization coupled with increased reliance of urban communities on rural areas for ecosystem service provision is a challenge faced by many Nations. The ability of urban households to directly support restoration efforts in surrounding rural regions represents an underappreciated funding stream for ecological restoration. This study explored the willingness of urban households to support forest restoration in Vietnam. We surveyed 211 households (HHs) in the capital city Hanoi, Vietnam. A Maximum Likelihood Estimator (MLE) model allowed us to obtain the parameters of our model and quantify mean Willingness-to-pay (WTP) for a program of forest restoration in addition to identifying factors influencing the decision of WTP. Generally, over forty percent of the households surveyed are willing to pay for forest restoration and the mean value of WTP is 37,830 VND ($1.73) per household per month. WTP depends on endogenous and exogenous factors including level of education, income, female-to-male ratio in the household, attitude toward payment for monthly electricity consumption, and awareness of payment for environmental service. Our results suggest that urban household's demand for forest restoration is real and represents an untapped source of restoration funding. Policy-makers should take actions to apply water bill to turn this potential into reality for restoration projects in Vietnam if the benefits from restoration outweigh the costs based on our findings.

4.1. INTRODUCTION

Deforestation and forest degradation has become a serious issue in Vietnam, attracting much attention from the government and international organizations. Across 7 ecoregions, the Northwest ecoregion is experiencing one of the highest rates of forest loss and forest degradation

(JICA, 2012; Khuc et al., 2018). Two main reasons are conversion of forests to agriculture via slash-and-burn and illegal logging (Nguyen, 2007). During the 1990s, this region lost thousands of hectares of forest in an area where half is protected for providing water to the Hoa Binh hydroelectric plant (JICA, 2012; Khuc et al., 2018).

Loss and degradation of protected forests in Northwest Vietnam seriously affects the supply of water and electricity for urban residents and businesses in the lowland including the capital city of Hanoi. The Vietnamese government responded to that issue by enhancing forest protection and rehabilitation programs (De Jong and Van Hung, 2006). However, forest rehabilitation programs have had limited success due to lack of participation from local communities. The underlying reason being that financial support for forest rehabilitation was not sufficient (Sunderlin and Huynh, 2005). Associated with this challenging issue, a Payment for Environmental Service (PES) program was piloted in Son La and Lam Dong provinces beginning in 2008 (Nguyen, 2011; Pham et al., 2013).

In this PES program, environmental service providers (local households) agreed to protect a certain amount of forest in return for payment from the service buyers (hydroelectric power plants) (Nguyen, 2011). The PES program was successful and effective in terms of attracting local households for forest protection and management (Pham et al., 2013). However, the drawback of this PES program was a long delay in payment to local households (To et al., 2012). Also, there was a limited number of households willing to participate at the low rate of payment (De Jong and Van Hung, 2006). Thus, in this case, mobilizing a source of funding that supports local household participation in forest protection and restoration is imperative.

There have been several studies exploring the potential of payment from society for the conservation and restoration of ecosystems in Vietnam (Do and Bennett, 2007; Khai and Yabe, 2014). In a survey using a single-bounded dichotomous choice question format, Le Hoa & Lee (2009) found that households in Ho Chi Minh City were willing to pay at least 6,209 Vietnamese dollars (VND) per month for three years for the preservation of Lo Go – Xa Mat National Park in Tay Ninh province. Using the same method, Huynh and Yabe (2014) found that all respondents in Ho Chi Minh city were willing to pay 16,510 VND per household per month for biodiversity conservation in U Minh Thuong National Park (UMTNP). These results suggest that Mekong Delta urban residents have the potential to contribute about 200 billion VND annually for biodiversity conservation in UMTNP. Although these studies have contributed to identifying an untapped source of conservation funding for UMTNP, there has little attention on urban household's WTP for forest restoration in the Northwest upland region of Vietnam.

The objective of our study was to explore the willingness of urban households in Hanoi to pay for forest restoration programs in rural areas of Northwest Vietnam. Our overall goal was to estimate how large of an untapped resource the urban population is for supporting forest restoration in the upland area.

4.2. METHODS

4.2.1. Contingent Valuation Method

Contingent valuation method (CVM) is a survey-based approach for finding values people place on goods, services, and amenities (Boyle, 2003). The CVM is a simple, flexible nonmarket valuation method that is widely used in cost-benefit analysis and environmental services (Khuc, 2013). It requires individuals to state their preferences through their responses to specific willingness-to-pay (WTP) questions (Boyle, 2003). Three main CVM response formats are open-ended, payment card, and dichotomous and each of these response formats has its own strengths and weaknesses. While an open-end format often results in overestimating WTP, dichotomous-choice WTP questions only obtain a limited amount of information from each respondent. The payment card method is a question format in which the respondents are asked to pick a willingness to pay point estimate from a list of values predetermined by the surveyors. The payment-card and multiple-bounded response formats are advantageous as they provide more information per respondent (Boyle, 2003). Another advantage of payment card method is that it is simpler than open-ended format, so larger rate of response could be obtained. However, this method requires the interviewees to be literate (Yalfal et al., 2013). The urban residents in Hanoi capital may seem well meet this requirement of payment-card question. Thus, in this study we used a payment-card method to question the residents who live in Hanoi capital. A survey questionnaire was designed to follow previous studies (Alhassan, 2012; Boyle, 2003). For the survey used in this study, face-to-face interviews were used to complete the surveys since this method allow study team to obtain the data during short time period with high response rate that other methods such as email, phone, and mailing cannot deal with for that aspects.

4.2.2. The empirical model

In this study we used a payment card method following the procedure of Boyle (2003). Specifically, in a payment card survey, each respondent is confronted with a series of money amounts, and asked to circle their maximum WTP for forest restoration. The respondents were also given the option of indicating "zero" for WTP.

Following Boyle (2003) and Alhassan (2012) the payment card data was analyzed by modeling the intervals that are bounded by the bid amounts the respondent circled and the next highest amount on the payment card. The payment level, ($\mathrm{Y_i}$) lies within the interval defined by lower and upper thresholds $\mathrm{t_{1i}}$ and $\mathrm{t_{ui}}$, so ($\log \mathrm{Y_i}$) lies between ($\log \mathrm{t_{1i}}$) and ($\log \mathrm{t_{ui}}$). The $\mathrm{E(logY_i|x_i)}$ is the function of $\mathrm{g(x_i, \beta)}$. Where $\mathrm{x_i}$ is the vector of the independent variables of respondent and β is the vector of the coefficients estimated. β is estimated from the following function of the simplest case:

$$(\log Y_i) = x'_i\beta + u_i \qquad (1)$$

Where u_i is the random error term assumed to be distributed normally with mean, 0 and standard error, σ. Each pair of interval thresholds for $(\log Y_i)$ is standardized and expressed by the following formula:

$$\Pr Y_i \subseteq (t_{1i}, t_{ui}) = \Pr((\log t_{1_i} - x'_i\beta)/\sigma < Z_i < \log t_{u_i} - x'_i\beta)/\sigma) \qquad (2)$$

Where Z_i is the standard normal random variable. Equation (2) can be re-written as $\Phi(Z_{ui})$ - $\Phi(Z_{1i})$, where Φ is the cumulative standard normal density function, Z_{ui} and Z_{1i} present the lower and upper limits. For n independent observations, the joint probability density function can be interpreted as a likelihood function defined over the unknown parameters, β and σ. The log-likelihood function is expressed by the following formula:

$$\log L = \sum_{i=1}^{n} \log[\Phi(Z_{ui}) - \Phi(Z_{1i})] \qquad (3)$$

Next, Maximum likelihood estimation (MLE) procedure was used to estimate the equation (3). The mean and the median WTP was calculated by constructing the fitted values of $\operatorname{Log} Y_i$ after regression. $\operatorname{Log} Y_i$ is transformed into Y representing the median WTP value. Finally, the mean WTP was the product of the median WTP and $\exp(\frac{\sigma^2}{2})$.

4.2.3. Study Area

Deforestation and forest degradation in Northwest Vietnam has impact on the quantity and quality of water and electricity provided downstream to the Hanoi metropolitan area (Bishop and Landell-Mills, 2002; Nguyen et al., 2013). Hanoi is not only the capital but also one of the largest cities in Vietnam. Thus, Hanoi was selected as the survey population. A total of 220 HHs were chosen randomly to contact for an interview in two areas, Hoang Mai and Thanh Xuan districts, where the residents had been being affected by a lack of water and electricity in recent dry years. The main characteristics of respondent of the survey in terms of gender, age, education, household's gender structure, and gross household income are presented in Table 4.1.

Table 4.1. Characteristics of 211 urban respondents and their households from a survey of Willingness to Pay for upland forest restoration in Vietnam. Family income is presented in millions of Vietnamese dollars (MVND).

Characteristics	(HHs)	(%)	Characteristics	(HHs)	(%)
Sex of HHs head:			Education of HHs head:		
Male	77	36.5	No formal education	17	8.06
Female	134	63.5	Under 5	9	4.27
Age:			6-9	38	18.01
Under 25	8	3.79	10-12	81	38.39
26-35	62	29.38	12-16	53	25.12
36-45	54	25.59	>16	13	6.16
46-55	39	18.48	Gross family income (MVND):		
56-65	31	14.69	<50	3	1.42
Over 65	17	8.06	50-100	27	12.80
Ratio male to female:			100-200	73	34.60
0 (no male)	4	1.90	200-350	57	27.01
0-1 (more female)	71	33.65	350-500	43	20.38
1 (male is equal to female)	78	36.97	>500	8	3.79
>1 (more male)	58	27.49			

4.2.4. Data collection

The investigation was conducted in November 2014. First of all, a focus group of 8 people, who are seniors in Hanoi University of Science, was formed to test the questionnaire in terms of reliability and validity. All members of the focus group were asked every question in the questionnaire. The questionnaire was then revised and completed until it was well understood by the entire focus group. We acknowledge that the composition of this focus group was not ideal for testing a general public survey, but the focus group testing did result in substantial improvements to the clarity of the questionnaire. The questionnaire was designed to gather information on WTP for PFR. Specifically, lists of values on the payment card questionnaire were: 0 VND, 5 thousand VND, 10 thousand VND, 20 thousand VND, 40 thousand VND, 50 thousand VND, 100 thousand VND, 150 thousand VND, 200 thousand VND, and 250 thousand VND. The respondent was asked to select the highest amount that they would still vote for the project of forest restoration in the upland (Box 4.1).

In order to determine the factors influencing the magnitude of WTP for forest restoration, the survey team gather the relevant information group, including: (1) characteristics of respondents such as age, sex, education; (2) characteristics of the household livelihood like income, gender structure; (3) their opinion on payment for environmental service, and (4) their evaluation on household's monthly payment for electricity consumption.

Box 4.1. Payment card question format

If passage of the proposal would cost you some amount of money every year for the foreseeable future, what is the highest amount that you would pay monthly and still vote for the forest restoration program? (CIRCLE THE HIGHEST AMOUNT THAT YOU WOULD STILL VOTE FOR THE PROJECT OF FOREST RESTORATION IN THE UPLAND)
Associated payment card was:

□ 0	□ 5	□ 10	□ 20
□ 30	□ 40	□ 50	□ 60
□ 80	□ 100	□ 120	□ 150
□ 200	□ 250	□ >250	(Unit: 1,000 VND)

4.3. RESULTS

4.3.1. Willingness-to-pay responses

A total of 211 respondents agreed to answer the questionnaire among 220 households that were contacted, representing a ~96% response rate. The WTP bid interval was determined by the interval of the bid value circled and the next bid value on the payment card. If the respondent circled bid value of 5 thousand VND, for example, then the bid interval was determined to be between 5 thousand VND and 10 thousand VND. In this survey, among 211 respondents, 56.96% of them indicated a bid interval of (0; 5 thousand VND), while 44.96% of the sample had a different bid interval. The weighted average was calculated by taking the midpoint of the bid interval times the percentage of the respondent picking each bid value. The total weighted average of WTP was 23.84 thousand VND (Table 4.2).

Table 4.2. Willingness-to-pay bid levels on the payment card and it is presented in interval value, the weighted average is calculated by multiplying the average of willingness to pay and the percentage of response rate.

WTP bid (Thousand VND)	Interval (Thousand VND)	Average	(%)	Weight Average (Thousand VND)
0	0-5	2.5	56.96	1.42
5	5-10	7.5	9.0	0.68
10	10-20	15	4.3	0.65
20	20-40	30	10.4	3.12
40	40-50	45	1.4	0.63
50	50-100	75	11.8	8.85
100	100-150	125	5.2	6.50
150	150-200	175	0.5	0.88
200	200-250	225	0.5	1.13
250	250-300	275	0	0.00
Total:			100.00	23.84

4.3.2. Willingness-to- pay estimation

WTP was estimated using MLE models (Table 4.3 and Table 4.4). Median WTP was 6,276.17 VND with a mean of WTP of 37,830.51 VND. This indicates that the average respondent is willing to pay 37,830.51VND for forest restoration. The five significant independent variables were Edu, Rationmf, Lnincome, Fpayelect, and Votepes. Specifically, Votepes was considered the strongest factor in the model with confident level at 99%, it was followed by Ratiomf and Edu with confident level at 95%, and lastly Fpayelect and Lnincome with confident level at 90%. The coefficient of variable of Votepes was positive (2.5345), indicating that if the respondent agreed to support payment for environmental service (PES), then they tended to be willing to pay for forest restoration. This implies that higher or better awareness of PES, was associated with a higher WTP for forest restoration. The coefficient of Rationmf was negative (-0.4242), indicating that a higher ratio of females to males in the household was associated with a greater WTP for forest restoration. The coefficient of Edu was positive (0.0706), suggesting that more education was associated with a higher WTP for forest restoration. The coefficient of Lnincome was positive (0.4734) indicating that higher household income was associated with a greater WTP for forest restoration. Lastly, the coefficient of variable of Fpayelect was positive (0.3745), so it does reflect that if the respondent feels that current payment for water and electricity is high then they tend to be willing to pay for forest restoration.

Table 4.3. Lists of variables in the Maximum Likelihood Estimator model

Variable	Definition	Mean	Std. Dev.	Min	Max
Edu	Years of education (numbers)	10.97	4.80	0	20
Ratiomf	Ratio of male to female	1.22	0.75	0	4
Lnlncome	Logarithm of gross income (thousand VND)	19.079	0.617	17.399	20.723
Fpayelect	Feel that the paid money for electricity households' consumption monthly is very much=5; much=4;normal=3;little=2;very little=1)	3.29	0.73	0	5
Votepes	Dummy variable of vote for payment for environmental services (yes=1; no=0)	0.77	0.41	0	1
Wtpl	Lower bound of the WTP interval	16,327	30,372	0	200,000
Wtpu	Upper bound of WTP interval	31,279	46,020	5,000	250,000
Midwtp	Midpoint of the WTP interval	23,803	38,042	2,500	225,000
Lnwtpl	Logarithm of the lower bound of the WTP interval	4.339	5.042	0	12.206
Lnwtpu	Logarithm of the upper bound of WTP interval	9.45	1.25	8.51	12.42
Lnmidwtp	Logarithm of the midpoint of WTP interval	8.94	1.45	7.8240	13.384

Table 4.4. MLE model to estimate Willingness-to-pay Value

Variables	Coefficient	Std.Err.	Z	*P*>|z|	[95% Conf.	Interval]
Cons	-4.3049	4.874	2.06	0.377	-13.8579	5.2481
Edu	0.0706	0.034	-2.00	0.039	0.00351	0.1378
Ratiomf	-0.4242	0.212	1.90	0.045	-0.8394	-0.0089
Lnincome	0.4734	0.249	1.77	0.058	-0.0151	0.9620
Fpayelect	0.3745	0.211	5.07	0.076	-0.0396	0.7886
Votepes	2.5345	0.499	-0.88	0.000	1.5548	3.5152
σ	1.8954					
Log likelihood	-299.1913					
Prob>chi2	0.0000					
Mean WTP	37,830.51 VND					

4.4. DISCUSSION

There are two possible issues associated with WTP estimation in terms of understating and overstating a bid value (Alhassan, 2012). The first issue occurs due to a "zero" response, which may be protest bids. The second issue appears due to an actual "zero" response when the respondents place a no value on the goods (Boyle, 2003). In our survey, the total percentage of urban residents who were not willing to pay (both protest and actual zeros) was 56.96% (Table 4.2). Although both sources of error may have impacted our estimate of mean WTP, we cannot determine if estimated WTP is underestimated or overestimated. To some extent, each error may offset the other, so our WTP estimation is considered valid (Alhassan, 2012). One drawback of the payment card method that we used is that the respondent can pick their own price given the different payment levels, so we often get relatively low estimates on WTP (Blaine et al., 2005). The MLE models allowed us to estimate WTP for forest restoration. Urban residents in Hanoi were willing to pay around 37,830 VND per household per month for forest restoration, which is higher than what urban residents of Ho Chi Minh, Vietnam were willing to pay (16,510 VND per household) per month for biodiversity conservation in U Minh Thuong National Park (Khai and Yabe, 2014). These results indicate that the CVM method in general and MLE model specifically, are efficient for estimating WTP value for forest restoration or other environmental goods and services.

Our results from the MLE model suggest that WTP for forest restoration depends on social and economic factors of the respondent (Table 4.4). These results are consistent with the findings from similar studies in Vietnam (Do and Bennett, 2007; Khai and Yabe, 2014; Thuy, 2007). The coefficient of variable of Votepes was 2.5345 in the model, suggesting that the awareness of the respondents regarding the need for forest restoration is positive. This provides policy-makers a reliable foundation to continue to raise awareness as well as knowledge about the environmental role of forests and forest restoration programs. This may be a good approach to access the untapped source of restoration funding from urban residents.

4.5. CONCLUSIONS

This study employed a Contingent Valuation Method (CVM) to estimate urban household's Willingness to Pay (WTP) for forest restoration in the upland area of Vietnam. On average, each household was willing to pay 37,830 VND per month through water bill for forest restoration programs. Survey respondent's WTP for forest restoration was related to their level of education, income, female-to-male ratio in the household, attitude towards monthly household's electricity consumption, and awareness of payment for environmental service. Our findings suggest that either improving households' income and educational level or focusing on females in the family may improve access the untapped source of restoration funding among urban households.

Chapter 5 - CLIMATE CHANGE MITIGATION PROGRAMS IN NORTH CENTRAL, VIETNAM: TRADE-OFFS OF LAND USE IN UPLAND FORESTS

Summary

Optimal forestland use can be a farmer's central livelihood strategy, and the economic benefits from tree-planting might provide a strong incentive for investment in forest development programs. Low participation in Vietnam's REDD-plus (reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries) program, as well as low investors' involvement in AR-CDM (afforestation and reforestation clean development mechanism) projects, are current concerns for Vietnam. Success in these programs requires developing supportive forest policies and providing efficient information on land use options. To help close the gap in knowledge regarding these issues, we determined the opportunity costs of two main land use options, shifting cultivation and tree-planting. We employed a holistic approach including the analysis of total economic benefit and a cost-benefit analysis. We selected the communes of Chau Thai, Yen Na, and Luong Minh in Nghe An province for our study. These locations are in the central coastal region of Vietnam, where rapid deforestation and forest degradation has taken place over the last decade. Importantly, this study derived different scenarios for forest plantation accounting for uncertainties in bank interest rates and carbon prices. Results showed that by practicing shifting cultivation, a farmer at Yen Na and Luong Minh can benefit from food production and earn income. Depending on the interest rates and carbon prices, the calculated economic benefit of plantation forests varied from -\$6 to \$437.4 ha^{-1} y^{-1} for *Acacia auriculiformis* at Yen Na commune and -\$7 to \$335.4 ha^{-1} y^{-1} for *A. mangium* at Luong Minh commune; and -\$10 to \$310.4 ha^{-1} y^{-1} for *A. mangium* at Chau Thai commune. Our results illustrate several

important policy implications for forest restoration, the AR-CDM project and the REDD+ program in Vietnam: Vietnam should prioritize economic policy tools to control bank interest rates in a timely, flexible, and reasonable manner and negotiate competitive prices for temporary certified emission reductions (tCERs). With the appropriate policy guidance, forest plantations can provide higher economic benefits to farmers than shifting cultivation.

5.1. INTRODUCTION

Seeking innovative solutions for mitigating climate change has been a top priority for the international community. The Afforestation and Reforestation Clean Development Mechanism (AR-CDM) and Reducing Emissions from Deforestation and forest Degradation (REDD+) initiatives were born in that context. The AR-CDM project was formed based on the Kyoto Protocol (UNFCCC, 1997). The objective of this flexible program is to provide a cost-effective mechanism for developed countries to offset greenhouse gas emissions and to assist sustainable development by transferring new low carbon technologies to developing nations that host CDM projects (Gutiérrez et al., 2006; Hugé et al., 2010; Lederer, 2011; Paulsson, 2009). REDD+ was first proposed in 2005 and was then negotiated under the United Nationals Framework Convention on Climate Change (UNFCCC) with the objective of mitigating climate change by reducing net emissions of greenhouse gases through enhanced forest management in developing countries (Thomas et al., 2010; UNFCCC, 2011). Although AR-CDM is different from REDD+, both aim to mitigate climate change through forest resources and can potentially contribute to sustainable development in developing countries. Thus, the success of AR-CDM and REDD+ is essential to the international community as well as to nations involved in these programs.

AR-CDM and REDD+ have been implemented in Vietnam over the past few years, yet the success of the programs has been challenged by low household participation (Pham et al., 2012) and low investors' involvement (there have been AR-CDM projects in Cao Phong and Hoa Binh; over 253 CDM projects were registered in Vietnam) (MONRE, 2017; Thomas et al., 2010). This low investors' participation can partly be attributed to a lack of economic incentive that is strongly associated with inappropriate land use policies. Information about the costs and benefits of planting forests is crucial for stakeholders before they decide to become involved in AR-CDM and REDD+ projects. In practice, both investors and farmers have little such information. To date, farmers have maintained a negative impression of previous forest development projects (De Jong and Van Hung, 2006). Earlier projects such as those titled 327, 661, and others had active involvement by farmers in forest protection and management activities, but the farmers received very little benefit (\$2.50 ha^{-1} y^{-1} for protection of natural forests) (Sunderlin and Huynh, 2005). Information regarding tradeoffs in land use options is central and fundamental for policy formulation to provide appropriate incentives for farmers and investors in forest development practices. Because of a lack of such information, current preferential loan policies for assisting farmers to plant forests are insufficient and ineffective. Thus, it can be concluded that, although current forestry policies in Vietnam provide a platform from which AR-CDM and REDD+ programs could develop and contribute to sustainable forest and rural development, this policy environment is incomplete. Therefore, success in the AR-CDM and REDD+ programs requires coherent forest policies and efficient basic information on land use option tradeoffs.

5.2. BACKGROUND ON UPLAND USE SYSTEM IN VIETNAM

The upland land use system in Vietnam has been shaped by the recent history of the country, which has experienced war and extreme poverty. After 1945, Vietnam fell under decades of fierce warfare, which devastated the country and its infrastructure and left millions of people dead or injured. After the country was unified in 1975, Viet Nam entered a period of economic crisis and declining standards of living (i.e. serious food shortages) (Glewwe, 2004; Herring, 2013; Sunderlin and Huynh, 2005). The annual per capita output of rice, the main staple food, was the same in 1942 and 1990, at 280 kg (Pingali and Xuan, 1992). The extreme poverty lasted for several decades and only began to decrease with economic reform in 1986 and land reform in 1993 (Dollar, 2004; Glewwe, 2004; Nguyen et al., 2009; Nguyen, 2012). Shifting cultivation, the traditional agricultural cultivation mode, was closely linked to the expansion of agricultural land in forested regions, which had become a common pathway for household income, particularly in mountainous regions (Sam, 1994; Sunderlin and Huynh, 2005; Tachibana et al., 2001). Since land reform in the forestry sector was implemented in 1995, forestland was allocated to all stakeholders in the economy, including individuals, households, and forest enterprises. Land privatization has promoted changes in forest management in Vietnam (Nguyen et al., 2010). Forest-based economic development gradually became an important livelihood option for many households in addition to traditional shifting cultivation, paddy rice, or other permanent cultivation (e.g. maize, or fruit tree, etc.). In parallel with forestland reform, the government actively implemented several programs of forest rehabilitation and afforestation (327, 661, and others) (De Jong and Van Hung, 2006; McElwee, 2009; McElwee, 2016b). At the same time, plantation forest projects supported by many international organizations were implemented. These caused a large transition in Vietnam's forests, with the national forest cover rate increasing from 27.2% in 1990 to 39.5% in 2015 (MARD, 2007, 2016a). In the following sections, we present two main land use options in the uplands of Vietnam: shifting cultivation and forest practices.

5.2.1. Shifting cultivation

Shifting cultivation, also known as "Swidden agriculture," refers to a rotational farming technique in which forest land is cleared for cultivation, normally by fire, and then allowed to lie fallow to regenerate for a few years. It is also pejoratively named "slash-and-burn" (Dove, 1983; Mertz et al., 2009). In the highlands of Vietnam, this mode of agricultural production has been practiced for centuries (Fox et al., 2000; Mertz et al., 2009). Among a total of 54 ethnic groups, there are 50 groups practicing shifting cultivation with around 2.8 million farmers in almost 0.5 million households. While only a few of the Kinh people, the dominant ethnic group, are thought to practice shifting agriculture, the percentage of people in the other ethnic groups practicing shifting cultivation in the early 1990s were 7% (Tay), 16% (Nung), 45% (Thai) and 100% (almost all the remaining ethnic groups) (Sam, 1994).

There are two main types of shifting cultivation: pioneer shifting cultivation and rotational shifting cultivation. The first type refers to full use of soil fertility; the land is then abandoned without intended further use by the same cultivators. This type has been mainly practiced by the H'Mong people living in the high mountains. The second type is rotational shifting cultivation, which has been used by most of the remaining ethnic groups. In this type, the fallowing period is usually 10-15 years, depending on conditions. However, in the last few decades, because of high population pressure and forest planting and forest rehabilitation planning, the land available for shifting cultivation has been limited in some places and people have moved to new areas. In addition, in the Central Highlands, shifting cultivation farmers have been displaced by coffee farmers (Meyfroidt et al., 2013). This has led to a trend toward pioneer shifting cultivation under four main scenarios (Sam, 1994): (a) farmer attempts to practice shifting cultivation far from home without intending to return to the old site; (b) the existing rotational fallow land has been transferred between the farmer and the Kinh people for money and forests continue to be cut for shifting cultivation; (c) shortened fallowing periods and more exhaustively exploited soil; and (d) farmers migrating to new settlement areas or to the south to continue cutting forests for shifting cultivation.

5.2.2. Forest practices under the national forest development programs

Exploiting forests has a long history in Vietnam but forest management (forest protection, planting forests) has been promoted for only the past two decades. Remarkably, forest transition in Vietnam has occurred since the 1990s (Meyfroidt and Lambin, 2008b), at the same time as the introduction of land laws (1993, 2003) and forest protection and management laws (1991, 2004). A critical point highlighted in these laws is that the legal rights of many agents—individuals, households, forest enterprises, etc.—was acknowledged and forestland was clearly classified as either special forest land, production forest, or protected forest (McElwee, 2016b). At the national scale, an increase in forest cover has been attributed to two national forest development programs (De Jong and Van Hung, 2006): the Greening the Barren Hills program (program 327) and the Five Million Hectare Reforestation Project (5MHRP). Program 327 was begun and completed during the 1990s, while the 5MHRP began in 1998 and ended in 2010 (Ohlsson et al., 2005). Household involvement was encouraged in planting and protecting forests in the 327 and 5MHRP programs. The state made two offers to farmers: (1) to receive degraded forestland (bare land) on which to plant forests or (2) to receive forest land to protect. For the first option, the farmer received VND 1,000,000 ($80) ha^{-1} for forestlands under natural regeneration with additional tree-planting and VND 2,500,000 ($208) ha^{-1} for forestlands under afforestation (McElwee, 2016b; PM, 1998). For the second option, people were paid VND 50,000 ($4.20) for protection of 1 ha of forest per year (Tran et al., 2011; Sunderlin and Huynh, 2005). This level of support increased over time depending on the socioeconomic conditions of each region and locale (e.g., in Dien Bien farmers received VND 192,000 ($9.80) for protection of 1 ha of forest per year). Further, households could benefit from a certain share of timber and non-timber forest products (firewood, bamboo shoots, honey, medicinal herbs, etc.). Generally, those national forest programs were somewhat successful (De Jong and Van Hung, 2006) in terms of their contribution to an increase in national forest cover, but they had little impact on improving livelihoods (Sunderlin and Huynh, 2005).

5.2.3. Potential forest practices under AR-CDM

AR-CDM projects must be formulated, registered, implemented, monitored, and verified according to certain rules and procedures set by the United Nations Framework Convention on Climate Change (UNFCCC). AR-CDM was initially developed within the context of the UNFCCC to set up a framework for reduction of greenhouse gas (GHG) emissions and to stabilize GHG in the atmosphere and prevent its dangerous impacts on the climate system. The Kyoto Protocol is a UNFCCC protocol that was officially approved by 192 parties in Kyoto, Japan, in December 1997. The Clean Development Mechanism (CDM) is one of the three mechanisms mentioned in the Kyoto Protocol that is of practical significance to developing countries such as Vietnam. There are two CDM schemes. One is CDM for GHG reduction, another is CDM for GHG absorption by creating carbon sinks (Afforestation/Reforestation CDM or AR-CDM) (JICA, 2006, 2008). The afforestation/reforestation clean development mechanism (AR-CDM) is one of the flexible mechanisms under the Kyoto Protocol that relates to eligible project activities in the forestry sector. AR-CDM is the mechanism regulating the generation of stored carbon in forests in developing countries and the sale of carbon stocks, so-called carbon credits, measured in temporary certified emission reductions (tCERs), to developed countries. This carbon sale is a GHG reduction target under the Kyoto Protocol (Figure. 1).

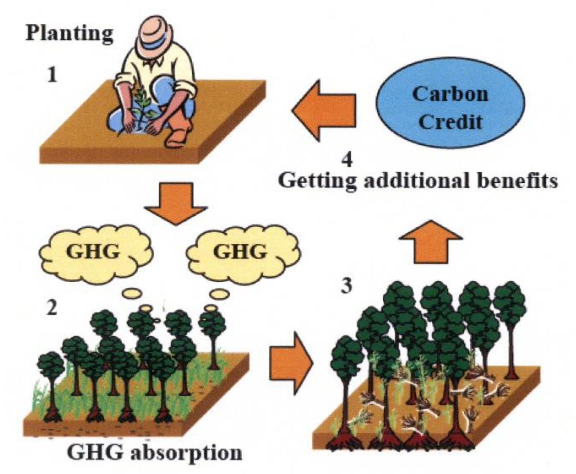


Figure 5.1. AR-CDM project cycle. Source: JICA (2006).

The AR-CDM program is an example of payment for environmental services (Börner et al., 2017) provided by forests and their host countries, and much is expected from AR-CDM in terms of financing the future conservation and restoration of forests. For many developing countries with little industry and only natural resources to depend on for revenue, AR-CDM is one way to generate income and is expected to achieve additional environmental benefits. Possible types of AR-CDM projects include agro-forestry, monocultural or mixed industrial plantations, forest landscape restoration projects on degraded or protected lands, community forest projects, and other afforestation/reforestation projects that focus on timber production, biomass energy, and watershed management. In summary, opportunities and challenges exist alongside AR-CDM. The implementation of AR-CDM requires complex preparation and a long process that can provide both the investor and the farmer with higher outcomes from carbon credit-based economic value.

The overall goal of this paper is to achieve better understanding of tradeoffs of upland use options that might ultimately assist policy-makers to improve forest policy and help farmers as well as investors potentially increase their participation in AR-CDM and REDD+. To accomplish this, we investigated the opportunity cost of land use options between shifting cultivation and tree-planting in Nghe An province, and estimate the different total benefit value scenarios associated with possible levels of bank interest rates and carbon prices. We then make recommendations on the potential of AR-CDM as well as REDD+ programs in Vietnam.

5.3. METHODS

5.3.1. Conceptual and analytical framework

Land use refers to the total arrangements, activities, and inputs undertaken in a certain land cover type and the social and economic purposes for which land is managed (e.g., timber extraction, grazing, conservation) (Noble et al., 2000). Thus, land use must involve stakeholders or agents whose behavior is associated with choices and decisions regarding land use. According to decision theory (Hansson, 2005), when stakeholders/agents make decisions or choose between options, they try to obtain as positive an outcome as possible based on some standard of what is desirable. Importantly, most current economic theory is based on the idea that individuals maximize their holdings as measured in money. In our study, two key stakeholders or agents in the upland land use system in Vietnam are the investor, who potentially invests financial capital in planting forests, and the farmer, who can invest labor capital and available land in forest activities. The investor and the farmer will be involved in forest practices if the value of those practices surpasses alternative options for their capital, labor and land.

These tradeoffs can be analyzed through the notion of opportunity costs, which includes both cost-benefit comparisons and usage value comparisons among different options. With respect to the value of the upland use options, we followed the tradeoff models in Figure. 2. Shifting cultivation (A), regular planting forests (B), and planting forests under AR-CDM (C) share revenue as an output in common. However, the absolute advantage of shifting cultivation (A) over planting forests is food provision, while the absolute advantage of tree planting (B & C) are forests products (wood, chips), and carbon sequestration capacity. This is because even though shifting cultivation also has some carbon sequestration like plantation forests, its carbon sequestration-based revenue has not been implemented in practices of the uplands in Vietnam.

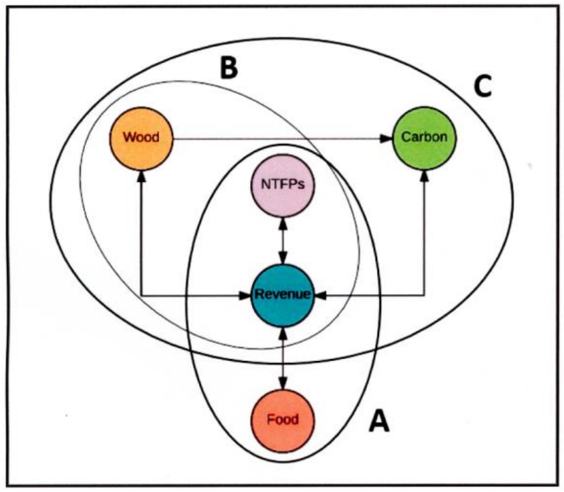


Figure 5.2. Tradeoffs between shifting cultivation (A), which provides food, revenue, non-timber forest products (NTFPs); plantation forests (B), which generate revenue, NTFPs, and timber; and tree-planting under the international afforestation and reforestation clean development mechanism (AR-CDM) of the Kyoto Protocol (C), which has an additional output of carbon sequestration compared to plantation forests.

We followed the empirical framework in Figure 5.3 to assess tradeoffs between shifting cultivation and plantation forests (tree-planting and AR-CDM). In this model, there are two options for using forestland: shifting cultivation and forest-planting. The agents in the model are the investor and the farmer. The investor is involved in AR-CDM while the farmer takes part in shifting cultivation practices. Fundamentally, the first decision regarding land use options depends upon a comparison between two options. A cost-benefit analysis (CBA) and total economic benefit (TEB) approach were used. Total economic benefit 1 (TEB1) refers to the sum of net present value (NPV) of forest products (wood/chip and carbon) while total economic benefit 2 (TEB2) represents the aggregate value of the NPV of agricultural crops (upland rice, corn and cassava). The first decision was made based on the comparison of TEB1 and TEB2. If TEB2 exceeded TEB1, then shifting cultivation was preferred to planting forests. In the opposite case, the agents moved to the next phase of the model. Satisfying the economic criteria does not assure that a decision to implement AR-CDM will be made since factors of land value, social issues, and transition costs and constraints were also crucial factors that influenced a final choice. The model ends with a second yes/no decision. If yes, tree planting (AR-CDM) will be chosen, and if no, the farmer returns to shifting cultivation practices.

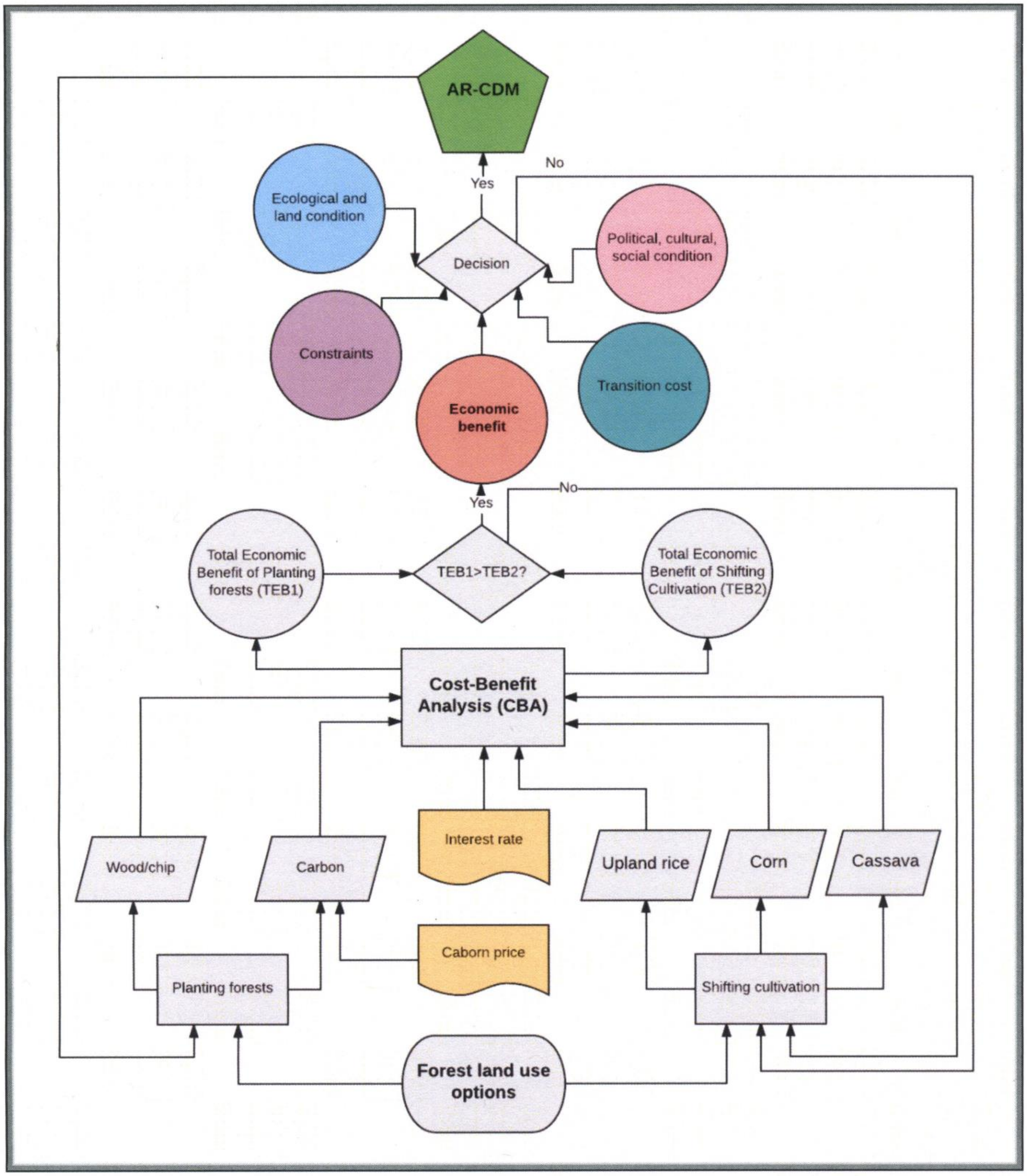


Figure 5.3. Analytical framework for land use options (shifting cultivation and tree-planting) under afforestation and reforestation-clean development mechanism (AR-CDM) project. The conditions for the adoption of AR-CDM by the farmer and investor exist if the total economic benefit of tree-planting exceeds that of shifting cultivation in a cost-benefit analysis and if constraints (transition cost, socio-ecological conditions) are overcome. The gold color-filled box showing interest rate and carbon price highlights these two critical variables that can be influenced by policy.

5.3.2. Study site

The study area is in two high mountainous districts. The first is the Tuong Duong district, which is located in the western part of Nghe An province, nearly 200 kilometers from Vinh city and 90 kilometers from the Laos boundary by Highway 7A. The total area is 281,129 ha, accounting for 17% of the province. The agricultural land in 2009 was only 901 ha, equivalent to 0.32% of the total area; the remaining is forest and other land. Natural resources are diverse and plentiful. The total population is about 75,993 people, including six major ethnic groups: Thai, Mong, Taypoong, Odu, Kinh, and Khomu. The population is unevenly distributed, mainly along Highway 7A, especially in the town of Hoa Binh. The population density is 0.27 people ha^{-1}. Agricultural production is the main economic income of Tuong Duong.

The second is the Quy Hop district, which is in the eastern part of Nghe An province. There is a total area of 94,128 ha and 120,000 people. Due to favorable soil and market conditions, plantation forests have quickly developed over the past decade. Around 40% of the total area is covered by forests. The natural forest at Quy Hop has high biodiversity and high volume with many precious trees.

The choice of communes to study was made in discussion with district and commune leaders, and was based on land use status, ethnic diversity, and other official data available for all communes. The study team ultimately selected three sites for our study (Figure. 4).

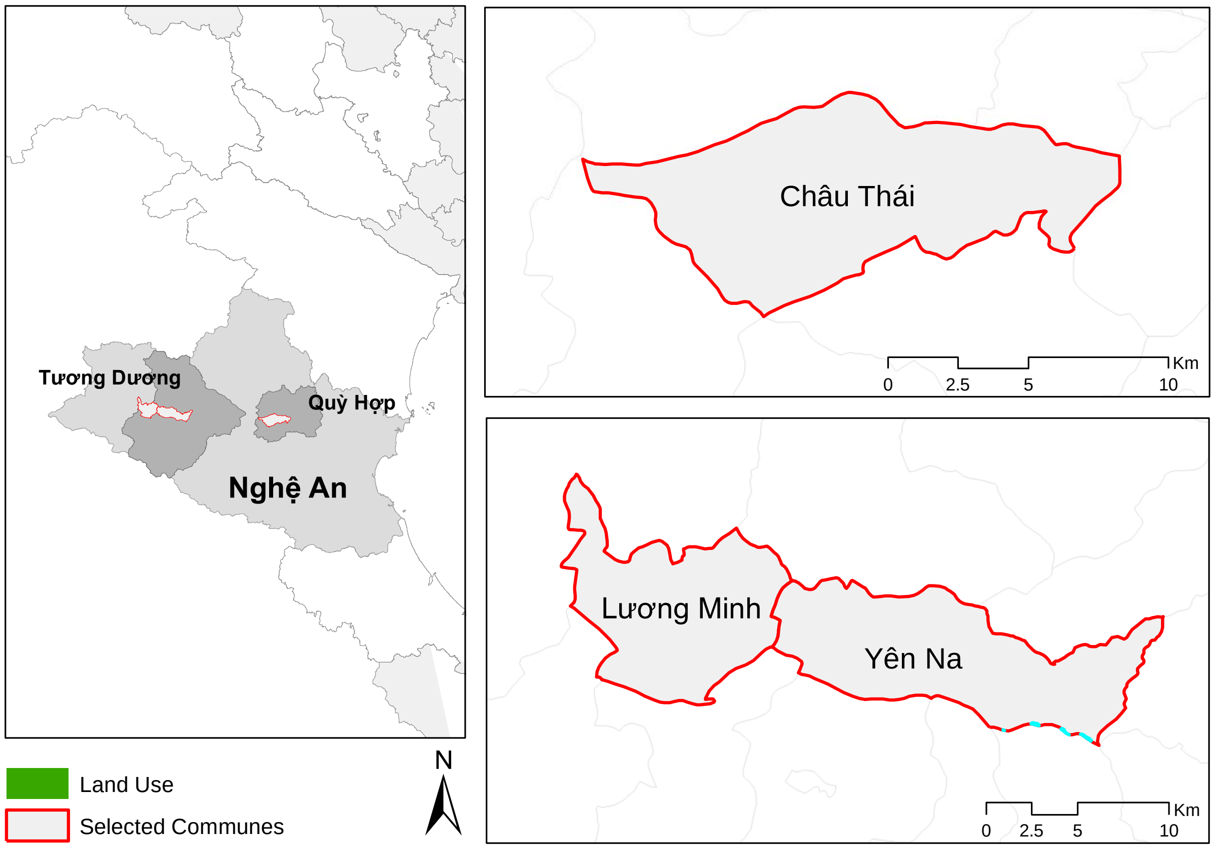


Figure 5.4. Locations in the highlands of Vietnam where opportunity costs of various land use options were studied.

Site 1 is situated at the Yen Na commune (Tuong Duong district). Before 1990, natural forest had been cut for shifting cultivation in several rotations except for rocky mountainous forests. At that time, those areas formed a mosaic between open area and fallow land. Forestland was managed by local governments. From 1990 to 2002, people freely burned forests for shifting cultivation and cut timber for building houses. Some areas were protected by villagers with village regulation. From 2003 to the present, forest and forestland have been allocated to households in accordance with the 163 Decree of State Government. Farmers invest in their allocated land themselves with some help from the government. Shifting cultivation areas have been planned and controlled by local government.

Site 2 is located at the Luong Minh commune (Tuong Duong district). Before 1990, this area included rich forest ecosystems with standing stock above 200 m^3 ha^{-1} (MARD, 2009; McElwee, 2016). These forest ecosystems had an insignificant risk of excessive exploitation because local people only selected suitable-sized wood for their buildings. In the period 1990-2003, forest and forest land was allocated to local authorities to manage by community convention to effectively tackle deforestation for timber. However, during this time, the forest area was significantly reduced because of rapid population growth, shifting cultivation, an expanded and rebuilt road systems, and incessant exploitation from local households and state companies. From 2004 to the present, the forest and forest land have been assigned to the Tuong Duong Forest Protection Management Board to protect against illegal exploitation and deforestation for agriculture. However, the remaining forest areas have experienced degradation because illegal activities have not been eliminated.

Site 3 is situated at the Chau Thai commune (Quy Hop district). Primary forest has been cut for a long time for shifting cultivation and selective harvesting. Because of good soil conditions and a low intensity of shifting cultivation, forest regenerates very rapidly on fallow land. The status of the land before 1990 was a mosaic between agricultural areas and fallow land. Natural forest was burned for shifting cultivation several times in rotation with a high intensity that created bare land, shrub land, and degraded forest. Since 1998, forest and forestland has been allocated to the Youth Union in Nghe An Province. Bare land has been used for reforestation purposes but due to a lack of funds and labor a large area of bare land remains untouched.

5.3.3. Data collection and initial processing

5.3.3.1. Socio-economic data

Information on the local socioeconomic context is essential for AR-CDM because it strongly links to the farmer's land use options. In this study, the many land use types involved (forests, bare land, etc.) were defined according to the Vietnamese forest classification system in Circular No. 34 of the Ministry of Agriculture and Rural Development (MARD, 2009). In May 2010, we used a participatory rapid appraisal (Pingali and Xuan, 1992) tool with questionnaires and conducted a socioeconomic survey. We investigated the economic situation of households in the study areas to examine land use and its benefits as well as issues that households confront. In total we interviewed 35 households, including 15 farmers in the Luong Minh and 20 farmers in the Yen Na communes (Supplementary Table S5.1). The households were classified into three income categories—rich, medium, and poor—and their shifting cultivation activities were described. The information on shifting cultivation included land use history, usable land area, productivity, and output. To prepare for determining a cost-benefit analysis of shifting cultivation, we carefully interviewed for information on costs and revenue from the different crops (upland rice, corn, and cassava).

We collected the data on plantation forests using a different approach. The total economic value of the forest was divided into use value (wood/chip) and non-use value (carbon capture value). To increase the reliability of the determination of the economic value of wood/chip, we selected two typical fast-growing tree species, *Acacia mangium* and *Acacia auricoliformis*, for analysis. This selection was based on the tree-planting model in the AR-CDM Cao Phong project, which began in 2009. This survey followed the standard guide of the Ministry of Agricultural and

Rural Development (MARD, 2005) via group discussion, community workshops, and semi-structured interviews with local people (Supplementary Figures S5.6).

5.3.3.2. Carbon sequestration measurement of shifting cultivation

Carbon storage is a fundamental output of different land use options. For shifting cultivation, we considered a 3-4-year fallowing, which was classified as short-fallow swiddening by Ziegler et al. (2012). To measure carbon sequestration, we followed equation (1,2) of FFPRI (2007) and Unwin and Kriedemann (2000), as below:

$$\Delta C_I = C_I - C_{I-1} \quad (1)$$

$$C_I = AGB_I + BGB_I + L_I + DW_I + SOC_I \quad (2)$$

Where, ΔC_I: Net carbon sequestration increment in interval I, (t C)

C_I: Total cumulative carbon stored at end of interval I, (t C)

AGB_I: Carbon in above ground biomass pool at end of interval I, (t C)

BGB_I: Carbon in below ground biomass pool at end of interval I, (t C)

L_I: Carbon in litter pool at end of interval I, (t C)

DW_I: Carbon in dead wood pool at end of interval I, (t C)

SOC_I: Carbon in soil pool at end of interval I, (t C)

(t C): Ton carbon

To parameterize these equation, we followed several steps presented in FFPRI (2007), UNFCCC (2006), and Unwin and Kriedemann (2000) to measure carbon stock in carbon pools, the weight of carbon dioxide, and total net carbon sequestration by vegetation.

Firstly, biomass data were collected from different fallow lands varying by time of regeneration. For above ground biomass and below ground biomass, we collected data in a total of 18 representative square plots measuring 20 x 20m. In each plot, five square subplots of 2 x 2m

(Figure 5.5) were randomly selected without replacement for destructive collection of biomass on fallow lands at 1, 2, 4, 6, 8, and 10 years (Supplementary Figures S5.2-5.5; S5.7-5.9). Total weight of the above ground biomass (ABG) and below ground biomass (BGB) was the sum of the mass of all organs of the tree/shrub including the mass of stems, branches, leaves, and roots. We measured above-ground biomass in the field by collecting all above-ground biomass in each sub-plot and we classified it into grasses and shrubs. For grass the process was to weigh all; for shrubs the leaves, stems, and trunks were separated and weighed. For below-ground biomass in the field, in each subplot soils were extracted to a depth of 30cm. The roots were extracted from the soil and weighed, and we randomly selected 500g of roots for dry biomass and carbon quantification.

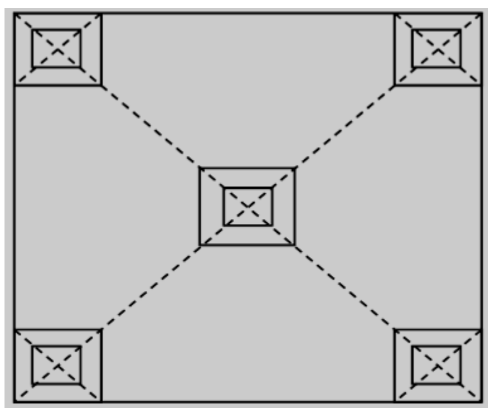


Figure 5.5. Sub-plot setting in a Sample Plot

Biomass samples were taken to the Vietnam Forestry University laboratory to dry and calculate the amount of carbon stored following guidelines in (IPCC, 2003b, 2006). The dry weight of the vegetation which was determined based on the long process, in which biomass samples were put into an oven to dry at 105°C until constant mass. After that, the total dry biomass in the vegetation was determined by aggregating the dry biomass of each organ in the vegetation. The weight of carbon was determined by multiplying the dry weight of the tree by an assumed 50% fraction (Unwin and Kriedemann, 2000).

Secondly, deadwood and litter measurements, which are conducted by collecting the same sample plots in which tree measurements are conducted. Since there was no presence of deadwood in the fallowed plots, it was excluded in carbon sequestration measurement. For litter measurement, we first placed clip plot frame at the selected point, then we collect all litter inside the frame. A knife was used to cut pieces that fall on the border of the sampling frame. All litter was extracted and returned to the lab for dry weight quantification following the protocols used for AGB and BGB. The weight of carbon of deadwood and litter was then determined by multiplying the dry weight of the carbon pools by an assumed 37% fraction (UNFCCC, 2008).

Thirdly, soil carbon is soil organic carbon (SOC), which refers to carbon sequestered and stored in soil. To determine SOC, in each representative plot, we removed the coarse litter layer and dug 30 cm deep and about 40 cm wide hole. We then took samples from 0-10, 10-20 and 20-30 cm depth using a core sampler of equal size. Next, all soil from the core sampler was transferred into a plastic bag, mixed, and sub-sample for dry weight quantification in the lab, following protocols for AGB and BGB. SOC was determined by the multiplication of carbon concentration, soil depth, and bulk density (IPCC, 2003b).

Fourthly, the weight of sequestered carbon dioxide was determined by multiplying the weight of carbon in the vegetation by the ratio between the mass of a carbon dioxide molecule (CO_2) to a carbon atom (C) (i.e. 3.67) (Unwin and Kriedemann, 2000). This allowed us to determine total net carbon sequestration of shifting cultivation, which was the sum of net carbon dioxide sequestered in the carbon pools of above ground biomass, below ground biomass, litter, and soil carbon.

5.3.3.3. Carbon sequestration measurement of plantation forests

For carbon sequestration of plantation forests under AR-CDM, we selected *Acacia mangium* and *Acacia auriculiformis* for estimation. We used published growth tables (JICA, 2008; Le Dinh, 2000) of *Acacia mangium* and *Acacia auriculiformis* (Supplementary Table S.11), then employed formulas (3-6) to identify carbon accumulation during a 15-year cycle.

$$N(t)i = NA(t)i + NB(t)i \qquad (tCO2\ ha^{-1}) \qquad (3)$$

where N(t)i: total carbon stock in each stratum at time t under the project scenario, NA(t)i: carbon stock above ground at time t under the project scenario, and NB(t)i: carbon stock below ground at time t under the project scenario, $tCO_2\ ha^{-1}$: ton CO_2. The above ground carbon stock estimate was derived using:

$$NA(t)i = T(t)i \times Cfrac \qquad (4)$$

$$T(t)i = SV(t)i \times BEF \times WD \qquad (5)$$

where T(t)i is above ground biomass of tree i at time t under the project scenario (total dry matter per ha - t.d.m ha^{-1}), Cfrac is carbon fraction of dry matter, SV(t)i is stem volume from the growth tables of tree i at time t under the project scenario ($m^3\ ha^{-1}$), BEF is the biomass expansion factor from stem to total above-ground biomass, and WD denotes wood density (t.d.m m^{-3}). We followed (IPCC, 2003b, 2006) to arrive at the default values of BEF, WD, and Cfrac for the two tree species. Then below ground carbon stock was estimated following:

$$NB(t)i = Exp(-1.085 + 0.9256 \times lnT(t)i) \times 0.5 \qquad (6)$$

5.3.3.4. Estimation of temporary certificated emission reduction

Under the clean development mechanism (CDM) of the Kyoto Protocol, forest projects can receive returns for carbon sequestration via crediting instruments, including temporary certified emission reductions (tCERs). In this study, tCERs are linked to the benefit value of tree-planting under AR-CDM, so it is used for a tradeoff analysis between land use options (shifting cultivation and forest practices). To calculate tCERs, we used the formula of (UNFCCC, 2006) as follows:

$$\mathrm{tCERs}_{(\mathrm{tv})} = \sum_{\mathrm{t}=0}^{\mathrm{tv}} \mathrm{ER}_{\mathrm{AR-CDM,t}} * \Delta \mathrm{t} \qquad (7)$$

where $\mathrm{tCERs}_{(\mathrm{tv})}$ is temporary certificated emission reduction at the year of assumed verification t_v, Δt is time increment (1 year), and $\mathrm{ER}_{\mathrm{AR-CDM,t}}$ is net anthropogenic greenhouse gas (GHG) removals by sinks (tCO_2e $year^{-1}$), which was determined as:

$$\mathrm{ER}_{\mathrm{AR-CDM,t}} = \Delta \mathrm{C}_{(\mathrm{PROJ,t})} - \Delta \mathrm{C}_{(\mathrm{BSL,t})} - \mathrm{GHG}_{\mathrm{PROJ,t}} - \mathrm{Lt} \qquad (8)$$

where $\Delta \mathrm{C}_{(\mathrm{PROJ,t})}$ is GHG removals by sinks at time t (tCO_2e $year^{-1}$), $\Delta \mathrm{C}_{(\mathrm{BSL,t})}$ is baseline net GHG removals by sinks (tCO_2e $year^{-1}$) which set to the shifting cultivation carbon levels, $\mathrm{GHG}_{\mathrm{PROJ,t}}$ is project emission (tCO_2e $year^{-1}$), and L_t is leakage attributable to the project activity at time t (tCO_2e $year^{-1}$). See the detail at AR-AMS001 (UNFCCC, 2006).

5.3.4. Data analysis

5.3.4.1. Cost-benefit analysis

A social cost-benefit analysis (CBA) is an assessment method that quantifies in monetary terms the value of all consequences of a policy to all members of society. It is a widely-used appraisal technique for public investment and public policy. This tool was first introduced in the 19th century (Pearce et al., 2006). In this type of CBA, the costs and benefits to society as a whole are considered (Boardman et al., 2011). The method compares the gains (economic benefits) and losses (costs) over a given period of time associated with an investment project/policy (Mishan and Quah, 2007). A policy decision is justified when benefits surpass costs. When there are many policies and limited budgets, the method provides criteria for making choices and setting priorities among several alternatives competing for limited resources (Nguyen et al., 2010). CBA has proved to be an effective approach for evaluation of programs focused on agriculture, forestry, and the environment (Mishan and Quah, 2007; Plottu and Plottu, 2007). We used CBA to identify the tradeoff of forestland use options.

In general, there are 9 steps in performing CBA (Boardman et al., 2011): (1) specifying the set of alternative projects; (2) deciding whose benefits and costs are accounted to obtain present values; (3) identifying the impact categories, catalogue them and select measurement indicators; (4) predicting the impacts quantitatively over the life of the project; (5) monetizing (attach dollar values to) all impacts; (6) discounting benefits and costs to obtain present values; (7) computing the net present value of each alternative; (8) performing sensitivity analysis; (9) making a recommendation. We here followed the three steps proposed in (Nguyen et al., 2010): (1) identifying and estimating all costs and benefits; (2) discounting future costs and benefits to render current and future effects comparable; and (3) comparing the costs and benefits if the benefits exceed the costs. CBA has three key criteria: net present value (NPV), internal rate of return (IRR), and benefit cost ratio (BCR). It is well known that the usage of NPV, IRR, and BCR help reduce misleading decisions. In this study, NPV and IRR were used to support our comparison of the economic benefits of shifting cultivation and plantation forests (regular tree-planting and AR-CDM).

5.3.4.2. Tradeoff analysis of tree planting and shifting cultivation

We adopted the tradeoff model of tree-planting and shifting cultivation (Figure 5.6). The magnitude of the total economic benefit (TEB) of two land use options was graphed. Zone A corresponds to the space where the benefit value of tree-planting is greater than that of shifting cultivation, while zone B and C identifies where shifting cultivation's value is higher than that of tree-planting and tree-planting under CDM, respectively. $X(r_1)$ and $X(r_2)$ are the values, which depend on interest rate, making the benefit value of regular plantation forests and plantation forests under AR-CDM equals the TEB of shifting cultivation, respectively.

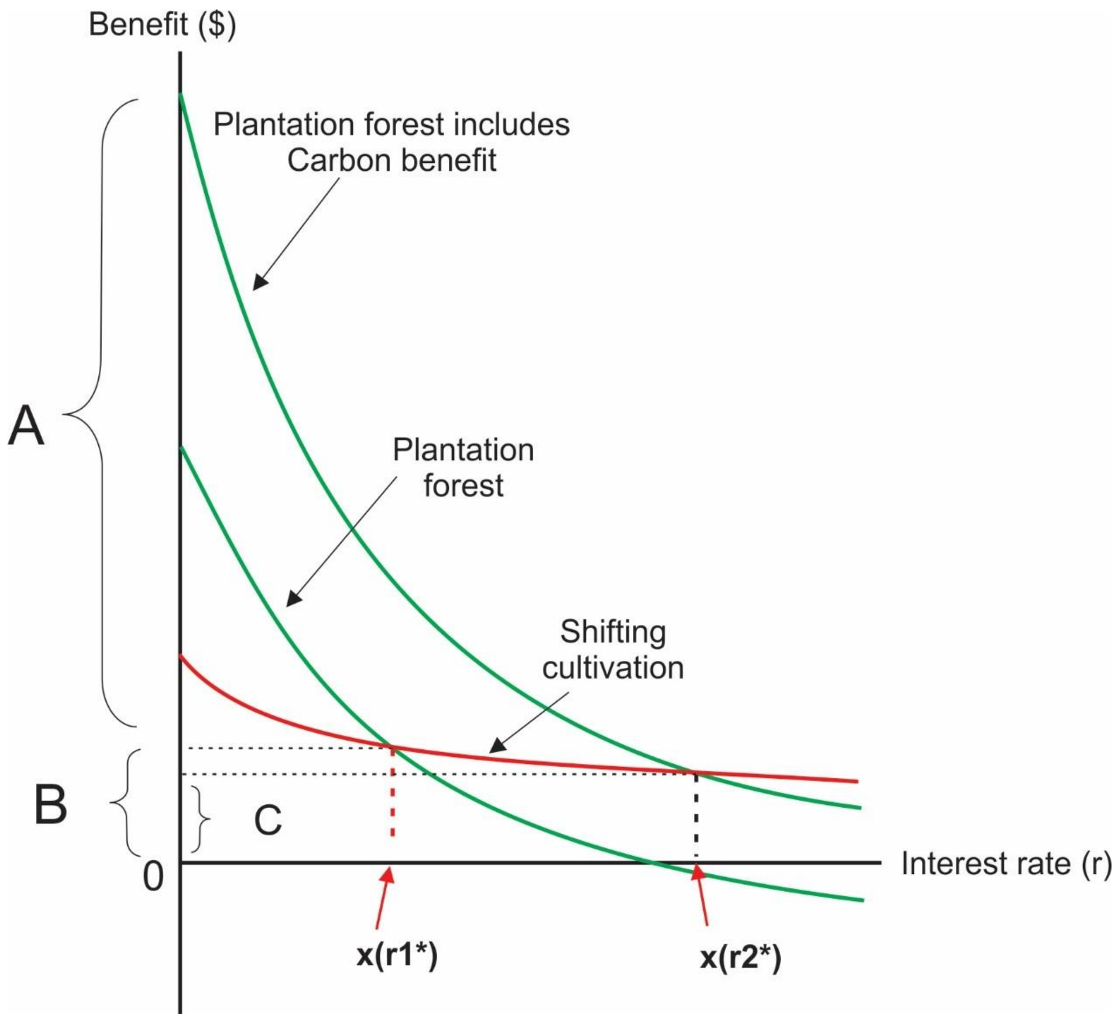


Figure 5.6. The changing total economic benefit (TEB) of forestland use options: shifting cultivation versus forest-planting and the interaction between inputs of interest rate and carbon price. Interval A: the farmer gains from planting forests compared with shifting cultivation; intervals B and C: the farmer loses from plantation forests and tree-planting under the clean development mechanism (CDM) project compared with shifting cultivation; $X(r_1^*)$: the targeted threshold for the recommended policy to influence the total economic benefit of forest-planting.

We calculated the total economic benefit for each land use option in the Yen Na, Luong Minh, and Chau Thai communes. The total economic benefit of shifting cultivation (TEB_1) is the sum of the net present value of agricultural crops such as NPV_{rice}, NPV_{corn}, and $NPV_{cassava}$ while the total net economic benefit of planting forests (TEB_2) is the sum of the NPV value from wood/chip ($NPV_{w/c}$) and the economic value of carbon (EV_c) for a 15-year period. The change in NPV depends upon the change in interest rate (r). We selected the interval of interest rate from 0%

to 15% as commonly used and presented in (Nguyen et al., 2010; VBSP, 2017). For the calculations of shifting cultivation, we considered that the farmers only cultivate agricultural crops for a one-year period due to infertile land at the study sites; they return after three to four-year fallow, so we took a total of four times their cultivation into account during a 15-year period to calculate NPV of shifting cultivation. For the NPV calculation in forest-planting, the economic value of carbon relies on the amount of tCERs (Supplementary Table S5.10) and the carbon price on the global carbon market. Based on the observations of the fluctuation in carbon prices (FFPRI, 2007) and the tentative tCERs used in the Cao Phong AR-CDM project (JICA, 2008), we selected a carbon price interval of from \$0 to \$10 per tCERs to estimate the economic value of carbon from tree-planting under AR-CDM.

Notably, we highlighted the total economic benefit of land use options under four representative scenarios with variable interest rate (r) and carbon price (C_P) at the study site. Interest rates of 6.6% and 9.6% were selected because those are the current preferential interest rates for poor farmers and small and medium-sized enterprises (SMSE) that invest in forest development plans and SMSE without forest development plans (VBSP, 2017), respectively. For regular forest-planting, which does not have a carbon benefit, the carbon price is set to \$0; the pilot AR-CDM Cao Phong project used \$2 per tCERs for making calculations (JICA, 2008) so this level was selected. The total economic benefit of tree-planting was calculated for all three communes while the value of shifting cultivation was only calculated in Yen Na and Luong Minh. This is because shifting cultivation is not practiced in the Chau Thai commune.

5.4. RESULTS

5.4.1. Outputs of shifting cultivation

5.4.1.1. Food

Food is the principal output of shifting cultivation and consists of several agricultural crops. We used a questionnaire to interview the informants along with direct observation in the field study to understand this output. The features of the output of shifting cultivation in Yen Na and Luong Minh are presented in Table 5.1. Upland rice, corn, and cassava are three main agricultural crops of shifting cultivation in this region. At the Yen Na commune, upland rice makes up the largest area (15.18 ha), while cassava constitutes the smallest area (1.5 ha) in local households' land use. A similar preponderance of upland rice was found in the Luong Minh commune (9.38 ha), while corn constitutes the smallest area (1.5 ha). The land area owned by household groups is different, but the poor group owns the larger land area at both the Yen Na and Luong Minh communes.

Table 5.1. Features of shifting cultivation of households in the study sites

Group	Species	Yen Na			Luong Minh		
		(Ha)	(Kg)	($ ha^{-1})	(Ha)	(Kg)	($ ha^{-1})
Poor	Upland rice	6.20	5,704	174.0	6.38	7,450	292.2
	Corn	1.70	1,300	93.2	1.20	1,520	168.9
	Cassava	1.30	11,300	218.6	2.08	10,000	75.9
Medium	Upland rice	2.45	2,400	225.6	2.00	2,500	250.0
	Corn	2.10	1,680	123.5	0.25	300	0.6
	Cassava	0.10	4,000	842.1	-	-	-
Rich	Upland rice	6.53	6,800	251.5	1.00	400	94.7
	Corn	1.80	3,550	235.8	0.05	100	315.8
	Cassava	0.10	4,000	842.1	0.20	1,500	118.4
Total	Upland rice	15.20	14,904	190.6	9.40	10,350	278.3
	Corn	5.60	6,530	107.8	1.50	1,920	186.4
	Cassava	1.50	8,000	403.2	2.30	11,500	77.9

Note: Area, output, and revenue of agricultural crops (upland rice, corn, cassava) are measured in (Ha), (Kg), and ($ ha^{-1}), respectively.

5.4.1.2. Revenue and total economic benefit

Farmers in different locations earn different revenue from shifting cultivation. At Yen Na, cassava provides the highest value ($403.2 ha^{-1}), followed by upland rice ($190.6 ha^{-1}) and corn ($107.8 ha^{-1}). At Luong Minh, upland rice brings the most income ($278.3 ha^{-1}), while cassava yields the least revenue ($77.9 ha^{-1}). Based on the result of CBA, the NPV of shifting cultivation at Luong Minh is higher than that at Yen Na (Table 5.2).

Table 5.2. Net present value (NPV) of shifting cultivation under uncertainty of interest rate (r), which ranged from 0% to 15% during 15-year cycles at the study sites.

Communes	Interest rate (%)							
	0	2	5	6.6	9.6	10	12	15
Yen Na	25.07	22.43	19.4	18.14	16.23	16.01	15.04	13.87
Luong Minh	28.38	25.51	22.21	20.82	18.73	18.49	17.42	16.12

Note: Units ($ ha^{-1} year^{-1})

5.4.2. Outputs of plantation forests

5.4.2.1. Wood, carbon, and carbon credit

Forests provide the farmer with wood and non-timber forest products (NTFPs) (Figure 5.2). In this study area, fallows provide only very little wood to farmers, so the wood value of shifting cultivation was not considered here. In the virtual project, we excluded NTFPs from the usage value of the plantation forests and we did the same for the shifting cultivation land uses**.** Generally, *Acacia auriculiformis* plantations do better than *A. mangium* plantations in providing wood (Table 5.3; Supplementary Table S5.11). This may be partly because *A. mangium* does not have a second thinning in the 13th year while *A. auriculiformis* does. Often farmers prefer native tree species to fast-growing exotic trees for housing construction due to wood quality, but exotic *A. mangium* and *A. auriculiformis* are used for many applications (furniture, fencing, firewood, etc.).

Table 5.3. Products of plantation forests (*Acacia auriculiformis* and *Acacia mangium)* during a 15-year cycle.

Year	Item	Products	*Acacia auriculiformis* (m^3)	*Acacia mangium* (m^3)	Average (m^3)
9	The first thinning	Chip wood	6.53	20.9	13.72
13	The second thinning	Chip wood	20.37	NA	20.37
		Timber	107.85	96.6	102.23
		C=40cm	26.96	24.2	25.58
		C=50cm	40.44	36.2	38.32
		C=60cm	40.44	36.2	38.32
15	Felling	Chip wood	26.96	24.2	25.58
Total			269.55	238.3	253.93

In the context of climate change, carbon absorption is a leading role for forests, particularly fast-growing trees. For the AR-CDM project, the carbon sequestration benefit was added to the total economic benefit of planted forests. We measured carbon sequestration capacity under shifting cultivation, which is short-fallow swiddening, and under plantation forests, which are *A. mangium* and *A. auriculiformis* plantations (Figure. 7). Short-fallow swiddening provides the average net stored carbon of 6.08 (tCO_2) ha^{-1} y^{-1} during 15-year period. However, during a similar time frame, *Acacia mangium* and *Acacia auriculiformis* can store, on average, 12.02 and 13.72 (tCO_2) ha^{-1} y^{-1}, respectively (Supplementary Tables S5.2-5.9).

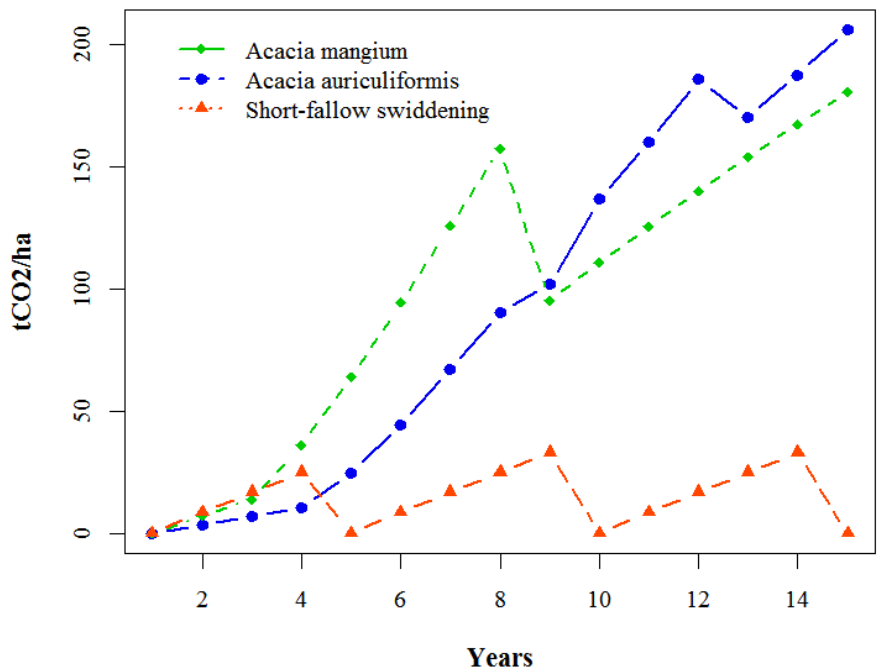


Figure 5.7. Net carbon sequestration (tCO_2 ha^{-1}) for shifting cultivation and plantation forests during a 15-year period. Plantation forests include *Acacia auriculiformis* and *Acacia mangium.*

For plantation forests under AR-CDM, carbon credit is the most important output, and is evaluated through emission unit and temporary certificated emission reduction (tCERs). We measured tCERs for both *Acacia auriculiformis* and *Acacia mangium* at the study site using the method in (IPCC, 2003b, 2006; Supplementary Figure S5.1). The calculated average tCERs for plantation forests at the study sites (Yen Na, Luong Minh, Chau Thai) is 10.64 ha^{-1} (Supplementary Table S5.10). The following subsection is the heart of this paper, where credit-based value was taken into account to estimate the total economic benefit of plantation forest under AR-CDM.

5.4.2.2. Total economic benefit under uncertainty

The economic benefits of forest plantations are important for both the farmer who has land and labor capital and the investor who has financial capital. For plantation forests, the internal rate of return, net present value, and benefit cost ratio were calculated. The IRR of the tree species in the study (*Acacia auriculiformis* and *Acacia mangium*) ranges from 12.7% to 14.0%. During a 15-

year cycle, the net present value varies depending on the interest rate. The Yen Na commune is an example. Given interest rates from 0% to 15%, the NPV of *Acacia auriculiformis* has a minimum value of -\$6 and a maximum value of \$331 ha^{-1} y^{-1} (Table 5.4). The total economic benefit (TEB) depends on both interest rates and carbon prices. In the ideal condition (interest rate is at its lowest value and carbon price is at its highest value), the possible TEB has the highest values at the Yen Na commune (\$437.4 ha^{-1} y^{-1}), Luong Minh commune (\$335.4 ha^{-1} y^{-1}), and the Chau Thai commune (\$310.4 ha^{-1} y^{-1}), respectively. In practice, it is likely that the carbon price will be between \$2 and \$5 and the interest rate between 6% and 10%. In this case, the TEB ranges from \$42.1 to \$127.2 ha^{-1} y^{-1} at the Yen Na commune, \$29.1 to \$94.2 ha^{-1} y^{-1} at the Luong Minh commune, and 23.1 to \$83.2 ha^{-1} y^{-1} at the Chau Thai commune. A detailed matrix of the total economic benefit is presented in Tables 5-7.

Table 5.4. Cost-benefit analysis of plantation forests by study site (Yen Na, Luong Minh, Chau Thai commune) and by interest rate (r), which ranges from 0% to 15%.

Commune	Tree species	IRR (%)	NPV (\$ ha^{-1} year^{-1})		BCR	
			Min (r=15%)	Max (r=0%)	Min (r=15%)	Max (r=0%)
Yen Na	*Acacia auriculiformis*	14.0	-6	331	0.91	2.89
Luong Minh	*Acacia mangium*	13.6	-7	229	0.89	2.53
Chau Thai	*Acacia mangium*	12.7	-10	204	0.84	2.17

Note: Internal rate of return (IRR) and net present value (NPV) are measured in percentage (%) and (\$ ha^{-1} y^{-1}), respectively. Benefit cost ratio (BCR) was measured in floating-point value, which is always non-negative.

Table 5.5. Total economic benefit (TEB) ($\$ ha^{-1} y^{-1}$) of *Acacia auriculiformis* at the Yen Na commune given the uncertainty of annual interest rates (%) and carbon prices ($\$ tCERs^{-1}$).

r (%)	Carbon price ($\$ tCERs^{-1}$) **0**	1	2	3	4	5	6	7	8	9	10
0	**331**	341.64	352.27	362.91	373.55	384.18	394.82	405.46	416.09	426.73	437.37
1	**277**	286.16	295.32	304.49	313.65	322.81	331.97	341.13	350.3	359.46	368.62
2	**231**	238.9	246.81	254.71	262.61	270.52	278.42	286.32	294.23	302.13	310.03
3	**192**	198.83	205.65	212.48	219.31	226.14	232.96	239.79	246.62	253.45	260.27
4	**158**	163.91	169.81	175.72	181.62	187.53	193.44	199.34	205.25	211.16	217.06
5	**130**	135.12	140.23	145.35	150.47	155.58	160.7	165.81	170.93	176.05	181.16
6	**105**	109.44	113.88	118.31	122.75	127.19	131.63	136.07	140.51	144.94	149.38
7	**84**	87.86	91.71	95.57	99.42	103.28	107.13	110.99	114.84	118.7	122.55
8	**66**	69.35	72.71	76.06	79.41	82.77	86.12	89.47	92.82	96.18	99.53
9	**50**	52.92	55.84	58.76	61.68	64.6	67.52	70.44	73.36	76.28	79.2
10	**37**	39.55	42.09	44.64	47.19	49.73	52.28	54.82	57.37	59.92	62.46
11	**26**	28.22	30.45	32.67	34.89	37.12	39.34	41.56	43.78	46.01	48.23
12	**16**	17.94	19.89	21.83	23.77	25.72	27.66	29.6	31.55	33.49	35.43
13	**7**	8.7	10.4	12.1	13.8	15.5	17.2	18.9	20.61	22.31	24.01
14	**0**	1.49	2.98	4.47	5.96	7.45	8.94	10.43	11.92	13.41	14.9
15	**-6**	-4.69	-3.39	-2.08	-0.77	0.54	1.84	3.15	4.46	5.76	7.07

Note: TEB is measured in ($\$ ha^{-1} y^{-1}$). The red and green colors represent the TEB for plantation forests that is less than and greater than the TEB for shifting cultivation at the highest interest rate (15%), respectively.

Table 5.6. Total economic benefit (TEB) ($ ha^{-1} y^{-1}) of *Acacia mangium* at the Luong Minh commune given the uncertainty of annual interest rate (%) and carbon price ($ $tCERs^{-1}$).

r	Carbon price ($ $tCERs^{-1}$)										
(%)	0	1	2	3	4	5	6	7	8	9	10
0	**229**	239.64	250.27	260.91	271.55	282.18	292.82	303.46	314.09	324.73	335.37
1	**192**	201.16	210.32	219.49	228.65	237.81	246.97	256.13	265.3	274.46	283.62
2	**160**	167.9	175.81	183.71	191.61	199.52	207.42	215.32	223.23	231.13	239.03
3	**133**	139.83	146.65	153.48	160.31	167.14	173.96	180.79	187.62	194.45	201.27
4	**109**	114.91	120.81	126.72	132.62	138.53	144.44	150.34	156.25	162.16	168.06
5	**89**	94.12	99.23	104.35	109.47	114.58	119.7	124.81	129.93	135.05	140.16
6	**72**	76.44	80.88	85.31	89.75	94.19	98.63	103.07	107.51	111.94	116.38
7	**57**	60.86	64.71	68.57	72.42	76.28	80.13	83.99	87.84	91.7	95.55
8	**45**	48.35	51.71	55.06	58.41	61.77	65.12	68.47	71.82	75.18	78.53
9	**34**	36.92	39.84	42.76	45.68	48.6	51.52	54.44	57.36	60.28	63.2
10	**24**	26.55	29.09	31.64	34.19	36.73	39.28	41.82	44.37	46.92	49.46
11	**16**	18.22	20.45	22.67	24.89	27.12	29.34	31.56	33.78	36.01	38.23
12	**9**	10.94	12.89	14.83	16.77	18.72	20.66	22.6	24.55	26.49	28.43
13	**3**	4.7	6.4	8.1	9.8	11.5	13.2	14.9	16.61	18.31	20.01
14	**-2**	-0.51	0.98	2.47	3.96	5.45	6.94	8.43	9.92	11.41	12.9
15	**-7**	-5.69	-4.39	-3.08	-1.77	-0.46	0.84	2.15	3.46	4.76	6.07

Note: TEB is measured in ($ ha^{-1} y^{-1}). The (red and green) colors represent the TEB for plantation forests that is less than and greater than the TEB for shifting cultivation at the highest interest rate (15%), respectively.

Table 5.7. Total economic benefit (TEB) (($ ha^{-1} y^{-1}) of *Acacia mangium* at the Chau Thai commune given the uncertainty of annual interest rate (%) and carbon price ($ $tCERs^{-1}$).

r	Carbon price ($ $tCERs^{-1}$)										
(%)	0	1	2	3	4	5	6	7	8	9	10
0	**204**	214.64	225.27	235.91	246.55	257.18	267.82	278.46	289.09	299.73	310.37
1	**170**	179.16	188.32	197.49	206.65	215.81	224.97	234.13	243.3	252.46	261.62
2	**141**	148.9	156.81	164.71	172.61	180.52	188.42	196.32	204.23	212.13	220.03
3	**116**	122.83	129.65	136.48	143.31	150.14	156.96	163.79	170.62	177.45	184.27
4	**95**	100.91	106.81	112.72	118.62	124.53	130.44	136.34	142.25	148.16	154.06
5	**77**	82.12	87.23	92.35	97.47	102.58	107.7	112.81	117.93	123.05	128.16
6	**61**	65.44	69.88	74.31	78.75	83.19	87.63	92.07	96.51	100.94	105.38
7	**48**	51.86	55.71	59.57	63.42	67.28	71.13	74.99	78.84	82.7	86.55
8	**36**	39.35	42.71	46.06	49.41	52.77	56.12	59.47	62.82	66.18	69.53
9	**26**	28.92	31.84	34.76	37.68	40.6	43.52	46.44	49.36	52.28	55.2
10	**18**	20.55	23.09	25.64	28.19	30.73	33.28	35.82	38.37	40.92	43.46
11	**10**	12.22	14.45	16.67	18.89	21.12	23.34	25.56	27.78	30.01	32.23
12	**4**	5.94	7.89	9.83	11.77	13.72	15.66	17.6	19.55	21.49	23.43
13	**-1**	0.7	2.4	4.1	5.8	7.5	9.2	10.9	12.61	14.31	16.01
14	**-6**	-4.51	-3.02	-1.53	-0.04	1.45	2.94	4.43	5.92	7.41	8.9
15	**-10**	-8.69	-7.39	-6.08	-4.77	-3.46	-2.16	-0.85	0.46	1.76	3.07

Note: TEB is measured in ($ ha^{-1} y^{-1}). The (red and green) colors represent the TEB for plantation forests that is less than and larger than the TEB for shifting cultivation at the highest interest rate (15%), respectively. The yellow color represents the TEB for *Acacia mangium* within the shifting cultivation's TEB at the Yen Na ($13.87 ha^{-1} $year^{-1}$) and Luong Minh communes ($16.12 ha^{-1} y^{-1}).

5.5. DISCUSSION

Under expected conditions (current interest rates and carbon prices), the total economic benefit of plantation forests under AR-CDM (in the virtual project) is higher than that of shifting cultivation. The magnitude of the difference relies on interest rates and carbon prices. Excluding a carbon-based economic benefit, tree planting is still more profitable than shifting cultivation if the interest rate equals certain levels (i.e., an *r* of less than around 12% and 11% for the Yen Na and Luong Minh communes, respectively) (Figure 5.8). In practice, when taking part in afforestation and reforestation programs (i.e., the 5MHRP program), the farmer was supported by the state and got preferential interest loans (6.6%-8%) (Nguyen et al., 2010; VBSP, 2017). Thus, the calculated total economic benefit suggests that improving farmer's income through tree-planting under AR-CDM is relatively promising economically (Figure. 9).

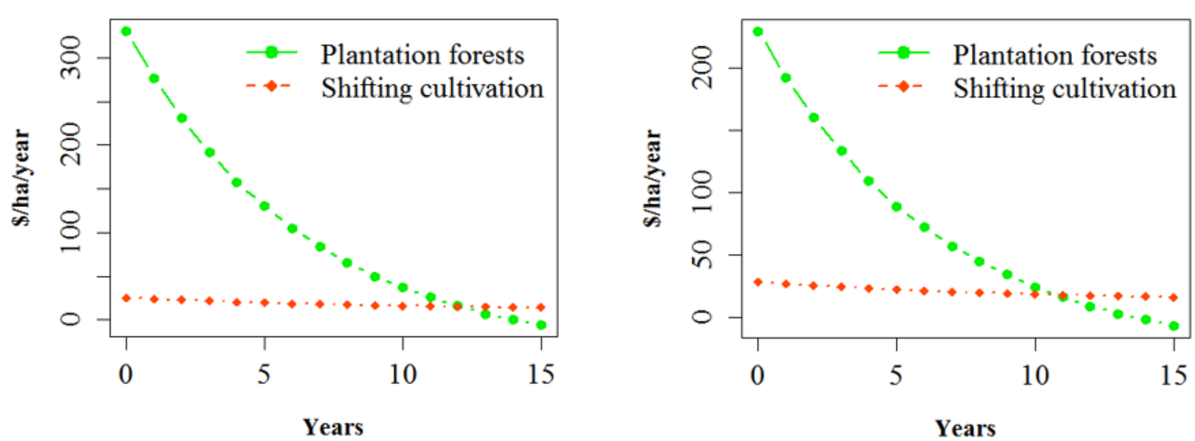


Figure 5.8. Net Present Value of shifting cultivation and plantation forests corresponding to uncertain interest rates (r) that ranged from 0% to 15% at Yen Na (left), Luong Minh (right). TEB is measured in ($ ha^{-1} year^{-1}).

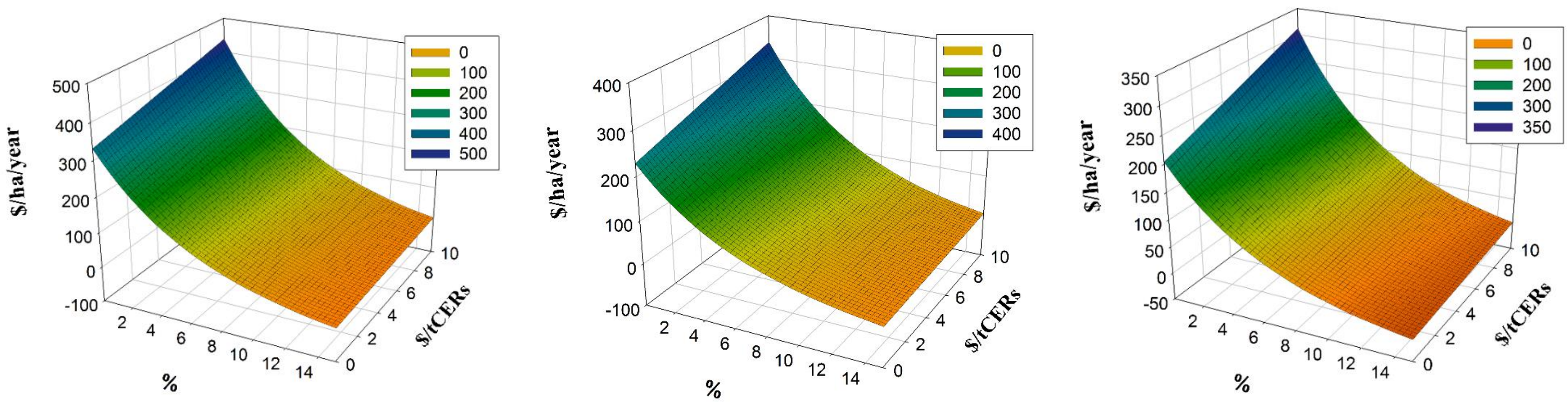


Figure 5.9. Total economic benefit (TEB) of plantation forests under the clean development mechanism (CDM) project under uncertain interest rates (r) that ranged from 0% to 15% at Yen Na (left), Luong Minh (right), and Chau Thai (middle). TEB and carbon price are measured in ($ ha^{-1} y^{-1}) and ($ $tCERs^{-1}$), respectively.

Interest rates significantly influence the total economic benefit of forest-planting. The current interest rate that the Vietnamese government has set for small and medium sized enterprises (SMSE) is 9.6%, and 6.6% for SMSE investment in forest development (VBSP, 2017). At first glance, we can conclude that the investor can profit from regular tree-planting (Figure. 10). However, this may not be the case for AR-CDM because the investor must bear the high transition costs associated with preparation and implementation (JICA, 2008). Therefore, the carbon benefit plays a vital role in making AR-CDM profitable. However, the current market price for carbon is unfavorable to the investor. Notably, the carbon price decreased from \$20 $tCERs^{-1}$ in 1998 to \$2 $tCERs^{-1}$ in 2012. Carbon price trends are highly volatile and difficult to predict (FFPRI, 2007), which affects the uncertainty and unpredictability in global carbon price and increases the investor's risk level. This finding is important because it partly explains why up to now few investors have been involved in the AR-CDM program in Vietnam and other developing countries, and more importantly, it helps us determine the required threshold carbon price that will enable the AR-CDM program to be effective.

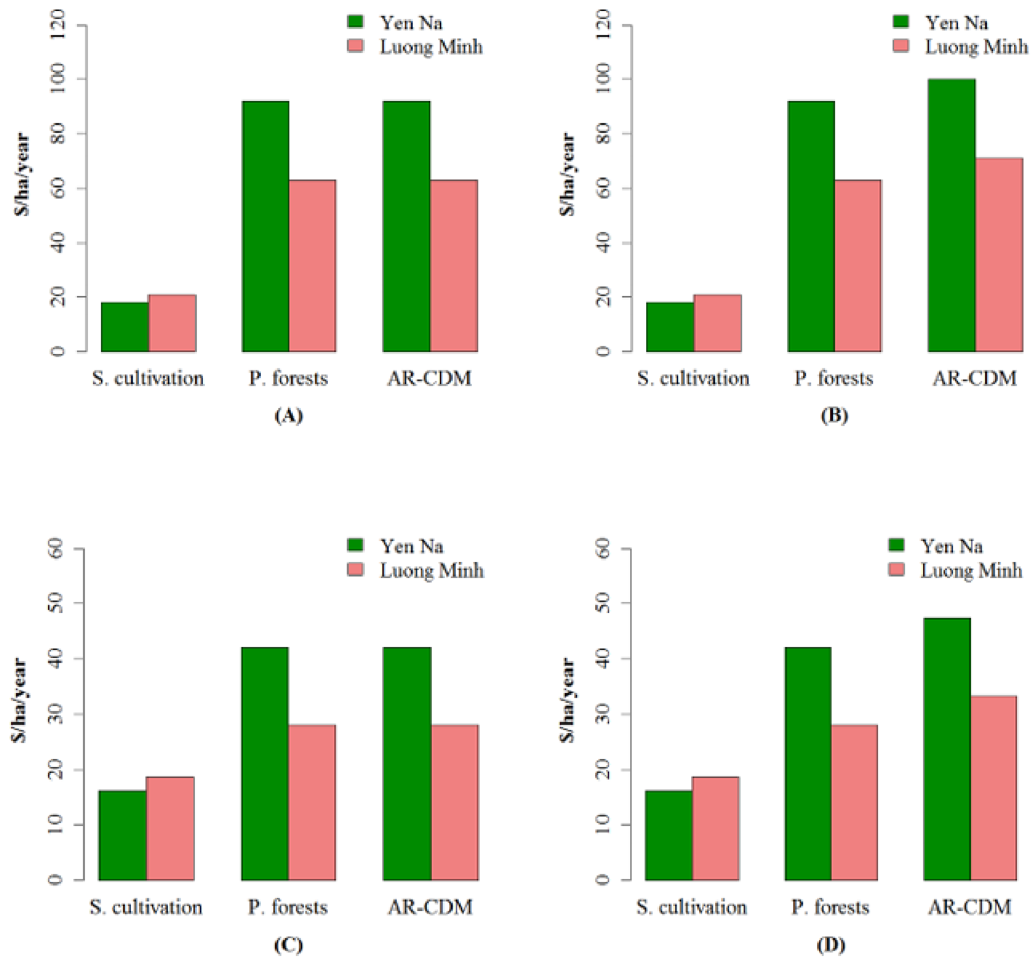


Figure 5.10. Total economic benefit (TEB) of shifting cultivation (S. cultivation), plantation forests (P. forests), and tree-planting under the clean development mechanism (AR-CDM) under the four most common scenarios with changes in the interest rate (r) and carbon prices (C_P) per tCERs at Yen Na and Luong Minh commune. Scenarios A: [r=6.6%, C_P =0], Scenarios B: [r=6.6%, C_P=$2], Scenarios C: [r=9.6%, C_P =0], Scenarios D: [r=9.6%, C_P=$2].

Program 327, 5MHRP, and REDD+ are the leading forest development projects in Vietnam. Lessons learned from these programs are that success and failure are strongly linked to farmers' participation (De Jong and Van Hung, 2006; Pham et al., 2012). In many places, farmers are not interested in forest practices (Ohlsson et al., 2005), particularly the REDD+ program (Pham et al., 2012). This might be due to three factors. The first is economic motivation. Although the tradeoff analysis in this study indicates that there is a revenue gap between shifting cultivation and forest protection activities (i.e., under current conditions at an interest rate of 6.6%, current plantation forests are clearly more profitable than shifting cultivation), the actual situation is different from the farmer's expectation to some degree. With little support or even without any support from the local government, it is common for farmers to have difficulty selling timber at competitive prices due to coercion by local traders. As a result, the real benefit of tree-planting declines significantly. The second reason is the demand for short-term income and food security. This demand is significant because the study sites are in the mountainous communes, where a large proportion of farmers live under the poverty line and suffer food shortages. The final reason is the pattern of cultivation. Shifting cultivation has been a traditional mode of cultivation for local farmers for a long time, so the transformation from shifting cultivation to tree-planting has a cultural significance. Thus, farmer's low motivation to be involved in forest protection and management is understandable. Our finding that mere economic calculations cannot explain all the decision-making process is very important because it provides valuable information on how to improve the level of support for forest protection activity in the REDD+ project as well as upcoming forest restoration projects.

The topic of transition cost is beyond the scope of this study, but the AR-CDM program must consider it to some extent. Including preparation costs and implementation costs (FFPRI, 2007), transition costs can constitute a large share of the total project cost (JICA, 2008). In this regard, the AR-CDM's challenges in transition land costs with regards to both scale and quality of land at not only at the study site but the upland area in Vietnam is significant. Small AR-CDM projects are designed to sequester at least 8,000 tCERs per year (FFPRI, 2007; JICA, 2008). This means that the minimum area for small AR-CDM projects ranges from approximately 400 ha to 1,000 ha depending on the land quality. However, the land holdings of households are small and fragmented (Marsh et al., 2007), with areas of forestland from under 1 to 5 hectares (GSO, 2011; Sam, 1994), so the land assemblage required for a small AR-CDM project must be at least 100 households. In practice, agricultural land consolidation has been intensively implemented for a few years (Dung, 2010; Marsh et al., 2007), but the accumulation of forestland has still not been widespread, particularly for small landholders. To accumulate enough forestland for a small AR-CDM project will take time and costs for dealing with farmers. Additionally, fertile land has already been used for existing afforestation and reforestation programs (JICA, 2006), so the remaining land is either relatively unfertile or remote, also increasing the transition costs.

The tradeoff analysis of land use options refers to the cost-benefit value, but the evaluation of the usage value is important and cannot be ignored. Shifting cultivation improves food security and provides additional income while planting forests provides revenue, wood, firewood, and environmental values. Additionally, the significant difference in carbon sequestration capacity between shifting cultivation and tree-planting is crucial for analyzing the tradeoffs among upland use options. For the farmer, the value of shifting cultivation and tree-planting vary depending upon local and regional socioeconomic features and household livelihood. Theoretically, a farmer can earn income from planting forests, then trade the income for food. However, in practice this pathway is difficult in isolated locations. For instance, when people suffer from severe food shortages, food security is often more important than revenue. In this case, the farmer's preference for shifting cultivation is reasonable. Shifting cultivation remains in much of Vietnam and some developing countries for several reasons (Hurni et al., 2013; Sam, 1994; Van Vliet et al., 2013) but swidden systems have been undergoing change with the replacement by other forms of agriculture (Mertz, 2009; Rasul and Thapa, 2003; Vongvisouk et al., 2014). In cases where shifting cultivation is still practiced, fallow lengths usually become shorter (Schmidt-Vogt et al., 2009). The tradeoff analysis indicates that excluding usage value considerations while focusing only on economic indicator comparisons may be a serious mistake. Considering socioeconomic factors and household livelihoods along with a tradeoff analysis are important and mandatory for optimizing land use options between shifting cultivation and forest-planting.

This study has some limitations. Making an economic analysis of land use options under AR-CDM alone is the first shortcoming because AR-CDM is associated with several political, technological, socioeconomic, and cultural factors. Another limitation of our analysis is that it excludes the value of preserving natural forests. AR-CDM can help reduce the pressure on natural forests to some extent because a certain area of natural forest is preserved from shifting cultivation and illegal logging, etc. In this way, after conversion into monetary value, the potential economic benefit from AR-CDM might be significant. Finally, we selected plantation forests that are like possible real AR-CDM projects for analysis. This is a virtual project but it was updated and modified according to the real conditions of the study sites in Nghe An province. Yet, using a virtual project may also be a limitation of this study.

5.6. CONCLUSIONS

The AR-CDM and REDD+ programs have been considered valuable for climate change mitigation and sustainable development for developing countries, yet only a few investors and farmers in Vietnam are involved in those projects (Pham et al., 2012; Thomas et al., 2010; Yamanoshita and Amano, 2012). The underlying reason might lie in a lack of profitable outcomes associated with poor policy and limited information to stakeholders regarding investment in land. For these reasons, we have attempted to provide fundamental information in the form of a tradeoff analysis of land use options in the upland area of Vietnam to inform the investors who might invest in a forest project such as AR-CDM, the farmers who could contribute their land and labor, and the policy-makers who could enact appropriate policies in the future. We used total economic benefit (TEB) and cost-benefit analysis (CBA) tools to determine the economic benefits of shifting cultivation and tree-planting (plantation forests) by envisioning a virtual project.

First, as projected, the total economic benefit (TEB) of tree-planting under AR-CDM is greater than that of shifting cultivation. The magnitude of the difference in TEB depends on interest rates and carbon prices. These are two core subjects for future policy-makers to consider. Without a carbon-based economic benefit, and if the interest rate is not less than 11%-12% for the Yen Na, Luong Minh, and Chau Thai communes, the benefit from the investment in a virtual AR-CDM project is not larger than that of shifting cultivation. In this case, it is likely that farmers will opt for shifting cultivation instead of forest-planting. This finding has been consistent with the farmer's low participation in tree-planting projects and the low number of investors recently involved in AR-CDM and REDD+ projects. Government could maintain and control bank interest rates as a mechanism for farmers and investors to profit from forest practices. In parallel with interest rate management, government policies should support investors to gain a competitive carbon price on the carbon market even though this process is very challenging.

Second, transition costs are a serious concern for investors since they often constitute a large share of total project costs. In Vietnam, transition costs may increase considerably due to land fragmentation and land aggregation issues. Additionally, conflict in land use options, including current reforestation programs and AR-CDM, may result in additional transition costs. Government policies should support forestland aggregation in an optimal manner to reduce transition costs.

Third, it would be a mistake if the tradeoff analysis focused on the cost-benefit analysis only while missing a usage value comparison. Even if tree-planting is more profitable than shifting cultivation, this does not mean that it is more feasible and more appropriate than shifting cultivation. Thorough consideration of both economic and usage value comparisons in land use tradeoffs is not only highly recommended but strictly required in regular tree-planting and AR-CDM.

Finally, besides the economic benefit, risk is a central concern of the investor and AR-CDM (Yamanoshita and Amano, 2012). That is probably why there has been a substantial difference in the registered CDM projects between the forest sector and the energy sector in Vietnam in the past. Seeking appropriate and smart ways to significantly reduce the risks in AR-CDM merits further research.

Chapter 6 - CONCLUSIONS AND RECOMMENDATIONS

6.1. Overall summary and Conclusions

The main objective of this study was to obtain a deeper understanding of forest transition and forest restoration and their proximate drivers as well as trade-offs of land use in upland forests in Vietnam. The dissertation addressed these goals and objectives through four independent studies. From what has been shown and discussed in four chapters above, I conclude that Vietnam's forest change is consistent with forest transition: deforestation decreases and forest restoration increases, and these changes are associated with several socio-economic driving forces. The support of society for forest restoration is real and promising. Plantation forests and shifting cultivation offer a role in the rural upland livelihood system. Climate change mitigation programs have great potential to develop. Forest development and economic growth can co-exist. The following summarizes the major components and findings from each study.

Chapter 2 quantified the drivers of deforestation and forest degradation at a national scale in Vietnam. Geographic information system tools, a structural regression model (structural model), and a regression tree method were employed to quantify the extent as well as the proximate causes of deforestation and forest degradation across 46 provinces in Vietnam. The results of this study show that around 1.77 and 0.65 million hectares of forests were lost and degraded, respectively, from 2000 to 2010. Deforestation and forest degradation declined in Vietnam between 2000 and 2010, but these processes remain significant. Deforestation and forest degradation were most notable in the north central, northeast, central highland, and northwest areas of the nation. Several underlying indicators of deforestation and forest degradation were found, of which the top drivers were poverty, initial forest, governance, and population growth.

Chapter 3 investigated the extent of restored forest and the proximate drivers of reforestation at the local-communal scale in Dien Bien Province. Geographic information system tools based on official Government of Vietnam forest cover maps were used as well as field survey across 40 communes, and a structural regression model based on a unique panel dataset was implemented. This chapter showed that around 118,000 hectares of forests were restored between 1990 and 2010. Restored forest contributed the largest share (above 84%) to total forest gain and this share increased from 1990-2000 to 2000-2010. The presence of migration, lower population density, higher income, and the implementation of forestry policies were the top drivers of restored forest expansion in this study.

Chapter 4 explored the willingness of urban households to support forest restoration in Vietnam. A CVM was employed while the payment card response format was used to interview randomly over 200 households in the capital city, Hanoi. A MLE model was used to obtain the parameters of our model and quantify WTP for a program of forest restoration. The results from this study show that over forty percent of the households surveyed were willing to pay for forest restoration and that the top determinants of WTP are households' income, educational level, and gender within family.

Chapter 5 analyzed the potentials and challenges of climate change mitigation programs in north central Vietnam. Three mountainous communes were selected for this study. A CBA was extensively employed to determine the economic indicators for plantation forests and shifting cultivation under several scenarios. Real carbon measurement for the vegetation within a shifting cultivation system was implemented while a virtual project with fast growing species was used to determine economic value and carbon quantity. This chapter demonstrated that plantation forests play a significant role in household livelihood. No matter what scenarios associated with many levels of uncertainties were examined, the total economic value of plantation forests is greater than that of shifting cultivation under normal interest rate (less than 10%). The absolute advantages of shifting cultivation over plantation forests regarding food and short income rotation, which is coupled with several constraints of plantation forests regarding financial capital, labor, markets, are the key reasons for the fact that shifting cultivation is currently preferred by the famers.

6.2. Thesis limitation

Although these studies were conducted with attention to detail, there are still a number of limitations. The first drawback is the inferior quality of some datasets. For the first two chapters, official Vietnamese government forest cover maps were extensively used to determine the extent and magnitude of deforestation, forest degradation, and restored forest. The dataset was accessed through a visual interpretation of relevant satellite images and it was verified by "ground-truth" so it contains a certain inaccuracy rate. In addition, the study used and analyzed material from a socio-economic dataset that was obtained from the field survey; thus, the bias from the interviewers and respondents is unavoidable. The second concern is the quality of the empirical regression model. My study extensively employed a structural model for quantification and in-depth analysis. This model appeared to be a relatively strong and reliable tool for unraveling the complex interactions of social, political, and economic processes that affect forest transition (deforestation and reforestation) within a land use system, but it contains certain limitations because no model is perfect. The third concern is sample size. The study used a cross-sectional format dataset for 46 provinces in Chapter 2 and a panel dataset for 40 communes in Chapter 3, so the sample size was relatively small. As a result, as the degrees of freedom were limited due to sample size, I had to restrict the number of variables to test. This might limit the understanding of some variables that could influence dependent variables (deforestation, forest degradation, and forest restoration).

Finally, I used virtual plantation forests that are like possible real AR-CDM projects for analysis in Chapter 5. The virtual plantations were well updated and meticulously modified according to real conditions of the study sites in Nghe An Province, this virtual project may also be a limitation of this study.

6.3. Recommendations

The findings and limitations of the four independent studies that comprise this dissertation offer a number of possibilities for further research.

Chapter 2 quantified the drivers of deforestation and forest degradation at the national scale in Vietnam. A cross-sectional dataset from 46 provinces was used but this sample size is relatively small, which limits the understanding of certain variables. The recommendation is that the panel dataset should be used for further study because it offers information on the temporal course of forest restoration with less multicollinearity and increased degrees of freedom compared to the cross-sectional dataset. Accordingly, the model should include more relevant variables such as biophysical aspects, accessibility, etc. Furthermore, because the study used the dataset up to year 2010, an updated dataset for additional years should be used for further study.

Chapter 3 investigated drivers of forest restoration at the local-communal scale in Dien Bien Province. A panel dataset for 40 mountain communes was used but this sample size is still relatively small, which limits the generalizations of the conclusion for the northwest region. The recommendation is that either the sample size in Dien Bien should be extended or the study area should be extended to other provinces in northwest region (i.e., Lai Chau, Son La, Hoa Binh) for further study because it would offer insight into forest restoration and forest transition in the northwest region of Vietnam. Further, because the socio-economic dataset was extensively used for in-depth analysis, greater care in study design, focus group training, and questionnaires is warrented for future work. This, coupled with an extended variables model and updated dataset, would help improve the internal and external validity of the study.

Chapter 4 explored the willingness of urban households to support forest restoration in Vietnam. A CVM was employed with a payment card response format to randomly interview over 200 households in the capital city, Hanoi. The findings of this study might be more beneficial to policy-makers and society if the sample size were higher and the study locations were extended to other cities (e.g., Ho Chi Minh City, Hai Phong) in further studies. A dichotomous response format and an open-ended response format would likely make the estimated WTP value more robust.

Chapter 5 analyzed the potentials and challenges of climate change mitigation programs in north central Vietnam. The economic value of plantation forests was measured and the difficulties for forest practices were quantitatively evaluated. The tradeoff analysis of land use options between plantation and shifting cultivation were made based on different locations, which might reduce the quality of the finding. A further study should focus on communes that include both shifting cultivation systems and plantation practices. For a total economic value measurement of plantation forests, carbon should be measured in real plantation forests rather than in a virtual AR-CDM project. Finally, the findings of such a study would be more persuasive and valuable if the quantification and analysis of transition costs were included.

LITERATURE CITED

Alhassan, M., 2012. Estimating farmers' willingness to pay for improved irrigation: an economic study of the Bontanga irrigation scheme in Northern Ghana. MS thesis, Colorado State University, Fort Collins, USA.

Anselin, L., Ibnu, S., Youngihn, K., 2006. GeoDa: An Introduction to Spatial Data Analysis. Geographical Analysis 38, 5-22.

Anselin, L., Rey, S.J., 2014. Modern spatial econometrics in practice: A guide to GeoDa, GeoDaSpace and PySAL, Geoda Press LLC, Chicago, USA.

Anwar, S., Nguyen, L.P., 2011. Financial development and economic growth in Vietnam. Journal of Economics and Finance 35, 348-360.

Barbier, E.B., Burgess, J.C., Grainger, A., 2010. The forest transition: Towards a more comprehensive theoretical framework. Land use policy 27, 98-107.

Barbier, E.B., Delacote, P., Wolfersberger, J., 2017. The economic analysis of the forest transition: A review. Journal of Forest Economics 27, 10-17.

Bernstein, L., Bosch, P., Canziani, O., Chen, Z., Christ, R., Riahi, K., 2008. Climate change 2007: synthesis report. IPCC, Geneva, Switzerland, 104 pp.

Bhattarai, M., Hammig, M., 2001. Institutions and the environmental Kuznets curve for deforestation: a crosscountry analysis for Latin America, Africa and Asia. World Development 29, 995-1010.

Bishop, J., Landell-Mills, N., 2002. Forest environmental services: an overview. Earthscan Publications, London, UK.

Blaine, T.W., Lichtkoppler, F.R., Jones, K.R., Zondag, R.H., 2005. An assessment of household willingness to pay for curbside recycling: A comparison of payment card and referendum approaches. Journal of environmental management 76, 15-22.

Boardman, A., Greenberg, D., Vining, A., Weimer, D., 2011. Cost-benefit analysis: concepts and practice. Pearson, London, England.

Bofin, P., du Preez, M.-L., Standing, A., Williams, A., 2011. REDD Integrity: Addressing governance and corruption challenges in schemes for Reducing Emissions from Deforestation and Forest Degradation (REDD). Chr. Michelsen Institute, Bergen, Norway, 83 pp.

Börner, J., Baylis, K., Corbera, E., Ezzine-de-Blas, D., Honey-Rosés, J., Persson, U.M., Wunder, S., 2017. The effectiveness of payments for environmental services. World Development 96, 359-374.

Boyle, K.J., 2003. Contingent valuation in practice. in: Champ, P.A., Boyle, K.J., Brown, T.C., Peterson, L.G., (Eds.), A primer on nonmarket valuation. Kluwer Academic Publishers, Dordrecht, the Netherlands, pp. 111-170. Springer.

Call, M., Mayer, T., Sellers, S., Ebanks, D., Bertalan, M., Nebie, E., Gray, C., 2017. Socio-environmental drivers of forest change in rural Uganda. Land Use Policy 62, 49-58.

Calle, L., Canadell, J.G., Patra, P., Ciais, P., Ichii, K., Tian, H., Kondo, M., Piao, S., Arneth, A., Harper, A.B., 2016. Regional carbon fluxes from land use and land cover change in Asia, 1980–2009. Environmental Research Letters 11, 074011.

Canadell, J.G., Raupach, M.R., 2008. Managing forests for climate change mitigation. science 320, 1456-1457.

Castella, J.-C., Boissau, S., Thanh, N.H., Novosad, P., 2006. Impact of forestland allocation on land use in a mountainous province of Vietnam. Land use policy 23, 147-160.

Ceddia, M.G., Bardsley, N.O., Gomez-y-Paloma, S., Sedlacek, S., 2014. Governance, agricultural intensification, and land sparing in tropical South America. Proceedings of the National Academy of Sciences 111, 7242-7247.

Chakravarty, S., Ghosh, S., Suresh, C., Dey, A., Shukla, G., 2012. Deforestation: causes, effects and control strategies. Global Perspectives on Sustainable Forest Management 1, 1-26.

Chazdon, R.L., Brancalion, P.H., Laestadius, L., Bennett-Curry, A., Buckingham, K., Kumar, C., Moll-Rocek, J., Vieira, I.C.G., Wilson, S.J., 2016. When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. Ambio 45, 538-550.

Chhatre, A., Agrawal, A., 2009. Trade-offs and synergies between carbon storage and livelihood benefits from forest commons. Proceedings of the national Academy of sciences 106, 17667-17670.

Chowdhury, R.R., Moran, E.F., 2012. Turning the curve: A critical review of Kuznets approaches. Applied Geography 32, 3-11.

CIE, 2002. Vietnam poverty analysis. Centre for International Economics, Canberra and Sydney, Australia, 118 pp.

Clement, F., Orange, D., Williams, M., Mulley, C., Epprecht, M., 2009. Drivers of afforestation in Northern Vietnam: assessing local variations using geographically weighted regression. Applied Geography 29, 561-576.

Cochard, R., Ngo, D.T., Waeber, P.O., Kull, C.A., 2016. Extent and causes of forest cover changes in Vietnam’s provinces 1993–2013: a review and analysis of official data. Environmental Reviews, 1-19.

Coxhead, I., Cuong, N.V., Vu, L.H., 2015. Migration in Vietnam: New Evidence from Recent Surveys.

Culas, R.J., 2007. Deforestation and the environmental Kuznets curve: An institutional perspective. Ecological Economics 61, 429-437.

Damtoft, J.S., Lukasik, J., Herfort, D., Sorrentino, D., Gartner, E.M., 2008. Sustainable development and climate change initiatives. Cement and concrete research 38, 115-127.

Dao, N., 2015. Rubber plantations in the Northwest: rethinking the concept of land grabs in Vietnam. Journal of Peasant Studies 42, 347-369.

Davidar, P., Sahoo, S., Mammen, P.C., Acharya, P., Puyravaud, J.-P., Arjunan, M., Garrigues, J.P., Roessingh, K., 2010. Assessing the extent and causes of forest degradation in India: Where do we stand? Biological Conservation 143, 2937-2944.

De Jong, W., Van Hung, T., 2006. Forest Rehabilitation in Vietnam: Histories, Realities, and Future: Histories, Realities, and Future. Center fo international of forestry research (CIFOR), Bogor, Indonesia.

De, J.W., 2010. Forest rehabilitation and its implication for forest transition theory. Biotropica 42, 3-9.

DeFries, R.S., Rudel, T., Uriarte, M., Hansen, M., 2010. Deforestation driven by urban population growth and agricultural trade in the twenty-first century. Nature Geoscience 3, 178-181.

Do, T.N., Bennett, J., 2007. Willingness to pay for wetland improvement in Vietnam's Mekong River Delta. Australian Agriculture and Resource Economics Society. http://ageconsearch.umn.edu (access 13 April 2016).

Dollar, D., 1994. Macroeconomic Management and the Transition to the Market in Vietnam. Journal of Comparative Economics 18, 357-375.

Dollar, D., 2004. Reform, Growth, and Poverty. Economic growth, poverty, and household welfare in Vietnam 842, 29.

Dollar, D., Glewwe, P., Litvack, J., 1998. Household welfare and Vietnam's transition. World Bank regional and sectoral studies. The World Bank, Washington, D.C. USA.

Dove, M.R., 1983. Theories of swidden agriculture, and the political economy of ignorance. Agroforestry systems 1, 85-99.

Dung, L.C., 2010. Land accumulation and Economics to Scale of Land Use in Rural mekong Delta: Case Study in An Giang Province. Science journal, Can Tho University 15a 293-302.

Duong, P.B., Izumida, Y., 2002. Rural development finance in Vietnam: A microeconometric analysis of household surveys. World Development 30, 319-335.

Ernst, C., Mayaux, P., Verhegghen, A., Bodart, C., Christophe, M., Defourny, P., 2013. National forest cover change in Congo Basin: deforestation, reforestation, degradation and regeneration for the years 1990, 2000 and 2005. Global change biology 19, 1173-1187.

FAO, 2011. Assessing forest degradation: Towards the development of globally applicable guidelines. Forest Resources Assessment Working Paper 177, Rome, Italy.

FFPRI, 2007. The Study on Capacity Development for AR-CDM Promotion in the Socialist Republic of Vietnam: Guidebook for Small Scale AR-CDM, Hanoi, Vietnam.

Fox, J., Truong, D.M., Rambo, A.T., Tuyen, N.P., Cuc, L.T., Leisz, S., 2000. Shifting cultivation: a new old paradigm for managing tropical forests. BioScience 50, 521-528.

FSSP, 2014. Forestry sector development report, Hanoi, Vietnam, 50 pp (In Vietnamese).

FSSP, 2015. Forestry sector development report, Hanoi, Vietnam, 51 pp (In Vietnamese).

Ghazoul, J., Chazdon, R., 2017. Degradation and Recovery in Changing Forest Landscapes: A Multiscale Conceptual Framework. Annual Review of Environment and Resources 42, 161-188.

Glewwe, P., 2004. An overview of economic growth and household welfare in Vietnam in the 1990s. Economic growth, poverty and household welfare in Vietnam, 1-26.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C., 2010. Food security: the challenge of feeding 9 billion people. science 327, 812-818.

Gorte, R.W., 2009. Carbon sequestration in forests. DIANE Publishing, PA, USA.

Grainger, A., 1995. The forest transition: an alternative approach. Area, 242-251.

Griscom, B.W., Adams, J., Ellis, P.W., Houghton, R.A., Lomax, G., Miteva, D.A., Schlesinger, W.H., Shoch, D., Siikamäki, J.V., Smith, P., 2017. Natural climate solutions. Proceedings of the National Academy of Sciences 114, 11645-11650.

GSO, 2010a. Results of the living standard survey. The statistics publishing house, Hanoi, Vietnam (In Vietnamese).

GSO, 2010b. Statistical yearbook of Vietnam. The statistics publishing house, Hanoi, Vietnam (In Vietnamese).

GSO, 2011. General survey on rural, agricultural and fisheries. Statistics publishing house, Hanoi, Vietnam.

GSO, 2015. Statistical yearbook of Vietnam. The statistics publishing house, Hanoi, Vietnam (In Vietnamese).

Gutiérrez, V.H., Zapata, M., Sierra, C., Laguado, W., Santacruz, A., 2006. Maximizing the profitability of forestry projects under the Clean Development Mechanism using a forest management optimization model. Forest Ecology and Management 226, 341-350.

Hansen, J., Sato, M., Ruedy, R., Lo, K., Lea, D.W., Medina-Elizade, M., 2006. Global temperature change. Proceedings of the National Academy of Sciences 103, 14288-14293.

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S., Tyukavina, A., Thau, D., Stehman, S., Goetz, S., Loveland, T., 2013. High-resolution global maps of 21st-century forest cover change. Science 342, 850-853.

Hansson, S.O., 2005. Decision theory: A brief introduction. Royal Institute of Technology (KTH), Stockholm, Sweden.

Hardy, J.T., 2003. Climate change: causes, effects, and solutions. John Wiley & Sons, New York, USA.

Herring, G., 2013. America's longest war: the United States and Vietnam, 1950-1975. McGraw-Hill Higher Education, New York, USA.

Hogarth, N.J., Belcher, B., Campbell, B., Stacey, N., 2013. The role of forest-related income in household economies and rural livelihoods in the border-region of Southern China. World Development 43, 111-123.

Hosonuma, N., Herold, M., De Sy, V., De Fries, R.S., Brockhaus, M., Verchot, L., Angelsen, A., Romijn, E., 2012. An assessment of deforestation and forest degradation drivers in developing countries. Environmental Research Letters 7, 044009.

Hugé, J., Le Trinh, H., Hai, P.H., Kuilman, J., Hens, L., 2010. Sustainability indicators for clean development mechanism projects in Vietnam. Environment, Development and Sustainability 12, 561-571.

Hurni, K., Hett, C., Heinimann, A., Messerli, P., Wiesmann, U., 2013. Dynamics of shifting cultivation landscapes in Northern Lao PDR between 2000 and 2009 based on an analysis of MODIS time series and Landsat images. Human Ecology 41, 21-36.

Hyde, W.F., Amacher, G.S., Magrath, W., 1996. Deforestation and forest land use: Theory, evidence, and policy implications. The World Bank Research Observer 11, 223-248.

IPCC, 2003a. Definitions and methodological options to inventory emissions from direct humaninduced degradation of forests and devegetation of other vegetation types. IPCC National Greenhouse Gas Inventories Programme, Hayama, Japan, 30 pp.

IPCC, 2003b. Good Practice Guidance for Land Use, Land-Use Change and Forestry, Hayama, Kanagawa, Japan.

IPCC, 2006. Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). IGES, Japan. .

IPCC, 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IPCC, 2014a. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014b. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

ITTO, 2002. ITTO guidelines for the restoration, management and rehabilitation of degraded and secondary tropical forests. ITTO Policy Development Series No. 13. Yokohama, Japan, 86 pp.

Jenkins, R., 2004. Vietnam in the global economy: trade, employment and poverty. Journal of International Development 16, 13-28.

JICA, 2006. The study on capacity development for AR-CDM promotion in the socialist republic of Vietnam, Hanoi, Vietnam. Inception report, 58 pp.

JICA, 2008. The study on capacity development for AR-CDM promotion in the socialist republic of Vietnam, Hanoi, Vietnam. Inception report, 310 pp.

JICA, 2012. Potential forests and land related to climate change and forest in Vietnam, Hanoi, Vietnam, pp 219 (in English and Vietnamese).

JOFCA, 2012. Survey report of characteristics of nature and socio-economics in Dien Bien province to implement REDD+ program. Hanoi, Vietnam, 110pp.

Kaimowitz, D., Angelsen, A., 1998. Economic models of tropical deforestation: a review. Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Kanninen, M., Brockhaus, M., Murdiyarso, D., Nabuurs, G.-J., 2010. Harnessing forests for climate change mitigation through REDD+. IUFRO (International Union of Forestry Research Organizations) Secretariat, Vienna, Austria.

Kauppi, P.E., Ausubel, J.H., Fang, J., Mather, A.S., Sedjo, R.A., Waggoner, P.E., 2006. Returning forests analyzed with the forest identity. Proceedings of the National Academy of Sciences 103, 17574-17579.

Khai, H.V., Yabe, M., 2014. The demand of urban residents for the biodiversity conservation in U Minh Thuong National Park, Vietnam. Agricultural and Food Economics 2, 10.

Khang, L.N., Bao, T.Q., 2015. Impacts of socio-economic conditions to the deforestation, forest degradation and proposing solutions for REDD+ implementation in Dien Bien province. Journal of Agricultural and Rural development 15, 132-141 (In Vietnamese).

Khuc, Q.V., 2013. Household's willingness-to-pay estimation for safe drinking water: a case study in Vietnam. Master thesis, Colorado State University, Fort Collins, USA.

Khuc, V.Q., Tran, Q.B., Meyfroidt, P., Paschke, M.W., 2018. Drivers of deforestation and forest degradation in Vietnam: An exploratory analysis at the national level. Forest Policy and Economics 90, 128-141.

Kimmins, J., 2004. Forest Ecology: a foundation for sustainable forest management and environmental ethics in forestry, 3rd Edit. Prentice Hall, Upper Saddle River, NJ, USA.

Kissinger, G., Herold, M., de Sy, V., 2012. Drivers of deforestation and forest degradation: A synthesis report for REDD+ policymakers. The Government of the UK and Norway.

Köthke, M., Leischner, B., Elsasser, P., 2013. Uniform global deforestation patterns—an empirical analysis. Forest Policy and Economics 28, 23-37.

Kull, C.A., 2017. Forest transitions: a new conceptual scheme. Geographica Helvetica 72, 465-474.

La, N.K., 2014. Research on zoning priorities and proposed solutions to implementing REDD+ program at Dien Bien province. Vietnamese Journal of Forest Science and Technology 4, 71-84.

La, N.K., 2015. The study on theory and practices for finding solutions to impletement REDD+ program in Dien Bien. Dissertation, Vietnam National University of Forestry, Hanoi, Vietnam, 132pp (In Vietnamese).

La, N.K., Tran, Q.B., 2015. Impacts of socio-economic conditions to the deforestation, forest degradation and proposing solutions for REDD+ implementation in Dien Bien province. Journal of Agricultural and Rural development 15, 132-141 (In Vietnamese).

Lambini, C.K., Nguyen, T.T., 2014. A comparative analysis of the effects of institutional property rights on forest livelihoods and forest conditions: Evidence from Ghana and Vietnam. Forest Policy and Economics 38, 178-190.

Lang, C., 2001. Deforestation in Vietnam, laos and Cambodia, Deforestation, environment, and sustainable development: A comparative analysis. Praeger: Westport, Connecticut and London, pp. 111-137.

Le Dinh, K., 2000. Studies on natural hybrids of Acacia mangium and A. auriculiformis in Vietnam. Journal of Tropical Forest Science 12, 794-803.

Le Quéré, C., Moriarty, R., Andrew, R.M., Canadell, J.G., Sitch, S., Korsbakken, J.I., Friedlingstein, P., Peters, G.P., Andres, R.J., Boden, T.A., 2015. Global carbon budget 2015. Earth System Science Data 7, 349-396.

Lederer, M., 2011. From CDM to REDD+—What do we know for setting up effective and legitimate carbon governance? Ecological economics 70, 1900-1907.

Leisz, S.J., 2009. Dynamics of land cover and land use changes in the upper Ca river basin of Nghe An, Vietnam. Japanese Journal of Southeast Asian Studies 47, 287-308.

Leisz, S.J., Rasmussen, M.S., 2012. Mapping fallow lands in Vietnam's north-central mountains using yearly Landsat imagery and a land-cover succession model. International journal of remote sensing 33, 6281-6303.

Lund, H.G., 2014. Definitions of forest, deforestation, afforestation, and reforestation. Forest Information Services, Gainesville, Virginia, U.S.A.

Maginnis, S., Rietbergen-McCracken, J., Sarre, A., 2012. The forest landscape restoration handbook. Routledge, New York, USA.

Mansourian, S., 2005. Overview of forest restoration strategies and terms, Forest restoration in landscapes. Springer, New York, USA, pp. 8-13.

MARD, 2005. Decision 16/2005 - MARD checklist of the species for afforestation/reforestation of production forest in 9 ecological zones of Vietnam, Hanoi, Vietnam.

MARD, 2007. Vietnam Forestry Development Strategy (2006-2020), Hanoi, Vietnam.

MARD, 2009. Circular No. 34/2009/ TT-BNNPTNT. Criteria for determining and classifying forests, Hanoi, Vietnam.

MARD, 2016a. Decision No 3158/QĐ-BNN-TCLN. Proclaim about forest status in 2015, Hanoi, Vietnam.

MARD, 2016b. Status of forest 2015. Hanoi, Vietnam (In Vietnamese), 13pp.

Marsh, S.P., MacAulay, T.G., Hung, P.V., 2007. Agricultural development and land policy in Vietnam: policy briefs. ACIAR Monograph No. 126. Australian Centre for International Agricultural Research (ACIAR), Canberra ACT 2601, Australia.

Martin, T.G., Watson, J.E., 2016. Intact ecosystems provide best defence against climate change. Nature Climate Change 6, 122.

Mather, A., 1992a. The Forest Transition. Area, 24, 367-379. Perz, SG and Skole, DL (2003). Secondary Forest Expansion in the Brazillian Amazon and the Refinement of the Forest Transition Theory. Society and Natural Resources 16, 277-294.

Mather, A.S., 1992b. The forest transition. Area, 367-379.

Mather, A.S., Needle, C., 1998. The forest transition: a theoretical basis. Area 30, 117-124.

McElwee, P., 2009. Reforesting "bare hills" in Vietnam: Social and environmental consequences of the 5 million hectare reforestation program. Ambio: A Journal of the Human Environment 38, 325-333.

McElwee, P., 2016a. Forests are gold: Trees, people, and environmental rule in Vietnam. University of Washington Press, Seattle, USA.

McElwee, P.D., 2016b. Forests are gold: Trees, people, and environmental rule in Vietnam. University of Washington Press, Seattle, USA.

Mertz, O., 2009. Trends in shifting cultivation and the REDD mechanism. Current Opinion in Environmental Sustainability 1, 156-160.

Mertz, O., Padoch, C., Fox, J., Cramb, R.A., Leisz, S.J., Lam, N.T., Vien, T.D., 2009. Swidden change in Southeast Asia: understanding causes and consequences. Human Ecology 37, 259-264.

Meyfroidt, P., 2013. Environmental cognitions, land change and social-ecological feedbacks: local case studies of forest transition in Vietnam. Human ecology 41, 367-392.

Meyfroidt, P., 2016. Approaches and terminology for causal analysis in land systems science. Journal of Land Use Science 11, 501-522.

Meyfroidt, P., Lambin, E.F., 2008a. The causes of the reforestation in Vietnam. Land use policy 25, 182-197.

Meyfroidt, P., Lambin, E.F., 2008b. Forest transition in Vietnam and its environmental impacts. Global Change Biology 14, 1319-1336.

Meyfroidt, P., Lambin, E.F., 2011a. Global forest transition: prospects for an end to deforestation. Annual review of environment and resources 36, 343-371.

Meyfroidt, P., Lambin, E.F., 2011b. Global forest transition: prospects for an end to deforestation. Annual review of environment and resources 36.

Meyfroidt, P., Vu, T.P., Hoang, V.A., 2013. Trajectories of deforestation, coffee expansion and displacement of shifting cultivation in the Central Highlands of Vietnam. Global environmental change 23, 1187-1198.

Miles, L., Kapos, V., 2008. Reducing greenhouse gas emissions from deforestation and forest degradation: global land-use implications. science 320, 1454-1455.

Mishan, E.J., Quah, E., 2007. Cost-benefit analysis. Routledge, Florence, Kentucky, USA.

MONRE, 2017. Lists of projects has been registered as a CDM project in Vietnam <http://www.noccop.org.vn> (accessed 5.15.2017).

Morales-Barquero, L., Borrego, A., Skutsch, M., Kleinn, C., Healey, J.R., 2015. Identification and quantification of drivers of forest degradation in tropical dry forests: A case study in Western Mexico. Land Use Policy 49, 296-309.

Muller, D., Zeller, M., 2002. Land use dynamics in the central highlands of Vietnam: a spatial model combining village survey data with satellite imagery interpretation. Agricultural Economics 27, 333-354.

Nguyen, B., Nguyen, Q., Sunderlin, W.D., Yasmi, Y., 2009. Forestry and poverty data in Viet Nam: status, gaps, and potential uses. The Center for People and Forests (RECOFTC), Bangkok, Thailand.

Nguyen, H.N., 2007. Forest Rehabilitation in Vietnam. in: Don Koo Lee (Eds.), Keep Asia Green, Volume I "Southeast Asia", IUFRO World Series Volume 20-1. Vienna, 209-242 pp.

Nguyen, L.D., Raabe, K., Grote, U., 2015. Rural–urban migration, household vulnerability, and welfare in Vietnam. World Development 71, 79-93.

Nguyen, Q.T., 2011. Payment for environmental services in Vietnam: An analysis of the pilot project in Lam Dong province. Institute for Global Environmental Strategies (IGES), Kamiyamaguchi, Hayama, Kanagawa, Japan.

Nguyen, Q.T., Nguyen, B.N., Tran, N.T., Sunderlin, W., Yasmi, Y., 2008. Forest Tenure Reform in Viet Nam: Case Studies from the Northern Upland and Central Highlands Region. The Center for People and Forests (RECOFTC), Bangkok, Thailand.

Nguyen, T.T., 2012. Land reform and farm production in the Northern Uplands of Vietnam. Asian Economic Journal 26, 43-61.

Nguyen, T.T., Bauer, S., Uibrig, H., 2010. Land privatization and afforestation incentive of rural farms in the Northern Uplands of Vietnam. Forest Policy and Economics 12, 518-526.

Nguyen, T.T., Koellner, T., Le, Q.B., Lambini, C.K., Choi, I., Shin, H.-j., 2014. An economic analysis of reforestation with a native tree species: The case of Vietnamese farmers. Biodiversity and conservation 23, 811-830.

Nguyen, T.T., Pham, V.D., Tenhunen, J., 2013. Linking regional land use and payments for forest hydrological services: A case study of Hoa Binh Reservoir in Vietnam. Land Use Policy 33, 130-140.

Nikolic, N., Schultze-Kraft, R., Nikolic, M., Böcker, R., Holz, I., 2008. Land degradation on barren hills: a case study in northeast Vietnam. Environmental Management 42, 19-36.

Noble, I., Bolin, B., Ravindranath, N., Verardo, D., Dokken, D., 2000. Land Use, Land-Use Change, and Forestry. Cambridge University Press, England.

Ohlsson, B., Sandewall, M., Sandewall, R.K., Phon, N.H., 2005. Government plans and farmers intentions: A study on forest land use planning in Vietnam. AMBIO: A Journal of the Human Environment 34, 248-255.

Paulsson, E., 2009. A review of the CDM literature: from fine-tuning to critical scrutiny? International environmental agreements: politics, law and economics 9, 63-80.

Pearce, D., Atkinson, G., Mourato, S., 2006. Cost-benefit analysis and the environment: recent developments. Organisation for Economic Co-operation and development.

Pham, B.D., Izumida, Y., 2002. Rural development finance in Vietnam: A microeconometric analysis of household surveys. World Development 30, 319-335.

Pham, T.T., Bennett, K., Vu, T.P., Brunner, J., Le, N., Nguyen, D.T., 2013. Payments for forest environmental services in Vietnam: from policy to practice. Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Pham, T.T., Moeliono, M., Nguyen, T.H., Nguyen, H.T., Vu, T.H., 2012. The context of REDD+ in Vietnam: drivers, agents and institutions. Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Philip, D., Rayhan, M.I., 2004. Vulnerability and Poverty: What are the causes and how are they related. ZEF Bonn, center for Development Research, University of Bonn, Germany, 28pp.

Phung, N.L., Phan, N.H., Trieu, V.H., Nguyen, N.T., Le, T.C., 2006. Natural forest ecosystem in Vietnam. Hanoi, Vietnam, 102 pp (In Vietnamese).

Pingali, P.L., Xuan, V.T., 1992. Vietnam: Decollectivization and rice productivity growth. Economic development and cultural change 40, 697-718.

Pirard, R., 2012. Market-based instruments for biodiversity and ecosystem services: A lexicon. Environmental science & policy 19, 59-68.

Plottu, E., Plottu, B., 2007. The concept of Total Economic Value of environment: A reconsideration within a hierarchical rationality. Ecological economics 61, 52-61.

PM, 1998. Decision No. 661/QĐ-TTg on objectives, tasks, policies and implementation organization of the 5 million hectares reforestation project, Hanoi, Vietnam.

Putz, F.E., Redford, K.H., 2010. The importance of defining ‘forest’: tropical forest degradation, deforestation, long-term phase shifts, and further transitions. Biotropica 42, 10-20.

Rasul, G., Thapa, G.B., 2003. Shifting cultivation in the mountains of South and Southeast Asia: regional patterns and factors influencing the change. Land Degradation & Development 14, 495-508.

Rebecca, M., Steven, S., Hoang, V.A., Phuong, V.T., Le, V.T., Vo, T.S., Monika, B., Corinna, R., Julia, T., Kate, T., Lera, M., 2013. Generating Forest Biomass Carbon Stock Estimates for Mapping the Potential of REDD+ to deliver biodiversity conservation in Vietnam. SNV– The Netherlands Development Organisation, Ho Chi Minh City, Vietnam.

Reich, R.M., 2008. Spatial statistical modeling of ecosystem resources and the environment. Colorado State University, Fort Collins, U.S.A, 415 pp.

Ripple, W.J., Wolf, C., Newsome, T.M., Galetti, M., Alamgir, M., Crist, E., Mahmoud, M.I., Laurance, W.F., 15, s.s.f.c., 2017. World Scientists’ Warning to Humanity: A Second Notice. BioScience 67, 1026-1028.

Rudel, T.K., Schneider, L., Uriarte, M., 2010. Forest transitions: An introduction. Land use policy 27, 95-97.

Rudel, T.K., Sloan, S., Chazdon, R., Grau, R., 2016. The drivers of tree cover expansion: Global, temperate, and tropical zone analyses. Land Use Policy 58, 502-513.

Ruiz-Jaen, M.C., Mitchell Aide, T., 2005. Restoration success: how is it being measured? Restoration Ecology 13, 569-577.

Sam, D.D., 1994. Shifting cultivation in Vietnam: its social, economic and environmental values relative to alternative land use. IIED forestry and land use series No. 3. International Institute for Environment and Development (IIED), London, UK.

Schmidt-Vogt, D., Leisz, S.J., Mertz, O., Heinimann, A., Thiha, T., Messerli, P., Epprecht, M., Van Cu, P., Chi, V.K., Hardiono, M., 2009. An assessment of trends in the extent of swidden in Southeast Asia. Human Ecology 37, 269.

SER, 2004. The SER international primer on ecological restoration. Society for Ecological Restoration International, NW, USA http://www.ser.org/.

Shi, M., Yin, R., Lv, H., 2017. An empirical analysis of the driving forces of forest cover change in northeast China. Forest Policy and Economics 78, 200-209.

Shriar, A.J., 2002. Food security and land use deforestation in northern Guatemala. Food Policy 27, 395-414.

Sikor, T., 2001. The allocation of forestry land in Vietnam: did it cause the expansion of forests in the northwest? Forest Policy and Economics 2, 1-11.

Southworth, J., Nagendra, H., Cassidy, L., 2012. Forest transition pathways in Asia–studies from Nepal, India, Thailand, and Cambodia. Journal of land use science 7, 51-65.

Stanturf, J., Lamb, D., Madsen, P., 2012. Forest landscape restoration: Integrating natural and social sciences. Springer Science & Business Media.

Stanturf, J.A., 2005. What is forest restoration, Restoration of boreal and temperate forests. CRC Press, Boca Raton, Florida, pp. 3-11.

Stern, D.I., Common, M.S., Barbier, E.B., 1996. Economic growth and environmental degradation: the environmental Kuznets curve and sustainable development. World development 24, 1151-1160.

Stibig, H.-J., Achard, F., Carboni, S., Rasi, R., Miettinen, J., 2014. Change in tropical forest cover of Southeast Asia from 1990 to 2010. Biogeosciences 11, 247-258.

Stock, J.H., Watson, M.W., 2003. Introduction to econometrics. Addison Wesley Boston.

Sunderlin, W.D., Angelsen, A., Belcher, B., Burgers, P., Nasi, R., Santoso, L., Wunder, S., 2005. Livelihoods, forests, and conservation in developing countries: an overview. World development 33, 1383-1402.

Sunderlin, W.D., Huynh, T.B., 2005. Poverty alleviation and forests in Vietnam. Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Thomas, S., Dargusch, P., Harrison, S., Herbohn, J., 2010. Why are there so few afforestation and reforestation Clean Development Mechanism projects? Land use policy 27, 880-887.

Thompson, I.D., Guariguata, M.R., Okabe, K., Bahamondez, C., Nasi, R., Heymell, V., Sabogal, C., 2013. An operational framework for defining and monitoring forest degradation. Ecology and Society 18, 20.

Thuy, T.D., 2007. Willingness to pay for conservation of the Vietnamese Rhino. Economy and Environment Program for Southeast Asia, Los Baños, Laguna 4031 Philippines, 27pp.

To, P.X., Dressler, W.H., Mahanty, S., Pham, T.T., Zingerli, C., 2012. The prospects for payment for ecosystem services (PES) in Vietnam: a look at three payment schemes. Human Ecology 40, 237-249.

To, X.P., Tran, H.N., 2014. Forest land allocation in the context of forestry sector restructuring: opportunities for forestry development and upland livelihood improvement. Tropenbos International Viet Nam, Hue, Vietnam.

Tran, N.T., Sikor, T., 2006. From legal acts to actual powers: Devolution and property rights in the Central Highlands of Vietnam. Forest Policy and Economics 8, 397-408.

Tran, Q.B., 2012. Final report on field survey to identify the driving forces of deforestation and reforestation/regeneration in Dien Bien province. Vietnam National University of Forestry, Hanoi, Vietnam 98pp.

Turner, S., 2012a. “Forever Hmong”: Ethnic Minority Livelihoods and Agrarian Transition in Upland Northern Vietnam. The Professional Geographer 64, 540-553.

Turner, S., 2012b. Making a living the Hmong way: an actor-oriented livelihoods approach to everyday politics and resistance in upland Vietnam. Annals of the Association of American Geographers 102, 403-422.

UNFCCC, 1997. Kyoto protocol to the United Nations framework convention onclimate change. United Nations Framework Convention on Climate Change, FCCC/CP/L.7/Add1, Kyoto.

UNFCCC, 2006. AR-AMS0001 Simplified baseline and monitoring methodologies for small-scale afforestation and reforestation project activities under the CDM implemented on settlements <https://cdm.unfccc.int> (accessed 4.7.2017).

UNFCCC, 2008. AR-TOOL12. A/R Methodological tool: Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities <https://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-12-v3.0.pdf> (accessed 9.2.2017).

UNFCCC, 2011. The Cancun Agreements: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention. United Nations Framework

Convention on Climate Change, FCCC/CP/2010/7/Add.1 <https://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf> (accessed 3.15.2017).

Unwin, G.L., Kriedemann, P.E., 2000. Principles and processes of carbon sequestration by trees. Research and Development Division, State Forests of New South Wales, Sydney, Australia. Technical paper, 29 pp.

Van Vliet, N., Mertz, O., Birch-Thomsen, T., Schmook, B., 2013. Is there a continuing rationale for swidden cultivation in the 21st century? Human Ecology 41, 1-5.

VBSP, 2017. Interest interest for loan <http://vbsp.org.vn> (accessed 5.10.2017).

VCCI, 2010. Policy research report USAID/VNCI No 15 province competitiveness index in Vietnam, Hanoi, Vietnam (in Vietnamese) http://pcivietnam.org.

VCCI, 2016. Province competitiveness index in Vietnam, Hanoi, Vietnam (in Vietnamese) http://pcivietnam.org.

Viña, A., McConnell, W.J., Yang, H., Xu, Z., Liu, J., 2016. Effects of conservation policy on China's forest recovery. Science advances 2, e1500965.

Vongvisouk, T., Mertz, O., Thongmanivong, S., Heinimann, A., Phanvilay, K., 2014. Shifting cultivation stability and change: Contrasting pathways of land use and livelihood change in Laos. Applied geography 46, 1-10.

VUSTA, 2011. Research report on rural labour and employment in Vietnam. International Labour Office, CH-1211 Geneva 22, Switzerland.

WB, 2010. World Development Report 2010 : Development and Climate Change. Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/4387 License: CC BY 3.0 IGO.

WB, 2012. Not Yet Done: Vietnam's Remarkable Progress on Poverty Reduction and the Emerging Challenges. World Bank Vietnam, Hanoi, Vietnam.

Wunder, S., 2001. Poverty alleviation and tropical forests—what scope for synergies? World development 29, 1817-1833.

Yalfal, T.T., Ayalneh, B., Mengistu, K., 2013. Willingness to pay for rehabilitation of degraded forest: Implications for community based forest recovery, management and forest policy. Lambert Academic Publishing, Saarbrücken, Germany.

Yamanoshita, M.Y., Amano, M., 2012. Capability development of local communities for project sustainability in afforestation/reforestation clean development mechanism. Mitigation and adaptation strategies for global change 17, 425-440.

Yeo, I.-Y., Huang, C., 2013. Revisiting the forest transition theory with historical records and geospatial data: A case study from Mississippi (USA). Land use policy 32, 1-13.

Yin, R., Xiang, Q., 2010. An integrative approach to modeling land-use changes: multiple facets of agriculture in the Upper Yangtze basin. Sustainability Science 5, 9-18.

SUPPLEMENTARY

Chapter 2

Table S2.1. Forest loss and forest degradation by provinces in Vietnam between 2000 and 2010.

#	Provinces	Total natural area (ha)	Deforestation (ha)	Forest degradation (ha)	Deforestation and forest degradation (ha)
1	Da Nang City	96,573	6,809	8,233	15,042
2	Dong Nai	586,116	25,871	NI	25,904
3	Dong Thap	338,392	6,300	NI	6,300
4	Dac Nong	651,177	NI	NI	NI
5	Dak Lak	1,315,371	40,992	7,255	48,247
6	Dien Bien	956,225	NI	NI	NI
7	An Giang	353,005	NI	NI	NI
8	Ba Ria - VTau	189,772	3,039	NI	3,039
9	Binh Dinh	609,340	15,357	6,148	21,505
10	Binh Duong	269,430	6,020	NI	6,020
11	Binh Phuoc	688,213	86,415	8,602	95,017
12	Binh Thuan	794,909	41,664	9,507	51,171
13	Bac Lieu	255,010	2,719	NI	2,719
14	Bac Giang	389,108	21,573	9,468	31,041
15	Bac Kan	485,918	45,018	3,230	48,248
16	Bac Ninh	82,027	NI	NI	NI
17	Ben Tre	233,611	1,508	NI	1,508
18	Ca Mau	522,225	17,946	NI	17,946
19	Cao Bang	675,027	75,638	2,876	78,514
20	Can Tho	139,074	NI	NI	NI
21	Gia Lai	1,554,851	70,142	84,788	154,930
22	Ha Giang	796,384	50,292	15,809	66,101
23	Ha Noi City	335,738	NI	NI	NI
24	Ha Nam	86,225	NI	NI	NI
25	Ha Tinh	596,635	23,942	31,726	55,668
26	Ho Chi Minh City	206,752	NI	NI	NI
27	Hoa Binh	463,867	43,578	3,865	47,443
28	Hung Yen	92,884	NI	NI	NI
29	Hai Duong	166,939	NI	NI	NI
30	Hai Phong City	138,149	NI	NI	NI
31	Hau Giang	166,852	NI	NI	NI
32	Khanh Hoa	484,407	30,894	17,749	48,643
33	Kien Giang	632,841	2,699	NI	2,699
34	Kon Tum	970,167	51,296	36,492	87,788

35	Lao Cai	636,433	46,646	29,689	76,335
36	Lam Dong	980,056	23,124	21,879	45,003
37	Lai Chau	906,869	48,595	25,146	73,741
38	Lang Son	833,366	47,840	1,511	49,351
39	Long An	449,393	16,881	NI	16,881
40	Nam Dinh	166,008	NI	NI	NI
41	Nghe An	1,646,288	129,641	45,171	174,812
42	Ninh Binh	136,262	NI	NI	NI
43	Ninh Thuan	335,652	22,092	3,419	25,511
44	Phu Tho	352,826	20,310	3,187	23,497
45	Phu Yen	502,059	42,779	5,665	48,444
46	Quang Binh	800,310	44,723	73,354	118,077
47	Quang Nam	1,059,341	39,503	35,282	74,785
48	Quang Ngai	517,244	41,219	8,281	49,500
49	Quang Ninh	566,059	21,111	479	21,590
50	Quang Tri	473,949	24,139	32,338	56,477
51	Soc Trang	327,759	NI	NI	NI
52	Son La	1,410,821	70,647	23,295	93,942
53	Tay Ninh	403,962	2,396	308	2,704
54	Thai Binh	158,675	NI	NI	NI
55	Thai Nguyen	352,431	27,878	2,275	30,153
56	Thua Thien - Hue	491,280	21,495	21,899	43,394
57	Thanh Hoa	1,107,902	102,041	21,180	123,221
58	Tien Giang	239,060	1,229	NI	1,229
59	Tra Vinh	230,647	1,868	NI	1,868
60	Tuyen Quang	585,380	50,591	12,323	62,914
61	Vinh Long	152,517	NI	NI	NI
62	Vinh Phuc	123,719	7,689	1,934	9,623
63	Yen Bai	688,233	39,825	22,491	62,316

Note: NI denotes not included.

Table S2.2. Results from test of normality data for per capita area of deforestation, forest degradation, deforestation and forest degradation between 2000 and 2010.

Tests of Normality	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Deforestation	.175	46	.001	.821	46	.000
Forest degradation	.254	46	.000	.683	46	.000
Deforestation and forest degradation	.170	46	.002	.849	46	.000

Table S2.3. Results of Wilcoxon test for comparing the mean of three groups: Deforestation, Forest Degradation, and Deforestation and Degradation between 2000-2005 & 2005-2010.

Items	Deforestation (N=46)	Forest degradation (N=35)	Deforestation and forest degradation (N=46)
P value (R)	0.01572	0.0005915	0.003044

Figure S2.1. Deforestation and forest degradation across 8 regions of Vietnam.

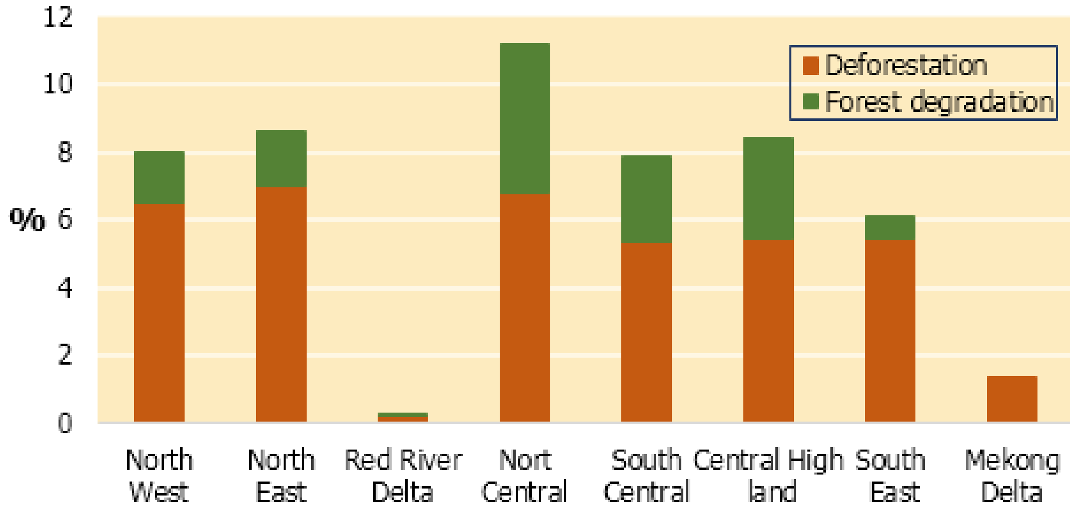
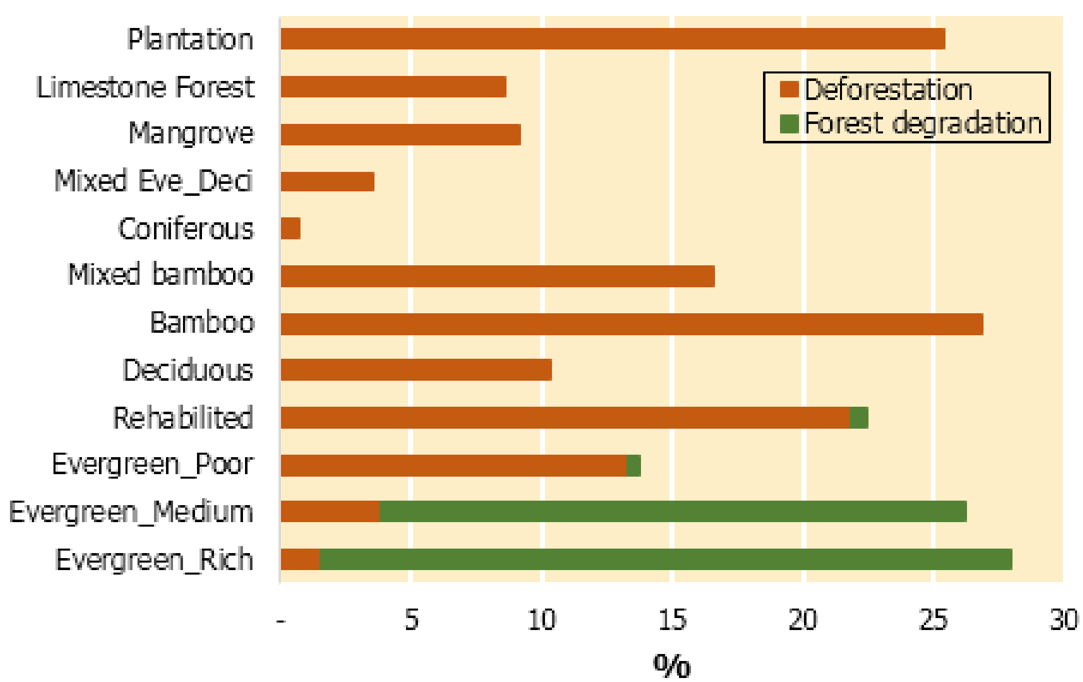


Figure S2.2. Deforestation and forest degradation over 12 forest types of Vietnam.



Chapter 3

Table S3.1. Summary of key national forest restoration programs in Vietnam (CP, 2011; De Jong & Van Hung, 2006).

Content	Scattered Tree Planting	PAM (World Food Program)	Program 327 (Greening Bare Hill program)	Program 5MHRP (Five Million Reforestation Project)
Time	1950s	1975	1993-1998	1998-2010
Budget ($)	-	~500 Million	~213 Million	~1.6 billion
Priority objectives	-	Supply food to rural communities; provide equipment and materials for forest plantation; construct forest roads, organize fire protection teams; improve forest extension services.	Regreen open land and barren hills; protect existing forests; assist natural regeneration and reforestation; utilize coastal alluvia, promote aquaculture; develop long-term industrial crops and fruit trees; expand cultivated land in delta areas; build infrastructure, promote social welfare and recruit labor to project areas.	Reforest 5 million ha of land; assure a forest product supply to reduce pressure on natural forests; create employment for people, and increase income of people in forest area, contributing to poverty alleviation, hunger eradication and the development of rural mountainous areas.
Outputs/ Achievements	Approximately 3.6 billion scattered trees planted	Large areas of land have been planted to trees; jobs were created; livelihoods in community improved, forest plantation and agroforestry techniques have been transferred; gender equity was promoted.	Around 299,000 ha of forest were successfully regenerated; ~ 397,000 ha of new plantations were established; ~5.4 million ha of forest was protected; nearly 88,000 ha of industrial crops and fruit trees were yielded; ~466,000 jobs and 5,000 km of road were created and built.	Almost 1.69 million ha of forestland was zoned for regeneration; ~ 2.45 million ha forest was planted. Nearly 1.25 million households got involved in project; many models in garden-forest were created; economic structure in mountainous area was positively changed.

Table S3.2. Restored forests and forest gain by targeted communes in Dien Bien province, Vietnam between 1990 and 2010.

#	Communes	Total natural area (ha)	1990-2000		2000-2010		1990-2010	
			Restored forests (ha)	Forest gain (ha)	Restored forests (ha)	Forest gain (ha)	Restored forests (ha)	Forest gain (ha)
1	Ang Cang	5,432	347	347	1,131	1,175	1,310	1,354
2	Cha Cang	19,587	4,228	4,726	3,869	3,910	5,648	6,106
3	Cha Nua	9,848	4,730	4,783	1,258	1,258	4,095	4,130
4	Chieng So	6,185	306	314	996	1,001	1,126	1,131
5	Chung Chai	20,982	3,574	3,910	2,209	2,220	3,928	4,220
6	Hua Ngai	24,226	2,183	2,318	3,717	3,729	5,156	5,202
7	Huoi So	5,942	234	665	223	287	246	701
8	Keo Lom	13,975	517	653	2,156	2,159	2,324	2,407
9	Leng Su Sin	18,035	4,724	5,191	2,569	2,827	4,786	5,237
10	Muong Dang	6,549	294	300	633	633	708	708
11	Muong Lan	4,042	479	479	685	694	1,007	1,016
12	Muong Loi	32,833	2,280	2,736	7,531	7,637	8,448	8,805
13	Muong Mun	21,098	1,008	1,684	2,014	2,062	1,701	2,305
14	Muong Nha	27,642	2,623	2,829	5,194	5,225	6,685	6,823
15	Muong Nhe	21,777	2,909	3,210	4,203	4,236	5,230	5,615
16	Muong Pon	12,509	1,807	2,131	3,733	4,339	4,444	5,326
17	Muong Tung	17,058	3,216	3,430	2,561	2,693	3,339	3,468
18	Muong Toong	23,094	8,434	8,436	5,031	5,246	10,482	10,934
19	Na Bung	14,477	2,374	2,419	2,177	2,194	2,862	2,880
20	Na Hy	15,202	2,519	2,544	3,484	3,485	3,564	3,565
21	Na Khoa	12,381	861	1,104	2,510	2,550	2,022	2,096
22	Na Say	13,822	303	357	1,790	1,792	1,784	1,834
23	Na Co Sa	12,818	634	652	3,649	3,654	2,862	2,876
24	Na Son	7,088	51	70	964	964	872	891
25	Nam Ke	15,603	3,310	3,462	1,455	1,461	3,166	3,278
26	Nam Vi	6,163	747	795	401	424	686	751
27	Nua Ngam	12,202	1,293	1,882	2,033	2,189	2,656	3,082
28	Pa My	6,822	1,338	1,387	1,749	1,751	2,088	2,118

29	Pa Tan	16,605	2,450	3,475	3,426	3,445	4,483	5,403
30	Phinh Sang	12,714	597	810	1,499	1,540	1,728	1,967
31	Pu Nhi	10,642	435	446	1,519	1,533	1,657	1,682
32	Quai Cang	3,897	290	396	392	527	590	725
33	Quang Lam	10,522	2,842	2,842	3,233	3,233	4,303	4,304
34	Sa Long	8,404	492	991	2,051	2,062	2,355	2,394
35	Sen Thuong	17,364	1,812	2,058	2,835	2,866	3,645	3,677
36	Si Pa Phin	12,867	212	615	283	290	418	429
37	Sin Thau	16,360	1,660	1,799	1,698	1,947	2,597	2,677
38	Ta Ma	10,663	416	585	1,384	1,407	1,564	1,750
39	Thanh An	2,014	-	48	230	260	231	266
40	Tua Thang	8,847	525	777	1,631	1,674	1,957	2,223
Total		538,291	69,054	77,656	90,106	92,579	118,753	126,356

Note: Forest gain is the total area of restored forests, plantation forests, and other forests.

Table S3.3. Forest types and codes used in a forest distribution map for Vietnam and the study region between 1990 and 2010

Land use type	Code	Vietnam	Study region
Forest			
Rich evergreen	1	☑	☑
Rich evergreen	2	☑	☑
Rich evergreen	3	☑	☑
Restored forest	4	☑	☑
Deciduous	5	☑	
Bamboo	6	☑	☑
Mixed bamboo	7	☑	☑
Coniferous	8	☑	
Mixed Evergreen Deciduous	9	☑	
Mangrove	10	☑	
Limestone forest	11	☑	☑
Plantation	12	☑	☑
Non-forest		☑	☑
Limestone	13	☑	☑
Bare land	14	☑	☑
Waterbody	15	☑	☑
Residential	16	☑	☑
Other land	17	☑	☑

Note: Checked box means the type of forest or non-forest is available in either Vietnam or study region.

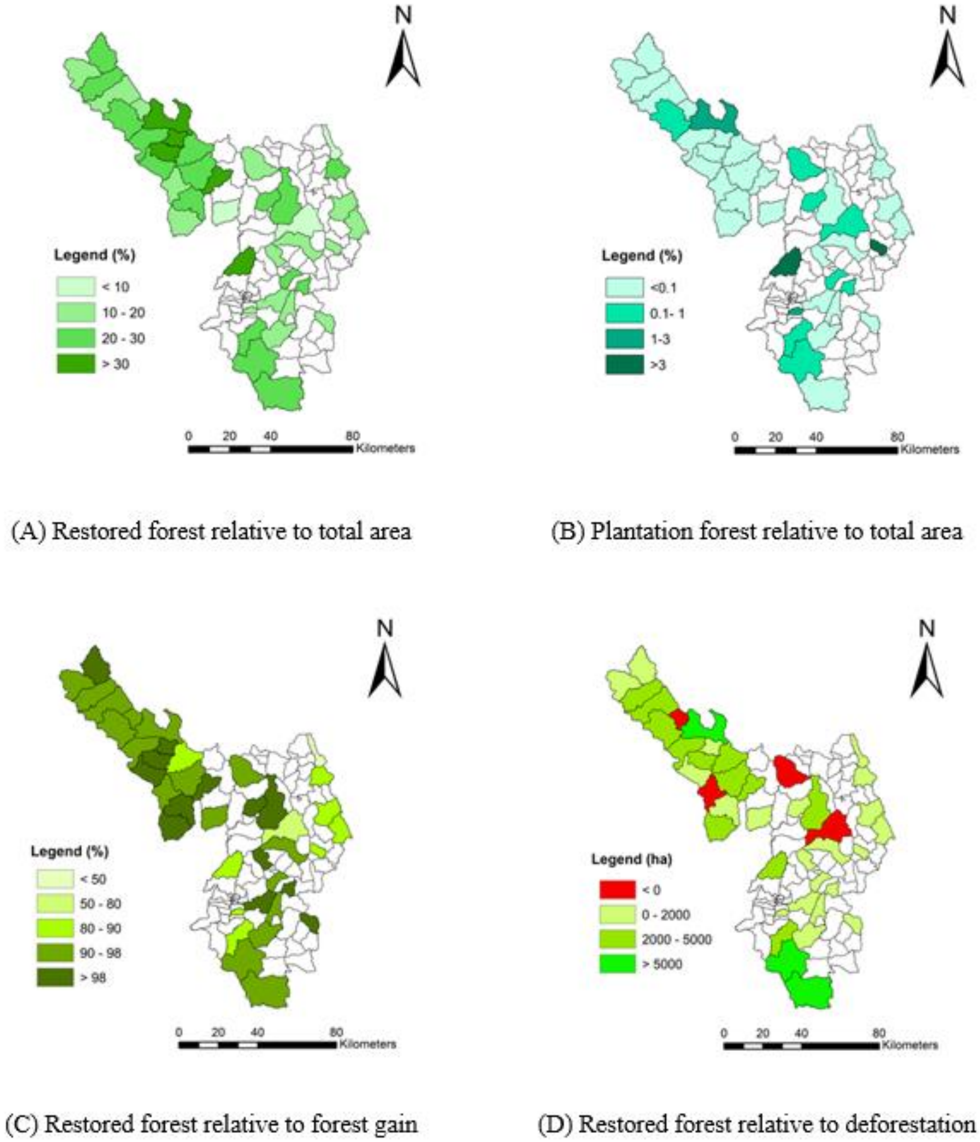
Table S3.4. Shapiro-Wilk normality test for candidate variables in the structural model by period from 1990 to 2010.

VARIABLES	Period 1: 1990-2000	Normally Distributed Data	Period 2: 2000-2010	Normally Distributed Data
RESTO	W = 0.82259, p-value = 2.076e-05	No	W = 0.91879, p-value = 0.007058	No
RESTO1	W = 0.84646, p-value = 7.391e-05	No	W = 0.98336, p-value = 0.8111	Yes
RESTO2	W = 0.60535, p-value = 3.704e-09	No	W = 0.94998, p-value = 0.0757	Yes
FGAIN	W = 0.85473, p-value = 0.0001174	No	W = 0.9204, p-value = 0.007929	Yes
FGAIN1	W = 0.87316, p-value = 0.0003459	No	W = 0.98187, p-value = 0.7585	No
FGAIN2	W = 0.60705, p-value = 3.91e-09	Yes	W = 0.93862, p-value = 0.03108	No
PADRI	W = 0.56204, p-value = 9.834e-10	No	W = 0.60314, p-value = 3.454e-09	No
ETHNIC	W = 0.95756, p-value = 0.1382	Yes	W = 0.95557, p-value = 0.118	Yes
LITER	W = 0.90486, p-value = 0.002656	No	W = 0.64965, p-value = 1.594e-08	No
ELEV	W = 0.92248, p-value = 0.009221	No	W = 0.92248, p-value = 0.009221	No
INCOM	W = 0.94513, p-value = 0.05163	Yes	W = 0.89698, p-value = 0.001564	No
FINCOM	W = 0.93322, p-value = 0.02054	No	W = 0.88002, p-value = 0.000527	No
FOODCAP	W = 0.94413, p-value = 0.04771	No	W = 0.87737, p-value = 0.0004475	No
CASHCAP	W = 0.59229, p-value = 2.459e-09	No	W = 0.87789, p-value = 0.000462	No
FUDE	W = 0.83978, p-value = 5.131e-05	No	W = 0.83992, p-value = 5.168e-05	No
WODE	W = 0.97062, p-value = 0.3764	Yes	W = 0.98632, p-value = 0.9021	Yes
POPDEN	W = 0.56457, p-value = 1.06e-09	No	W = 0.86803, p-value = 0.0002544	No
DIST	W = 0.95907, p-value = 0.1556	Yes	W = 0.95907, p-value = 0.1556	Yes
ROADDEN	W = 0.88742, p-value =0.0008396	No	W = 0.88742, p-value =0.0008396	No
REDBOOK	W = 0.9462, p-value = 0.05616	Yes	W = 0.9462, p-value = 0.05616	Yes
FCOVER	W = 0.91734, p-value = 0.006358	No	W = 0.94946, p-value = 0.07267	Yes

Table S3.5. Wilcoxon signed rank test for restored forest, forest loss, forest gain variables between 1990 and 2010.

Variable 1	Variable 2	Period 1	Period 2	Period 3	P Value	Statistically difference
RESTO	NI	1990-2000	2000-2010	NI	V = 210, p-value = 0.006372	Yes
RESTO1	NI	1990-2000	2000-2010	NI	V = 184, p-value = 0.001863	Yes
RESTO2	NI	1990-2000	2000-2010	NI	V = 484, p-value = 0.3269	No
FGAIN	NI	1990-2000	2000-2010	NI	V = 251.5, p-value = 0.03369	Yes
FGAIN1	NI	1990-2000	2000-2010	NI	V = 231, p-value = 0.01527	Yes
FGAIN2	NI	1990-2000	2000-2010	NI	V = 540, p-value = 0.08171	No
RESTO	DF	1990-2000		NI	V = 646, p-value = 0.0003632	Yes
RESTO1	DF1	1990-2000		NI	V = 652, p-value = 0.000263	Yes
RESTO2	DF2	1990-2000		NI	V = 656, p-value = 0.0002113	Yes
RESTO	DF	NI	2000-2010	NI	V = 704, p-value = 2.843e-05	Yes
RESTO1	DF1	NI	2000-2010	NI	V = 710, p-value = 1.806e-05	Yes
RESTO2	DF2	NI	2000-2010	NI	V = 675, p-value = 0.0003776	Yes
RESTO	DF	NI	NI	1990-2010	V = 761, p-value = 1.634e-07	Yes
RESTO1	DF1	NI	NI	1990-2010	V = 780, p-value = 6.813e-07	Yes
RESTO	FGAIN	1990-2000	NI	NI	V = 0, p-value = 1.188e-07	Yes
RESTO1	FGAIN1	1990-2000	NI	NI	V = 0, p-value = 1.188e-07	Yes
RESTO2	FGAIN2	1990-2000	NI	NI	V = 0, p-value = 1.188e-07	Yes
RESTO	FGAIN	NI	2000-2010	NI	V = 0, p-value = 1.749e-07	Yes
RESTO1	FGAIN1	NI	2000-2010	NI	V = 0, p-value = 2.584e-07	Yes
RESTO2	FGAIN2	NI	2000-2010	NI	V = 0, p-value = 1.749e-07	Yes
RESTO	FGAIN	NI	NI	1990-2010	V = 0, p-value = 5.461e-08	Yes
RESTO1	FGAIN1	NI	NI	1990-2010	V = 0, p-value = 8.051e-08	Yes

Note: RESTO denotes area (ha) of restored forest, RESTO1: percent of restored forest area relative to total area, RESTO2: per capita of restored forest area (m^2 $person^{-1}$), FGAIN: area (ha) of forest gain, FGAIN1: percent of forest gain area relative to total area, FGAIN2: per capita of forest gain (m^2 $person^{-1}$), DF: area (ha) of deforestation, DF1: percent of deforested area relative to total area, DF2: per capita of deforestation area (m^2 $person^{-1}$).



(A) Restored forest relative to total area

(B) Plantation forest relative to total area

(C) Restored forest relative to forest gain

(D) Restored forest relative to deforestation

Figure S3.1. Map of restored forest and plantation forest relative to total forest area, forest gain, and deforestation in 40 communes of Dien Bien province, Vietnam.

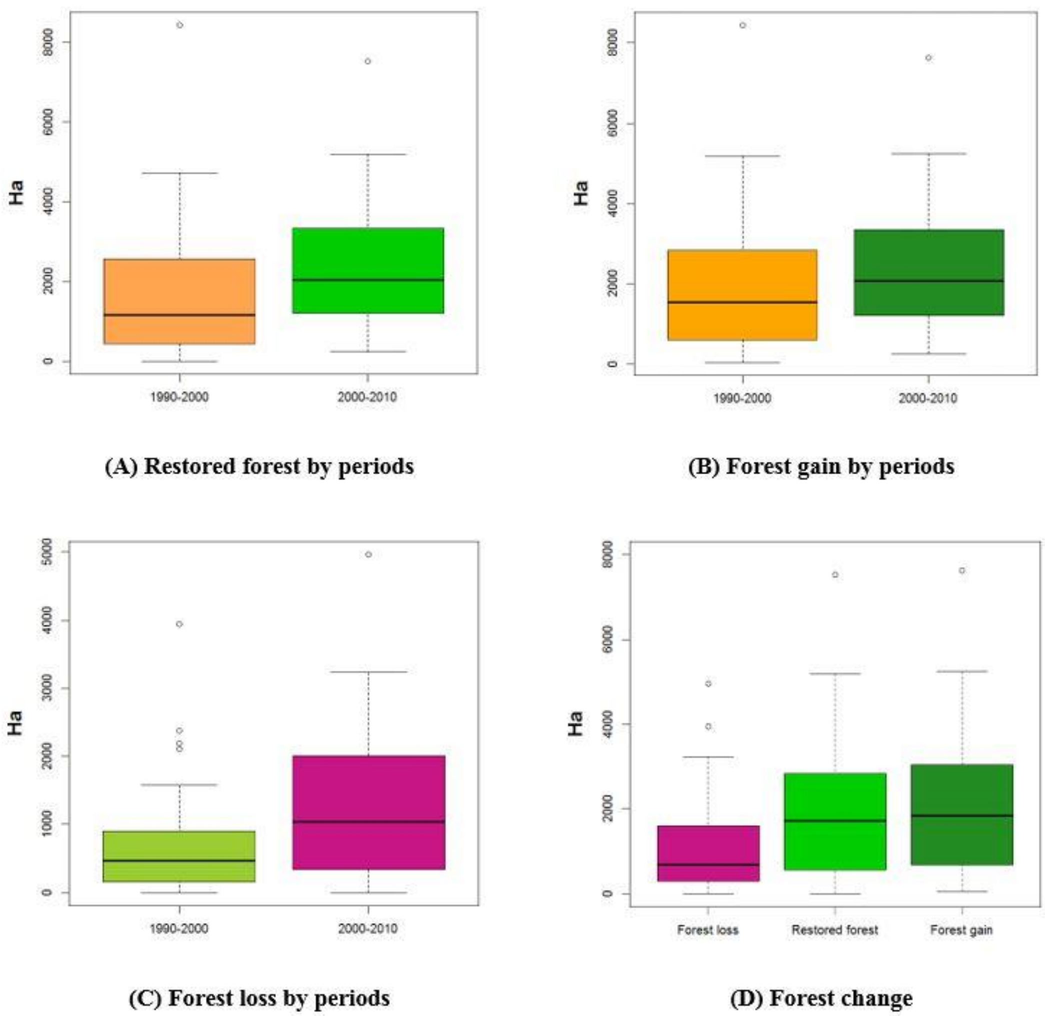


Figure S3.2. Boxplot of restored forest, forest gain, and forest change by time in Dien Bien province, Vietnam between 1990 and 2010.

Chapter 5

Table S5.1. Household Information of Shifting cultivation

#	Name	Communes	Area (ha)	Revenue (1,000VND)	Cost (1,000VND)
1	Quang Văn Tuyến	Yen Na	1.025	16,320	2,910
2	Kha Văn Nguyên	Yen Na	1.0	1,600	3,745
3	Lô Thanh Tần	Yen Na	3.0	600	390
4	Lương Văn Bon	Yen Na	1.0	1,600	1,000
5	Lô Văn Chành	Yen Na	1.5	4,340	4,260
6	Lô Văn Uyên	Yen Na	1.6	2,940	525
7	Lương Văn Thắng	Yen Na	1.85	3,238	350
8	Lương Thanh Hoàng	Yen Na	1.4	1,830	300
9	Vi Văn Tiến	Yen Na	1.2	6,535	300
10	Lử Xuân Lâm	Yen Na	1.2	4,100	300
11	Pịt Hồng Liên	Yen Na	0.1	300	550
12	Lư Văn Hoàng	Yen Na	0.4	0	0
13	Xeo Việt Quý	Yen Na	1.8	6,300	990
14	Lô Hoài Quý	Yen Na	3.1	10,200	520
15	Lữ Văn Muy	Yen Na	0.0	0	0
16	Lương khăm Phăn	Yen Na	2.4	5,210	700
17	Lô Văn Thành	Yen Na	0.1	2,400	200
18	Lô Văn thái	Yen Na	0.3	200	100
19	Lô Văn Thưởng	Yen Na	0.0	0	0
20	Lô Văn Chung	Yen Na	0.0	0	0
21	Ốc Văn Hưng	Luong Minh	0.5	3,300	4,600
22	Lữ Văn Việt	Luong Minh	0.9	5,300	0
23	Lô Văn Hoa	Luong Minh	1.5	6,000	1,650
24	Vy Văn Cầu	Luong Minh	0.8	4,030	1,200
25	Ốc thị Kéo	Luong Minh	0.4	2,100	530
26	Mong văn Đình	Luong Minh	2.0	8,100	0
27	Mong Văn Nguyên	Luong Minh	1.3	6,860	0
28	Cụt Thị Hợi	Luong Minh	0.5	2,400	2,500
29	Mong Văn Hợi	Luong Minh	1.1	5,600	2,910
30	Cụt thị My	Luong Minh	0.8	6,120	3,745
31	Lữ Hoài Thanh	Luong Minh	1.3	2,550	390
32	Lữ Thị Lan	Luong Minh	0.3	1,000	1,000
33	Mong thị nhiệm	Luong Minh	0.5	2,175	4,260
34	Mong Thị Phương	Luong Minh	1.1	2,580	0
35	Mong Văn Kỷ	Luong Minh	1.1	1,320	0

Note: 1 VND equals 0.0000513 USD (at the time in December 2010); Source: Tran Quang Bao

Table S5.2. Result of biomass analysis

#	Name of sample	fresh sample weight (g)	Dried sample weight (g)	Ratio of dried sample compared with fresh sample (%)
1	*Acronychia pedunculata*	200	112.33	56.17
2	*Solanum torvum*	500	252.55	50.51
3	Ca ton [Thai]	210	127.30	60.62
4	*Mallotus paniculatus* (branch)	500	276.83	55.37
5	*Mallotus barbatus* (branch)	160	74.08	46.30
6	*Broussonetia papyrifera* (branch)	500	181.13	36.23
7	*Blumea balsamifera* (branch)	500	166.58	33.32
8	*Trema orientalis* (branch)	250	149.83	59.93
9	Dead wood (branch)	500	456.27	78.04
10	*Clerodendrum cyrtophyllum (branch & leaf)*	250	105.47	42.19
11	*Lagerstroemia calyculata* (branch)	500	253.82	50.76
12	*Cratoxylum cochinchinense* (branch)	500	255.30	51.06
13	Shrub 1	160	102.03	63.77
14	Shrub 2	240	95.07	39.61
15	Shrub 3	200	94.38	47.19
16	*Bridelia balansae*	130	53.09	40.84
17	Cây Đắng (Thái)	130	53.09	40.84
18	*Cyperus diffusus* Vahl	500	216.97	43.39
19	*Centosteca latifolia*	250	115.27	49.30
20	*Eupatorium odoratum*	500	254.55	50.91
21	*Engelhardtia roxburghiana*	350	179.78	51.37
22	*Thysanolaena maxima*	140	42.62	31.95
23	convolve	200	124.36	35.56
24	*Cyclosorus parasiticus*	400	135.95	39.15
25	*Clerodendrum cyrtophyllum*	300	151.34	50.45
26	*Bridelia monoica*	130	68.60	52.77
27	*Bridelia balansae*	150	85.47	56.98
28	*Alchornea rugosa*	550	212.93	38.71
29	*Randia spinosa*	160	111.02	69.39
30	*Trema orientalis*	300	145.50	48.50
31	*Xanthium strumarium*	320	148.57	46.43
32	*Cinnadenia paniculata*	310	160.86	51.89
33	*Mallotus paniculatus* (Leaf)	500	221.33	44.27
34	Mallotus barbatus (Leaf)	250	103.25	41.30
35	Acronychia pedunculata (Leaf)	200	116.12	58.06
36	Acronychia pedunculata (Leaf)	200	116.12	58.06
37	Broussonetia papyrifera (Leaf)	500	127.49	25.50

38	Broussonetia papyrifera (Leaf)	500	127.49	25.50
39	Blumea balsamifera (Leaf)	500	102.16	20.43
40	Trema orientalis (Leaf)	500	208.79	41.76
41	Litsea monopetala (Leaf)	350	116.10	33.17
42	Diospyros eriantha (Leaf)	150	107.75	71.83
43	Lagerstroemia calyculata (Leaf)	500	206.37	41.27
44	sp5 (Leaf)	370	112.67	30.45
45	Cratoxylum cochinchinense (Leaf)	450	158.31	35.18
46	Wrightia pubescens (Leaf)	50	19.10	38.20
47	Vang trang [Thai] (Leaf)	350	129.70	37.06
48	*Psychotria rubra*	470	195.52	56.47
49	*Clausena indica*	250	140.83	56.33
50	Mat nai [Thai]	130	81.48	36.32
51	*Microcos paniculata*	550	281.89	51.25
52	*Melastoma sanguineum*	200	77.03	38.52
53	*Schizostachyum aciculare*	130	76.23	58.64
54	Ngoi pa [Thai]	110	41.56	37.78
55	*Diospyros eriantha*	450	247.19	54.93
56	*Streblus ilicifolius*	150	113.03	75.35
57	Pan pa [Thai]	190	45.54	23.97
58	Root	850	408.84	46.44
59	*Amomum villosum*	500	165.89	33.18
60	sp1	50	23.65	47.30
61	sp4	210	55.65	36.51
62	*Ficus racemosa*	370	60.59	15.47
63	Litter and dead wood	200	158.15	80.45
64	*Cratoxylum cochinchinense*	270	150.12	55.60
65	*Mallotus paniculatus*	1,150	643.00	55.91
66	*Mallotus barbatus*	500	285.52	57.10
67	*Litsea monopetala*	300	148.62	49.54
68	Vang trang [Thai]	650	211.19	32.49
69	Shrub 1	350	128.50	36.71
70	*Broussonetia papyrifera*	550	310.52	56.46
71	*Blumea balsamifera*	500	221.65	44.33
72	*Clerodendrum cyrtophyllum*	500	286.45	57.29
73	*Lagerstroemia calyculata*	550	321.37	58.43
74	sp4	500	269.99	54.00
75	sp5	800	231.83	28.98
76	*Cratoxylum cochinchinense*	270	150.12	58.05
77	*Wrightia pubescens*	200	75.96	37.98
78	*Aporosa dioica*	420	177.12	42.17

Table S5.3. Carbon in the grass layer

Plot #	Stop cropping year	Name of species	Weight of species in the Sub-Plot (kg)					Average (kg)	Ton fresh ha^{-1}	% dry/fresh	Ton dry ha^{-1}	Ton carbon ha^{-1} (species)	Ton carbon ha^{-1} (Plot)
			1	2	3	4	5						
1	2009	Convolve	3.90	2.10	0.45	0.00	0.25	1.34	3.350	35.56	1.191	0.596	5.082
2	2008	Convolve	0.25	0.10	0.40	0.20	0.25	0.24	0.600	35.56	0.213	0.107	5.666
3	2008	Grass	1.70	1.25	1.20	0.25	1.25	1.13	2.825	49.30	1.393	0.696	3.955
4	2009	Co lao	2.10	2.60	1.75	0.65	1.05	1.63	4.075	50.91	2.075	1.037	1.742
5	2008	Co lao	7.20	5.00	8.80	7.80	5.30	6.82	17.050	50.91	8.680	4.340	4.389
6	2008	Convolve	0.13	0.20	0.00	0.00	0.00	0.066	0.165	35.56	0.059	0.029	6.677
7	2008	Convolve	0.20	0.00	0.00	0.00	0.00	0.04	0.100	35.56	0.036	0.018	0.036
8	2006	Co lao	5.95	5.75	5.80	5.60	9.40	6.50	16.250	50.91	8.273	4.136	4.262
9	2004	Co lao	5.60	8,25	9.20	7.90	6.20	7.43	18.575	50.91	9.457	4.728	5.369
10	2008	Chit	4.50	1.70	0.00	0.00	2.80	1.80	4.500	31.95	1.438	0.719	5.527
11	2004	Co lao	0.35	0.65	0.00	0.70	0.45	0.43	1.075	50.91	0.547	0.274	0.274
12	2002	Co lao	1.90	5.40	2.40	0.10	0.00	1.96	4.900	50.91	2.495	1.247	1.581
13	2000	Co lao	0.60	6.10	2.50	3.50	4.60	3.46	8.650	50.91	4.404	2.202	2.983
14	2000	Co lao	0.30	0.00	0.00	0.00	0.60	0.18	0.450	50.91	0.229	0.115	0.816
15	2009	Convolve	1.45	0.00	1.50	0.55	0.20	0.74	1.850	35.56	0.658	0.329	1.402
16	2008	Grass	0.00	2.10	0.00	0.55	1.20	0.77	1.925	49.30	0.949	0.475	0.710
17	2009	Co lao	1.45	1.30	1.65	1.25	0.95	1.32	3.300	50.91	1.680	0.840	2.058
18	2006	Co lao	3.55	4.50	3.85	8.60	9.30	5.96	14.900	50.91	7.586	3.793	3.868

Source: Tran Quang Bao

Table. S5.4. Carbon in the shrub layer

Plot #	Stop cropping year	Name of species	Weight of species in the Sub-Plot (kg)					Average (kg)	Ton fresh ha^{-1}	% dry/fresh	Ton dry ha^{-1}	Ton carbon ha^{-1} (species)	Ton carbon ha^{-1} (Plot)
			1	2	3	4	5						
1	2009	sp	0.00	0.00	4.20	0.00	0.00	0.84	2.100	47.30	0.993	0.497	0.497
2	2008	sp	0.00	2.70	0.00	0.00	0.00	0.54	1.350	47.30	0.639	0.319	0.319
3	2008	Ké ngựa	0.65	0.00	0.00	0.00	0.00	0.13	0.325	46.43	0.151	0.075	1.707
4	2009	Sung rừng	0.95	0.00	0.00	0.15	0.25	0.27	0.675	15.47	0.104	0.052	0.192
5	2008	Mắt nai	0.50	0.00	0.00	0.00	0.00	0.10	0.250	36.32	0.091	0.045	0.102
6	2008	Đom Đóm	0.00	0.55	0.00	0.00	0.00	0.11	0.275	38.71	0.106	0.053	0.739
7	2008	Pàu pả (*Thai*)	0.19	0.00	0.00	0.00	0.00	0.038	0.095	23.97	0.023	0.011	3.624
8	2006	Sp	0.16	0.00	0.00	0.00	0.00	0.032	0.080	47.30	0.038	0.019	0.033
9	2004	Sp	-	-	-	-	-	-	-	-	-	-	-
10	2008	Mé cò ke	0.00	0.00	0.55	0.42	0.00	0.194	0.485	51.25	0.249	0.124	0.124
11	2004	Găng Gai	0.40	0.90	1.70	0.60	0.70	0.86	2.150	69.39	1.492	0.746	1.269
12	2002	Bùm bụp	0.25	0.00	0.00	0.00	0.00	0.05	0.125	41.30	0.052	0.026	0.517
13	2000	Thừng Mực	0.25	0.00	0.00	0.00	0.00	0.05	0.125	37.98	0.047	0.024	0.159
14	2000	Đắng cảy	1.30	0.00	0.00	0.00	0.00	0.26	0.650	57.29	0.372	0.186	2.383
15	2009	Kháo	0.00	1.30	0.00	0.00	0.00	0.26	0.650	51.89	0.337	0.169	0.745
16	2008	Hu Đay	0.50	0.00	0.00	0.00	0.00	0.10	0.250	48.50	0.121	0.061	0.688
17	2009	Găng	1.20	0.00	1.05	0.65	0.70	0.72	1.800	69.39	1.249	0.624	0.624
18	2006	Cà tồn (*Thai*)	0.30	0.00	0.00	0.00	0.00	0.06	0.150	60.62	0.091	0.045	0.045

Source: Tran Quang Bao

Table S5.5. Carbon in the root

Plot #	Stop cropping year	Name of species	Weight of root in the Sub Sample Plot (kg)					Average (kg)	Ton fresh ha^{-1}	% dry/fresh	Ton dry ha^{-1}	Ton carbon ha^{-1} (species)
			1	2	3	4	5					
1	2009	Root	1.40	0.70	0.50	0.60	0.90	0.82	8.20	46.44	3.808	1.904
2	2008	Root	0.55	1.35	0.65	0.70	0.90	0.83	8.30	46.44	3.855	1.927
3	2008	Root	0.65	0.25	0.95	0.65	0.60	0.62	6.20	46.44	2.879	1.440
4	2009	Root	0.60	0.45	0.35	0.65	0.45	0.50	5.00	46.44	2.322	1.161
5	2008	Root	0.35	0.70	0.80	0.65	0.45	0.59	5.90	46.44	2.740	1.370
6	2008	Root	0.32	0.27	1.30	2.50	0.50	0.978	9.78	46.44	4.542	2.271
7	2008	Root	0.45	0.90	1.10	0.50	1.50	0.89	8.90	46.44	4.133	2.067
8	2006	Root	1.10	0.50	0.42	0.50	1.00	0.704	7.04	46.44	3.270	1.635
9	2004	Root	0.35	0.65	0.45	0.67	0.50	0.524	5.24	46.44	2.434	1.217
10	2008	Tulb of amomum	4.00	3.00	1.50	0.00	1.80	2.06	20.60	46.44	9.366	4.683
11	2004	Root	1.05	0.45	0.45	0.40	0.40	0.55	5.50	46.44	2.554	1.277
12	2002	Root	0.85	1.82	1.60	0.65	0.80	1.144	11.44	46.44	5.313	2.657
13	2000	Root	0.35	1.05	0.50	0.35	0.55	0.56	5.60	46.44	2.601	1.300
14	2000	Root	0.40	1.00	1.15	0.55	0.85	0.79	7.90	46.44	3.669	1.834
15	2009	Root	0.90	0.50	1.60	1.25	0.90	1.03	10.30	46.44	4.784	2.392
16	2008	Root	0.30	0.20	1.70	0.60	0.55	0.67	6.70	46.44	3.112	1.556
17	2009	Root	0.65	0.70	1.05	0.95	0.80	0.83	8.30	46.44	3.855	1.927
18	2006	Root	0.80	0.30	0.50	0.35	0.40	0.47	4.70	46.44	2.183	1.091

Source: Tran Quang Bao

Table S5.6. Carbon in the litter

Plot #	Stop cropping year	Name of species	Weight of litter in the Sub Sample Plot (kg)					Average (kg)	Ton fresh ha^{-1}	% dry/fresh	Ton dry ha^{-1}	Ton carbon ha^{-1} (species)
			1	2	3	4	5					
1	2009	Litter	4.30	4.30	2.70	0.90	1.05	2.65	6.625	80.45	5.330	2.665
2	2008	Litter	0.35	0.40	0.65	0.25	0.45	0.42	1.050	80.45	0.845	0.422
3	2008	Litter	0.45	0.45	0.35	0.65	0.20	0.42	1.050	80.45	0.845	0.422
4	2009	Litter	0.50	0.95	1.25	1.35	1.20	1.05	2.625	80.45	2.112	1.056
5	2008	Litter	0.50	0.31	1.20	0.70	1.10	0.762	1.905	80.45	1.533	0.766
6	2008	Litter	1.10	1.00	0.70	2.50	2.00	1.46	3.650	80.45	2.936	1.468
7	2008	Litter	1.90	1.55	2.90	1.10	1.50	1.79	4.475	80.45	3.600	1.800
8	2006	Litter	1.90	0.90	0.65	1.50	1.10	1.21	3.025	80.45	2.434	1.217
9	2004	Litter	2.10	3.40	3.25	2.70	2.95	2.88	7.200	80.45	5.792	2.896
10	2008	Litter	3.80	3.70	1.45	1.70	1.50	2.43	6.075	80.45	4.887	2.444
11	2004	Litter	2.50	2.40	2.90	1.80	2.60	2.44	6.100	80.45	4.907	2.454
12	2002	Litter	1.25	-	-	-	1.00	1.125	2.813	78.04	2.195	1.097
13	2000	Litter	2.50	1.50	0.00	0.00	0.00	0.80	2.000	80.45	1.609	0.804
14	2000	Litter	0.75	0.00	0.00	0.55	2.10	0.68	1.700	78.04	1.327	0.663
15	2009	Litter	1.30	0.50	0.80	0.60	0.65	0.77	1.925	80.45	1.549	0.774
16	2008	Litter	2.40	1.90	0.70	1.30	2.60	1.78	4.450	78.04	3.473	1.736
17	2009	Litter	2.15	2.35	1.95	2.40	2.20	2.21	5.525	80.45	4.445	2.222
18	2006	Litter	0.50	0.25	0.30	0.40	0.50	0.39	0.975	78.04	0.761	0.380

Source: Tran Quang Bao

Table S5.7. Soil Carbon

Fallow Years	Stop cropping year	Weight capacity 0-10 cm	10-20 cm	20-30 cm	BD (g cm^{-3})	OM% 0-10 cm	10-20 cm	20-30 cm	Average OM (%)	D (cm)	SOC (g cm^{-2})	SOC (ton ha^{-1})
1	2009	1.1	1.2	1.3	1.2	2.87	1.61	1.21	1.9	30	396,720	39.67
2	2008	1.3	1.4	1.4	1.37	1.95	1.32	0.98	1.42	30	338,500	33.85
3	2008	1.2	1.3	1.4	1.3	2.13	1.15	1.1	1.46	30	330,252	33.03
4	2009	1.2	1.3	1.3	1.27	2.18	1.55	1.32	1.68	30	371,246	37.12
5	2008	1.2	1.3	1.3	1.27	1.49	1.26	0.92	1.22	30	269,596	26.96
6	2008	1.2	1.3	1.2	1.23	1.84	1.21	1.03	1.36	30	291,067	29.11
7	2008	1.1	1.2	1.2	1.17	2.18	1.09	0.23	1.17	30	238,189	23.82
8	2006	1.2	1.3	1.3	1.27	2.13	1.15	0.69	1.32	30	291,694	29.17
9	2004	0.9	1.1	-	1	2.13	-	-	2.13	30	370,620	37.06
10	2008	1	1.1	1.1	1.07	3.33	1.61	1.61	2.18	30	405,872	40.59
11	2004	1.2	1.3	1.2	1.23	1.78	1.03	0.98	1.26	30	269,665	26.97
12	2002	1.1	1.2	1.3	1.2	2.36	0.86	0.86	1.36	30	283,968	28.4
13	2000	1.2	-	-	1.2	1.72	-	-	1.72	30	359,136	35.91
14	2000	1.1	1.2	1.3	1.2	2.41	1.61	1.61	1.88	30	392,544	39.25
15	2009	1.1	1.2	1.2	1.17	2.53	1.72	1.38	1.88	30	382,730	38.27
16	2008	1.1	1.1	1.2	1.13	1.32	1.32	0.8	1.15	30	226,113	22.61
17	2009	1.1	1.3	1.2	1.2	2.36	1.61	1.32	1.76	30	367,488	36.75
18	2006	1.3	1.3	1.4	1.33	1.72	1.38	0.98	1.36	30	314,731	31.47

Source: Tran Quang Bao

Table S5.8. Carbon stock in the carbon pools for shifting cultivation

Fallow years	Plot #	Stop cropping year	Trees (t CO2)	Grass (t CO2)	Shrub (t CO2)	Roots (t CO2)	Dried Litters (t CO2)	Soil Carbon (t CO2)	Total (t CO2)
1	1	2009	0	18.63	1.82	6.98	9.77	145.46	182.66
1	4	2009	0	6.39	0.70	4.26	3.87	136.11	151.33
1	15	2009	0	5.14	2.73	8.77	2.84	140.32	159.8
1	17	2009	0	7.55	2.29	7.07	8.15	134.75	159.81
2	2	2008	0	20.78	1.17	7.07	1.55	124.12	154.69
2	3	2008	0	14.50	6.26	5.28	1.55	121.11	148.7
2	5	2008	0	16.09	0.37	5.02	2.81	98.85	123.14
2	6	2008	0	24.48	2.71	8.33	5.38	106.74	147.64
2	7	2008	0	0.13	13.29	7.58	6.60	87.34	114.94
2	10	2008	0	20.27	0.45	17.17	8.96	148.83	195.68
2	16	2008	0	2.60	2.52	5.71	6.37	82.90	100.1
4	8	2006	39.46	15.63	0.12	6.00	4.46	106.96	172.63
4	18	2006	0	14.18	0.17	4.00	1.39	115.39	135.13
6	9	2004	48.89	19.69	-	4.46	10.62	135.89	219.55
6	11	2004	10.05	1.00	4.65	4.68	9.00	98.89	128.27
8	12	2002	0.06	5.80	1.90	9.74	4.02	104.13	125.65
10	13	2000	21.68	10.94	0.58	4.77	2.95	131.67	172.59
10	14	2000	64.43	2.99	8.74	6.72	2.43	143.92	229.23

Table S5.9. Net carbon sequestration for shifting cultivation and plantation forests

Fallow (year)	Long-fallow swiddening (tCO_2)	Short-fallow swiddening (tCO_2)	*Acacia auriculiformis* (tCO_2)	*Acacia mangium* (tCO_2)
1	0	0	0	0
2	8.565	8.565	3.52	7.08
3	16.932	16.932	6.94	13.94
4	25.101	25.101	10.41	36.21
5	33.072	0	24.81	64
6	40.845	8.565	44.26	94.39
7	48.42	16.932	66.81	125.79
8	55.797	25.101	90.2	157.28
9	62.976	33.072	101.89	95.15
10	69.957	0	136.66	110.49
11	76.74	8.565	159.95	125.39
12	83.325	16.932	185.54	139.83
13	89.712	25.101	170.18	153.78
14	95.901	33.072	187.46	167.27
15	101.892	0	205.8	180.28

Source: Tran Quang Bao

Table S5.10. tCERs Calculation

		1			2			3		
Items		Stem volume at time t under the project scenario			Above ground biomass at item i under the project scenario			Carbon stock in above ground at time t under the project scenario		
Symbol		SV(t)i			T(t)i			NA(t)i		
Formula		-			SV(t)i x BEF x WD			T(t)i x 0.5		
Unit		$m^3\ ha^{-1}$			t.d.m ha^{-1}			t C ha^{-1}		
Year	Age	mangi	mangi	auri	mangi	mangi	auri	mangi	mangi	auri
1	0	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	1	4.20	0.00	2.00	2.94	0.00	1.44	1.47	0.00	0.72
3	2	8.37	4.20	4.00	5.86	2.94	2.88	2.93	1.47	1.44
4	3	22.10	8.37	6.04	15.47	5.86	4.35	7.74	2.93	2.18
5	4	39.42	22.10	14.61	27.59	15.47	10.53	13.80	7.74	5.27
6	5	58.49	39.42	26.31	40.94	27.59	18.97	20.47	13.80	9.48
7	6	78.29	58.49	39.98	54.80	40.94	28.83	27.40	20.47	14.41
8	7	98.22	78.29	54.23	68.75	54.80	39.10	34.38	27.40	19.55
9	8	58.97	98.22	61.37	41.28	68.75	44.25	20.64	34.38	22.12
10	9	68.63	58.97	82.68	48.04	41.28	59.61	24.02	20.64	29.81
11	10	78.04	68.63	97.00	54.63	48.04	69.94	27.31	24.02	34.97
12	11	87.17	78.04	112.77	61.02	54.63	81.31	30.51	27.31	40.65
13	12	96.00	87.17	103.30	67.20	61.02	74.48	33.60	30.51	37.24
14	13	104.55	96.00	113.95	73.19	67.20	82.16	36.59	33.60	41.08
15	14	112.81	104.55	125.27	78.97	73.19	90.32	39.48	36.59	45.16

Source: Tran Quang Bao, Nguyen Van Thi

Table S5.10. tCERs Calculation (con.t)

4			**5**			**6**	**7**	**8**	**9**
Carbon stock in below ground at time t under the project scenario			Total carbon stock in each strata at time t under the project scenario			Total carbon stock at time t under the project scenario	Actual net CO2 removals per year	Project emissions	Actual net CO2 removals by C sinks at time t
NB(t)i			N(t)i			N(t)	ΔCproj.t	GHGproj.t	ΔCactual.t
Exp(-1.085+0.9256 x lnT(t)i) x 0.5			[NA(t)i+NB(t)i] x Ai			N(t)i	N(t)-N(t-1)		ΔCproj.t-GHGproj.t
t C ha^{-1}			t C			t C	t CO2-e $year^{-1}$	t CO2-e $year^{-1}$	t CO2-e $year^{-1}$
mangi	mangi	auri	mangi	mangi	auri				
0.00	0.00	0.00	-	-	-	-	-	-	-
0.46	0.00	0.24	46	-	30	76	279	-	279
0.87	0.46	0.45	91	39	59	188	412	-	412
2.13	0.87	0.66	237	76	88	401	779	-	779
3.64	2.13	1.49	419	197	210	825	1,557	-	1,557
5.25	3.64	2.57	617	349	374	1,340	1,886	-	1,886
6.87	5.25	3.79	823	514	564	1,901	2,059	-	2,059
8.48	6.87	5.03	1,029	686	762	2,476	2,107	-	2,107
5.29	8.48	5.64	622	857	861	2,340	(499)	-	-
6.09	5.29	7.43	723	519	1,154	2,395	203	-	-
6.85	6.09	8.61	820	602	1,351	2,773	1,385	-	1,385
7.59	6.85	9.90	914	683	1,567	3,165	1,437	-	1,437
8.30	7.59	9.13	1,006	762	1,437	3,205	147	-	147
8.98	8.30	10.00	1,094	838	1,583	3,515	1,137	-	1,137
9.64	8.98	10.92	1,179	912	1,738	3,829	1,150	-	1,150

Source: Tran Quang Bao, Nguyen Van Thi

Table S5.10. tCERs Calculation (con.t)

10	11	12	13	14
Leakge of project activites at time t	Biomass carbon store at time t in case of no project activity	Net anthropogenic CO2 removals by sinks	Net anthropogenic CO2 removals by sinks (accumulative)	tCERs (temporary certificated emission reductions)
Lt	B (t C)	ERarcdm.t	ERarcdm.t	*(0, if tCERs < 0)*
ΔCactual.t x 0.15 (0, if Lt 0)	B (t C)	ΔCactual.t - GHGproj.t-Lt-t C)		
t CO2-e year^{-1}	t C	t CO2-e year^{-1}	t CO2-e	
-	14.53	(14.53)	(14.53)	
42	14.53	222	208	
62	14.53	336	543	
117	14.53	647	1,191	
234	14.53	1,309	2,500	
283	14.53	1,589	4,089	
309	14.53	1,735	5,824	
316	14.53	1,776	7,601	
-	14.53	(14.53)	7,586	
-	14.53	(14.53)	7,572	
208	14.53	1,163	8,734	
216	14.53	1,207	9,941	
22	14.53	110	10,052	
171	14.53	952	11,004	
172	14.53	963	11,966	11,966

Note: Biomass expansion factor from stem to total above ground biomass (BEF) for Acacia *mangium* and Acacia *auriculiformis* is 1.4; Wood density (WD) for Acacia *mangium* and Acacia *auriculiformis* is 0.5 and 0.52, respectively; carbon fraction factor (Cfrac) for Acacia *mangium* and Acacia *auriculiformis* is 0.5. Source: Tran Quang Bao, Nguyen Van Thi.

Table S5.11. General information for trees

#	Species	Acacia *mangium*	Acacia *auriculiformis*
1	Forest type	Production forest	Production forest
2	Area (ha)	1.0	1.0
3	Rotation (year)	15.0	15.0
4	Estimated thinning volume (m^3 ha^{-1})	20.9	20.37
5	Estimated standing volume at felling (m^3 ha^{-1})	120.8	134.81
6	Timber use rate (%)	80.0	80.0
7	Fuelwood use rate (%)	20.0	20.0
8	Timber price (VND m^{-3})		
	Round wood (d>15cm): C=40cm	720,000	850,000
	C=50cm	850,000	1,100,000
	C=60cm	930,000	1,250,000
	Timber price (USD m^{-3})		
	Round wood (d>15cm): C=40cm	37.9	44.7
	C=50cm	44.7	57.9
	C=60cm	48.9	65.8
9	Chip wood price (VND m^{-3})	576,000	576,000
	Chip wood price (USD m^{-3})	30.3	30.3

Source: Tran Quang Bao

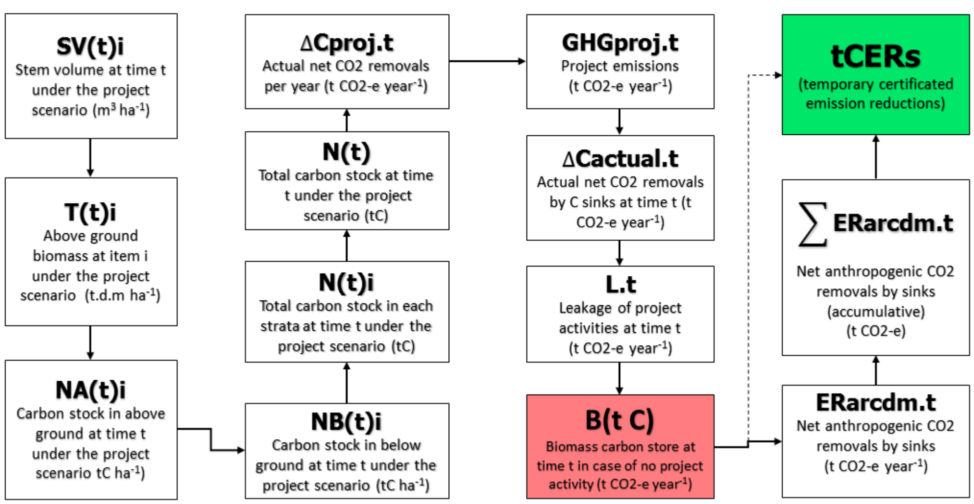


Figure 5.1. Flowchart for tCERs calculation

Figure S5.2. Presurvey in Nghe An Province (JICA & VFU). Source: Tran Quang Bao

Figure S5.3. Boundary survey (Field survey team of VFU. Source: Tran Quang Bao

Figure S5.4. Sample plot. Source: Tran Quang Bao

Figure S5.5. Collecting biomass in the sub sample plot. Source: Tran Quang Bao

Figure S5.6. Meeting with farmers for site selection. Source: Tran Quang Bao

Figure S5.7. Actual Vegetation in Tuong Duong District. Source: Tran Quang Bao

Figure S5.8. Actual Vegetation in Quy Hop District. Source: Tran Quang Bao

Figure S5.9. Actual Vegetation in Tuong Duong District. Source: Tran Quang Bao

PUBLICATIONS DURING CANDIDATURE

In English

1. Khuc, V.Q., Alhassan, M., Loomis, J.B., Paschke, M.W., 2016. Estimating Urban Households' Willingness-to-pay for Upland Forest Restoration in Vietnam. Open Journal of Forestry, 6, 191-198.

2. Khuc, V.Q., Tran, Q.B., Meyfroidt, P., Paschke, M.W., 2018. Drivers of deforestation and forest degradation in Vietnam: An exploratory analysis at the national level. Forest Policy and Economics 90, 128-141.

3. Nguyen, H.T., Cook, M., Field, J., L., Khuc, V.Q., Paustian, K. High-resolution trade-off analysis and optimization of ecosystem services and disservices in agricultural landscapes. Environmental Modelling & Software (*In revision*).

4. Khuc, V.Q., Tran, Q.B., Meyfroidt, P., Nguyen, H.T., Tran, D.T., Loomis, J.B., Pham, V.D., Leisz, S.J., Paschke, M.W. Socio-Economic Driving Forces of Forest Restoration in Upland Northwest Vietnam: An Exploratory Analysis at a Local-Communal Scale. World Development (*Submitted*).

5. Khuc, V.Q., Tran, Q.B., Nguyen, H.T., Meyfroidt, P., Le, T.T.A., Bui, T.M.N., Tinkham, Paschke, M.W. Climate change programs and household livelihood in North Central, Vietnam: Tradeoffs of land use in upland forests. Land Use Policy (*Planned submission*).

In Vietnamese

6. Khuc, V.Q., Tran, D.T., Tran, Q.B., 2016. Estimating households' willingness to pay for wildfire prevention in the buffer zone of U Minh Thuong National Park, Kien Giang. Journal of Forest Science and Technology 01, 10-18.

7. Khuc, V.Q., Tran, Q.B., 2016. Determinants of the economic growth of the forestry sector during 2001-2014. Journal of Agriculture and Rural development 12, 3-8.

8. Khuc, V.Q., Tran, Q.B., 2016. Determinants of students' satisfaction in education quality at Vietnam National University of Forestry in the period 2015-2016. Journal of Forest Science and Technology 6, 12-20.

9. Khuc, V.Q., Tran, Q.B., Hoang, L.S., 2016. Determinants of income diversification of households in the buffer zone of U Minh Ha National Park, Ca Mau. Journal of Agriculture and Rural development 01, 118-125.

10. Khuc, V.Q., Tran, Q.B., Pham, V.D., Vo, D.H., Nong, N.D., Tran, T.T.H., Ha, T.M., 2017. Applying Markov chain model for forecasting evergreen forests change in Vietnam. Journal of Agriculture and Rural development 10 118-125.

PUBLICATIONS INCLUDED IN THIS DISSERTATION

This dissertation includes four jointly authored articles. Two are published papers; two have been submitted for review. I conducted the majority of the work contained within these articles, including original idea, study design, data analysis, interpretation, synthesis, writing, revising, and completing the manuscript.

Chapter two

Khuc, V.Q., Tran, Q.B., Meyfroidt, P., Paschke, M.W., 2018. Drivers of deforestation and forest degradation in Vietnam: An exploratory analysis at the national level. Forest Policy and Economics 90, 128-141.

Chapter three

Khuc, V.Q., Tran, Q.B., Meyfroidt, P., Nguyen, H.T., Tran, D.T., Loomis, J.B., Pham, V.D., Leisz, S.J., Paschke, M.W. *(submitted)*. Socio-Economic Driving Forces of Forest Restoration in Upland Northwest Vietnam: An Exploratory Analysis at a Local-Communal Scale. World Development.

Chapter four

Khuc, V.Q., Alhassan, M., Loomis, J.B., Paschke, M.W., 2016. Estimating Urban Households' Willingness-to-pay for Upland Forest Restoration in Vietnam. Open Journal of Forestry 6, 191-198.

Chapter five

Khuc, V.Q., Tran, Q.B., Nguyen, H.T., Meyfroidt, P., Le, T.T.A., Bui, T.M.N., Tinkham, Paschke, M.W. *(Planned submission)*. Climate change programs in North Central, Vietnam: Tradeoffs of land use in upland forests. Land Use Policy.