FACTORS INFLUENCING GREENHOUSE GAS EMISSIONS FROM LAND USE, LAND-USE CHANGE, AND FOREST ACTIVITIES

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Dedicated to the unconditional love from my family

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ABSTRACT

Greenhouse gas (GHG) emissions are a major global issue because of their effects on climate and the resulting environmental and human impacts. The primary greenhouse gases (GHGs), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), are emitted into the atmosphere from a myriad of human activities such as energy supply, manufacturing, transportation, commercial and residential buildings, and waste. Additionally, management activities on agricultural and forest lands can influence GHG emissions substantially. Even though GHGs can be released into the air via the sectors mentioned, GHGs, especially CO_2, can be removed from ecosystems through certain management activities, enhancing the storage of GHGs in soils, plants, and trees. Examples of GHG emission reduction strategies include decreased land clearing for agriculture, extended rotations for forest stands, afforestation and reforestation, and conservation management strategies for agriculture and forestry. Consequently, addressing GHG emissions and sinks from land use, land-use change, and forest activities (LULUCF) are critical scientific and policy questions. This dissertation examines the issue of LULUCF and the factors affecting GHG emission levels from this sector. The study is separated into three chapters encompassing an analysis of the factors driving GHG emissions from LULUCF on a global and national scale in the first two chapters and the willingness of individuals to pay for reductions in the third chapter. The results indicate that population growth was the major cause of GHG emissions from LULUCF. Policy alternatives are provided to address the emissions and sinks from LULUCF.

Keywords: Economics; greenhouse gases; carbon emission; land use, land-use change, forestry

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INTRODUCTION

Greenhouse gas (GHG) emissions are a major global issue because of the resulting climate effects. Examples of the significant implications of climate change were precipitation, recession of glaciers and sea ice, and sea level (Ramanathan and Feng, 2009). The primary GHGs, CO_2, CH_4, and N_2O, are emitted into the atmosphere from a myriad of human activities such as energy supply, manufacturing, transportation, commercial and residential buildings, and waste. Additionally, management activities on agricultural and forest lands can influence GHG emissions substantially (Houghton et al., 1990; Turner, 1990). Even though they can be released into the air via the sectors mentioned, GHGs, especially CO_2, can be removed from ecosystems through certain management activities, enhancing the storage of GHGs in soils and plants/trees.

The United States Environmental Protection Agency (US EPA) summarized the key GHGs emitted by human activities from all sectors (EPA, 2014). The largest share of global GHG emissions can be attributed to electricity and heat production (25%), followed by agriculture, forestry and other land uses (24%), manufacturing (21%), transportation (14%), other energy (10%), and buildings (6%) (IPCC, 2014). Carbon dioxide (CO_2) is the primary global GHGs. Based on 2010 global emissions estimates, approximately 76% of global CO_2 was emitted from fossil fuel use, industrial processes, forestry, and other land uses (EPA, 2014). Agricultural activities, waste management, energy use, and biomass burning generate CH_4. Activities from the agriculture sector are also a source of N_2O. Additionally, biomass burning produces N_2O. The major sources of fluorinated gases (F-gases) are industrial processes, refrigeration, and the use of a variety of consumer products can contribute hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) (IPCC, 2014). Boden et al. (2015) found that in 2011 China emitted the most CO_2 (28%), followed by the United States (U.S.) (16%), EU-28 (10%), Russian Federation (6%), India (6%), and Japan (4%).

Although GHGs emissions can be released into the atmosphere by the sectors mentioned above, GHGs, especially CO_2, can be removed from the atmosphere by sequestering carbon in biomass, organic matter, and soils. Thus the land use, land use change, and forestry (LULUCF) sector plays the most important role in removing GHG (e. g., CO_2, CH_4, and N_2O) from the environment. The primary global GHGs from LULUCF are CO_2, CH_4, and N_2O (Watson, 2000). Following combustion of fossil fuels, conversion of forests to agricultural and other uses (often deforestation and forest degradation) is the largest contributor of CO_2 (IPCC, 2014). Clearing forests is one of the most important causes of land conversion and GHG emissions/sinks. The high rates of deforestation are associated with a change of land use, especially for cultivation to support population growth and reduce poverty (Allen and Barnes, 1985; Mather and Needle, 2000). Additionally, economic development, industrialization, and urbanization drive forest change (Mather, 1990; Walker, 1993; Mather and Needle, 1998). Hecht (1985) also mentioned that tropical deforestation could be driven by evolving economic opportunities connected to changes in society, politics, and infrastructure.

Clearing forests can accelerate the decay of dead wood and litter, as well as below-ground organic carbon, but the decomposition rate depends on local climate and soil conditions (IPCC, 2000). Additionally, carbon emissions and sequestration vary with forest type and the length of fallow (Lambin et al., 2001). Under some conditions, for example, carbon could be emitted more during continuous cultivation than shifting agriculture (Detwiler, 1986). Wetlands are another source of carbon stocks released by aerobic respiration when they are converted to agricultural or pasture lands (Minkkinen and Laine, 1998). Also shorter periods of crop rotation drain soil carbon more rapidly than longer rotations (IPCC, 2000). Carbon can be released into the atmosphere through the indirect effect of damaging or destroying up to a third of the original forest biomass from selective logging as well (IPCC, 2000).

Soil disturbance such as tillage is another carbon emission driver because tillage can cause soil to be more susceptible to breakdown, allowing its organic material to easily decompose due to aeration and increased soil temperature (Tisdall and Oades, 1982; Elliot, 1986; Beare et al., 1994). Soil erosion can be a source of carbon emissions through the removal or decomposition of soil particles and organic matter (IPCC, 2000). Conversely, soil erosion or redistribution may not release carbon because carbon can be accumulated again on the landscape instead of being emitted into the atmosphere (Lal et al., 1998; Stallard, 1998; van Noordwijk et al., 1997).

The primary sources of CH_4 from LULUCF are enteric fermentation related to domestic livestock, natural gas systems, and decomposition of wastes in landfills. The fertilizer for crops and manure decomposition are major sources of N_2O while there was no evidence of direct F-gases emissions from the LULUCF sector (EPA, 2016).

In addition to land management, weak natural resource policies, inadequate law enforcement, corruption, and illegal logging exacerbate deforestation and environmental impacts (Lambin et al., 2001). Moreover, devaluation of the national currency, changes in the market price of agricultural commodities, contract farming, human migration, urbanization, globalization, and social conflicts are socio-economic triggers to clear lands for supporting the demand of local populations (Mertens et al., 2000; Lambin et al., 2001; Lambin and Meyfroidt, 2010).

This dissertation is focused on GHGs from LULUCF and the drivers of these GHG emissions. The research addresses GHG emissions from LULUCF on a global and national scale. Specifically, emissions from all Annex I countries and from the U.S. were examined. A survey to investigate attitudes of Bangkok residents regarding their willingness to pay for GHG emission reductions was conducted also. The research objectives were to:

1.) assess the impacts of LULUCF on GHG emissions,

2.) identify factors influencing GHG flux from LULUCF globally and in the U.S.,

3.) determine Bangkok residents of willingness to donate to efforts to reduce GHG emissions from LULUCF, and

4.) review key methods to mitigate GHG emissions and increase GHG sequestration from LULUCF.

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CHAPTER I

FACTORS INFLUENCING NET GLOBAL GREENHOUSE GAS EMISSIONS FROM LULUCF

Abstract

Many researchers have evaluated the effects of economic activity and demographics on greenhouse gas (GHG) emissions, but little research has explored the factors influencing GHG emissions from land use, land-use change and forestry (LULUCF). Greenhouse gas emissions data were obtained for Annex I countries to assess the relative importance of a variety of social and economic factors on emissions from LULUCF. The results revealed that population was significantly related to GHG and carbon dioxide (CO_2) emissions. For methane (CH_4), both linear and quadratic term of population were significant. The results also demonstrated that value added in agriculture per capita, female employment in agriculture, and population was negatively related to GHG and CO_2 emissions, while male employment were positively significant for net GHG and CO_2 emissions. Population was significantly related to CH_4 emissions and the relationship between population and emissions was U-shaped, while female employment exhibited an inverted U-shape relationship with CH_4 emissions. Population was the most important driver of GHG emissions from LULUCF.

Keywords: greenhouse gas, emissions, LULUCF, fixed effects, Environmental Kuznets Curve

Introduction

Greenhouse gas (GHG) emissions have resulted in increasing global temperatures for the past several decades, causing a number of significant consequences including fluctuations in temperature and precipitation regimes, recession of glaciers and sea ice, and sea level rise (Ramanathan and Feng, 2009). Human activities are the main drivers of the emissions and climate change, due largely to a rising population driving increased demands for resources such as food, fuel, fiber, and water (Foley et al., 2005; Butchart et al., 2010; Defries et al., 2010; Foley et al., 2011; Weinzettel et al., 2013).

The major global GHG released into the atmosphere from land use, land-use change and forestry (LULUCF) are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (Watson, 2000). Following combustion of fossil fuels, the largest source of CO_2 emissions are the conversion of forests to agricultural lands and other uses, often resulting in deforestation and forest degradation (IPCC, 2014). The emissions from deforestation and forest degradation constitute about 20% of global CO_2 emissions (Van der Werf et al., 2009). In addition, CO_2, CH_4 and N_2O are emitted through biomass burning (e.g., decay of biomass and from soils), shifting cultivation, secondary vegetation/forests (a consequence of regeneration in vegetation/forests established naturally after a dramatic disturbance such as logging for timber, firewood collection, clearing land for agriculture, and hunting (Corlett, 1994; Liss et al., 2003)), logging, deforestation and forest degradation, burning intact forests, synthetic fertilizer, breakdown of nitrogen in livestock manure and urine, manufacture of charcoal, and burning of firewood and charcoal (Fearnside, 2000; EPA, 2014). Carbon dioxide is emitted primarily from clearing forests for agricultural activities and harvesting wood for human use (Houghton et al., 1999), while CH_4 and N_2O emissions occur from wetland disturbance, livestock production, biomass burning and fertilization of forests (Watson, 2000). The current study focused specifically on CO_2 and non-CO_2 (e.g., CH_4) from LULUCF and assessed if emissions and socio-economic factors followed an Environmental Kuznets Curve (EKC).

While a wealth of literature exists regarding the factors affecting GHG emissions in the energy and manufacturing sectors (e. g., Wyckoff and Roop, 1994; Cole, 1998; Hendriks et al., 1998; Nässén et al., 2007; Hamit-Haggar, 2012), little is known about the drivers of emissions resulting from LULUCF. This study evaluates the factors influencing net GHG, CO_2, and CH_4 emissions from LULUCF in Annex I countries between 1990 and 2012. The specific research objectives are to:

1.) analyze net global GHG, CO_2, and CH_4 emissions from activities related to LULUCF,

2.) identify the factors influencing global GHG, CO_2, and CH_4 fluxes from LULUCF,

3.) summarize the major causes of emissions and assess methods to mitigate GHG emissions from LULUCF.

Effects of LULUCF on net GHG emissions

The exchange of atmospheric CO_2, vegetation carbon, and soil carbon between terrestrial ecosystems and the atmosphere can be affected by LULUCF as shown in Figure 1.1 (Goodwin et al., 2015). Trees absorb GHGs through the processes of photosynthesis and respiration, but when lands are disturbed or forests are cleared by cutting or burning the LULUCF change GHG stocks, especially CO_2 (IPCC, 2000). Houghton (1991) categorized the types of land-use change which could be drivers in carbon stock changes: converting natural ecosystems to permanent croplands, shifting cultivation, or pasture; abandoning croplands or pastures; harvesting timber; and establishing tree plantations. Causes of global land-use change are mainly from deforestation, rangeland modifications, agricultural intensification, and urbanization (Allen and Barnes, 1985; Mather and Needle, 2000; Lambin et al., 2001; Vitousek et al., 2008). Therefore, socio-economic, environmental, political, and demographical characteristics and technological development affect GHG emissions over the long run (Turner et al., 1993; Lowe and Gregory, 2005). Lambin and Meyfroidt (2010) report that socio-ecological feedbacks (e.g., resource-limited growth, land scarcity) and socio-economic changes (e.g., economic modernization, market access, land ownership) are explanatory frameworks of land use transitions that affect forest transition, as shown in Table 1.1.

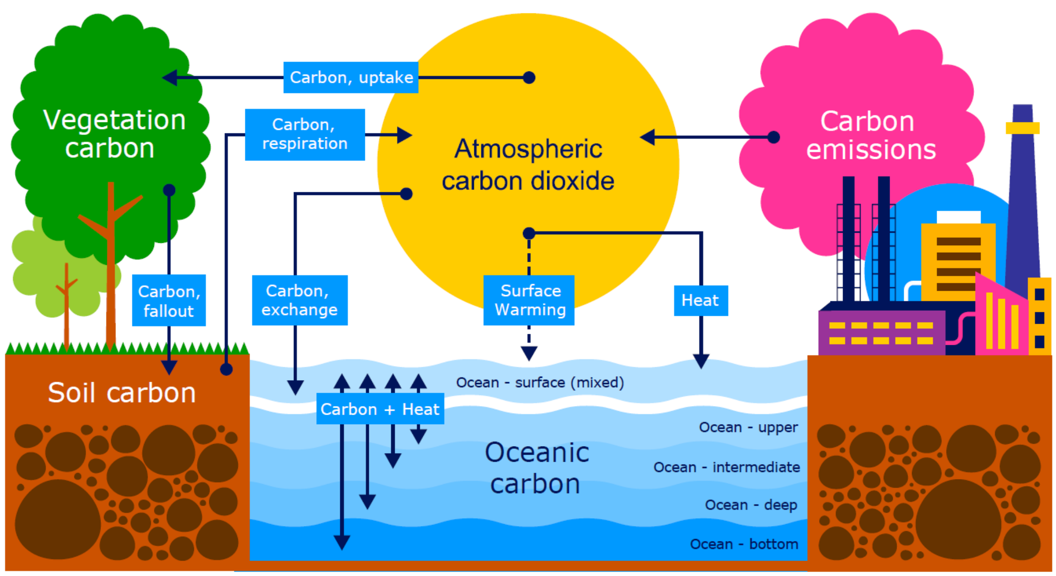

Figure 1.1. Cycle of atmospheric CO_2 (Goodwin et al., 2015).

Table 1.1. Example of main relationships between forest transition pathways and explanatory frameworks of land use transitions.

Explanatory frameworks	Forest transition pathways				
	Forest activity	State policy	Economic development	Globalization	Smallholder intensification
Socio-ecological feedbacks					
Resource-limited growth	X				
Land scarcity, intensification	X				X
Land use adjustment		X	X		X
Socio-economic changes					
Economic modernization			X	X	
Market access		X	X	X	X
Land ownership		X		X	X
Global trade				X	
Diffusion of conservation ideas		X		X	

Source: Lambin and Meyfroidt, 2010.

Population is the significant facor in land-use change (Lugo et al., 1981; Allen and Barnes, 1985; Panayotou and Sungsuwan, 1989; Rudel, 1989; Meyer and Turner, 1992; Jorgenson and Burns, 2007). When population increases, agricultural production expands to meet the demand for food, often resulting in additional forest clearing (Lambin and Meyfroidt, 2010). In addition to population growth, economic development, industrialization, and urbanization have been identified as factors of forest change (Mather, 1990; Walker 1993; Mather and Needle, 1998). Hecht (1985) also mentioned that tropical deforestation could be driven by changing economic opportunities which are connected to changes in society, politics, and infrastructure.

Forest clearing can also accelerate the decay of dead wood and litter as well as below-ground organic carbon, but the decomposition rate depends on local climate and soil conditions (IPCC, 2000). Carbon emissions and sequestrations vary by forest type and the length of fallow

(Lambin, 2001). For example, under some conditions carbon could be emitted more during continuous cultivation than shifting cultivation (Detwiler and Hall, 1986). Wetlands are another source of carbon stocks when they are converted to agricultural lands or pasture. The carbon is not emitted from wetland soils but they are released by aerobic respiration (Minkkinen and Laine, 1998). Also, shorter periods of crop rotation drain soil carbon more rapidly than long rotations (IPCC, 2000). Moreover carbon can be released through the indirect effect of damaging or destroying the original forest biomass from selective logging (IPCC, 2000).

Soil disturbance such as tillage is another carbon emission driver because tilling can cause soil to be more susceptible to breakdown and make it possible for the organic material to easily decompose because of aeration and soil temperature (Tisdall and Oades, 1982; Elliot, 1986; Beare et al., 1994; Rastogi et al., 2002). Additionally, soil or land erosion can be a source of carbon emissions through the removal or decomposition of soil particles and organic matter (IPCC, 2000). Conversely, soil erosion or redistribution does not necessarily result in carbon loss because the carbon can be accumulated again on the landscape instead of being emitted to the atmosphere (van Noordwijk et al., 1997; Lal et al., 1998; Stallard, 1998).

Temperature is an important driver in increasing soil carbon emissions. When temperature increases, it stimulates microbial decomposition of organic matter and root respiration in soils (Rastogi et al., 2002; Davidson and Janssens, 2006; Chevallier et al., 2015). Therefore, determining the effect of increasing temperatures in soil C is critical for estimating the role of land use on climate change (Rastogi et al., 2002). Precipitation also is correlated with global CO_2 efflux (Raich and Potter, 1995). Raich and Potter (1995) found that less than 2 centimeters (cm) per month of precipitation rate decreased soil CO_2 fluxes to less than 50% of their potential in non-wetland sites.

Also CH_4 and N_2O are significant GHG emissions from LULUCF. The primary sources of CH_4 are from rice cultivation and livestock (enteric fermentation), while N_2O sources include the processes of denitrification and nitrification in soils (IPCC, 2000). Therefore, all activities above can cause changes in land use which are reasons of GHG emissions and sequestration (IPCC, 2000; Foley et al., 2005).

Reduction of GHG emissions

A variety of options exists for reducing CO_2 emissions from LULUCF, such as increases in forest cover (e.g., afforestation, reforestation), reduced soil erosion and/or sediment loads, modified national policies, alterating tillage practices, crop rotation, residue management, and improved irrigation and nutrient management (Kern and Johnson, 1993; Lee et al., 1993; Cole et al., 1997; Rudel et al., 2005). Altering management practices for rice cultivation, livestock feeding, and fertilizer use could decrease CH_4 and N_2O (Kroeze et al., 1999; IPCC, 2000). The management of forests, savannas, and wetlands as nature reserves and recreation areas could affect the carbon stocks as well (IPCC, 2000).

In addition to land management, GHG emissions from LULUC is affected by weak natural resource policies, which can increase deforestation rates due to inadequate law enforcement, corruption, and illegal logging (Lambin et al., 2001). Moreover, devaluation of the national currency, changes in the market prices of agricultural commodities, contract farming, human migration, urbanization, globalization, and social conflicts can encourage land clearing (Mertens et al., 2000; Lambin et al., 2001; Lambin and Meyfroidt, 2010).

Background on the empirical Environmental Kuznets Curve (EKC)

Simon Kuznets' 'curve' has become popular for explaining the relationship between environmental quality and economic development (Shafik, 1994). Kuznets noted that the link between environmental degradation and income level can be represented as an inverted U, now known as an Environmental Kuznets curve, EKC (Kuznets, 1955; Stern, 2004). That is, various measures of environmental quality tend to decline in the initial stages of economic growth, but as average income increases beyond some threshold, levels of environmental degradation such as pollution decrease (Shafik, 1994).

After inspection of the effects on the environment, the environment-income relationship could be categorized into two phases: environmental quality decay and environmental quality improvement as depicted in Figure 1.2. Precisely, *decay* means cases in which economic growth deteriorates environmental and natural resources and includes monotonic increasing, U-shape and N-shape cases. *Improvement* infers that environmental quality is improved with economic growth (Yandle et al., 2002; Li et al., 2007).

Cramer (1998) assessed the relationship between population growth and air quality in 56 California (CA) counties from 1980 to 1990. The results revealed that the impact of population growth depends on 1.) different gases, 2.) structure of production and consumption, and 3.) interrelationships and tradeoffs among source categories. Cramer noted that levels of the precursors of ozone (e.g., reactive organic gases (ROG) oxides of nitrogen (NO_x)) and carbon monoxide (CO) are strongly influenced by population growth. Comparing levels in 1980 and 1990, population growth affected NO_x levels more, with CO being the least affected in CA. Cramer also concluded that some county emissions result from population growth elsewhere because of exports, so the link between population growth and pollutants would have to consider boundary issues.

Some studies examined the relationship between population and GHG emissions. Shi (2003) concluded that the relationship is a linear, positive one, with per capita GDP being positively related to emissions, but squared per capita GDP and services negatively related. Shi concluded that population is the most important factor driving CO_2 increases and that population growth is related to CO_2 emissions differently across countries with different level of per capita income. Cole and Neumayer (2004) examined the effects of demographic factors on two air pollutants (CO_2 and Sulfur dioxide (SO_2)). They concluded that increased population is related to increased emissions while higher rates of urbanization and smaller household size are significantly related to CO_2 emissions. They did not find a Kuznets relationship between CO_2 emissions and economic or population growth. They found a U-shaped relationship between population and SO_2 emissions at higher population levels.

Methods and Procedures

Data collection

All data were obtained from United Nations Framework Convention on Climate Change (UNFCCC) and the World Bank 1990 - 2012 (UNFCCC, 2014a, 2014b, 2014c ; The World Bank, 2016). Data collected included the amount of net global GHG fluxes from LULUCF activities for each Annex I country[1] serving as the dependent variable. Net global GHG fluxes included

[1] Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom (UK), and the United States (U.S.).

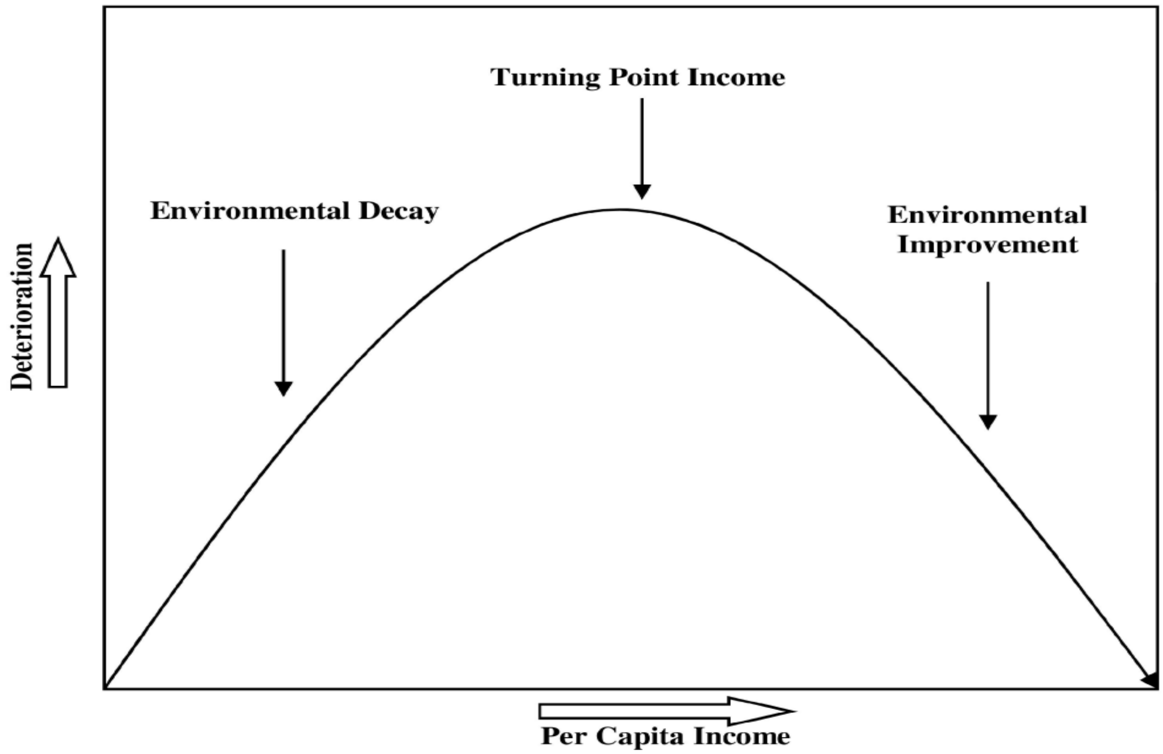

Figure 1.2. Example of inverted U-shaped of environmental degradation and economic development (Source: Yandle et al., 2002).

emissions and removals of CO_2, CH_4, and N_2O which are the primary GHG. The dependent variable derived from UNFCCC was the total net GHG and CO_2 emissions/removals of Annex I countries. Monaco was excluded due to lack of information. Independent variables consisted of agricultural value added per capita, female and male employment in agriculture, rural population, and the number of population for each country between 1990 to 2012 obtained via the World Bank's database. The definitions and hypothesized signs of independent variables are shown in Table 1.2.

Annex I countries have to report the GHG emissions from LULUCF followed to the Revised 1996 IPCC Guidelines, the 2006 IPCC Guidelines, 2003 LULUCF Good Practice Guidance, 2013 Wetlands Supplement, and 2013 IPCC Revised Supplementary Methods and Good Practive Guidance Arising from the Kyoto Protocol for Annex I parties to the Kyoto Protocol (Iverson et al., 2014).Greenhouse gas emissions from LULUCF of Annex I countires were determined and calculated by using methodologies from Volume 4: Agriculture, Forestry and Other Lanc Use in 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

Fixed and random effects

Fixed and random effects models typically are utilized for panel or cross-sectional time-series data. Models of fixed and random effects are similar but the model becomes a fixed effects model when we assume that the unobserved effect α_i is correlated to each independent variable in all time periods (Equation 1.1), while the random effects model includes an intercept (β_0) so that we can assume that α_i has a zero mean. The model becomes a random effects model when we assume that α_i is uncorrelated with each independent variable shown as Equation 1.2 (Wooldridge, 2009).

$$y_{it} = \beta_1 x_{it1} + \beta_2 x_{it2} + \cdots + \beta_k x_{itk} + \alpha_i + \varepsilon_{it},\ t = 1, 2, \ldots, T, \tag{1.1}$$

$$y_{it} = \beta_0 + \beta_1 x_{it1} + \beta_2 x_{it2} + \cdots + \beta_k x_{itk} + \alpha_i + \varepsilon_{it},\ t = 1, 2, \ldots, T. \tag{1.2}$$

One of these models was used for each pollutant evaluated (GHG, CO_2, and CH_4) as dependent variables. y is total emissions of net GHG, CO_2, or CH_4 from LULUCF (which includes emissions from forestland, cropland, grassland, wetlands, developed lands (e.g., residential and commercial building), other land, and other (e.g., harvested wood products)). Emissions data were obtained from UNFCCC for all Annex I countries i (except Monaco). The βs represent the coefficients for each independent variable (X_{it}) which represents the time-variant $1\times$ k regressor matrix, α_i (i = 1,…,n) is the unknown intercept for each entity, and ε_{it} is the error term (Torres-Reyna, 2014). The null hypothesis of F statistic for overall significance of a regression is below:

$$H_0: \beta_1 = \beta_2 = \cdots = \beta_k = 0, \tag{1.3}$$

where the null hypothesis is hypothesized that all coefficients in the model are not different from zero while the alternative hypothesis is that at least one of coefficients is different from zero (Wooldridge, 2009).

Hausman test for fixed versus random effects

The Hausman test was applied to decide between fixed or random effects. The null hypothesis is the errors ε_i are uncorrelated with the independent variables in the model. The chi-square test based on the Wald criterion is used to test the null hypothesis shown in Equation 1.4.

$$W = \chi^2[K\text{-}1] = [b\text{-}\hat{\beta}]'\hat{\psi}^{-1}[b\text{-}\hat{\beta}], \tag{1.4}$$

where χ^2 is chi-squared, K-1 is degree of freedom, b-$\hat{\beta}$ is the covariance matrix of the difference vector, and $\widehat{\psi}$ is the estimated covariance matrices of the slope estimator in the fixed effects model or and the estimated covariance matrix in the random effects, excluding the constant term (Var[b] – Var[$\hat{\beta}$]) (Greene, 2003).

Multicollinearity

If two or more independent variables are highly correlated, the standard errors can be biased and affect the estimated coefficients and inferences (Mansfield and Helms, 1982). Variance inflation factors (VIF) were applied to assess the collinearity among independent variables, and calculated by Equation (1.5) (Afifi and Clark, 1984; Fox, 1984),

$$\mathrm{VIF} = \frac{1}{1\text{-}R^2}, \tag{1.5}$$

where R^2 is the coefficient of determination of the regression of an independent variable on all the other independent variables (Nagelkerke, 1991). If the VIF value is greater than 10, multicollinearity may exist among the independent variables (Neter et al., 1985).

Heteroskedasticity

Heteroskedasticity occurs when the variance of the error is not constant (Wooldridge, 2009). Test of heteroskedasticity is considered under an assumption of

$$E(\varepsilon_{it}^2 | X_i, Z_i, \alpha_i) = \sigma_{it}^2 = \sigma_v^2 h(\gamma^T z_{it}), \tag{1.6}$$

where $h(.)$ is a strictly positive, twice differentiable function, σ_v^2 is a positive constant, and z_{it} is a vector of exogenous variables that may account for heteroscedasticity, which can be taken as a subset or all of x_{it}, and z_{it} (Juhl and Sosa-Escudero, 2014).

Also, Juhl and Sosa-Escudero (2014) showed that $\varepsilon_i \equiv (\varepsilon_{i1}, \dots, \varepsilon_{iT})'$ and

$$\begin{aligned} \sum\nolimits_i &= E(\varepsilon_i \varepsilon_i^T | X_i, Z_i, \alpha_i), \\ &= \sigma_v^2 \begin{pmatrix} h(\gamma^T z_{i1}) & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & h(\gamma^T z_{iT}) \end{pmatrix}. \end{aligned} \quad (1.7)$$

Under the null hypothesis is $H_0: \sigma_i^2 = \sigma^2$ for all i (the null hypothesis is homoscedasticity or constant variance), a modified Wald statistic is used to test for groupwise heteroskedasticity in the residuals of a fixed effect regression model. If the null hypothesis is rejected, it concludes the presence of heteroskedasticity then robust-standard error will be applied to control for heteroskedasticity (Greene, 2000; Torres-Reyna, 2014).

Serial correlation

Serial correlation is the error correlation between two different time periods ($\mathrm{Corr}(\varepsilon_t, \varepsilon_{t-1})$ or rho (ρ)) (Wooldridge, 2009). Serial correlation is considered to be a potential problem for regressions with cross-sectional data (Gujarati and Porter, 2009). If serial correlation is present, the errors are correlated across time. The null hypothesis (H_0) is that the errors are serially uncorrelated:

$$H_0: \rho = 0. \quad (1.8)$$

If H_0 is rejected at the 5% level (p-value < 0.05), there is serial correlation among the error terms (Wooldridge, 2009).

Empirical model

The following empirical fixed effects models were specified to examine factors influencing emissions from LULUCF in Annex I countries (i) at time (t) (Equation 1.1). The equation for the net emissions of GHG, CO_2, and CH_4 are presented below in Equations 1.9 – 1.11, respectively:

$$\mathrm{GHG_{it}} = \beta_1 \mathrm{AGRI_{it1}} + \beta_2 \mathrm{AGFE_{it2}} + \beta_3 \mathrm{AGMA_{it3}} + \beta_4 \mathrm{RURA_{it4}} + \beta_5 \mathrm{POPU_{it5}} + \alpha_i + \varepsilon_{it}, \quad (1.9)$$

$$\mathrm{CARBON_{it}} = \beta_1 \mathrm{AGRI_{it1}} + \beta_2 \mathrm{AGFE_{it2}} + \beta_3 \mathrm{AGMA_{it3}} + \beta_4 \mathrm{RURA_{it4}} + \beta_5 \mathrm{POPU_{it5}} + \alpha_i + \varepsilon_{it}, \quad (1.10)$$

$$\mathrm{METHANE_{it}} = \beta_1 \mathrm{AGRI_{it1}} + \beta_2 \mathrm{AGFE_{it2}} + \beta_3 \mathrm{AGMA_{it3}} + \beta_4 \mathrm{RURA_{it4}} + \beta_5 \mathrm{POPU_{it5}} + \alpha_i + \varepsilon_{it}, \quad (1.11)$$

where $\mathrm{GHG_{it}}$, $\mathrm{CARBON_{it}}$, and $\mathrm{METHANE_{it}}$ are the emissions of GHGs, CO_2, and CH_4 for country i (i = 1, 2, …, 41) at time t (t = 1990, 1991, …, 2012); β_i are parameters estimated using maximum likelihood; and ε is a random error term. $\mathrm{GHG_{it}}$, $\mathrm{CARBON_{it}}$, and $\mathrm{METHANE_{it}}$ were specified as a function of socio-economic factors on emissions of LULUCF.

For testing EKC, Equations 1.9 – 1.11 the squared term for each independent variable was added as shown below:

$$\begin{aligned}\mathrm{GHG_{it}} = {} & \beta_1 \mathrm{AGRI_{it1}} + \beta_2 (\mathrm{AGRI}^2)_{\mathrm{it2}} + \beta_3 \mathrm{AGFE_{it3}} + \beta_4 \left(\mathrm{AGFE}^2\right)_{\mathrm{it4}} + \beta_5 \mathrm{AGMA_{it5}} \\ & + \beta_6 (\mathrm{AGMA}^2)_{\mathrm{it6}} + \beta_7 \mathrm{RURA_{it7}} + \beta_8 (\mathrm{RURA}^2)_{\mathrm{it8}} + \beta_9 \mathrm{POPU_{it9}} + \beta_{10} (\mathrm{POPU}^2)_{\mathrm{it10}} \\ & + \alpha_i + \varepsilon_{it}, \quad (1.12)\end{aligned}$$

$$\begin{aligned}\mathrm{CARBON}_{it} = {} & \beta_1 \mathrm{AGRI}_{it1} + \beta_2 (\mathrm{AGRI}^2)_{it2} + \beta_3 \mathrm{AGFE}_{it3} + \beta_4 \left(\mathrm{AGFE}^2\right)_{it4} + \beta_5 \mathrm{AGMA}_{it5} \\ & + \beta_6 (\mathrm{AGMA}^2)_{it6} + \beta_7 \mathrm{RURA}_{it7} + \beta_8 (\mathrm{RURA}^2)_{it8} + \beta_9 \mathrm{POPU}_{it9} + \beta_{10} (\mathrm{POPU}^2)_{it10} \\ & + \alpha_i + \varepsilon_{it}, \end{aligned} \tag{1.13}$$

$$\begin{aligned}\mathrm{METHANE}_{it} = {} & \beta_1 \mathrm{AGRI}_{it1} + \beta_2 (\mathrm{AGRI}^2)_{it2} + \beta_3 \mathrm{AGFE}_{it3} + \beta_4 \left(\mathrm{AGFE}^2\right)_{it4} + \beta_5 \mathrm{AGMA}_{it5} \\ & + \beta_6 (\mathrm{AGMA}^2)_{it6} + \beta_7 \mathrm{RURA}_{it7} + \beta_8 (\mathrm{RURA}^2)_{it8} + \beta_9 \mathrm{POPU}_{it9} + \beta_{10} (\mathrm{POPU}^2)_{it10} \\ & + \alpha_i + \varepsilon_{it}. \end{aligned} \tag{1.14}$$

With the quadratic term of variables, if the linear term became statistically insignificant in the models, indicating that the relationship between that independent variable and net emissions was not quadratic. For this reason, only the linear terms were included in the estimations unless both the linear and quadratic terms were significant.

Results

Net global GHG and CO_2 emissions averaged -1,678,500 and -1,761,913 gigagram carbon dioxide equivalent (Gg CO_2 Eq), respectively during the period examined (Figure 1.3). In 2012, average GHG removals of Annex I countires from LULUCF were -1,970,155 Gg CO_2 Eq, which included sequestering about 862,999 Gg CO_2 Eq more than in 1990. The difference of net CO_2 sinks in Annex I countries between 1990 and 2012 increased by 862,999 Gg CO_2 Eq. Overall net global removals from LULUCF increased by 51.6% between 1990 and 2012 (Figure 1.3). The data indicate that CO_2 and GHG removals were similar, primarily because CO_2 is the largest component of GHGs for LULUCF. Conversely, CH_4 increased from about 846 Gg CO_2 Eq in 1990 to 1,437 Gg CO_2 Eq by 2012 (Figure 1.4). Figure 1.5 presented some sample net emissions/removals for Annex I countries including Australia, Canada, Russian Federation, and the U.S. On average, Australia and Canada had the highest GHG emissions among Annex I countries from 1990 to 2012, while the Russian Federation and U.S. had the highest GHG sequestrations.

Table 1.2. Definition of independent variables from Annex I countries at year 1990 to 2012.

Variable	Definition	Hypothesized sign
AGRI	Agriculture, value added per capita (US$). Value added per capita is the net output of a sector after adding up all outputs and subtracting intermediate inputs and it is divided by population. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. The origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3. Data are in constant 2005 U.S. dollars.	+
AGFE	Employment in agriculture, female (% of female employment). Employment is definced as persons of working age who were engaged in any activity to produce goods or provide services for pay or profit, whether at work during the reference period or not at work due to temporary absence from a job, or to working-time arrangement. The agriculture sector consists of activities in agriculture, hunting, forestry and fishing, in accoradance with division 1 (ISIC 2) or categories A-B (ISIC 3) or category A (ISIC 4).	-
AGMA	Employment in agriculture, male (% of male employment). Employment is definced as persons of working age who were engaged in any activity to produce goods or provide services for pay or profit, whether at work during the reference period or not at work due to temporary absence from a job, or to working-time arrangement. The agriculture sector consists of activities in agriculture, hunting, forestry and fishing, in accoradance with division 1 (ISIC 2) or categories A-B (ISIC 3) or category A (ISIC 4).	+
RURA	Rural population growth (annual %). Rural population refers to people living in rural areas as defined by national statistical offices. It is calculated as the difference between total population and urban population.	+
POPU	Total actual population in 1,000 heads. Total population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship. The values shown are midyear estimates.	+

Source: The World Bank, 2016 (http://data.worldbank.org/indicator).

Australia had the positive value of net emissions in 1990 (130,521 Gg CO_2 Eq) and began to sequester more GHG by 1999 (-7,039 Gg CO_2 Eq). The trend of net GHG emissions in Australia fluctuated between 1990 and 2012. Canada's GHG emissions varied during the period, but did not exhibit an increasing or decreasing trend. On the other hand, the U.S. started with GHG sinks in 1990 with -817,400 Gg CO_2 Eq and sequestrations increased until reaching -941,543 Gg CO_2 Eq in 2012. The Russian Federation exhibited the greatest decline in emissions; GHG emissions were 164,571 Gg CO_2 Eq in 1990 and declined to -542,017 Gg CO_2 Eq in 2012. The U.S. emitted the least amount of GHG from LULUCF between 1990 and 2012, averaging -852,939 Gg CO_2 Eq (Figure 1.5). In summary, the mean GHG and CO_2 for all Annex I countries was negative because countries were storing more than emitting for LULUCF.

Based on the Hausman test results, fixed effects was selected for the data analysis. To test for the presence of a EKC, the model evaluated a non-linear relationship between the independent variables and pollution emissions by including a quadratic term of each variable as shown in Equation 1.12 – 1.14. Only the squared terms of female employment in agriculture (AGFE^2) and population (POPU^2) were significant for net CH_4 emissions and, therefore, included in the model. The quadratic terms of all variables in the GHG and CO_2 models were statistically insignificant, indicating that the relationship between the variables and net emissions was not quadratic.

More than 200 observations were excluded from the GHG and CO_2 regressions, while 249 were deleted from the CH_4 regression because of missing data. P-values for the GHG, CO_2, and CH_4 models were 0.040, 0.042, and 0.000, respectively. No evidence of multicollinearity or serial correlation was detected in the models, but heteroscedasticity was presented. This was addressed by utilizing robust standard errors for each model (Equation 1.12 – 1.14). Because the data were panel data, I also checked time-fixed effects and failed to reject the null hypothesis that the coefficients for all years were jointly equal to zero, indicating that no time fixed effects were needed.

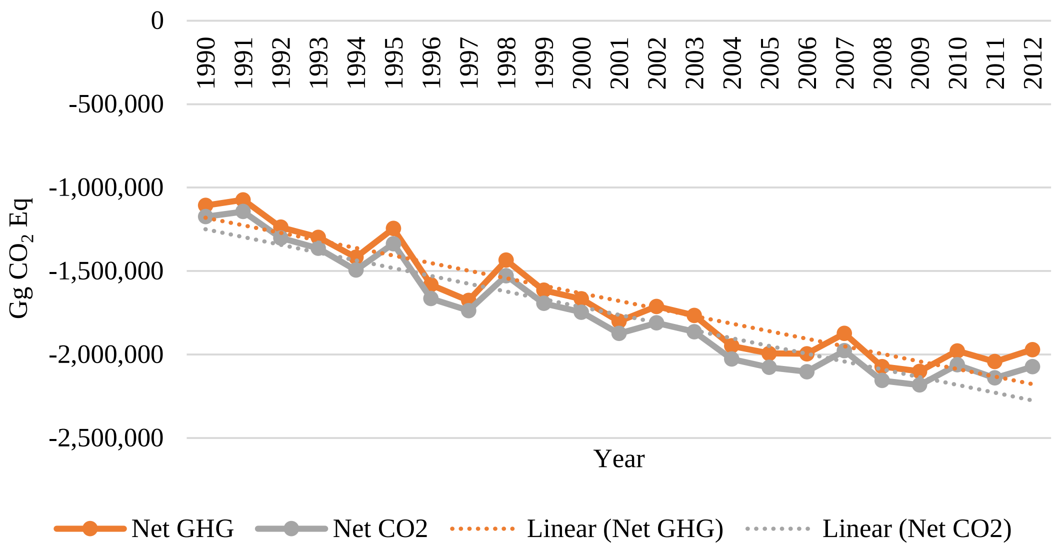

Figure 1.3. Net global LULUCF GHG and CO_2 emissions from 1990 to 2012 (Source: UNFCCC, 2014a, 2014b).
Note: The negative value of net emissions was equivalent to removals, sinks or sequestration.

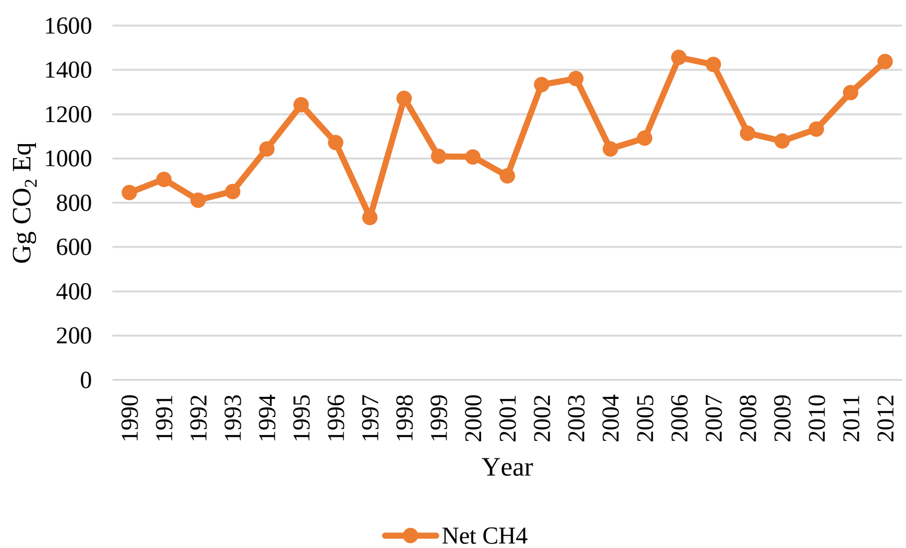

Figure 1.4. Net global CH_4 emissions from 1990 to 2012 (Source: UNFCCC, 2014c).

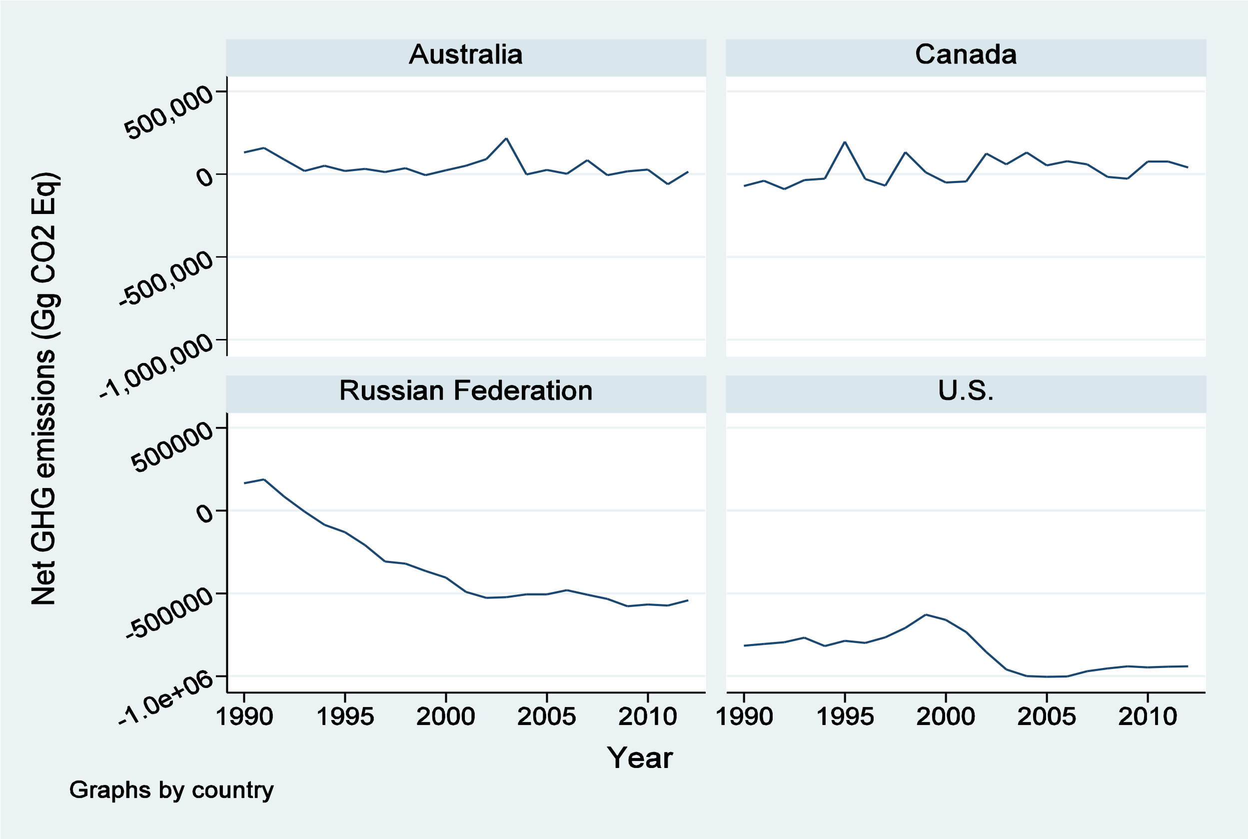

Figure 1.5. Examples of net GHG emissions in Annex I countries from 1990 to 2012 (Source: UNFCCC, 2014a).

The results generally held to the hypothesized relationships provided in Table 1.2. The regression results for the fixed effects model for GHG emssions are listed in Table 1.3, Part I. Since all variables were expressed in actual values, the elasticity values were used to measure the instantaneous effect on the dependent variable of a one percent change in a independent variable, when the other covariates are fixed. For example, value added in agriculture per capita (AGRI) was negatively related to GHG emissions and the elasticity was -0.018, indicating that a one (1%) percent increase in AGRI led to a 0.018% decrease in GHG emissions. The elasticity value for female employment in agriculture (AGFE) was -0.029, indicating that when female employment increases by 1% emissions declined by 0.029%. GHG emissions increased by 0.040% with a 1% change in male employment in agriculture. The estimated population (POPU) was negatively related to emissions. The elasticity of emissions on population suggested that a 1% change in population decreased emissions by 0.188%. The percentage of rural population was not significant in this model.

Part II of Table 1.3 provides the results of CO_2 emissions from LULUCF. The results indicate that value added in agriculture per capita (AGRI), female employment in agriculture (AGFE), and population (POPU) were negatively related to emissions, while male employment in agriculture (AGMA) was positively related. The elasticity value reveals that if agricultural value added per capita increased by 1%, CO_2 emissions decreased by 0.017%. Similarly, a one percent increase in women employed in agricultural resulted in emissions declining by 0.028%. Conversely, a percent increase in male employment resulted in CO_2 emissions increasing by 0.039%. CO_2 emissions increased by 0.186% with a 1% increase in population. As with the GHG model, the percentage of rural population was not significant in the CO_2 model.

Table 1.3. Results of the fixed effects regression for the total net GHG, CO_2, and CH_4 emissions in Annex I countries from 1990 to 2012.

Part I: Fixed effects for net GHG emissions				
Variable[a]	Coefficient	Elasticity	Robust standard errors	P-value
AGRI	-31.241	-0.018	0.010	0.062*
AGFE	-3698.634	-0.029	0.013	0.028**
AGMA	4509.206	0.040	0.024	0.090*
RURA	-896.933	-0.025	0.017	0.149
POPU	-5.972	-0.188	0.076	0.014**
Part II: Fixed effects for net CO_2 emissions				
Variable[a]	Coefficient	Elasticity	Robust standard errors	P-value
AGRI	-30.952	-0.017	0.009	0.061*
AGFE	-3768.419	-0.028	0.013	0.028**
AGMA	4594.882	0.039	0.024	0.091*
RURA	-933.528	-0.024	0.016	0.142
POPU	-6.096	-0.186	0.075	0.014**
Part III: Fixed effects for net CH_4 emissions				
Variable[a]	Coefficient	Elasticity	Robust standard errors	P-value
AGRI	-0.352	-0.233	0.265	0.379
AGFE	42.676	0.393	0.223	0.079*
$AGFE^2$	-0.343	-0.082	0.043	0.059*
AGMA	-52.555	-0.544	0.408	0.182
RURA	-8.891	-0.283	0.268	0.292
POPU	-0.113	-4.149	2.189	0.058*
$POPU^2$	3.62e-07	1.506	0.361	0.000***

[a] Variables were defined in Table 1.2.
Note: Significance at 1% (***), 5% (**), and 10% (*).

Part III of Table 1.3 depicts the results for CH_4 emissions model. The linear population (POPU), population squared (POPU^2), linear female employment (AGFE), and female employment squared (AGFE^2) terms were statistically significant. This indicates that emissions possess an inverted U-shaped relationship with female employment and a U-shaped relationship with population. Differentiating Equation 1.15 after adding AGFE^2 and POPU^2 with respect to female employment and population and setting these equal to zero allows us to identify the turning point of female employment and population. This occurred at approximately 62% of female employment and a population of 156,077,000 people. The U-shaped relationship between CH_4 emissions and population indicates that the rate of CH_4 emissions starts to decrease with increasing population but increases at population growth rates of more than 156 million people. On the other hand, CH_4 emissions increased with the higher percentage of female employment and then dropped after more than 62% employment in agriculture are female.

The inclusion of quadratic terms in Equation 1.15 means that we cannot interpret the estimated coefficients on POPU and POPU^2 as well as AGFE and AGFE^2as elasticities. Elasticity was calculated by partially differentiating Equation 1.15 which included the quadratic term of population squared (POPU^2) with respect to population and female employment (AGFE^2) with respect to female employment.

$$\begin{aligned} \mathrm{METHANE}_{it} = \beta_1 \mathrm{AGRI}_{it1} + \beta_2 \mathrm{AGFE}_{it2} + \beta_3 (\mathrm{AGFE}^2)_{it3} + \beta_4 \mathrm{AGMA}_{it4} + \beta_5 \mathrm{RURA}_{it5} \\ + \beta_6 \mathrm{POPU}_{it6} + \beta_7 \left(\mathrm{POPU}^2\right)_{it7} + \alpha_i + \varepsilon_{it}. \end{aligned} \tag{1.15}$$

After partially differentiating, the elasticity of CH_4 with respect to with female employment ($\mathrm{E_f}$) and population ($\mathrm{E_p}$) are shown in Equation 1.16 and 1.17, respectively:

$$\mathrm{E_f} = \beta_2 + 2\beta_3 (\mathrm{AGFE})_{it3}, \tag{1.16}$$

$$\mathrm{E_p} = \beta_6 + 2\beta_7 (\mathrm{POPU})_{it7}. \tag{1.17}$$

Equations 1.16 and 1.17 therefore allowed us to calculate elasticities for varying levels of population. We found that the elasticities were greater than one, indicating that female employment and population would be considered highly elastic.

Without the quadratic terms, the variance inflation factors (VIF) indicated no multicollinearity among independent variables. Within five variables in the regression for GHG and CO_2 emissions, the mean VIF was 2.53. Male employment in agriculture had the highest VIF with 4.58 and the lowest was the number of population, value added with 1.10 (Table 1.4). For CH_4 emissions, all variables' VIF were slightly different from GHG and CO_2 as shown in Table 1.4. But we can ignore the VIF when we add the quadratic term of a variable because they are definitely correlated (Allison, 2012).

Table 1.4. Results of variance inflation factors for the total net GHG, CO_2, and CH_4 models.

Variable	**VIF[a] for GHG and CO_2 emissions**	**VIF for CH_4 emissions**
AGMA	4.58	4.44
AGFE	4.01	4.00
RURA	1.69	1.78
AGRI	1.27	1.39
POPU	1.10	1.15
Mean VIF	2.53	2.55

[a] Variance inflation factors.

Discussion and Conclusions

This paper examined the factors influencing the primary global air pollutants from LULUCF. The results demonstrate that the relationship between emissions and socio-economic factors is complex. The results of the GHG and CO_2 models were similar except the elasticities and hypothesized signs, while CH_4 differed substantially. In the case of GHG and CO_2, the value added in agriculture per capita, female employment, and population were significantly and negatively related to GHG and CO_2, while male employment in agriculture was positively related to emissions of GHG and CO_2. Rural population was insignificant in both models.

In the case of CH_4, no variables were statistically significant except the linear and quadratic terms for population and female employment. Results revealed that the emissions-population elasticity was negative for very small population sizes, but increased rapidly as population increased. The similar results for GHG and CO_2 model were not surprising because CO_2 is the major GHG in activities of LULUCF, but CH_4 emissions differ in their sources. Emissions of CO_2 are generated by a variety of production and consumption in LULUCF activities that are influenced by socio-economic factors. Moreover, CO_2 can be stored aboveground (e.g., trees) and belowground (e.g., soil). For example, if land is cleared for agriculture, trees and lands are disturbed and CO_2 is released into the atmosphere. But if we conserve trees and reduce tillage, CO_2 can be reduced. In contrast, CH_4 emissions are derived primarily from livestock production. That is, more CH_4 emissions would be produced with an increasing population demanding more food, but other demographic variables would not influence emissions.

The results also indicate that as per capita valued added for agriculture increases, GHG emissions decline. This might be explained because the study included many developed countries. That is the reduced GHG emissions might be the result of increasing production on with decreasing conversion of grassland and carbon losses from the cultivation of organic soils, improving agronomic practices, and extending crop rotations. The countries may also adopt practices that improve soil carbon stocks, graze livestock and grow crops on partially forested land (agroforestry). Organic materials can also be returned to or left on the land to improve the productivity of croplands and grasslands, while rewetting, setting aside, or not draining organic soils; and restoring degraded soils can have significant mitigation and biodiversity benefits. Therefore, considering the management of cropland and grassland would be important for reducing climate change impacts from LULUCF (COM, 2012).

Cole et al. (1997) note that biofuel production is another alternative which has reduced 42% of CO_2, 16% of CH_4 and 10% of N_2O emissions from croplands. They also argued that the mitigation would depend on sustainable production. Farmers have adopted technologies such as no-till farming and strategic fertilizer placement that reduces emissions. Other reasons for reduced

GHG emissions with increased agricultural valued added are improved animal productivity (e.g., liveweight gain, milk production) and fertility (e.g., lower culling, lower replacement rates) (Crosson et al., 2011). Crosson et al. (2011) also found that agricultural soils play an important role on carbon sequestration because they can offset emissions from pasture for livestock production. On a global scale, livestock production contributes about 18% of GHG emissions, primarily CH_4 (e.g., domestic animals or livestock manures) and N_2O (e.g., land applied manures and grazed lands (Kebread et al., 2006; Masse et al., 2011). On-farm biogas production can be another solution to reduce GHG emission related to livestock productions. Because anaerobic bacteria can digest agricultural wastes (Yiridoe et al., 2009) and then produce renewable energy as biogas, it can be substitute for fossil fuel such as coal, oil and natural gas (Masse et al., 2011).

Additional options for reducing emissions from agricultural and forest activities include enhanced transformation of cropland to forest land, reduced soil erosion to minimize losses in soil carbon storage, planting more trees or plants after land disturbance (EPA, 2014), and increased afforestation and reforestation (UNFCCC, 2013). Afforestation and reforestation can mitigate climate change by biosequestering (capturing) atmospheric carbon and storing it in living and dead biomass in the ecosystem (e.g., soil organic carbon, tree biomass) (UNFCCC, 2013). The co-benefits of afforestation and reforestation plan could help in economic, ecological-environmental, socio-political, and cultural development. Examples of economic co-benefits from afforestation and reforestation include increased availability of wood and non-wood products (e.g., timber, fuel wood, honey wax), additional income and economic engagement (e.g., share in carbon revenue), enhanced energy conservation, forest resource conservation, and infrastructure protection (e.g., reduced silting of reservoir; protection of roads, canals, railways and habitations) (UNFCCC, 2013). From an ecological-environmental perspective, urban areas could reduce air pollution and noise, while rural areas could be protected from wind and dust-storms. The scheme of afforestation and reforestation could also promote community action and learning, increase participatory governance, civic and educational awareness, and enhance well-being, stress-relief, and community cohesion from green spaces (UNFCCC, 2013).

As for agricultural employment, the results reveal that female employment was negatively related while male employment positively related to net GHG and CO_2 emissions. The reasons that female employment could reduce emissions might be explained by a study by O'Connor et al. (2002, p. 11) that found that "women are more likely than men to think that climate change will occur, but they are particularly likely to think that false causes such as pesticides and nuclear power contribute to climate change." Several studies indicate that women are more concerned about the environment than are men and are more sensitive to the assault of nature than the men who exploit it (Griffin, 1978; Caldecott and Leland, 1983; Merchant, 1990; Somma and Tolleson-Rinehart, 1997). Blocker and Eckberg (1997) also found that women's nurturance orientation pulls them to be worried on healthy and safety issues and this is reflected in higher levels of environmental concern. Parenthood status of women as traditional role should be expected for women to be concerned about environmental damage (Blocker and Eckberg, 1997).

Even though internationally women constitute a large portion in the farming population, they still lag behind men in terms of access to land, labor, education, water, rural infrastructure, technology, credit, market-related information, training, and advisory services (FAO, 2011; Havemand and Muccione, 2011). Shea et al. (2005) also mentioned that the community-based LULUCF projects designed under Clean Development Mechanism (CDM) or other mechanisms need to address the gender issues, and facilitate the development of the necessary social capital required for the equitable participation of women. Therefore, women's participation in the global effort to mitigate climate change might reduce GHG emissions from LULUCF.

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CHAPTER II

FACTORS INFLUENCING NET GREENHOUSE GAS EMISSIONS FROM LULUCF IN THE U.S.

Abstract

This research examined the factors influencing U.S. greenhouse gas (GHG) emissions from land use, land-use change, and forestry (LULUCF). Results reveal that population, education, and precipitation are negatively related to net GHG emissions. Reasons that population had a negative impact on net GHG emissions might be because the U.S. has many legislations to manage land-use change (e. g., forest, agricultural land) during the population growth. Education had a negative effect on emissions might be because education can affect to environmental attitudes and behavior and support for government programs. For precipitation, higher precipitation could reduce GHG emissions because it improves soil microbial respiration and make plants to catch more carbon for growing. Therefore, more researches in population, educational attainment and precipitation should be necessary to effectively create models to predict ecosystem response to climate change.

Keywords: Greenhouse gas emission, the U.S., LULUCF

Introduction

Trends of U.S. greenhouse gas emission in all sectors

As with other countries, the major greenhouse gases (GHGs) within the U.S. consist of CO_2, CH_4, N_2O, and F-gases (e.g., HFCs, PFCs and SF_6) (Konyar, 2001; EPA, 2014). The largest source of CO_2 in the U.S. is fossil fuel combustion, while the primary sources of CH_4 are from enteric fermentation relative to domestic livestock, natural gas systems, and decomposition of wastes in landfills (Heilig, 1994; Yusuf et al., 2012; EPA, 2014). Breaking down of agricultural soil and livestock manure and urine, stationary combustion, and nitric acid production are major sources of N_2O (Davidson, 1992; Robertson et al., 2000; Signor and Cerri, 2013). F-gases result from electrical transmission and distribution, semiconductor manufacturing, and HCFC-22 production. Overall, the primary sources of GHG emissions are electricity generation, transportation, manufacturing, agriculture, commercial and residential building (Fawcett and Sands, 2006; Olivier et al., 2005). While GHG can be stored through LULUCF, they also can serve as a source. (Post and Kwon, 2000; EPA, 2014).

Even though some prior research has been focused on GHG emissions from LULUCF (e. g., Turner et al., 1995; Fearnside, 2000; Searchinger et al., 2008), few studies have addressed the socio-economic factors affecting GHG emissions and sequestration (e. g., Dale, 1997; Vitousek et al., 1997). This research examines these factors and their links to emissions and mitigation of GHGs and assesses their relative importance on emission/sequestration levels in the United States. Specific research objectives are to:

1.) examine the level of U.S. GHG emissions from LULUCF,

2.) identify the factors influencing GHG emissions from LULUCF in the U.S., and

3.) assess the relative impact of these factors on these emissions.

Net GHG emissions increased in the U.S. by almost 5 percent between 1990 and 2012, rising from 6.2 million to 6.5 million gigagram carbon dioxide equivalent (Gg CO_2 Eq), (Figure 2.1) (EPA, 2014). GHG emissions reached a peak in 2007 for the period examined (Figure 2.2), primarily because of the expanding domestic economy in the 17 prior years and the resulting growth in emissions from electricity generation and transportation activities (EPA, 2009). As expected, CO_2 was the major GHG emitted from 1990 to 1996, driven primarily by fuel use switching from natural gas to more carbon-intensive coal due to colder winter conditions and an increase of natural gas prices, and increased consumption of petroleum-based fuels for transportation (U.S. Department of State, 2002). With the shutdown of several nuclear power plants in 1997, the use of coal increased to be an alternative energy for electrical generation (U.S. Department of State, 2002). By 1998, GHG emissions had risen only slightly, due to warmer winters, but emissions increased substantially due to hot summers and the increased demand for energy for air conditioning and increased gasoline consumption for transportation (U.S. Department of State, 2002). Transportation and residential and commercial heating fuel demand were the main factors of GHG emissions in 1999 as well (U.S. Department of State, 2002). In addition to fossil fuel combustion, the main sources of U.S. GHG emissions between 2000 and 2005 were non-energy product uses of fuels (e. g., lubricant and paraffin waxes) (IPCC, 2006), cement manufacturing, and municipal solid waste combustion (EPA, 2007) while between 2005 and 2012 GHG emissions were mainly emitted from urea consumption for non-agricultural purposes, biomass decay of forest land remaining forest land, ammonia and zinc production, and other Process Uses of Carbonates (EPA, 2014).

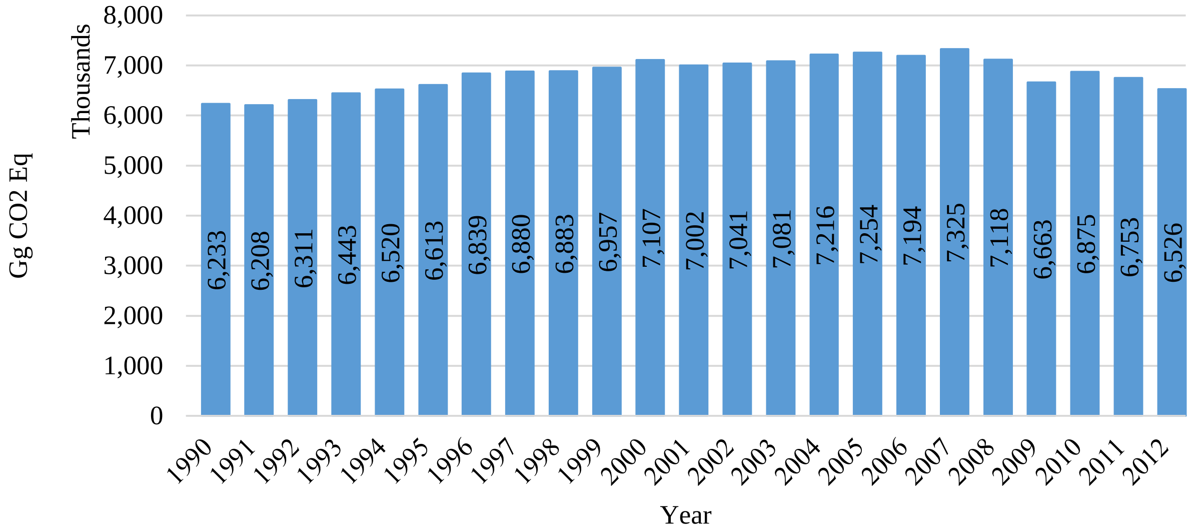

Figure 2.1. Summary of U.S. GHG emissions in all sectors from 1990 to 2012 (CAIT, 2015).

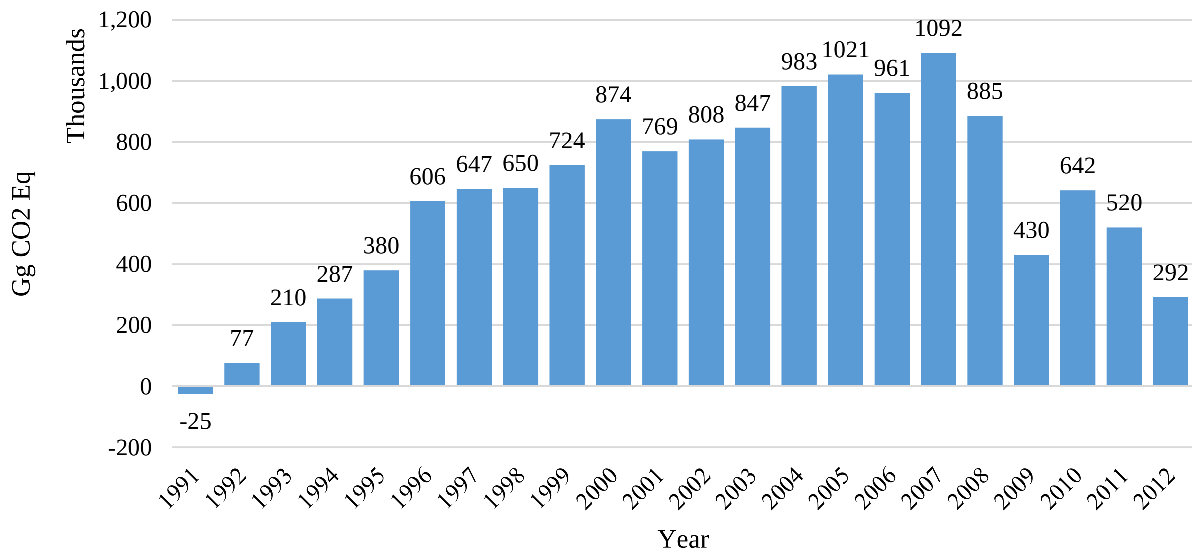

Figure 2.2. Annual U.S. GHG emissions compared to 1990 (CAIT, 2015).

History of GHG emission/sequestration from LULUCF in the U.S.

The exchange of GHGs between terrestrial ecosystems and the atmosphere is directly affected by land use and land use change. A number of factors and mechanisms drive increased emissions from land use change - namely technology, economic development, and population (IPCC, 2000). Conversely, land management offers a means by which GHG emissions can be reduced. For example, CO_2 can be stored belowground or aboveground if the soil or trees are not disturbed (Kimble et al., 2002). In the 18th and 19th century, clearing forests in the U.S. for wood and agriculture increased GHG emissions through increased wildfire, soil disturbance, and burning of wood residues. Through the 20th century, emissions from LULUCF began to decrease as wood fuel was replaced with fossil fuel, and conservation practices and policies such as conservation tillage and the Conservation Reserve Program (CRP) became more prevalent. The largest increase in stored carbon occurred in the 1950s and 60s, but the net flux of emissions was close to zero by the 1970s due to slower growing forests and a resurgence of fuel wood use. Houghton et al. (1999) reported that the net carbon flux was offset by 10 to 30% from land management. From 2000 to 2012, carbon sequestration increased by approximately 30% and the main cause of growth was the increase of net carbon accumulation rate in forest carbon stocks and urban trees (EPA, 2007; EPA, 2014).

Carbon stocks are changed due to a range of LULUCF activities, including converting natural ecosystems to permanent croplands, shifting cultivation, or pasture; abandonment of croplands, abandoning pastures; harvesting timber; and establishing tree plantations (Houghton, 1991). Additionally, CO_2 emissions are emitted by liming agricultural soils, urea fertilization, and undisturbed peatlands, while CH_4 is released from forest fires (EPA, 2014). Forest soils, settlement soils, forest fires, and undisturbed peatlands are drivers of N_2O emissions. Application of synthetic fertilizers to forest and settlement soils are the primary sources of N_2O (EPA, 2013; EPA, 2014).

The World Resources Institute (WRI) reported that in 1990 the U.S. GHGs from LULUCF was -898.61 Gg CO_2 Eq, while in 2000 the net sequestration was -702.93 Gg CO_2 Eq (Figure 2.3). The decrease was due to a decline in the rate of net carbon accumulation in forest carbon stocks and annual carbon accumulation in landfilled yard trimmings (EPA, 2002). In 2004, total GHG sequestrations from LULUCF increased by 394.82 Gg CO_2 Eq, compared to 2000 because of an increase in urban trees, landfilled yard trimmings, and food scraps, as well as a decrease in cropland and grassland area (EPA, 2006).

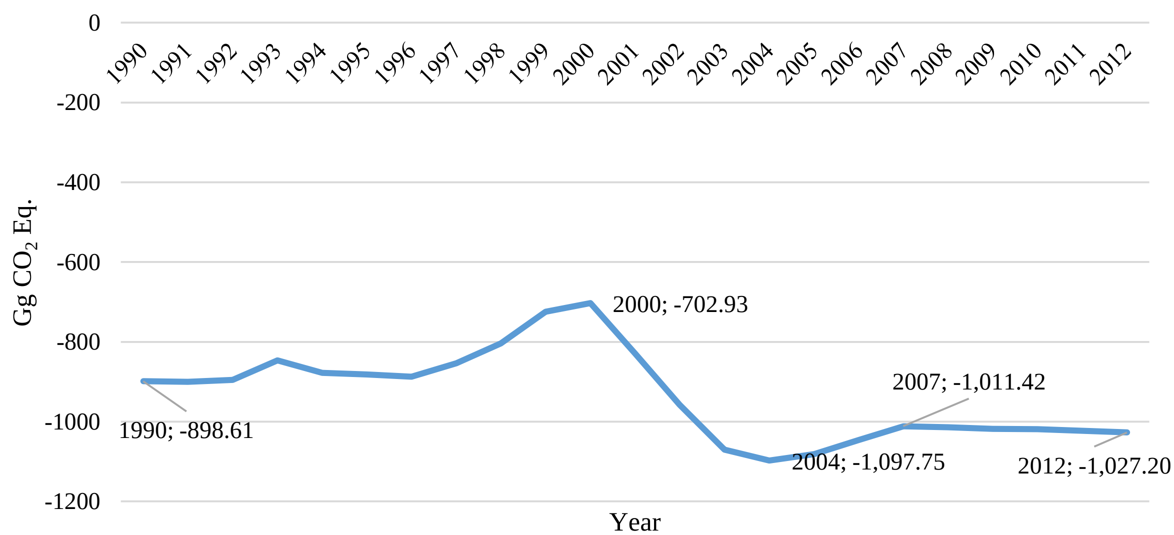

Figure 2.3. U.S. GHG emissions of LULUCF from 1990 to 2012 (CAIT, 2015).

Figure 2.4 depicts the annual change of GHG emissions from LULUCF compared to the previous year. The results reveal that the largest change in sequestration was 18.1% between 2000 and 2001, while the smallest change in sinks was -9.9% between 1998 and 1999.

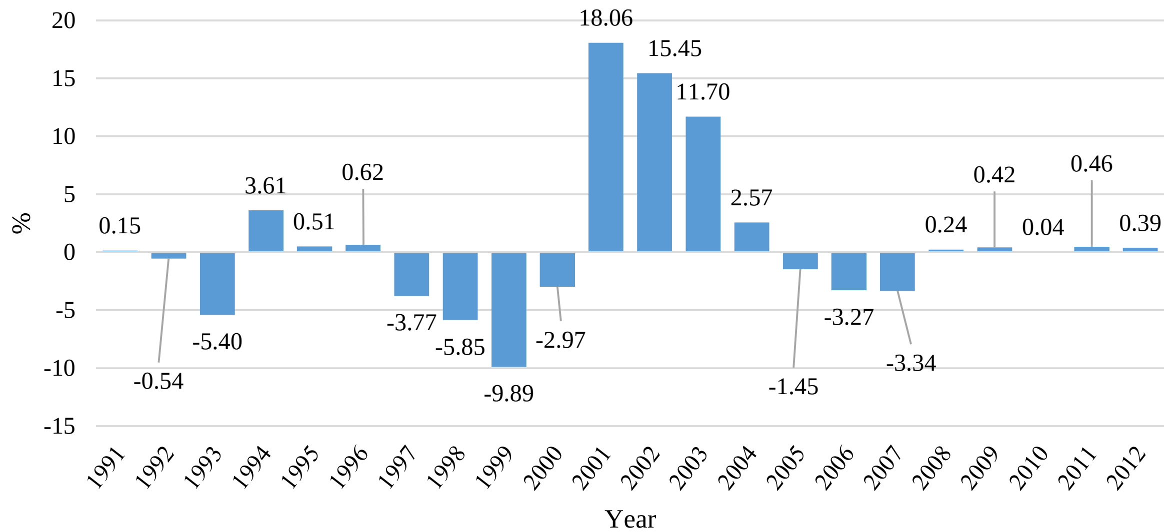

Figure 2.4. Annual percent change of U.S. GHG emissions from LULUCF (CAIT, 2015).

Prior research on factors affecting GHG emissions from LULUCF

A few studies have examined U.S. GHG emissions from LULUCF. Houghton et al. (1999) examined the effects of land-use change on U.S. carbon budgets, and reported the net effect was about 27 million Gg CO_2 Eq of carbon released into the atmosphere before 1945 and about 2 million Gg CO_2 Eq sequestered between 1945 and 1990. They also found that land management during the 1980s accumulated 10 to 30% of current U.S. fossil fuel emissions.

McCarl and Schneider (2001) investigated the cost of GHG mitigation in U.S. agriculture and forestry. They used a model called “ASMGHG” to check farmers’ choices across 63 regions among a broad set of crop and livestock management options including tillage, fertilization, irrigation, manure treatment, and feeding alternatives. The results indicate that at the highest carbon price level ($500) of activities, agricultural and forestry activities removed about 425,000 Gg CO_2 Eq, while only 53,900 Gg CO_2 Eq were removed and the lowest price level ($10).

Lubowski et al. (2006) estimated a carbon sequestration supply function for land-use change and carbon sinks. They investigated the cost of forest-based carbon sequestration by modelling six major private land uses in a comprehensive analysis of the contiguous U.S. The estimates were applied to encourage landowner responses to sequestration policies with subsidies and tax policy. Examples of the results include that a $100 per acre subsidy almost doubled forest area during the simulation period (1992-1997), from 405 to 754 million acres. With a subsidy or tax rate change of $250 per acre, forest land more than doubled in 25 years.

Searchinger et al. (2008) reported that GHG emissions increased by 50% as a result of producing biofuel from switchgrass grown on U.S. corn lands. This outcome was different than most prior studies that found that substituting biofuels for gasoline would reduce GHGs (e. g., Wang et al., 1999; Macedo et al., 2004; Wang, 2011). They summarized that when farmers use cropland to produce food, they averted GHG emissions from land-use change better than when converting lands for biofuels.

Methods and Procedures

Data collection

All state-level data for 1990-2012 were obtained from the CAIT Climate Data Explorer of the World Resources Institute (WRI), U.S. Census Bureau, U.S. Department of Agriculture Economic Research Service, and U.S. Department of Agriculture National Agricultural Statistics Service (U.S. ERS, 2010; CAIT, 2015; NOAA, 2015; U.S. Census Bureau, 2016; U.S. NASS, 2016). The data represent the net GHG fluxes from LULUCF activities for each state in the U.S. as the dependent variable and factors hypothesized to influence GHG emissions as independent variables. The independent variables include population, percent of residents who possess a college degree or higher (percentage of educational attainment), gross domestic product (GDP) per capita, percentage of land in farms, indices of hired labor input by state, temperature, and precipitation.

Net GHG emissions of LULUCF, population and GDP per capita for each state were derived from the CAIT Climate Data Explorer (CAIT, 2015). Data of U.S. State GHG emissions were comprised of changes in GHG level due to afforestation, deforestation, reforestation, forest management, and similar activities and derived from the State Inventory Tool (SIT) of the U.S. Environmental Protection Agency's (EPA's) Emissions Inventory Improvement Program (EIIP) (CAIT, 2015). Educational attainment was obtained from U.S. Census Bureau (U.S. Census, 2016). Percentage of land in farm was collected from U.S. Department of Agriculture National Agricultural Statistics (U.S. NASS, 2016). The Economic Research Service provided indices of hired labor input by state (U.S. ERS, 2010). Temperature and precipitation were obtained from the National Oceanic and Atmospheric Administration (NOAA, 2015). Each variable's definition and hypothesized sign are provided in Table 2.1.

Population was hypothesized to be negatively related to emissions from LULUCF. Although population continues to increase, national and state policies/activities, such as cap-and-trade, the Conservation Reserve Program, and the Environmental Quality Incentives Program, have been implemented that have reduced the land use change and, as a result, limited GHG emissions from LULUCF (Alig et al., 2003; FSA, 2008; Baker et al., 2010; Horowitz and Gottlieb, 2010). The percent of state residents who hold at least bachelor's degree or higher was assumed to be negatively related to emissions because they are more likely to believe that climate change is a significant issue that must be addressed (Berger, 1997; O'Connor et al., 2002; Dietz et al., 2009; Flamm, 2009).

Higher GDP per capita implies that people will consume more and, thereby affecting GHG emission levels (Tucker, 1995; Diet and Rosa, 1997). The percent of land in farms was hypothesized to positively related to emission levels due to net emissions from farming (Flessa et al., 2002) and land conversion (Fargione et al., 2008). The indices of hired worker in agriculture were assumed to have be positively related to GHG emissions. Following because this hypothesis was set up followed to the study of May and Caron (2009) which they implied that soil could be disturbed by farmers.

Temperature and precipitation were hypothesized with negative effects on emissions because some studies have shown that higher temperature and precipitation provided lower emissions (e. g., Ramanujan, 2002; Oertel et al., 2016). Some research reveals that as precipitation increases GHG emissions decrease. Lu et al. (2008) summarized that precipitation slightly affected carbon fluxes, soil carbon dynamics, and soil CO_2 emissions, but it was strongly related to soil N_2O and nitric oxide (NO) because the respiration of soil microbial increases at higher precipitation rates (Lu et al., 2008; Oertel et al., 2016). Plants also need CO_2 to grow, so higher precipitation (higher water and humidity) allows plants to capture more carbon. Thus precipitation can help carbon to be sequestered more in the soils and plants (Ramanujan, 2002).

Fixed and random effects

Fixed and random effects models typically are utilized for panel or cross-sectional time-series data. Both models are similar, but the fixed effects model assumes that the unobserved effect α_i is correlated to each independent variable in all time periods (Equation 2.1), while the random effects model includes an intercept (β_0) so that we can assume that α_i has zero mean. The model becomes the random effects when we assume that α_i is uncorrelated with each independent variable as shown as Equation 2.2 (Wooldridge, 2009).

Table 2.1: Definition and hypothesized sign of independent variables.

Variable	Definition	Hypothesized sign
POPU	Number of population (in 1,000 people). Population is the annual estimated total resident population for each state. These data are developed by the U.S. Census Bureau with the assistance of The Federal-State Cooperative Program for Population Estimates.	-
EDUC	Percentage of state residents who had bachelor's degree or higher (%)	-
GDPC	GDP per capita in U.S. dollars (US$). GDP by state is the value added in production by the labor and capital located in a state. GDP by state for a state is derived as the sum of the GDP by state originating in all industries in the state.	+
LAND	Percentage of land in farm compare to the previous year (%).	+
HIRE	Indices of hired labor input by state.	+
TEMP	Mean annual temperature (℃).	-
PREP	Mean annual precipitation (millimeter, mm).	-

$$y_{it} = \beta_1 x_{it1} + \beta_2 x_{it2} + \cdots + \beta_k x_{itk} + \alpha_i + \varepsilon_{it},\ t = 1, 2, \ldots, T, \tag{2.1}$$

$$y_{it} = \beta_0 + \beta_1 x_{it1} + \beta_2 x_{it2} + \cdots + \beta_k x_{itk} + \alpha_i + \varepsilon_{it},\ t = 1, 2, \ldots, T. \tag{2.2}$$

One of these models was used for each GHG evaluated as the dependent variable, with y being total emissions of net GHGs from LULUCF (which includes emissions from forestland, cropland, grassland, wetlands, developed lands (e.g., residential and commercial building), other lands, and other activities (e.g., harvested wood)). The βs represent the coefficients for each independent variable (x_{it}) which represents the time-variant 1× k regressor matrix; α_i (i = 1,…,n) is the unknown intercept for each entity; u_i is the random heterogeneity specific to the i observation and is constant through time, and ε_{it} is the error term (Greene, 2010; Torres-Reyna, 2014). The null hypothesis of F statistic for overall significance of a regression is below:

$$H_0: \beta_1 = \beta_2 = \cdots = \beta_k = 0, \tag{2.3}$$

where the null hypothesis is hypothesized that all coefficients in the model are not different from zero while the alternative hypothesis is that at least one of coefficients is different from zero (Wooldridge, 2009).

Hausman test for fixed versus random effects

The Hausman test was applied to determine which model was appropriate: fixed or random effects. The null hypothesis is the errors ε_i are uncorrelated with the independent variables in the model. The chi-square test based on the Wald criterion was used to test the null hypothesis shown in Equation 2.4.

$$W = \chi^2[K\text{-}1] = [b\text{-}\hat{\beta}]'\hat{\Psi}^{-1}[b\text{-}\hat{\beta}], \tag{2.4}$$

where χ^2 is chi-squared, K-1 is degree of freedom, b-$\hat{\beta}$ is the covariance matrix of the difference vector, and $\hat{\Psi}$ is the estimated covariance matrices of the slope estimator in the fixed effects model or and the estimated covariance matrix in the random effects, excluding the constant term (Var[b] – Var[$\hat{\beta}$]) (Greene, 2003). Therefore, the test statistic is

$$H = (\hat{\beta}_{FE}\text{-}\hat{\beta}_{RE})' \left[\mathrm{Asy.Var}[\hat{\beta}_{FE}] + \mathrm{Asy.Var}[\hat{\beta}_{RE}]\right]^{-1} (\hat{\beta}_{FE}\text{-}\hat{\beta}_{RE}), \tag{2.5}$$

where $\hat{\beta}_{FE}$ and $\mathrm{Asy.Var}[\hat{\beta}_{FE}]$ are the coefficient vector and estimated asymptotic covariance matrix, respectively, derived from the fixed effects while $\hat{\beta}_{RE}$ and $\mathrm{Asy.Var}[\hat{\beta}_{RE}]$ are obtained from the random effects (Greene, 2010).

Testing for random effects

If a random effects was preferred, the Breusch-Pagan Lagrange multiplier (LM) was used to determine if a random effects and a simple ordinary least squares (OLS) regression is warranted (Torres-Reyna, 2014). The null hypothesis is the variances across entities (states) is zero (Torres-Reyna, 2014).

$$H_0: \sigma_u^2 = 0 \tag{2.6}$$

$$H_1: \sigma_u^2 \neq 0.$$

The LM test for random effects is shown in Equation 2.7 (Greene, 2010):

$$LM = \frac{nT}{2(T\text{-}1)}\left[\frac{\sum_{i=1}^{n}\left[\sum_{t=1}^{T}\alpha_{it}\right]^2}{\sum_{i=1}^{n}\sum_{t=1}^{T}\alpha_{it}^2}\text{-}1\right]^2 = \frac{nT}{2(T\text{-}1)}\left[\frac{\sum_{i=1}^{n}(T\bar{\alpha}_i)^2}{\sum_{i=1}^{n}\sum_{t=1}^{T}\alpha_{it}^2}\text{-}1\right]^2. \tag{2.7}$$

If we reject the null hypothesis, we can conclude that the random effects model is appropriate. That is, there is evidence of significant differences across states. If we fail to reject the null hypothesis, we can run a simple OLS regression (Torres-Reyna, 2014).

Heteroskedasticity

Heteroskedasticity occurs when the variance of the error is not constant (Woodridge, 2009). The test for heteroskedasticity is considered under an assumption of

$$E(\varepsilon_{it}^2 | X_i, Z_i, \alpha_i) = \sigma_{it}^2 = \sigma_v^2 h(\gamma^T z_{it}), \tag{2.8}$$

where $h(.)$ is a strictly positive, twice differentiable function, σ_v^2 is a positive constant, and z_{it} is a vector of exogenous variables that may account for heteroscedasticity, which can be taken as a subset or all of x_{it}, and z_{it} (Juhl and Sosa-Escudero 2014).

Also, Juhl and Sosa-Escudero (2014) showed that $\varepsilon_i \equiv (\varepsilon_{i1}, \dots, \varepsilon_{iT})'$ and

$$\begin{aligned} \textstyle\sum_i &= E(\varepsilon_i \varepsilon_i^T | X_i, Z_i, u_i), \\ &= \sigma_v^2 \begin{pmatrix} h(\gamma^T z_{i1}) & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & h(\gamma^T z_{iT}) \end{pmatrix}. \end{aligned} \tag{2.9}$$

Under the null hypothesis is $H_0: \sigma_i^2 = \sigma^2$ for all i (the null hypothesis is homoscedasticity or constant variance), a modified Wald statistic was used to test for groupwise heteroskedasticity in the residuals of a fixed effect regression model. If the null hypothesis is rejected, heteroskedasticity exists and a robust-standard error will be applied (Greene, 2003; Torres-Reyna, 2014).

Multicollinearity

Farrar and Glauber (1967) noted that the interdependency among independent variables should be evaluated. Standard errors might be biased and harm the coefficients of estimators if two or more independent variables are highly correlated (Mansfield and Helms, 1982). Variance inflation factors (VIF) were estimated to assess collinearity among the independent variables. The variance inflation factors were calculated by Equation (2.10) (Afifi and Clark, 1984; Fox, 1984),

$$VIF = \frac{1}{1\text{-}R^2}, \tag{2.10}$$

where R^2 is the coefficient of determination of a regression of an independent variable on all the other independent variables (Nagelkerke, 1991). If the VIF value is greater than 10, multicollinearity may exist (Neter et al., 1985).

Empirical model

The model specified to examine the factors influencing net GHG emissions from LULUCF in each state of the U.S. (i) at time (t) was:

$$\mathrm{EMIS}_{it} = \beta_0 + \beta_1 \mathrm{POPU}_{it1} + \beta_2 \mathrm{EDUC}_{it2} + \beta_3 \mathrm{GDPC}_{it3} + \beta_4 \mathrm{LAND}_{it4} + \beta_5 \mathrm{HIRE}_{it5} + \beta_6 \mathrm{TEMP}_{it6} + \beta_7 \mathrm{PREP}_{it7} + \alpha_i + \varepsilon_{it}. \quad (2.11)$$

where EMIS_{it} was the net GHG emissions for state i (i = 1, 2, …, 50) at time t (t = 1990, 1991, …, 2012), β_i is the parameter to be estimated for variable i using maximum likelihood, α_i is the unknown intercept for each state, u_i is the random heterogeneity specific to the i observation and is constant through time, and ε is a random error term.

Results

All states except Arizona and Wyoming reported GHG sequestration from 1990 to 2012. Alabama reported the highest GHG sinks with an average of -55.55 Gg CO_2 Eq, while Arizona was the highest GHG emitter with the average of 4.09 Gg CO_2 Eq. On an annual basis, the largest level of GHG sequestration was in 2004 (-1,097.81 Gg CO_2 Eq) and the smallest sequestration level was reported in 2000 (-702.98). In terms of educational attainment, the largest average percent of population with at least a bachelor's degree was Maine (33.90%), followed by Colorado

(33.43%), Massachusetts (33.40%), Maryland (32.19%) The smallest percentage was West Virginia (15.42%), Arkansas (17.26%), Mississippi (18.86%), Kentucky (18.93%, and Indiana (19.03%).

Alaska reported the largest average GDP per capita with $58,317; Mississippi was the least at $27,102.04. Mississippi similarly reported the smallest average median household income at $40,355, followed by West Virginia ($41,054.57), Arkansas ($41,538.52), Louisiana ($44,014.70), and Montana ($44,413.57). The lowest percentage change of land in farms was Nevada in 1998 with -21.59% compared to 1997, with Rhode Island reporting the largest change between 2007 and 2008 (16.67%). California had the largest index of hired agricultural workers in 1999 (52.92), while Rhode Island had the lowest (0.06). The average temperature and precipitation among 50 states were 10.85 ℃ and 997.55 mm.

After running a Hausman test (Prob > chi2 = 0.0036) and test for random effects (Prob > chibar2 = 0.0000), the random effects model was selected. After test for heteroskedasticity, the Prob > chi2 (0.0000) was smaller than 0.05 indicating that we could reject the null hypothesis so there was not constant variance (Presence of heteroscedasticity in the errors). To avoid heteroskedasticity, robust standard errors were applied to the model. The p-value of F-statistic for overall significance of the regression was 0.004, indicating that at least one of the coefficients is different from zero. No multicollinearity was detected among the independent variables (Table 2.2).

The results in Table 2.3 reveal that population (POPU), percentage of educational attainment (EDUC), and precipitation (PREP) were negatively, and significantly, related to GHG emissions, while the other variables were insignificant. When population increased by a thousand, net GHG emissions decreased by 0.00000109 Gg CO_2 Eq, holding all other variables in the

Equation 2.11 constant. Similarly, a one percent increase in the percentage of people with at least a bachelor's degree, reduced net emissions by 0.00004 Gg CO_2 Eq. For precipitation, when the level of precipitation increased by one millimeter, net emissions decreased by 0.0001 Gg CO_2 Eq.

Table 2.2. Variance inflation factors (VIF) for U.S. GHG emissions model.

Variable	VIF
POPU	3.20
EDUC	1.20
GDPC	1.27
LAND	1.00
HIRE	2.93
TEMP	1.18
PREP	1.12
Mean VIF	1.70

Table 2.3. Results of marginal effects and p-values for U.S. GHG emissions model.

Variable	Marginal effects	P-value
POPU	-1.09e-06	0.065*
EDUC	-0.00004	0.048**
GDPC	1.34e-06	0.993
LAND	2.92e-07	0.838
HIRE	0.0005	0.360
TEMP	-0.0001	0.613
PREP	-0.0001	0.064*

Note: Significance at 1% (***), 5% (**), and 10% (*).

Discussion and Conclusions

This study examined a select set of factors influencing net GHG emissions in the U.S. using state-level data. The results reveal that population was the primary factor related to U.S. GHG emissions/sinks from LULUCF. Specifically, population exhibited a negative relationship with net GHG emissions. Changes in land use are the result of countless choices made by individuals, corporations, nongovernmental organizations, and governments, which are exacerbated by expanding populations. Given that policies related to population growth are exceedingly unpopular in the U.S., the primary option for enhancing carbon storage through LULUCF is developing policies to address land use.

Additionally, market-based policy instruments (e. g., carbon pricing), another method to enhance GHG sequestration from LULUCF (C2ES, 2013), is becoming a popular tool at the state level. California, Washington, Oregon, New York, Massachusetts, Rhode Island, Colorado (Boulder), and Vermont have proposed variants of carbon pricing policies (CTC, 2016). For example, California started cap-and-trade program in 2012 and the price of carbon tax was about US$0.013 per Gg CO_2 Eq (or $13 per ton of CO_2 Eq) (Kossoy, 2015). In New York, a carbon tax of US$0.02 per Gg CO_2 Eq was applied to the state in 2013 (CTC, 2016).

The Renewable Energy Portfolio Standard (RPS) and Energy Independence and Security Act of 2007 have been used to increase biofuel production (Baker et al., 2010) and this can help the U.S. from reducing GHG emissions from LULUCF by substituting fossil fuels with bioenergy. In addition, the agricultural sector can reduce GHG emissions and increase sequestration by plants and soils. Paustain et al. (2006) suggested ways which farmers could adapt to mitigate GHG -- reducing the frequency and intensity of soil tillage, including more hay crops in annual rotations, producing high-residue-yielding crops and reduced fallow periods, improving pasture and rangeland management, restoring degraded lands, using soil testing, optimizing fertilizer use, and utilizing nitrification inhibitors and controlled-released fertilizer.

Educational attainment (EDUC) was negatively related to net GHG emissions, possibly because education affects environmental attitudes and behavior (i.e. adoption of specific emissions-reducing activities (Diets et al., 2009), support for government programs (O'Connor et al., 2002), and decisions regarding vehicle ownership and use (Flamm, 2009). Precipitation had a negative effects on GHG emissions. Ramanujan (2002), Lu et al. (2008), and Oertel et al. (2016)

found that the respiration of soil microbial and plant growth increase at higher precipitation rates. Therefore, reducing GHG emissions may be another way to slow changing precipitation patterns (IPCC, 2013; Melillo et al., 2014).

A number of climate-related policies have been considered at the federal level, including a cap-and-trade (CAP) system that could reduce GHG emissions from the burning of fossil fuels by about 80% of U.S. emissions. The CAP could boost mitigation from agriculture by making agricultural activities eligible for offset credits (Horowitz and Gottlieb, 2010). Under the offset credits, farmers who increased their use of no-till practices or nitrogen fertilizer inhibitors could receive credits for the reduced emissions. A number of studies have documented the reduction in GHG emissions by increasing operational efficiency or adopting farming techniques such as no-tillage (Cole et al., 1997; Johnson et al., 2007). Sperow et al. (2003) found that the practice of no-tillage could sequester soil carbon sequestration. Similarly, forest landowners would have been able to receive credits for increasing carbon storage on their lands. Both also would have been allowed to trade their credits directly to industrial sources covered by the CAP permit requirement or to brokers. Another opportunity for farmers would be to modify their livestock and dairy operations to reduce CH_4 emissions. CH_4 from dairy and hog production during manure storage also can be captured to produce electricity by enteric fermentation known as “biogas” (Esfandiari et al., 2011). Franzluebbers (2005) conducted a review of studies in the southeastern U.S. and concluded that poultry litter applied as soil organic carbon to crop and pasture lands significantly enhanced carbon sequestration. In crop production, Fargione et al. (2008) also noted that farmers can mitigate GHG emissions by increasing the feedstocks used for biofuels such as switchgrass or installing wind turbines or solar panels on their land. The U.S. Environmental Protection Agency estimated that the allowance prices associated with congressional cap-and-trade proposal would range from \$12 to \$41 per ton CO_2 in 2013 and from \$13 to \$59 per ton of CO_2 in 2020.

Another policy adopted before carbon was considered, but which had a significant impact on GHG emissions is the Conservation Reserve Program (CRP). CRP is offered payments to farmers to voluntarily retire highly erodible or environmentally sensitive cropland from production, and planting grasses or trees to reduce water pollution, enhance wildlife habitat, sequester carbon, and provide other environmental benefits (Horowitz and Gottlieb, 2010). By March 2008, more than 34 million acres had been enrolled in CRP, sequestering an additional 48,000 Gg CO_2 Eq (FSA, 2008).

The Environmental Quality Incentives Program (EQIP) is another payment offered to farmer who adopt a wide range of conservation practices for crop and livestock production. Producers could participate in EQIP by agreeing to implement a specific conservation practice for 1 to 10 years. By 2008, EQIP had distributed \$42.5 million for conservation tillage on 2.7 million acres and paid out \$35.7 million for nutrient management on 4.0 million acres (Horowitz and Gottlieb, 2010).

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CHAPTER III

ATTITUDES REGARDING GREENHOUSE GAS EMISSIONS FROM LULUCF: CASE STUDY IN BANGKOK, THAILAND

Abstract

More than 800 Bangkok residents were surveyed to determine how much they were willing to pay (WTP) for reducing greenhouse gas (GHG) emissions from land use, land-use change and forestry (LULUCF). The survey collected information about the respondents knowledge of greenhouse gas emissions and their socioeconomic and demographic characteristics. A logistic regression was used to assess the factors influencing their willingness to pay for a reduction in greenhouse gas emissions. Seven variables significantly affected the respondents willingness to pay. The level of concern about climate change, support for a national climate policy, college education, and high income levels were positively related to WTP, while younger respondents, students, and those employed in the private sector exhibited lower WTP. The likelihood of WTP increased by 21 percent when respondents were concerned about environmental and natural resource issues compared to people who were not concerned. People who support national policies such as emission taxes and carbon credits were 26% more likely to be WTP than those who did not.

Keyword: Willingness-to-pay, WTP, logit, LULUCF

Introduction

Global climate change is driven by many factors, the most important of which is GHG emissions from human activities. In an attempt to identify policy alternatives, economists have assessed a range of mechanisms to finance policy options to reduce GHG emissions. Willingness to Pay (WTP) measures are considered useful for several reasons. First, they can directly inform policy makers, by providing information about how much people value goods or services, thereby offering specific pricing data (Hanley et al., 2003). Second, WTP measures can be important inputs in economic evaluations such as cost-benefit analyses (Loomes, 2001; Oliver et al., 2002; Negrín et al., 2008). Finally, WTP measures can be a convenient tool to compare and rank the desirability of goods and services, as well as policy options.

Carlsson et al. (2012), surveyed citizen's WTP for mitigating CO_2 emissions in three different countries - China, Sweden, and the United States. The majority of respondents in the three countries believed that the average global temperature had risen due to human activities. Swedish respondents exhibited the highest WTP for CO_2 emissions, followed by American and Chinese respondents, respectively. Brouwer et al. (2008) assessed air passenger WTP to offset the CO_2 emissions resulting from their travel. The study revealed that 75 percent (%) of the passengers were willing to pay a carbon travel tax. Europeans were the most willing participants, with 80% indicating that they were willing to pay, followed by American (75%) and Asian travelers (59%). The primary factors affecting the travelers' WTP were income, nationality, cost, passenger knowledge and awareness of the environmental impacts of flying, and level of concern. While there is a rich literature on the WTP for GHG reductions, no one has conducted a survey on individual WTP for reducing GHG emissions from LULUCF in Thailand. This paper describes a preliminary study survey conducted in Bangkok.

The total population of Thailand in 2014 was approximately 67.7 million people, with an annual growth rate of 0.34% (The World Bank, 2015). Approximately 13% of Thai citizens had at least a bachelor's or equivalent degree (UIS, 2015). Thailand has faced many environmental issues over the past several decades. The primary drivers of environmental deterioration from land-use change were socio-economic growth (Moran, 1990). Like many other developing countries, Thailand faces serious problems related to land use and forest activities, especially deforestation for agriculture and urbanization (Sangawonge et al., 2011). Changes from forest to agricultural land also have negative impacts such as soil erosion, water degeneration, and air pollution, including CO_2 emissions (Rajan et al., 1995). In 2014, net GHG emissions/removals from land use in Thailand totaled 15,966.64 Gg CO_2 Eq. (FAO, 2015). Even though all commercial logging in Thailand was banned in 1989 (Trisurat, 2007), illegal deforestation is still the most important driver of land use conversion in Thailand (Panayotou and Sungsuwan, 1989) as well as GHG emissions, especially CO_2 (Fearnside, 2000).

The study area of this research was in Bangkok, which is the capital city and home to approximately 8.4 million people (CIA, 2015). The green space for the entire city is moderate, or about 3.3 square meters per person (10 times less than the regional standard for urban areas) (Thaiutsa et al., 2008; The Nation, 2015). The research objectives of this case study are to:

1.) assess the attitudes of Bangkok residents regarding GHG emissions,

2.) determine the factors related to these attitudes, and

3.) estimate Bangkok residents' willingness to donate (WTD) to reduce GHG emissions from LULUCF.

Methods and Procedures

Data collection

The survey was conducted in Bangkok, Thailand between June 1 and June 30, 2014. The survey consisted of 26 questions including attitudes regarding greenhouse gas emissions (11 questions) and demographic characteristics (15 questions). The questionnaire was translated from English to Thai. Three students from Thonburi Vocational College and King Mongkut's University of Technology North Bangkok helped collect the data through face-to-face surveys for five days per week between 8 am to 5 pm. At the beginning, we conducted the surveys at the skytrain stations in different locations including Siam Square (Central of Bangkok), Chidlom (East of Bangkok), and Chatujak (North of Bangkok). We obtained very few responses during the first week (72 questionnaires), so the surveys locations were moved to two well-known universities in Bangkok (Chulalongkorn and Kasetsart Universities). The survey also was posted on Facebook to increase participation. The survey questionnaire is provided in Appendix I.

Logistic regression

Data for this chapter were obtained from the survey of 2014 Thai attitudes for reducing GHG emissions from LULUCF. Logit model is for binary response used to acquire whether Bangkok's residents were willing to donate for reducing GHG emissions released from LULUCF as dependent variable. If respondents answered yes in question 10 of the survey or checked the range of WTD (<1, 1.00-4.99, 5.00-8.99, 9.00-12.99 or >12.99 THB), the dependent variable was one, otherwise zero. Factors influencing willingness to donate were the independent variables. In a binary form, the model lies primarily in the response probability (Equation 3.1).

$$\Pr(y = 1) = \frac{1}{1+e^{-X\beta}}, \tag{3.1}$$

where $X\beta$ denotes a set of independent variables (Wooldridge, 2009).

Therefore, the logistic estimation of WTP can be derived from a latent variable model shown as Equation 3.2.

$$WTP^* = \beta_0 + X\beta + e, y = 1[y^* > 0], \tag{3.2}$$

where WTP^* is an unobserved, or latent, variable, β_0 is a constant term representing unknown parameter and $X\beta$ is a vector of $\beta_1 x_{1t} + \beta_2 x_{2t} + \ldots + \beta_i x_{it}$ for observation i at time t. Therefore, WTP is one if $WTP^* > 0$, and y is zero if $WTP^* \leq 0$. This model assumes that error term e is independent of x and that e either has the standard logistic distribution or the standard normal distribution (Wooldridge, 2009).

Marginal effects

The marginal effect at the means (MEMS) is of a continuous variable is (Barron, 2014):

$$\frac{\partial \Pr(WTP=1)}{\partial x_i} = \frac{e^{X\beta}}{(1+e^{X\beta})^2} * \frac{\partial(X\beta)}{\partial(x_i)} \tag{3.3}$$

$$= \frac{e^{X\beta}}{(1+e^{X\beta})^2} * \beta_i$$

$$= \Pr(WTP = 1) * \Pr(WTP = 0) * \beta_i$$

Additionally, the MEMS for a dummy variable is the difference between the expected value of $\mathrm{WTP}_{it}^{*}|\mathrm{WTP}_{it} > 0, \mathrm{x}_{i}$ when the dummy variable *k* changes from 0 to 1, holding other variables constant (Williams, 2015):

$$\text{Marginal effects } x_i = \Pr(\mathrm{WTP} = 1|x_i = 1) - \Pr(\mathrm{WTP} = 1|x_i = 0) \tag{3.4}$$

Maximum likelihood estimation

Maximum likelihood estimation (MLE) is applied to solve for the parameters that best fit the data (Czepiel, 2002). In estimating a limited dependent variable model, MLE is indispensable because MLE is obtained from the distribution of dependent variable given a set of explanatory variables (X), so the heteroscedasticity in Var(WTP|X) is automatically accounted for (Wooldridge, 2009). Assume that this study has a random sample of size n. To receive the maximum likelihood estimator, the density function of WTP_i given x_i can be written as (Equation 3.5):

$$\mathrm{f} = (\mathrm{WTP}|\mathrm{x}_i;\ \beta) = [\mathrm{G}(\mathrm{x}_i\beta)]^{\mathrm{WTD}}[1\text{-}\mathrm{G}(\mathrm{x}_i\beta)]^{1\text{-}\mathrm{WTD}}, \mathrm{WTP} = 0, 1, \tag{3.5}$$

where the intercept is absorbed into the vector of X. If $\mathrm{WTP} = 1$, we obtain $\mathrm{G}(\mathrm{x}_i\beta)$ and when $\mathrm{WTP} = 0$, we obtain $1\text{-}\mathrm{G}(\mathrm{x}_i\beta)$.

The log-likelihood function for observation i is a function of the parameters and the data $(\mathrm{x}_i, \mathrm{WTP}_i)$ and is derived by taking the log of Equation 3.5 (Wooldridge, 2009):

$$\mathrm{l}_i(\beta) = \mathrm{WTP}_i \log[\mathrm{G}(\mathrm{x}_i\beta)] + (1\text{-}\mathrm{WTP}_i) \log[1\text{-}\mathrm{G}(\mathrm{x}_i\beta)]. \tag{3.6}$$

The log-likelihood for an n sample size is obtained by summing (Equation 3.6) across all observations (Wooldridge, 2009):

$$L(\beta) = \sum_{i=1}^{n} l(\beta). \tag{3.7}$$

Test of goodness of fit

A goodness-of-fit test**,** in general, refers to measuring how well do the observed data correspond to the fitted (assumed) model. We will use this concept throughout the analysis as a way of checking the model fit. A goodness-of-fit statistic tests the following hypothesis:

H_0: the model L_0 fits

vs.

H_A: the model L_0 does not fit.

In this study, we used Pearson chi-squared to test for goodness of fit.

The Pearson chi-squared is calculated as Equation 3.8:

$$\chi^2 = \sum_j \frac{(O_j - E_j)^2}{E_j} \tag{3.8}$$

where O_j is the observed count in cell j, and E_j is the expected count in cell j under the assumption that null hypothesis is true, i.e. the assumed model is a good one (Allison, 2014).

Multicollinearity

Interdependency among explanatory variables is evaluated (Farrar and Glauber, 1967). If two or more independent variables are highly correlated, standard errors might be biased upward and harm the estimated coefficients and inferences (Mansfield and Helms, 1982). Variance inflation factors (VIF) are used to diagnose collinear relationships among independent variables. The variance inflation factors are calculated by Equation (3.9) (Afifi and Clark, 1984; Fox, 1984),

$$\mathrm{VIF} = \frac{1}{1\text{-}\mathrm{R}^2}, \tag{3.9}$$

where R^2 is the coefficient of determination of a regression of an independent variable on all the other independent variables (Nagelkerke, 1991). A value of VIF greater than 10 indicates that multicollinearity may exist among independent variables (Neter et al.,1985).

Results

Summary of data

The survey included 925 people, 697 from face-to-face surveys (72 from skytrain stations and 625 near the two universities) and 228 respondents from Facebook. Out of the 925 completed questionnaires, 62 were excluded because of missing values for question 10, the dependent variable in the survey (whether the respondent was willing to donate to reduce greenhouse gas emissions from land-use change or forest activities). If someone indicates that they are willing to pay 0 THB then they are unwilling. Therefore, the total number of respondents was 863. Each variable used in the analysis is defined in Table 3.1. Table 3.2 provides the frequencies of the variables in the survey. Of the total survey population, 570 were willing to pay for reducing GHGs from LULUCF (66.1%) while 293 indicated that they would not (33.9%).

The first question in the questionnaire asked respondents the degree to which they were concerned about environmental and natural resource issues. Of the 861 people who answered this question, 760 (88.27%) expressed some level of concern about environmental and natural resource issues, while 101 (11.73%) did not. Respondents then were asked whether they had heard of GHGs. Of the 861 responding to this question, 840 answered yes (97%) and 21 no (~3%). Those respondents who had heard of GHG were asked to indicate their sources of information on GHG (school, television (TV), newspaper, internet, friend, family, and others). The number of respondents who chose at least 1, 2, 3, 4, 5, 6, or all sources were 213, 148, 168, 50, 14, 12 and 8, respectively.

Question 3 asked which GHG was most often emitted from the choices of CO_2, CH_4, N_2O, F-gases, and other gases. More than 705 respondents indicated that CO_2 was the most emitted GHG, followed by CH_4 (57), F-gases (40), N_2O (22) and other gases (6). The results are presented in Figure 3.1.

Next the respondents were asked to indicate the most common source of greenhouse gas emissions generally and CO_2 specifically. As expected, 408 respondents responded that industry was the largest GHG emitter, followed by transportation, agriculture, electricity generation, commercial and residential building, and LULUCF. The answers for CO_2 were similar. The industry sector had the highest number of responses with 336, followed by transportation (328), LULUCF (63), electricity generation (32), and agriculture (30). Additionally, 90.3% of the respondents agreed that CO_2 could be emitted from LULUCF activities, while 9.7% indicating that CO_2 could not be released from LULUCF.

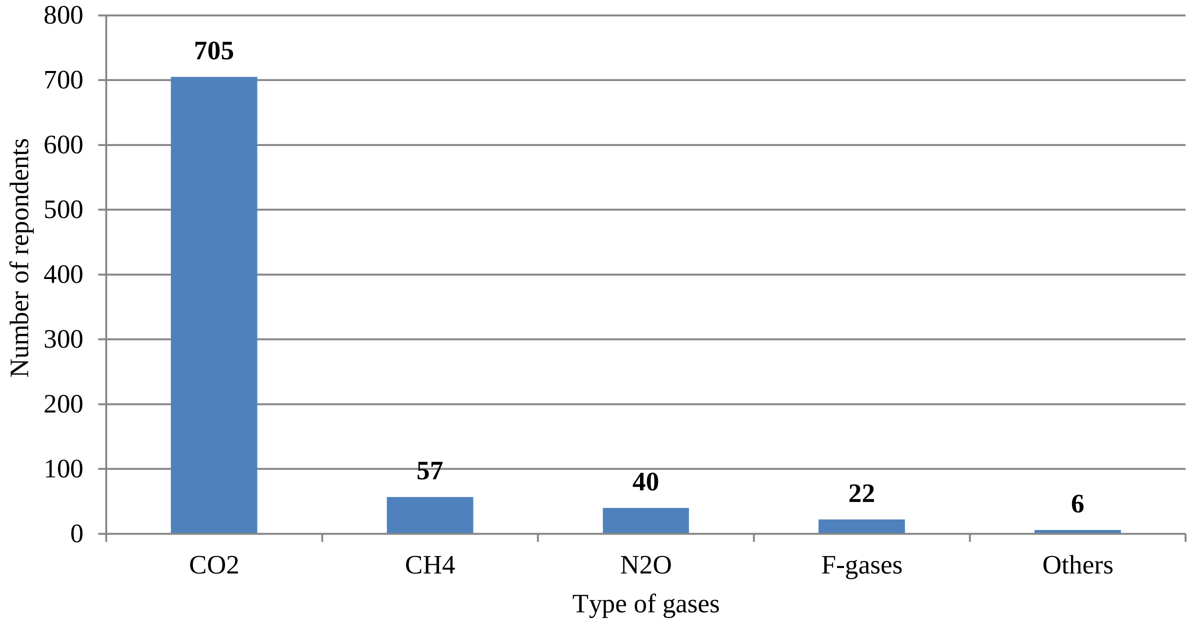

Figure 3.1. Respones to 'Which gas is most often emitted into the atmosphere?'.

Question 7 queried respondents on who should be responsible for paying on reducing GHG emissions - producers, consumers, or the government when you purchase products and services resulting from LULUCF. Because respondents could indicate more than one category was responsible, the variable was transformed into a dummy variable, with a '1' indicating that consumers were responsible for paying for GHG reduction and '0' representing that governments, producers, or others should pay. With this transformation, 159 responses were recorded for consumers, while 702 responses indicated that the responsibility was government, producers or others. If people answered that consumers (or themselves), they would be more likely to pay for reducing GHG emissions than people who answered producers or the government. Next, respondents were asked if they would support a national policy requiring Thai citizens to pay for reducing GHG emissions from LULUCF. More than 68% were likely to support a national policy while 31% did not as shown in variable "SUPPORT" (Table 3.2). Question 9 asked respondents the percentage of the sales price they would be willing to pay as tax for reduced GHG emissions from LULUCF. The choices included 0.1, 0.2, 0.3, 0.4, 0.5 and >0.5% of the sales price. The most popular response was 0.10 %, with 337 respondents, followed by 0.20% with 158. The results were presented in Figure 3.2.

For those willing to pay (Question 10), if respondents answered yes or checked the range of WTD (<1, 1.00-4.99, 5.00-8.99, 9.00-12.99 or >12.99 THB), the dummy variable was one, otherwise zero. 168 indicated that they would pay the smallest category provided: 1.00 – 4.99 Thai Baht (THB), or about $0.03 - $0.15, while 126 respondents were willing to pay between 5.00 and 8.99 THB. Only 38 people indicated that they would pay 9.00 - 12.99 THB; 90 would pay less than 1 THB. Surprisingly, 135 respondents were willing to pay more than 12.99 THB (Figure 3.3). Eleven people were willing to pay for reducing GHGs but they did not answer how much they wanted to spend. For the 293 respondents who provided reasons for their unwillingness to pay any THB, the most prevalent reason was that they did not know the purpose of the donation. There were 43 of 293 people did not answer the reason (Figure 3.4).

Question 11 asked whether Thailand should pay more attention to reduce GHG emissions. More than half (424 respondents) strongly agreed, 356 agreed, 61 were neutral or didn't know, 9 disagreed, and 7 strongly disagreed. Because the surveys were administered near universities, the majority of respondents were young: 317 were between 18 and 24 years old and 198 between 25 and 30. There were 230 between 31 to 45 years, while 74 indicated that they were 46 – 55 years old. Only 38 respondents were older than 55. As a consequence, the age category of 18 - 24 was used as the reference category. Five hundred and twenty-two were Bangkok residents while 335 respondents were not.

At the time of survey, 522 respondents lived in Bangkok while 335 respondents did not. More than 500 people lived in Bangkok for 16 years or more years, while 298 people lived in Bangkok for less than 16 years. Approximately 80% of respondents worked in Bangkok but 20% did not work in Bangkok. Three hundred and twelve people worked in center of Bangkok while 290 people worked in other parts of Bangkok.

The survey was skewed toward those with at least an undergraduate degree (545 possessed at least a Bachelor's degree or 73.25% as the percentage of sample size (Table 3.2); 199 had less than a college degree), primarily because the majority of surveys were conducted near universities However, I solved this issue by using a weighting adjustment. Data from United Nations Educational, Scientific and Cultural Organization (UNESCO) showed that the percentage of Thai citizens with at least a Bachelor's degree was 13.1% in 2013, so this research used 13.1% as the population weight for sample size (UIS, 2015). The weight was obtained by dividing the population percentage by the sample percentage, the weight was 0.179.

Empirical model

The following empirical logistic model was specified to examine factors influencing the willingness to pay when respondents answered the survey. The model was expressed below (Equation 3.10).

$$\begin{aligned} \mathrm{WTP_i} = {} & \beta_0 + \beta_1\mathrm{CONCERN_i} + \beta_2\mathrm{CONSUMER_i} + \beta_3\mathrm{SUPPORT_i} + \beta_4\mathrm{AGE2_i} \\ & + \beta_5\mathrm{AGE3_i} + \beta_6\mathrm{AGE4_i} + \beta_7\mathrm{AGE5_i} + \beta_8\mathrm{AGE6_i} + \beta_9\mathrm{BANGKOK_i} \\ & + \beta_{10}\mathrm{LENGTH_i} + \beta_{11}\mathrm{DEGREE_i} + \beta_{12}\mathrm{STATUS2_i} + \beta_{13}\mathrm{STATUS3_i} \\ & + \beta_{14}\mathrm{STATUS4_i} + \beta_{15}\mathrm{CAREER1_i} + \beta_{16}\mathrm{CAREER2_i} + \beta_{17}\mathrm{CAREER3_i} \\ & + \beta_{18}\mathrm{CAREER4_i} + \beta_{19}\mathrm{INCOME2_i} + \beta_{20}\mathrm{INCOME3_i} + \beta_{21}\mathrm{INCOME4_i} \\ & + \beta_{22}\mathrm{INCOME5_i} + \beta_{23}\mathrm{INCOME6_i} + \mathrm{e_{ij}}, \end{aligned} \tag{3.10}$$

where WTP_i is the willingness to pay to reduce GHG emissions for each respondent i (i = 1, 2, …., 863) in 2014 when the survey was collected, β are parameters to be estimated using maximum likelihood, and e is a random error term. WTP_i was specified as a function of GHG information and respondent's personal characteristics. The definitions and hypothesized signs of variables are shown in Table 3.1.

Model results

The number of observations used in the model development was 863. The summary of mean, standard deviation, minimum and maximum values of variables is shown in Table 3.3. To avoid perfect collinearity, AGE1, STATUS1, CAREER5 and INCOME1 were set as reference categories. Table 3.4 presents multicollinearity diagnostics, revealing that the mean VIF was 1.96. The maximum VIF, with a value of 4.60, was CAREER1 and the minimum VIF was SUPPORT, with a value of 1.05. Because the VIFs are less than 10, multicollinearity is unlikely to affect the estimated coefficients or affect inferences drawn from test using the standard errors.

The regression results reveal that seven variables were significant in explaining the WTP of the respondents. The variables CONCERN, SUPPORT, DEGREE, and INCOME6 were positively related to WTP, while AGE2, CAREER1, and CAREER3 were negatively related (Table 3.5). The log likelihood was – 446.48. The likelihood ratio chi square with p-value of 0.000 indicates that the model fit the data. Marginal effects were applied as interpretation because they measure the instantaneous rate of change for the variables (Williams, 2015). Following the interpretation of marginal effects for logistic regression of Torres-Reyna (2014), the marginal effects showed the change in probability when the predictor or independent variable increases by one unit.

Table 3.1. Definitions of dependent and independent variables and hypothesized signs in willingness to pay.

Variable	Definition	Hypothesized Sign
Dependent Variable		
WTP	Respondent would be willing to pay to reduce GHG emissions from LULUCF.	NA
Independent Variables		
CONCERN	Respondent who were very concerned, concerned or slightly concerned about environmental and natural resource issues (yes=1; else=0).	+
CONSUMER	If the respondents answered that at least consumers should be responsible to pay for greenhouse gas emissions from land-use change and forest activities when you purchase products/service from these sections (yes=1; else=0).	+
SUPPORT	Respondent who would strongly support and support a national policy requiring Thai citizens to pay for reducing greenhouse gas emissions from LULUCF (yes=1; else=0).	+
AGE1[a]	Age of respondent between 18 and 24 years old (yes=1; else=0).	NA
AGE2	Age of respondent between 25 and 30 years old (yes=1; else=0).	+
AGE3	Age of respondent between 31 and 45 years old (yes=1; else=0).	+
AGE4	Age of respondent between 46 and 55 years old (yes=1; else=0).	+
AGE5	Age of respondent between 56 and 65 years old (yes=1; else=0).	+
AGE6	Age of respondent greater than 65 years old (yes=1; else=0).	+
BANGKOK	Respondent is a Bangkok resident (yes =1; else = 0).	
LENGTH	Length of living in Bangkok. Respondents lived more than 15 years in Bangkok (yes =1; else = 0).	+
DEGREE	Respondents who had at least bachelor's or higher degree.	+
STATUS1[a]	Respondent was single when he/she answered the survey (yes=1; else=0).	NA
STATUS2	Respondent was marriage when he/she answered the survey (yes=1; else=0).	+
STATUS3	Respondent was divorced when he/she answered the survey (yes=1; else=0).	+
STATUS4	Respondent was other status when he/she answered the survey (yes=1; else=0).	+
CAREER1	Respondent was a student when he/she answered the survey (yes =1; else=0).	–
CAREER2	Respondent worked as self-employed when he/she answered the survey (yes=1; else=0).	+
CAREER3	Respondent worked in private organization when he/she answered the survey (yes=1; else=0)	+
CAREER4	Respondent worked in government organization when he/she answered the survey (yes=1; else=0)	+
CAREER5[a]	Respondent worked in other organizations when he/she answered the survey (yes=1; else=0)	N/A
INCOME1[a]	Respondent who had less than 100,000 THB of annual estimated taxable household income (yes=1; else=0)	NA
INCOME2	Respondent who had annual estimated taxable household income between 100,000 - 500,000 THB (yes=1; else=0)	+
INCOME3	Respondent who had annual estimated taxable household income between 500,001 – 1,000,000 THB (yes=1; else=0)	+

Table 3.1 (cont.). Definitions of dependent and independent variables and hypothesized signs in willingness to pay.

Variable	Definition	Hypothesized Sign
Independent Variables		
INCOME4	Respondent who had annual estimated taxable household income between 1,000,001 – 1,500,000 THB (yes=1; else=0)	+
INCOME5	Respondent who had annual estimated taxable household income between 1,500,001 – 2,000,000 THB (yes=1; else=0)	+
INCOME6	Respondent who had annual estimated taxable household income more than 2,000,000 THB (yes=1; else=0)	+

[a] Reference categories excluded from logistics regression (NA = Not available).

For continuous variables, this represents the instantaneous change given that the unit may be very small, while for binary variables, the change is from 0 to 1 (Torres-Reyna, 2014; Gallistel, 2015). Results of the marginal effects suggested that holding other variables at their mean values, the likelihood of WTP increased by 21% among respondents concerned about environmental and natural resource issues compared to people who were not concerned. People who support national policies such as emission taxes and carbon credits had a 26% higher likelihood of WTP compared to those who did not. The likelihood of WTP decreased by approximately 12% when the age category of the respondents changed from 18 to 24 years to 25 to 30 years.

The likelihood of WTP increased by about 55% if respondents had bachelor’s degree or higher compare to people who did not. The likelihood of WTP would be decreased by 15.6% and 19.4% if the respondents were students and working at the private companies, respectively, relative to people working at other organizations. Finally, people who had household income more than 2,000,001 THB were 14.6% more likely to be WTP than people who had a household income less than 100,000 THB. Finally, it was hard to calculate for mean or median from the range of WTP in the survey but the likelihood of Thai citizens’ WTP was the range of 1.00 – 4.99 THB.

Table 3.2. Summary of frequency and percentage for variables used in the logistic model.

Variable	Category	Frequency	Percent (%)
WTP	0	293	33.95
	1	570	66.05
CONCERN[a]	0	101	11.73
	1	760	88.27
CONSUMER[b]	0	702	81.53
	1	159	18.47
SUPPORT[c]	0	266	31.04
	1	591	68.96
AGE[d]	AGE1	317	36.99
	AGE2	198	23.10
	AGE3	230	26.84
	AGE4	74	8.63
	AGE5	24	2.80
	AGE6	14	1.63
BANGKOK[e]	0	335	39.09
	1	522	60.91
LENGTH[f]	0	298	37.06
	1	506	62.94
DEGREE[g]	0	199	26.75
	1	545	73.25
STATUS[h]	STATUS1	586	68.94
	STATUS2	227	26.71
	STATUS3	26	3.06
	STATUS4	11	1.29
CAREER[i]	CAREER1	273	32.12
	CAREER2	169	19.88
	CAREER3	188	22.12
	CAREER4	154	18.12
	CAREER5	66	7.76
INCOME[j]	INCOME1	112	13.32
	INCOME2	309	36.74
	INCOME3	221	26.28
	INCOME4	87	10.34
	INCOME5	46	5.47
	INCOME6	66	7.85

[a] Respondents who were very concerned and concerned about environmental and natural resource issues.
[b] Consumers should be responsible to pay for GHG emissions from LULUCF when you purchase products/services
[c] Respondents who were strongly support and support a national policy requiring Thai citizens to pay for reducing GHG from LULUCF.
[d] AGE1 = age of 18 – 24 years old; AGE2 = age of 25 - 30 years old; AGE3 = age of 31 – 45 years old; AGE4 = age of 46 - 55 years old; AGE5 = age of 56 - 65 years old; AGE6 = age more than 65 years old.
[e] Respondent was a Bangkok resident.
[f] Respondents lived 16 years or more in Bangkok.
[g] Respondents who had at least bachelor's or higher degree. All values were calculated before using the weighting adjustment.
[h] STATUS1 = single; STATUS2 = marriage; STATUS3 = divorced; STATUS4 = other status.
[i] CAREER1 = student; CAREER2 = self-employed; CAREER3 = private organization, CAREER4 = government organization; CAREER5 = other organizations.
[j] INCOME1 = less than 100,000 THB of annual estimated taxable household income; INCOME2 = annual estimated 100,000 - 500,000 THB; INCOME3 = 500,001 – 1,000,000 THB; INCOME4 = 1,000,001 – 1,500,000 THB; INCOME5 = 1,500,001 – 2,000,000 THB; INCOME6 = more than 2,000,000 THB.

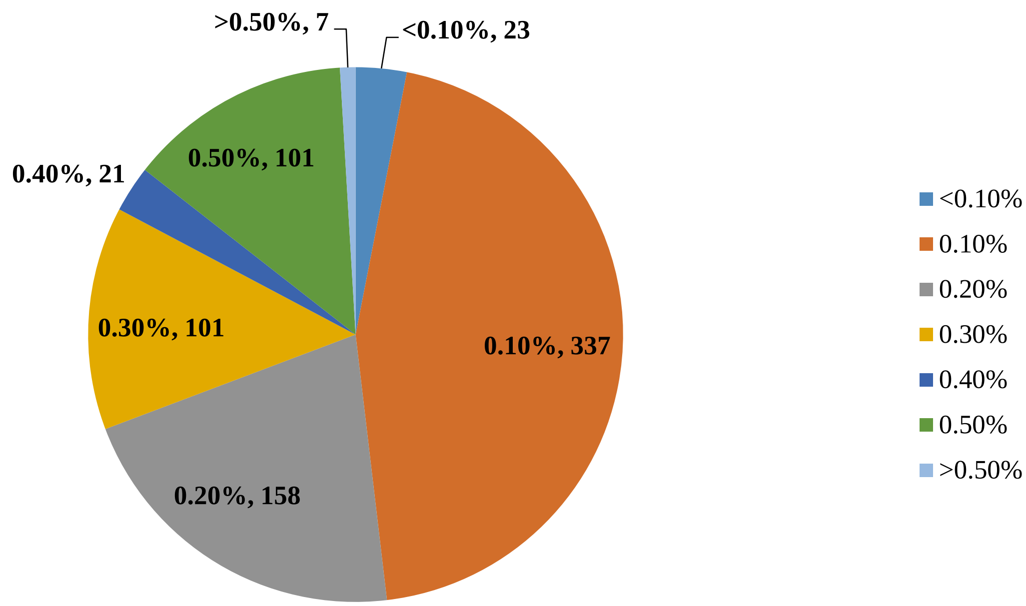

Figure 3.2. Responses to 'What percent of the price of an item or service would you be willing to pay as a tax to reduce the amount of greenhouse gases emitted from land-use change or forest activities?'

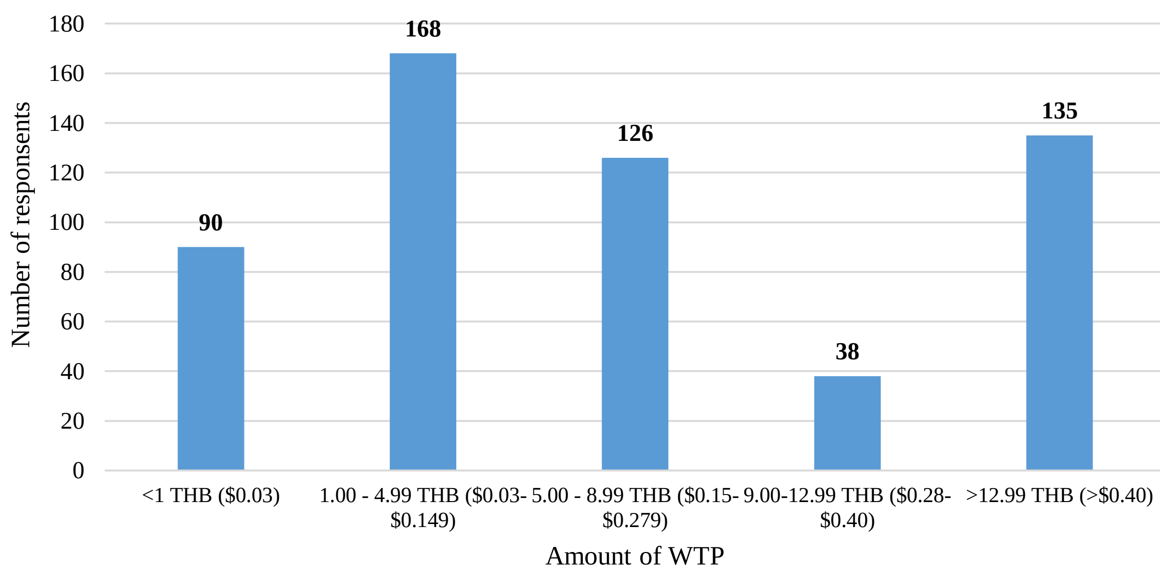

Figure 3.3. Amount Bangkok residents would be willing to donate for reducing GHG emissions from LULUCF.

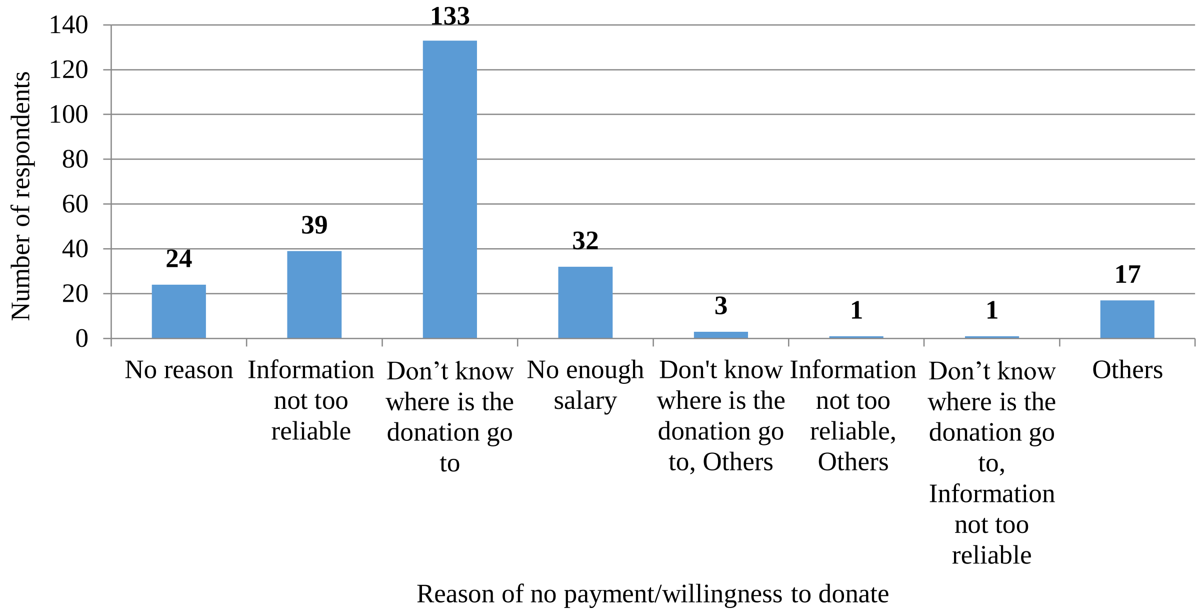

Figure 3.4. Number of respondents answering 'yes' with 0 THB or 'no, what are the reasons?'

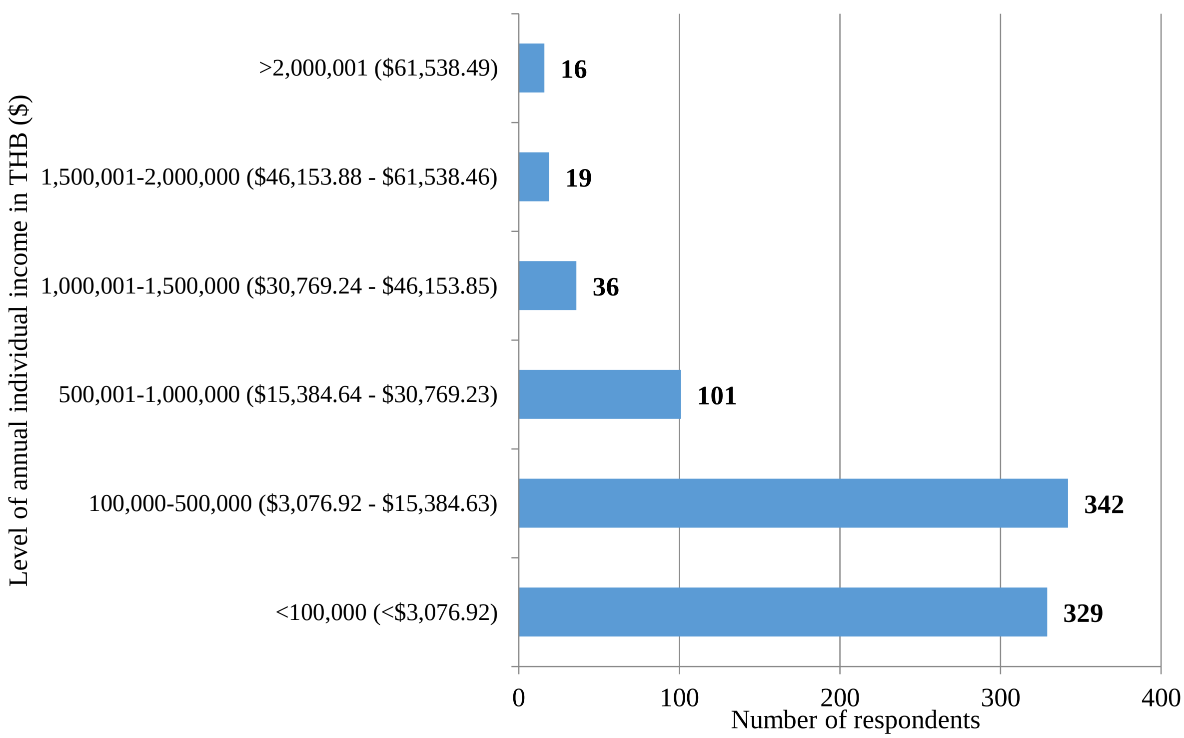

Figure 3.5. Annual individual income (Unit: THB).

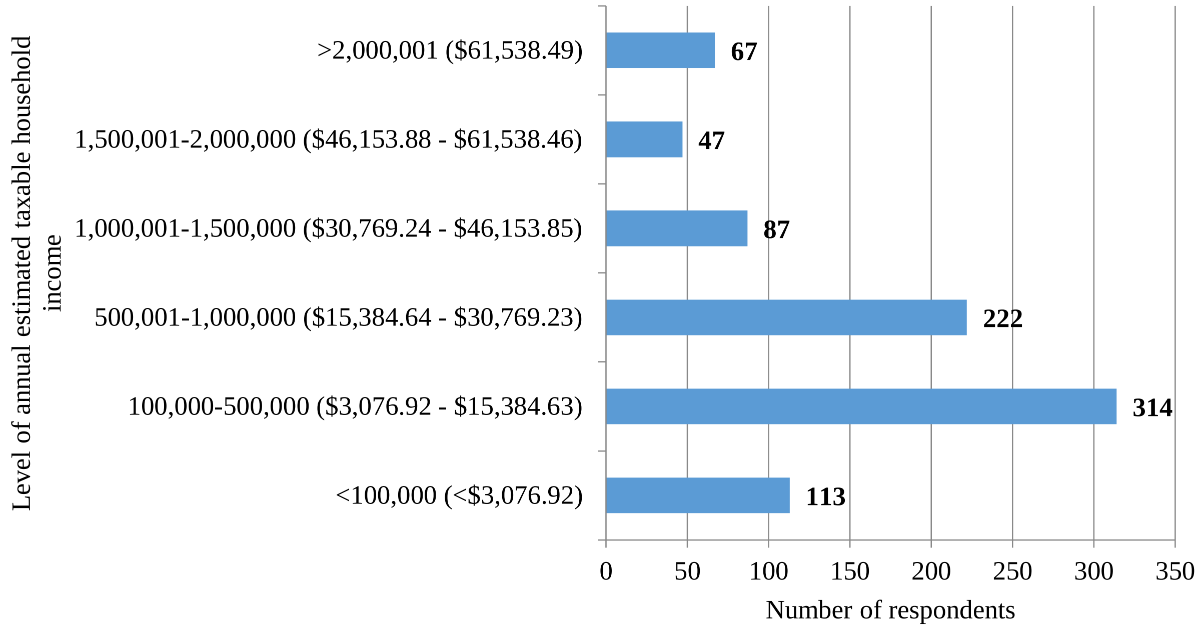

Figure 3.6. Total annual estimated taxable household income (Unit: THB).

Discussion and Conclusions

This chapter reports on a survey of respondents to a survey conducted in Bangkok regarding attitudes about reducing GHG emissions from LULUCF. The results reveal that 570 people were willing to pay for reductions, while 293 were not. A logistic method was used to fit the model and binary choice model was specified to represent the dichotomous decision to pay for GHG mitigation from LULUCF. The likelihood of WTP for reducing GHG from LULUCF was assumed to depend on respondent who were very concerned, concerned or slightly concerned about environmental and natural resource issues (CONCERN); the respondents answered that at least consumers should be responsible to pay for greenhouse gas emissions from land-use change and forest activities when you purchase products/service from LULUCF (CONSUMER);

Table 3.3. Summary of mean, standard deviation, minimum and maximum values.

Variable	Mean	Std. Dev.[a]	Min[b]	Max[c]
CONCERN[d]	0.883	0.322	0	1
CONSUMER[e]	0.185	0.388	0	1
SUPPORT[f]	0.689	0.463	0	1
AGE2[g]	0.231	0.422	0	1
AGE3[g]	0.268	0.443	0	1
AGE4[g]	0.086	0.281	0	1
AGE5[g]	0.028	0.165	0	1
AGR6[g]	0.016	0.127	0	1
BANGKOK[h]	0.609	0.488	0	1
LENGTH[i]	0.629	0.483	0	1
DEGREE[j]	0.735	0.442	0	1
STATUS2[k]	0.267	0.443	0	1
STATUS3[k]	0.031	0.172	0	1
STATUS4[k]	0.013	0.113	0	1
CAREER1[l]	0.321	0.467	0	1
CAREER2[l]	0.199	0.399	0	1
CAREER3[l]	0.221	0.415	0	1
CAREER4[l]	0.181	0.385	0	1
INCOME2[m]	0.367	0.482	0	1
INCOME3[m]	0.263	0.440	0	1
INCOME4[m]	0.103	0.305	0	1
INCOME5[m]	0.055	0.228	0	1
INCOME6[m]	0.078	0.269	0	1

[a] Standard deviation.
[b] Minimum value.
[c] Maximum value.
[d] Respondents who were very concerned and concerned about environmental and natural resource issues.
[e] Consumers should be responsible to pay for GHG emissions from LULUCF when you purchase products/services
[f] Respondents who were strongly support and support a national policy requiring Thai citizens to pay for reducing GHG from LULUCF.
[g] AGE1 = age of 18 – 24 years old; AGE2 = age of 25 - 30 years old; AGE3 = age of 31 – 45 years old; AGE4 = age of 46 - 55 years old; AGE5 = age of 56 - 65 years old; AGE6 = age more than 65 years old.
[h] Respondent was a Bangkok resident.
[i] Respondents lived more than 15 years in Bangkok.
[j] Respondents who had at least bachelor's or higher degree. All values were calculated before using the weighting adjustment.
[k] STATUS1 = single; STATUS2 = marriage; STATUS3 = divorced; STATUS4 = other status.
[l] CAREER1 = student; CAREER2 = self-employed; CAREER3 = private organization, CAREER4 = government organization; CAREER5 = other organizations.
[m] INCOME1 = less than 100,000 THB of annual estimated taxable household income; INCOME2 = annual estimated taxable household income between 100,000 - 500,000 THB; INCOME3 = annual estimated taxable household income between 500,001 – 1,000,000 THB; INCOME4 = annual estimated taxable household income between 1,000,001 – 1,500,000 THB; INCOME5 = annual estimated taxable household income between 1,500,001 – 2,000,000 THB; INCOME6 = annual estimated taxable household income more than 2,000,000 THB.
Note: reference categories excluded from logistic regression.

Table 3.4. Multicollinearity diagnostics for logistic model.

Variable	VIF[a]
CONCERN[b]	1.08
CONSUMER[c]	1.07
SUPPORT[d]	1.05
AGE2[e]	2.05
AGE3[e]	2.57
AGE4[e]	1.87
AGE5[e]	1.34
AGR6[e]	1.23
BANGKOK[f]	1.77
LENGTH[g]	1.84
DEGREE[h]	1.16
STATUS2[i]	1.51
STATUS3[i]	1.17
STATUS4[i]	1.06
CAREER1[j]	4.60
CAREER2[j]	3.13
CAREER3[j]	3.38
CAREER4[j]	3.08
INCOME2[k]	2.54
INCOME3[k]	2.49
INCOME4[k]	1.91
INCOME5[k]	1.41
INCOME6[k]	1.66

[a] Variance inflation factor.

[b] Respondents who were very concerned and concerned about environmental and natural resource issues.

[c] Consumers should be responsible to pay for GHG emissions from LULUCF when you purchase products/services

[d] Respondents who were strongly support and support a national policy requiring Thai citizens to pay for reducing GHG from LULUCF.

[e] AGE1 = age of 18 – 24 years old; AGE2 = age of 25 - 30 years old; AGE3 = age of 31 – 45 years old; AGE4 = age of 46 - 55 years old; AGE5 = age of 56 - 65 years old; AGE6 = age more than 65 years old.

[f] Respondent was a Bangkok resident.

[g] Respondents lived more than 15 years in Bangkok.

[h] Respondents who had at least bachelor’s or higher degree.

[i] STATUS1 = single; STATUS2 = marriage; STATUS3 = divorced; STATUS4 = other status.

[j] CAREER1 = student; CAREER2 = self-employed; CAREER3 = private organization, CAREER4 = government organization; CAREER5 = other organizations.

[k] INCOME1 = less than 100,000 THB of annual estimated taxable household income; INCOME2 = annual estimated 100,000 - 500,000 THB; INCOME3 = 500,001 – 1,000,000 THB; INCOME4 = 1,000,001 – 1,500,000 THB; INCOME5 = 1,500,001 – 2,000,000 THB; INCOME6 = more than 2,000,000 THB.

Table 3.5. Marginal effects from logistic model.

Variable	Marginal effects[a]	Std. Err.[b]
CONCERN[c]	0.209***	0.055
CONSUMER[d]	0.076	0.051
SUPPORT[e]	0.258***	0.038
AGE2[f]	-0.117*	0.063
AGE3[f]	-0.105	0.067
AGE4[f]	0.079	0.092
AGE5[f]	-0.157	0.119
AGR6[f]	-0.185	0.143
BANGKOK[g]	-0.081	0.051
LENGTH[h]	-0.033	0.051
DEGREE[i]	0.546***	0.208
STATUS2[j]	-0.052	0.050
STATUS3[j]	-0.046	0.108
STATUS4[j]	0.267	0.173
CAREER1[k]	-0.156*	0.087
CAREER2[k]	-0.032	0.083
CAREER3[k]	-0.194**	0.081
CAREER4[k]	-0.066	0.084
INCOME2[l]	0.109	0.058
INCOME3[l]	0.018	0.062
INCOME4[l]	0.087	0.079
INCOME5[l]	0.121	0.097
INCOME6[l]	0.146*	0.089

[a] A marginal effect indicates the change in predicted probability of WTP for a unit change in an explanatory variable. Marginal effects of continuous variables were calculated at the means of the data. For dummy variables, a value of 0 was used if the mean was less than 0.5 and a value of 1 if the mean was greater than or equal to 0.5.

[b] Standard error.

[c] Respondents who were very concerned and concerned about environmental and natural resource issues.

[d] Consumers should be responsible to pay for GHG emissions from LULUCF when you purchase products/services

[e] Respondents who were strongly support and support a national policy requiring Thai citizens to pay for reducing GHG from LULUCF.

[f] AGE1 = age of 18 – 24 years old; AGE2 = age of 25 - 30 years old; AGE3 = age of 31 – 45 years old; AGE4 = age of 46 - 55 years old; AGE5 = age of 56 - 65 years old; AGE6 = age more than 65 years old.

[g] Respondent was a Bangkok resident.

[h] Respondents lived more than 15 years in Bangkok.

[i] Respondents who had at least bachelor's or higher degree.

[j] STATUS1 = single; STATUS2 = marriage; STATUS3 = divorced; STATUS4 = other status.

[k] CAREER1 = student; CAREER2 = self-employed; CAREER3 = private organization, CAREER4 = government organization; CAREER5 = other organizations.

[l] INCOME1 = less than 100,000 THB of annual estimated taxable household income; INCOME2 = annual estimated 100,000 - 500,000 THB; INCOME3 = 500,001 – 1,000,000 THB; INCOME4 = 1,000,001 – 1,500,000 THB; INCOME5 = 1,500,001 – 2,000,000 THB; INCOME6 = more than 2,000,000 THB.

*, **, *** Significant at the 10%, 5%, and 1% levels, respectively.

respondent who would strongly support and support a national policy requiring Thai citizens to pay for reducing greenhouse gas emissions from LULUCF (SUPPORT); age of respondent between 25 and 30 years old (AGE2), 31 and 45 years old (AGE3), 46 and 55 years old (AGE4), 56 and 65 years old (AGE5), greater than 65 years old (AGE6); respondent is a Bangkok resident (BANGKOK); length of living in Bangkok. Respondents lived more than 15 years in Bangkok (LENGTH); respondents who had at least bachelor's or higher degree (DEGREE); respondent was marriage (STATUS2), divorced (STATUS3), other status (STATUS4); respondent was a student when he/she answered the survey (CAREER1), self-employed (CAREER2), worked in private organization (CAREER3), worked in government organization (CAREER4); respondent who had annual estimated taxable household income between 100,000 - 500,000 THB (INCOME2), between 500,001 – 1,000,000 THB (INCOME3), between 1,000,001 – 1,500,000 THB (INCOME4), between 1,500,001 – 2,000,000 THB (INCOME5), and more than 2,000,000 THB (INCOME6). Age of respondent between 18 and 24 years old (AGE1), respondent was single when he/she answered the survey (STATUS1), respondent worked in other organizations (CAREER5), and respondent who had less than 100,000 THB of annual estimated taxable household income (INCOME1) were set as reference categories.

There were no multicollinearity among variables. Marginal effects were applied to measure the effects of changes in an explanatory variable on the likelihood of WTP while holding other variables constant. Results reveal that seven significant variables affect the WTP of Thai citizens. Respondent who were very concerned, concerned or slightly concerned about environmental and natural resource issues (CONCERN), respondent who would strongly support and support a national policy requiring Thai citizens to pay for reducing greenhouse gas emissions from LULUCF (SUPPORT), respondents who had at least bachelor's or higher degree (DEGREE), and respondent who had annual estimated taxable household income more than 2,000,000 THB (INCOME6) were negatively related. The popular range of WTP for Thai citizens' WTP was the range of 1.00 – 4.99 THB.

Although no research has been conducted on the willingness to address GHG emissions resulting from LULUCF in Thailand, some researchers have investigated climate change or environmental and natural resources. Several researchers have reported that the greater the environmental concern, the larger the WTP (e.g., Kotchen and Reiling, 2000; Cooper et al., 2004; Liebe et al., 2011). Liebe et al. (2011) found that altruistic/moral behavior (e.g., supporting environmental projects) increased the probability of being willing to pay. But a study by O'Connor et al. (2002) in central Pennsylvania revealed that even though respondents were more likely to accept voluntary actions (e. g., buying efficient appliances and lights, using natural gas, and adjusting the thermostat in ways that reduce the utility bill) they did not vote for government programs to reduce GHG emissions.

Pettenella et al. (2013) concluded that people younger than 35 years of age are less willing to pay for GHG emission reductions and Carlsson et al. (2012) mentioned that age was negatively correlated to WTP in Sweden, but not significant in the U.S. or China. While some research suggests that younger people are more willing to pay for GHG emission reductions (e.g., Duan et al., 2014). Curry (2004) found that younger people were positively inclined toward WTP for climate change mitigation by $2.03 above the mean.

Also, much research reveals that higher educational attainment is related to greater WTP for climate change mitigation (e.g., Blomquist and Whitehead, 1998; Witzke and Urfei, 2001; Li et al., 2004; Hersch and Viscusi, 2005; Koundouri et al., 2009; Kotchen et al., 2011; Carlsson et al. 2012; Kotchen et al., 2013; Duan et al., 2014). Others reported that higher income increased

WTP (e.g., Batley et al., 2001; Damigos and Kaliampakos, 2003; Zarnikau, 2003; Wang et al., 2007). People who are concerned about environmental and natural resource issues and policies are more likely to be willing to pay for environmental protection because they might want to conserve biological diversity (e.g., plants, animals, microorganism and ecosystems) (Swingland, 2001) to enhance the likelihood of their survival. Undoubtedly, young adults between the ages of 25 and 45 years are not as willing to pay, possibly because they want to save money for retirement and spend income for living expenses and enhancing family life (e. g., house, car, children's tuitions). People with at least college degree were more likely to be willing to pay for reducing GHG because they might obtain more information about environmental degradation from classes or social media than less educated citizens. Finally, household income was positively related to WTP because those with larger incomes might be able to afford supporting GHG reductions from LULUCF.

The Office of Natural Resources and Environmental Policy and Planning (INDC) announced that Thailand intends to reduce its GHG emissions by 20% from the business-as-usual (BAU) level by 2030, but whether to include land use, land-use change and forestry will be decided later. The following plans were already approved or in the process of approval by the Cabinet: national economic and social development plans, climate change master plan (2015-2050), power development plan (2015-2036), power development plan (2015-2036), Thailand smart grid development master plan (2015-2036), energy efficiency plan (2015-2036), alternative energy development plan (2015-2036), environmentally sustainable transport system plan (2013-2030), national industrial development master plan (2012-2031), and waste management roadmap (ONEP, 2015).

Additionally, a number of scientists have recommended several plans which would help Thailand decrease GHG emissions and increase carbon sequestration from land-use change and forest activities - namely promoting bioenergy production (Chantawong and Dhakal, 2016); reducing agricultural emissions (e.g., reduced tillage agriculture) (Linn and Doran, 1984); improving land management (e.g., increase of reforestation and agroforestry, decrease of deforestation) (Dixon et al., 1993; Brown et al., 1996; Niles et al., 2002), and passing policies related to property rights, forest management, and agricultural land-use (Hyde et al., 1996). Therefore, not only farmers and producers, Thai government should stimulate all citizens to realize about the situation of climate change and persuade them to pay more attention to environment.

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Appendix

2014 Thai People's Attitude of Reducing Greenhouse gas (GHG) Emissions from Land Use, Land-Use Change, and Forest Activities Survey

You are invited to participate in a research study for Pattarawan Watcharaanantapong, a PhD student at the University of Tennessee, in the U.S. You will be asked about your opinion on various issues, with the main focus on understanding Thai attitudes regarding reducing greenhouse gas (GHG) emissions from land-use change and forest activities. There are no known risks associated with this survey. We cannot and do not guarantee or promise that you will receive any benefits from this study. Your participation in this survey will take approximately 15 minutes.

If you have read this survey and are willing to participate in this survey, please understand your participation is voluntary and you have the right to withdraw your consent or discontinue participation at any time. You may refuse to answer any particular question, and your responses will be completely confidential. Your responses will be aggregated with those from all participants. No attempt will be made to associate your name or identity with your answers. Therefore, please do not provide your name or address as part of your response.

If you have any questions, concerns, or complaints about this study, its procedures, risks, or benefits, please ask the Survey Director, Pattarawan Watcharaanantapong, utksurvey@gmail.com or you can write to:

Pattarawan Watcharaanantapong
Department of Forestry, Wildlife and Fisheries
The University of Tennessee
Knoxville, Tennessee
U.S.A. 37996-4518

Thank you for participating in this survey
Sincerely,

Pattarawan Watcharaanantapong

2014 Thai Attitudes for Reducing Greenhouse Gas (GHG) Emissions from Land-Use Change and Forest Activities Survey
Please check and give more information for each question

***Greenhouse Gas Information*:**

1. How concerned are you about environmental and natural resource issues?
______Very Concerned
______ Concerned
______ Neutral/Don't Know
______Slightly Concerned
______Not at all Concerned

2. Have you heard of greenhouse gases? Yes______ No______
if yes, what are your sources of greenhouse gas information? (check all that apply):
______School
______TV
______ Newspaper
______ Internet
______ Friend
______ Family
______ Others

3. Which gas is most often emitted into the atmosphere?
______Carbon dioxide
______ Methane
______ Nitrous Oxide
______ Fluorinated gases
______ Others, please define____________

4. What is the most common source of ***greenhouse gas*** emissions?
______Transportation
______ Industry
______ Agriculture
______ Electricity
______ Commercial and Residential Building
______ Land Use, Land-Use Change and Forestry
______ Others, please define____________

5. What is the most common source of ***carbon dioxide*** emissions?

______Transportation
______ Industry
______ Agriculture
______ Electricity
______ Commercial and Residential
______ Land Use, Land-Use Change and Forestry
______ Others, please define____________

6. Can carbon dioxide can be emitted from land-use change or forest activities (e.g., deforestation, forest degradation)

______ Yes
______ No

7. Who should be responsible to pay for greenhouse gas emissions from land-use change and forest activities when you purchase products/service from these sections?

_______ Government
_______ Consumers
_______ Producers
_______ Others

8. Would you support a national policy requiring Thai citizens to pay for reducing greenhouse gas emissions from land-use change or forest activities?

______Strongly Support
______ Support
______ Neutral/Don't Know
______Oppose
______Strongly Oppose

9. What percent of the price of an item or service would you be willing to pay as a tax to reduce the amount of greenhouse gases emitted from land-use change or forest activities?

_______ 0.1% (For example, how much for an item costing 20 baht)
_______ 0.2%
_______ 0.3%
_______ 0.4%
_______ 0.5%
_______>0.5%

10. Would you be willing to donate to reduce greenhouse gas emissions from land-use change or forest activities? Yes______ No_______

If yes, how much

_______0 THB

_______<1 THB

_______1.00 - 4.99

_______5.00- 8.99

_______9.00-12.99

_______>12.99

If you answered 0 THB, what are the reasons?

No reason______ Information not too reliable______ Don't know where is the donation go to______

No enough salary______ Others____

11. Should Thailand pay more attention to reduce greenhouse gas emissions?

______Strongly Agree

______ Agree

______ Neutral/Don't Know

______Disagree

______Strongly Disagree

Personal Information

12. Age (years): < 18 _____ 18-24_____ 25-30_____ 31-45_____ 46-55_____ 56-65______ > 65 _____

13. Where were you born? Center_____ North_____ East_____ West _____ South _____ Northeast_____

14. Are you a Bangkok resident? Yes_____ No_____15. Are you currently living in Bangkok? Yes_____ No_____

16. How long have you lived in Bangkok (Unit: years)? < 1 _____ 1-5 _____ 6-10_____ 11-15_____ 16-20_____

> 20_____

17. Do you currently work in Bangkok? Yes_____ No_____, if no, please go to Q.19.

18. In what area of Bangkok do you work? Center_____ East_____ West_____ North _____ South _____

19. Check highest degree received:

Less than Elementary ______ Elementary ______ Middle School _____ High school _____ GED _____ Associate _____ Bachelors _____ Graduate degree _____ No School_____

20. Number of years of formal education excluding kindergarten? ______

21. Status: Single _____ Marriage _____ Divorced _____ Others_____

22. How many children do you have? _____

23. Number of family members living in the household ______

24. Type of career: Student_____ Self-employed_____ Private _____ Government _____ Others_____

25. Annual individual income (Unit: THB):
_____< 100,000
_____ 100,000-500,000
_____ 500,001-1,000,000
_____ 1,000,001-1,500,000
_____ 1,500,001-2,000,000
_____ >2,000,001

26. Please check the category that best reflects your total annual estimated taxable household income (Unit: THB):
_____< 100,000
_____ 100,000-500,000
_____ 500,001-1,000,000
_____ 1,000,001-1,500,000
_____ 1,500,001-2,000,000
_____ >2,000,001

CONCLUSION

This dissertation examined the factors influencing GHG emissions from LULUCF. The main objectives of the study were to assess the impacts of LULUCF on GHG emissions at a global and national scale, determine the willingness of Bangkok residents to pay for reducing GHG emissions from LULUCF, and review methods to mitigate GHG emissions and increase GHG sequestration from LULUCF. Econometric methods such as fixed effects and logistic model were applied to analyze factors affecting GHG emissions from LULUCF.

Chapter 1 examined the variables related to GHG emissions as a whole, and specific component gases, in Annex I countries. Varibles that were significantly related to total GHG emissions included per capita value added in agriculture (AGRI), which was negatively related, with a 1% increase in AGRI leading to a 0.018% decrease in GHG emission; female employment in agriculture (AGFE) with a negative elasticity for emissions of -0.029. Conversely, a 0.040% increase in GHG emissions resulted from a 1% increase in male employment in agriculture (AGMA). Population (POPU) was negatively related to emissions, with a 1% increase in population decreasing emissions by 0.188%. The portion of rural population was not significant. Similar results were found for the CO_2 and CH_4 emissions models. The relationship between CH_4 emissions and population was characterized as U-shaped, meaning that the rate of CH_4 emissions started to decrease during the increased population increased when population exceeded 156.07 million people. The relationship between CH_4 emissions and the percentage of female employment was determined to be an inverted U-shape.

The GHG emission model described in Chapter 2 reveals that population, percent of the population at least a bachelor's degree, and precipitation were statistically significant. Population was negatively related to net GHG emissions, meaning that when the population increased, net

U.S. GHG emissions from LULUCF decreased. The negative relationship between net emissions and population might be due to a number of factors, including national and state public policies that either directly or indirectly reduce GHG emissions and/or increase sequestration. Market-based policies (e. g., carbon pricing), for example, have been adopted at the state level. Educational attainment was negatively related to net GHG emission levels as well possibly due to the effect of education could environmental attitudes and behaviors. Precipitation, another variable exhibiting a negative relationship with net GHG emissions can encourage plants to intake more CO_2.

Chapter 3 addressed the willingness of Bangkok residents to pay for reduced GHG emissions from LULUCF. Seven variables were identified as being significantly related to WTP. These included level of concern about environmental and natural resources (positively related to WTP), support for GHG national policies (positively related), age (negative), education (positive), employment type (negative), and income (positive). In terms of emission reductions, Bangkok residents' WTP varied by a number of variables related to demographic characteristics and attitudes. Even though no research has been conducted regarding willingness to pay on GHG emissions from LULUCF in Thailand, prior research investigated similar variables affecting on climate change or environmental and natural resources (Kotchen and Reiling, 2000; Batley et al., 2001; Witke and Urfei, 2001; Cooper et al., 2004; Liebe et al., 2011; Carlsson et al., 2012; Pettenella et al., 2013; Duan et al., 2014).

A variety of alternative policies and actions are available to mitigate GHGs based on these findings. Carbon pricing including emissions trading systems (ETS) and carbon taxes, for example, can be implemented to enhance carbon sequestration through land use (C2ES, 2013; CTC, 2016; Kossoy et al., 2016). The ETS, sometimes known as cap-and-trade (CAP), controls total GHG emissions by utilizing emissions allowances purchased from a market. This allows industries with low emissions to sell their extra permits to larger polluters, as well as allowances to be purchased from LULUCF actions.

Another carbon pricing mechanism is a carbon tax that establishes a per ton fee for carbon emissions. As a consequence, emitters are incentivized to cut emissions, thereby reducing their tax payments. By increasing the tax rate over time, emission levels could be reduced (Kossoy et al., 2016). A number of countries have adopted carbon taxes. Finland and Poland, for example, have used carbon taxes since 1990 to reduce emissions, while the Russian Federation and China initiated carbon pricing in 2009 and 2013, respectively (Kossoy et al., 2016). Within the U.S., California implemented an ETS 2012, while Washington and Oregon established adopted carbon tax policies in 2015, although they are still under consideration (Kossoy et al., 2016).

Hybrid approaches offer an alternative to reduce GHG emissions by setting ceilings on the price of emissions-trading allowances and combining a tradable permit system with a government promise to sell additional permits at specified prices (McKibbin and Wilcoxen, 2002; Aldy et al., 2003). Although the Kyoto Protocol was designed to allow trading among participating countries, there have been strong pressure to limit trading and force countries to make most of their reductions domestically. The EU implementation of the Kyoto Protocol allows full trading within the EU countries but limits the purchases of emissions permits from non-EU countries. The lesson from foreign-trade barriers, where price and quantity limits have a much longer history, is that the quantity limits imposed through quotas are extremely durable (Nordhaus, 2007). Tradable emission permits can be used for gases other than CO_2 such as SO_2, N_2O, CH_4, and F-gases (e. g., HFCs, PFCs, and SF6) (Schmalensee et al., 1998; Burtraw, 2000; Ellerman, 2000).

Joint implementation (JI) is another mechanism used to assist countries meet their obligations. Under Article 6 of the Kyoto Protocol, JI states that any Annex I country can invest in an emission reduction project in any other Annex I country as an alternative to reducing domestic emissions. In this case, countries can reduce the costs of emissions reduction by participating or funding efforts in countries with less expensive emissions reduction options and use the resulting Emission Reduction Units (ERUs) toward their commitment goal (Yamin, 2012; UNFCCC, 2014).

In addition, reducing emissions from deforestation and forest degradation (REDD or REDD+) is a method used for reducing GHG emissions in developing countries (Agrawal et al., 2011). Reducing emissions from deforestation (RED) was first emerged by UNFCCC in the debate at the 11th Conference of the Parties (COP), Montreal, Canada in 2005 (Pistorius, 2012). At COP 13 in 2007, forest degradation was included to RED, so it has become REDD (Pistorius, 2012). In 2009, three activities including conservation of forest carbon stocks, sustainable management of forest, and enhancement of forest carbon stocks were added into REDD and it has known as REDD plus (+) (Agrawal, 2011; Pistorious, 2012). The concept of RED(D+) is to compensate to a country mitigating emissions from deforestation and forestry degradation, conserving forest carbon stocks, and enhancing sustainable management of forest and forest carbon stocks known as payments for environmental services (PES) supported by voluntary contributions such as the World Bank's Forest Carbon Partnership Facility (FCPF), United Nations REDD, and other bilateral arrangements (Agrawal, 2011; Angelson et al., 2009).

The European Union (EU) Commission identified a number of options for reducing GHG emissions including decreasing the conversion of grassland and the carbon losses from cultivating organic soils, improving agronomic practices (e.g., planting more leguminous crops) and extending crop rotations. Agro-forestry practices were offered as another option by the EU Comission because they improve soil carbon stocks and utilize land for livestock and crops on land on which trees are also grown. Organic materials can also be returned to or left on the land to improve the productivity of croplands and grasslands; rewetting, setting aside. or not draining organic soils, including peat land, and restoring degraded soils can have significant mitigation and biodiversity benefits (COM, 2012).

Biofuel production is another LULUCF alternative that has been demonstrated to reduce emissions from croplands of CO_2 by 42%, CH_4 by 16%, and N_2O by 10% (Cole et al., 1997). Farmers have adopted technologies such as no-till farming and strategic fertilizer placement that reduce emissions.

Improvements in animal productivity (e.g., liveweight gain, milk production) and fertility (e.g., lower culling, lower replacement rates), and intensification of production can mitigate GHG emissions from cattle production system (Crosson et al., 2011). Crosson et al. (2011) also found that agricultural soils plays an important role in carbon sequestration because they can offset emissions from pastures used for livestock production. On a global scale, livestock production contributes about 18% of GHG emissions, particularly CH_4 (e.g., domestic animals or livestock manures) and N_2O (e.g., land applied manures and grazed lands (Kebread et al., 2006; Masse et al., 2011). On-farm biogas production can be another solution to reduce GHG emissions related to livestock production. Because anaerobic bacteria can digest agricultural wastes (Yiridoe et al., 2009) and then produce renewable energy as biogas, it can be used as a substitute for coal, oil, and natural gas (Masse et al., 2011).

Afforestation and reforestation can mitigate climate change by sequestering (capturing) atmospheric carbon and storing it into the living and dead biomass in the ecosystem (e.g., soil organic carbon, tree biomass) (UNFCCC, 2013). The co-benefits of afforestation and reforestation include economic, ecological-environmental, socio-political, and cultural development. Examples of economic co-benefits from afforestation and reforestation include increasing the availability of wood and non-wood products (e.g., honey, bee wax, floral greenery), income, and economic engagement (e.g., share in carbon revenue); enhancing energy conservation and forest resource conservation; and and protecting infrastructure (e.g., reduced silting of reservoir; protection of roads, canals, railways and habitations) (UNFCCC, 2013). Ecological-environmental benefits in urban areas are reduced air pollution and noise, while rural areas benefit from reduced severity of wind and dust storms. The scheme of afforestation and reforestation could also promote community action and learning, increase participatory governance and civic awareness, and enhance well-being and community cohesion from green spaces (UNFCCC, 2013).

Even though many policies have been directly and indirectly used to reduce GHG emissions and increase sequestration from LULUCF in global, national, and local scale, few countries take their GHG reduction targets seriously. Therefore, the significant steps to mitigate climate change are needed, not only in the form of regulations, but also policies addressing socio-economic, environmental, and natural resource factors. The results from three chapters demonstrate that population and education played important roles in net GHG emissions. In general, more people produce more global GHG emissions. Although it is really difficult to control the population around the world, promoting birth control options to slow the growth rate is needed. In addition, governments should require producers from all sectors to buy credits for emitting GHGs into the atmosphere. The price of credits should differ by source size (e. g., smaller farm pays lower than bigger farms). Products produced from verified sustainably managed lands should be assisted by the government, by purchasing products and selling them at prices lower than or equivalent to those of unverified goods. National governments also should develop campaigns supporting climate change policies and actions via television, radio, and all social media.

As mentioned earlier, education affects environmental attitudes and behavior (O'Connor et al., 2002; Dietz et al., 2006; Flamm, 2009). Supporting higher education and providing more information about the causes of climate change can reduce a myriad of environmental problems. All educational levels should incorporate environmental sciences or natural resource subjects as mandatory courses, to instill an awareness of the importance of environmental conservation. Limited funding may be an obstacle to education requiring public intervention. Additionally, more research funding, especially for environmental and natural resources, is needed to further address the causes of climage change and possible mitigation and adaptation strategies.

In summary, more research is needed to predict ecosystem responses to climate change and address policy options related to GHG emissions. Last but not least, people must realize that environmental and natural resource issues are the responsibility of everyone, so they should pay more attention to maintain environment for their and following generation.

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VITA

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