Chapter 2

Underlying causes of deforestation and proximate causes of forest degradation in the Terai Arc Landscape of Nepal

Abstract

Determining the causes of deforestation and forest degradation has become increasingly important to understand the viability of greenhouse gas emissions reduction under the proposed incentive mechanism called 'Reducing Emissions from Deforestation and forest Degradation (REDD+)'. This study incorporates both deforestation and degradation components of REDD+ to address these intertwined problems. We used a newly–assembled panel data set that combines census data, agriculture and forestry production data, forest cover and biomass data of the Terai Arc Landscape of Nepal over a 19-year period to determine the drivers of deforestation and forest degradation. The evidence suggests that population growth, agricultural yield and property rights are the major underlying causes of deforestation, while fuel wood and timber extraction are contributing to forest degradation. To achieve the desired outcome of REDD+ in the landscape, reconciliation of current forest policy is essential, targeting reform of existing property rights and management regimes, agricultural intensification, timber and fuel wood substitution and switching of forest-dependent communities to alternative livelihoods.

Keywords: Deforestation, Forest degradation, REDD+, Reference emission level, Terai Arc Landscape

2.1 Background

Deforestation and forest degradation in the tropics has drawn considerable attention among research communities in the context of on-going discussion on the incentive mechanism called ‘reducing emissions from deforestation and forest degradation (REDD+)’. The proposed incentive mechanism involves payment to countries for reduced emissions through avoided deforestation and forest degradation. The concept of REDD+ can be ambiguous. Some people believe that the total carbon (C) stock stored in the forest can be used to directly calculate payments to countries. But REDD+ payments are made for additional C stored in the forests against a reference emission level[1] as discussed in chapter 1.

A reference emissions scenario describes C emissions and removals from forest cover change in the absence of REDD+. Participating countries are requested to determine forest reference emission levels, i.e. a national emissions and/or deforestation scenario expected in the absence of REDD+ on the basis of drivers of deforestation and forest degradation (UNFCCC, 2010). Determining accurate and credible reference emissions levels scenarios is both critical and challenging (Sloan & Pelletier, 2012) as it has enormous implications for the payments to developing countries (Busch et al., 2009). Angelsen (2008) pointed out the need for research to determine reference levels or reference emissions levels and to accurately predict deforestation without REDD+, while other elements of the baseline could be left to the political negotiation processes.

In addition to implications on future scenarios, drivers of deforestation and forest degradation determine economic viability of REDD+. REDD+ costs depend on implementation of activities to address those drivers (implementation cost) as well as foregone benefits of avoiding other land use options (opportunity cost). Possible benefits of participating in REDD+ are estimated on the basis of these costs against the proposed incentive per unit of emissions reductions. It is imperative to understand the drivers of deforestation and forest degradation to determine the cost efficiency of emissions reduction at sub-national and national scales.

In this context, economic modelling has become increasingly important to analyse the causes of deforestation and forest degradation and their impacts in greenhouse gas emissions (Angelsen, 1999; Bluffstone, 1995; Brown & Pearce, 1994; Kaimowitz & Angelsen, 1998). Despite the boom in deforestation modelling, universal causes of deforestation in the tropics remain elusive. Because of the variation in regional and country causes, it may not be possible to derive a more unified theory, and general models of deforestation will continue to use inappropriate variables and lack predictive value (Damette & Delacote, 2012). Such studies limit the overall significance of the results to project accurate reference scenario. Regional or sub-national scenarios are required because national approaches may not capture changes caused by on-going deforestation and degradation processes or positive impacts through conservation, sustainable forest management and enhancement of Carbon stock on local or regional level (Eckert, Ratsimba, Rakotondrasoa, Rajoelison, & Ehrensperger, 2011).

2.2 Introduction

Deforestation is the complete removal of trees from forested areas. The 'narrow' definition of deforestation, as termed by Wunder (2000); is focused on 'change in land use with depletion of crown cover to less than 10%' or conversion to another land cover type. In line with this 'narrow' description, FAO (2001) defined deforestation as 'the conversion of forest to another land use of the long-term reduction of the tree canopy cover below the minimum 10 percent threshold.' It is the direct human-induced conversion of forested land to non-forested land (UNFCCC, 2001). Deforestation is the permanent loss of forest cover and transformation into another land use either by a continued human-induced or natural perturbation. It includes areas where tree cover cannot be sustained above a 10 percent threshold because of over-utilization, or other environmental disturbances. The term 'deforestation' excludes areas of forest temporarily un-stocked but expected to regenerate naturally or with the aid of silvicultural measures (FAO, 2001).

A problem with these 'narrow' definitions of deforestation is that a loss of crown cover from a higher level such as 90% to a level just above the 10% threshold will not be considered as deforestation. A 'broader' definition of 'deforestation' includes both 'forest land use conversion' and 'forest degradation' in terms of temporary or permanent deterioration in density and structure, ecological services, biomass stocks, species diversity and composition (Grainger, 1993; Wunder, 2000; Zhu & Li, 2007). Forest degradation is a change in forest attributes caused by increase in disturbances that leads to a lower productive capacity. This 'broader' definition of deforestation postulates that forest degradation and deforestation tend to be intertwined phenomena in the sense that the former often precedes the latter

(Wunder, 2000) with the time-scale of a few years to a few decades (Lambin, 1999). From a REDD+ perspective, forest degradation refers to a loss of carbon stored in forest biomass within the remaining forest land. We appllied this broader definition of forest degradation in this study.

Deforestation contributes to global warming by emitting carbon dioxide (CO_2) stored in forest biomass in terms of carbon which subsequently adds to the stock of gases that trap heat in the atmosphere. According to the Food and Agricultural Organization (FAO) estimates, annual average deforestation in the tropics was 14.63 and 12.91 Mha per annum for the periods of 1980-1990 and 1990-1995, respectively. Global carbon emissions from these tropical deforestation and land-use changes ranged from 0.8 to 2.4 Gt C yr^{-1} for the 1990s (Houghton et al., 2000; Raupach et al., 2007; Schimel et al., 2001), accounting for 12–28% of the total annual anthropogenic greenhouse gas emissions (Watson, 2000). Similarly, forest disturbances that lead to degradation have been estimated to affect roughly 100 million hectare globally per year (FAO, 2006) which is considerably higher than the total area affected by deforestation. These degradations can contribute substantially to forest carbon emissions (Asner et al., 2005; Souza & Roberts, 2005a) and are much more pervasive than once believed (Foley et al., 2007).

Current discourse on REDD+ demands sound understanding of drivers of both deforestation and forest degradation to address the problem. Deforestation in the tropics has received much attention, but measuring forest degradation and related C stock changes have not been well characterized and reported. While COP 13 in Bali recognized the role of forest degradation as a major source of greenhouse gas emissions (Asner et al., 2005; Lambin et al., 2003; Marklund & Schoene, 2006), research communities are still not disposed to focus on it. The major factors behind this neglect are that 'forest degradation' denotes subjective values those are more difficult to detect using remote sensing techniques (Putz & Redford, 2010) and different criteria and indicators used in subsequent forest resources assessments mean that it is impossible to use it for comparison. To ensure positive impact on net emission reduction and avoid the risk that action on deforestation may increase degradation, it is imperative to understand which drivers and activities have led to forest degradation to provide a reference emission level (Obersteiner et al., 2009; Skutsch et al., 2011).

2.3 Causes of deforestation and forest degradation

A huge number of research articles and reviews are available on land use changes and deforestation from many disciplines including: economics (Barbier, 2001; Brown & Pearce, 1994; Kaimowitz & Angelsen, 1998); geography (Fuller & Chowdhury, 2006; Grainger, 1999; Kim, 2010; Munthali & Murayama, 2012; Wyman & Stein, 2010); property rights, natural sciences and combinations of those disciplines (Agrawal & Ostrom, 2001; Brown & Pearce, 1994; Lambin, 1997). Deforestation and forest degradation could be exacerbated by proximate causes that directly result in a conversion of land use, or underlying causes that amplify the actions for proximate causes (Chowdhury, 2006). The links between proximate and underlying causes have been conceptualized by (Ojima, Galvin, & Turner, 1994), and more recently by (Geist & Lambin, 2002).

Proximate causes are human activities or immediate actions at the local level, such as timber extraction, that directly impact forest cover. These are the final or near final anthropogenic activities that directly affect the environment (Turner, 1990). On the other hand, underlying driving forces are fundamental social processes, such as human population dynamics or agricultural policies that underpin the proximate causes and either operate at the local level or have an indirect impact from the national or global level (Geist & Lambin, 2001). After meta-analysis of 152 sub-national case studies of deforestation in the tropics, Geist and Lambin (2002) concluded that economic factors, institutions, national policies, and remote influences are the underlying causes while agricultural expansion, such as wood extraction among others are the proximate causes of deforestation.

Population growth is widely considered as one of the major underlying causes of deforestation in the tropics. Malthusian theory suggests that human population will put severe pressure on natural resources such as land and forests (Palo, 1994). A positive correlation between population growth and deforestation is supported by Kothke et al. (2013); Mahapatr and Kant (2005); Palo at al. (1996); and Rudel and Roper (1996). The causal relationship is explained by decreased wage rate due to increased supply of labour, which leads to lower forest conversion costs for agricultural expansion to meet the increased demand for food leading to deforestation (Wunder, 2000). Recent study, however, correlated forest loss with urban population growth; rural population growth is not associated with forest loss (DeFries, Rudel, Uriarte, & Hansen, 2010). In addition, rural population growth data used at a national scale may inaccurately reflect population pressures at the local level because rural to rural migration will not emerge in national scale data on rural population change (López-Carr & Burgdorfer, 2013).

There is an ambiguous relationship between road networks and deforestation. Voluminous amounts of literature conclude that increased road density increases pressure on forests by reducing transportation costs, making extraction of forest products more feasible, raising land prices (Schneider, 1995), hence increasing pressure towards deforestation (Rudel & Roper, 1997; Tole, 1998). Considerable evidence from across the tropics (Chomitz & Gray, 1996; Lawrence & Foster, 2004; Liu, Iverson, & Brown, 1993; Ludeke, Maggio, & Reid, 1990; Mertens & Lambin, 1997; Pfaff, 1999; Sader & Joyce, 1988) suggests that roads are associated with deforestation. Several other studies have found no statistically significant relationship between road and deforestation in Northern Thailand (Cropper, Griffiths, & Mani, 1999) and in Jiangxi Province, China (Deng, Huang, Uchida, Rozelle, & Gibson, 2011). New evidence is required through refinement of data sets and methods used to reduce the ambiguity about the effect of roads on forests.

Deforestation in developing countries is mainly the result of land conversion for agricultural expansion and crop production (FAO, 2003). Many primary forests were cleared for commercial agriculture during the nineteenth and twentieth centuries (Barraclough & Ghimire, 1995), shifting cultivation (Rowe, Sharma, & Browder, 1992) and cattle ranching (Wunder, 2000). Shifting cultivation accounts for up to 50% of natural forest conversion in Southeast Asian countries and 70% in tropical Africa (Rowe et al., 1992). World Bank (1992) mentioned that new settlement for agriculture is responsible for 60% of total tropical deforestation. A fundamental economic approach to understand deforestation suggests that conversion of forests to agricultural land is mainly due to the higher land rents offered by agriculture. Higher returns from land use are achieved through agricultural production than from infrequent timber harvests from a site. Bilsborrow and Georres (1994) observe that increased production can also be achieved by higher yield through intensification such as increased use of fertilizers, pesticides, irrigation facilities and new hybrid varieties. Alternatively, improved agricultural technology often makes it possible to develop marginal lands for crop production, and thus reduce the pressure on forest land for conversion to agriculture (Mahapatr & Kant, 2005). In contrast, Coxhead, Shively, & Shuai (2002) argued that higher agricultural yields achieved through crop intensification and switching to less risky crops leads to less deforestation.

Institutional factors such as political stability or instability, property rights, and rule of law have been viewed as important determinants of deforestation. The intuition is that better quality of institutions and/or governance are related to forward looking behaviours, better environmental management, higher efficiency of resource use, and better enforcement of public policies leading towards decreased deforestation. In contrast, for example; weak and short-lived governments lack ability to enforce laws, hence, have an inability to stop deforestation. Kaufmann, Kraay, & Mastruzzi (2009) and Umemiya, Rametsteiner, & Kraxner (2010) enumerated the critical dimensions of governance as voice and accountability, political stability and absence of violence, government effectiveness, and regulatory quality, rule of law and control of corruption. Deacon (1995) found a relationship between better institutions and lower deforestation rates, which was later supported by Bhattarai & Hammig (2001), Culas (2007), and Nguyen-Van & Azomahou (2007). Southgate (1991) found that security of tenure is negatively related to deforestation. In contrast to those, Damette et al. (2012) did not find a significant relation between institutions and deforestation arguing that institutions had low time-variability.

Some authors have demonstrated that rate of deforestation is related to the size of forest area. Per unit pressure on forest areas will be less in countries with a higher percentage of forest area, thereby experiencing less deforestation, while countries with a smaller percentage of forest area will tend to deforest at a faster rate (Rudel, 1994). In contrast, Kant (1997) argued that the vastness of a forest area creates an impression of 'free common good attitude (FCGA)' and, as a consequence leads to deforestation (Kant & Redantz, 1997). The explanation is that the larger absolute forest area will reflect higher FCGA, higher consumption of round wood with lower prices, and hence more deforestation. On the other hand, as the forest area reduces over a period of time, wood consumption will automatically reduce due to the realisation of the scarcity of the resource if timber prices are determined locally (Kant & Redantz, 1997). Thus, effect of forest size on deforestation is still a research topic.

A majority of the studies are based on the one-way hypothesis of the effects of causal variables discussed above on deforestation. However, the underlying causes may have both positive and negative effects simultaneously affecting deforestation. Improved technology and agricultural intensification such as increased use of fertilizers, pesticides, irrigation facilities and new hybrid varieties can increase agricultural production (Bilsborrow, 1994;

Mahapatr & Kant, 2005). Therefore, the net effects of agricultural growth on deforestation depend on the combined effects of expansion and intensification. Similarly, some evidence (Allen & Barnes, 1985; Palo, 1994) showed that population growth has a negative or no effect on deforestation due to the introduction of new technologies (the Boserup hypothesis) and out-migration of rural population to urban areas (Bilsborrow, 1994). Road networks may decrease deforestation by controlling illegal logging through security patrolling and easier application of better management practices. Likewise, in the absence of rule of law in general and insurgency situations in particular, people may fear to enter into the forest for illegal logging and clearing.

Mahapatr and Kant (2005) attempted to tackle this unresolved problem by incorporating both positive and negative effects of all explanatory variables of the models and using two-tailed *t*-test to recognize the net effect phenomenon. Since the study covered limited countries in the tropics, the problem of heterogeneity (Damette & Delacote, 2012; Nguyen Van & Azomahou, 2007) among countries and regions are, however, still unaddressed limiting generalizability and overall significance of the result. The factors affecting deforestation and forest degradation might be case specific (Scrieciu, 2007), the magnitudes of their effects, the interaction between them and different capacities to respond may all vary significantly from one location to another(Kanninen et al., 2007).

For the purpose of REDD+ reference level, emissions from forest degradation should be reported, since degradation can contribute substantially to forest carbon emissions (Asner et al., 2005; Souza & Roberts, 2005b). However, detecting and quantifying forest degradation is more challenging than measuring deforestation and this has constrained forest degradation research. It can be monitored variously in terms of crown cover, tree density, biomass density and changes in species composition. The values require use of arbitrarily chosen criteria, and are difficult to detect using remote sensing techniques (Putz & Redford, 2010). If different criteria and indicators are used in subsequent forest resources assessments that makes the results ineligible for comparison studies (Acharya et al., 2009), and a data problem in forest degradation research. Sporadic attempts in the field of remote sensing (Lambin, 1999) have been made to resolve this data problem when monitoring forest degradation.

This data gap has constrained research on the effects of different drivers on forest degradation. As a consequence it is also rarely integrated with deforestation research. Acharya et al. (2011) enumerated possible drivers of forest degradation as over-extraction, intentional fire, free grazing, targeting of high-quality commercial tree species, illegal logging, encroachment, shifting cultivation and forest fragmentation. Sankhayan, Gurung, Sitaula, & Hofstad (2003) carried out a study in a watershed of Nepal and found that population growth and prices of major agricultural crops are the determinants of forest degradation. Hosonuma et al. (2012) found timber extraction and logging as the most important drivers of degradation followed by fuel wood collection and charcoal production, uncontrolled fires and livestock grazing. Similarly, Skutsch et al. (2011) enumerated proximate causes of degradation as extraction of forest products for subsistence and local markets as well as industrial or commercial purposes and uncontrolled anthropogenic wildfire. Eckert et al (2011) applied a geo-spatial model to monitor degradation in the *Analanjirofo* region, Madagascar, assuming that slash-and-burn agriculture and selective logging were the causes of degradation. However, econometric evidence to understand forest degradation is largely uncharted.

Despite the boom in deforestation modelling at global scale, limited evidence was reported from Nepal in general and the Terai region in particular. Forest of Terai region of Nepal has been under heavy pressure in recent decades (Rautiainen, 1999). More than 180 thousand ha of forest was cleared between 1956 and 1985 (FAO, 1999) and 5.8 to 4.6 million ha during 1985-1993 period (CBS, 1998). More recent study revealed that the forested area in the region has reduced to 12,649 sq. km in 2000 from 21, 774 sq. km in 1958 (Joshi, 2006). Forest degradation is also a severe problem in that most of the forest has a thin over-storey canopy of trees with virtually no regeneration (UNEP, 2001).

Bhattarai, Conway, and Yousef (2009) focused on the spatial driving forces of deforestation in the Central Development Region for 1975-2000 using satellite data along with socio-demographic variables. The regression analyses revealed that deforestation in the region is related to multiple factors such as; farming population, gender ratios at various ages, migration, land elevation, road, distance from road to forest, and most importantly the conversion of forestland into farmland mainly because of higher land return from agriculture (Bhattarai et al., 2009). Some argued that poverty is the underlying condition that facilitated deforestation and forest degradation (ADB, 2004; CBS, 2004) while others indicated it is human migration (MPFS, 1988; UNEP, 2001). More studies reported that commercial logging and agriculture land expansion to meet the food requirement of the growing population are the major causes of deforestation in the Terai (DFRS, 1999; UNDP, 1997). However, no study has been carried out, at least for the Terai region, which includes causal variables for both deforestation and forest degradation.

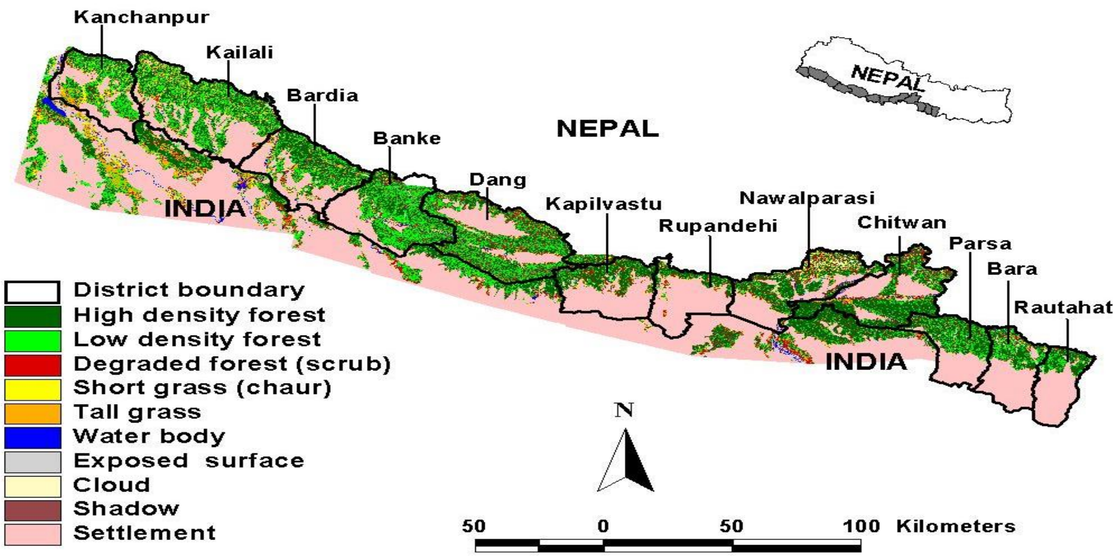
As a part of development of national strategies and action plans for REDD+, countries have to identify drivers of deforestation and forest degradation. Determination of underlying and proximate causes of deforestation and forest degradation at sub-national or landscape level is the key step to estimate the cost of emission reduction as well as to enable accurate projection of future land use. This study aims to determine the underlying causes and proximate causes of deforestation and degradation providing the parameter estimates to project the future land use and carbon storage scenarios in the Terai Arc landscape of southern Nepal without REDD+. I developed a synthesized econometric model of deforestation and forest degradation to address the intertwined phenomenon and complete the analysis using most the recent panel data available. The results of the study will be used to estimate the opportunity cost of REDD+ as well as expected to be an evidence-base for REDD+ policy formulation in the tropics in general and in the Terai Arc Landscape, Nepal, in particular.

2.4 Materials and methods

2.4.1 Characteristics of the study area

The Terai Arc Landscape (TAL) is a trans-boundary conservation endeavour spread over 49,500 square km, linking 11 trans-boundary protected areas in Nepal and India. In Nepal it covers 23,129 square km, stretching from Rautahat district in the east to Kanchanpur in the west covering 15 districts including part of Arghkhanchi, Palpa and Makwanpur districts of Southern Nepal. The elevation ranges from 200 m to 1000 m. It has a hot climate of annual average temperature 18.5-26.1^{0}C and heavy monsoon rain with mean precipitation of 1056-2929 mm/year. The land is composed of flat and highly fertile alluvium deposits.

Forests of TAL contribute 75% of the total forests of the *Terai* (HMG/N, 2004). The landscape supports the worlds' most spectacular biodiversity that includes 86 species of mammals, 47 of reptiles and amphibians, 556 species of birds, and more than 2100 species of flowering plants. Besides, it is the home of 340-350 Tiger, 612 Rhino and 120 Elephant population. TAL consists of two World Heritage sites and three Ramsar sites. It has 8 million people, and 10,872 sq. km of the largest commercially exploitable forest of Nepal. The study area is a mosaic of different property rights and forest management regimes viz; community forests, government-managed forests, buffer zone community managed and protected areas or national parks.



Map Source: Gurung & Kokh (2011)/*WWF Nepal Program*

Figure 2.1 Vegetation map of study area

Forests of this landscape have enormous commercial as well as subsistence importance (Webb & Sah, 2003). Under heavy pressure from anthropogenic activities, these forests have been depleted in the last few decades resulting in degradation and fragmentation of historically contiguous landscapes and posing threats to both biodiversity conservation and to local livelihoods (Timilsina, Ross, & Heinen, 2007). According to the latest forest inventory data, the annual deforestation rate was 1.25 % during 1978-1991 with large sub-regional variations. Rupendehi district which is located almost in the middle of the landscape had the highest annual deforestation rate of 3.8 %, while Kailali district in the western part had the largest deforestation (HMG/N & FINNIDA, 1994) in absolute area of 16,000 ha during the period (FAO, 1999).

2.4.2 The model description

A deforestation and degradation model is proposed for study (Fig 2.2). The model is based on earlier deforestation models of Mahaptr et al., (2005); Geist and Lambin (2002), and Barbier (2001) but with the inclusion of forest degradation which is overlooked in most earlier models. Those models are suitably modified to account for the characteristics of the landscape and availability of district-wise disaggregated panel data of several explanatory variables. In contrast to most of the previous studies, the deforestation model presented in figure 2.2 incorporates major socio-economic, demographic and institutional factors. Additional variables to those used in earlier models were taken into consideration. This model assumed that deforestation and forest degradation are intertwined phenomenon and the latter precedes the former in a gradual process as argued by Wunder (2000) and Lambin (1999).

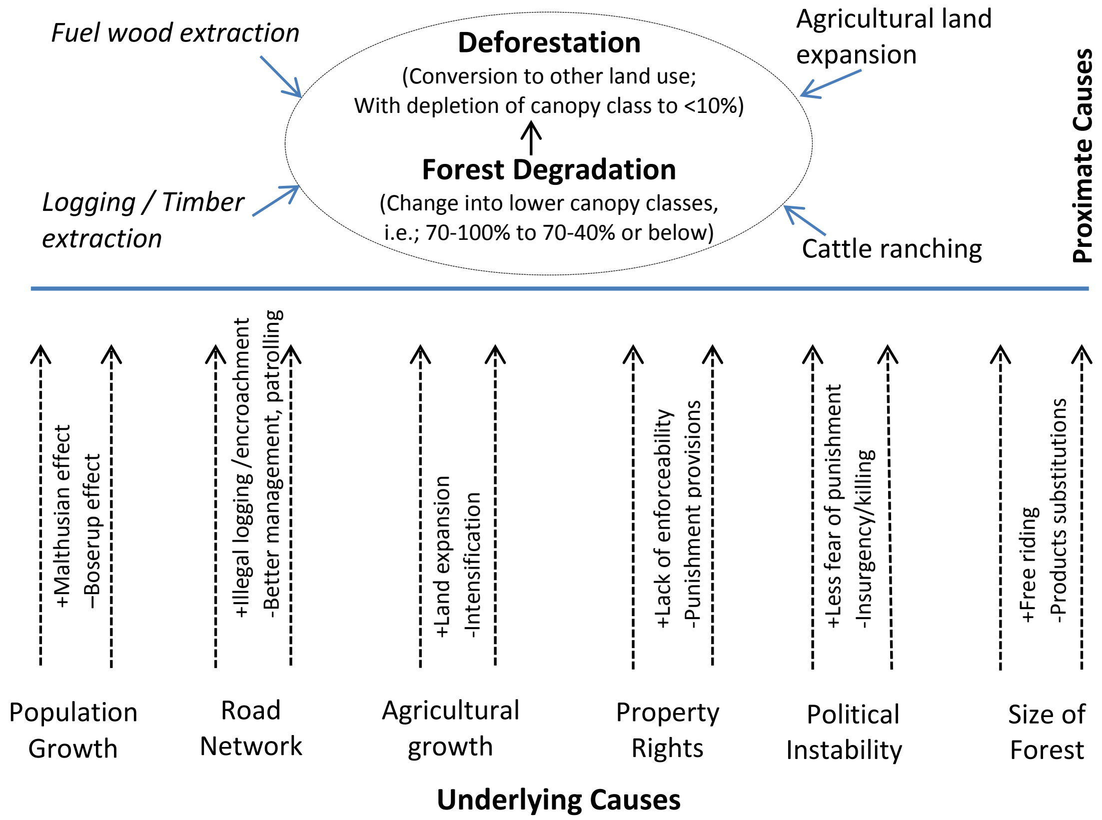


Figure 2.2 Effects of underlying causes on deforestation and forest degradation; *Modified from Mahapatr& Kant (2005)and Geist &Lambin(2002)*

The explanatory variables; population growth, road network, agricultural growth, size of forest area, property rights variables like community forest and buffer zone, protected areas and political instability may have both positive and negative effects simultaneously on deforestation as discussed in earlier section. The symbols '+' and '-' before the underlying causes denotes positive and negative effect on deforestation and forest degradation. The net effect of these variables on deforestation is the combination of both positive and negative effects. Based on the afore-mentioned description and effects of various underlying explanatory variables, the general form of empirical model for deforestation used in this research is given by Equation (i).

$$\Delta DEFO_{it} = \alpha_0 + \alpha_1 \Delta POPU_{it} + \alpha_2 \Delta ROAD_{it} + \alpha_3 \Delta AGRI_{it} + \alpha_4 \Delta FORE_{it} + \alpha_5 \Delta CFBZ_{it} + \alpha_6 \Delta PROT_{it} + \alpha_7 \Delta POLI_{it} + \varepsilon_{it} \quad \text{(i)}$$

Where:

DEFO = *Deforestation*

POPU = *Population growth*

ROAD = *Road density*

AGRI = *Agricultural yield growth*

FORE = *Size of forest area*

CFBZ = *Community forest and buffer zone area*

PROT = *Protected area*

POLI = *Political assassinations*

E = *Error term*

Δ = *change (%, annual)*

i = *District*

t = *Year*

The forest degradation empirical model expressed in equation (ii) below, measures forest degradation in terms of forest biomass that includes tree, shrub, litter and belowground biomass. The biomass has high detection potential through field survey and can be affected by various drivers of degradation (Acharya et al., 2011).

$$\Delta BIOMASS_{it} = \beta_0 + \beta_1 \Delta AGRI\_EXPAN_{it} + \beta_2 \Delta TIMB\_EXTRAC_{it} + \beta_3 \Delta LIVE\_POPU_{it} + \beta_4 \Delta FUEL\_EXTRAC_{it} + \varepsilon_{it} \qquad \text{(ii)}$$

i = *1*, …, *n* districts, and *t* = year; $\Delta BIOMASS_{it}$ is the percentage change in forest biomass as a forest degradation in district *i*, year *t*; $\beta_0$the intercept term for district *i*; β_i the coefficients to be estimated; $AGRI\_EXPAN_{it}$ the agricultural land expansion; $TIMB_EXTRAC_{it}$timber extraction; $LIVE_POPU_{it}$livestock population; and $FUEL_EXTRAC_{it}$is the fuel wood extraction. Δ denotes percentage change in the values of the variables.

2.4.3 Data and data sources

We used the narrow definition of 'forest' as applied by FAO to define forest and deforested areas. Forest data available at WWF/Winrock Nepal were based on satellite images of Landsat Thematic Mapper^{TM} and Enhanced Thematic Mapper (ETM^+) for years 1990, 1999, and 2009. The imageries were selected from September to December to avoid seasonal variations. In this study, we used 'percentage change' as a measure of deforestation and degradation so that it does not discriminate between districts on the basis of forest area and biomass stock.

Population data is based on the census years 1981, 1991, 2001 and 2011 available in Central Bureau of Statistics. We used average annual growth rates of population from 1990-1999, and 1999-2009 in the districts. Weighted yield of all agricultural crops is used to measure agricultural yield growth. The agricultural data was assembled from 'Statistical Information on Nepalese Agriculture' published by Ministry of Agriculture Development, Government of Nepal. Time series data of roads was compiled from 'Nepal Road Statistics' published by Department of Road (DoR), Ministry of Works and Transport, Government of Nepal.

The data of numbers of people killed during the decade long insurgency were collected from 'Informal Sector Service Centre (INSEC) Nepal'. District-wise disaggregated data is available in the 'Nepal Human Rights Year Book' published each year. This variable was used as a proxy for government's inability to enforce and maintain laws and order. Similarly, data related to area of forest under the control of different management and property rights regimes are available at Department of Forest (DoF) and Department of National Parks and Wildlife Conservation (DNPWC). Community forestry data was obtained from Community Forestry Development Division, Kathmandu.

Data related to proximate causes of degradation were also collected from various sources. Quantities of timber and fuel-wood harvested from different forest management regimes were compiled from *'Hamro Ban'*, a published annually by Department of Forest and various district forest offices. The study used the 1992/93 year's data of fuel wood and timber harvest due to the unavailability of 1990 data of the variables. Data on cattle population and area under agricultural crops are available at 'Statistical Information on Nepalese Agriculture', a yearly publication of Ministry of Agricultural Development (MOAD).

2.5 Results and Discussions

2.5.1 Deforestation

The synthesized empirical model [equation (i)] was applied to a panel analysis of deforestation in the landscape over the periods of 1990-1999 and 1999-2009. Descriptive statistics of deforestation and forest degradation variables are shown in Table 2.1.

Table 2.1 Descriptive statistics of deforestation variables by period 1990-99 and 1999-09

	Period	Deforestation rate*	Population growth*	Agri-yield growth*	Road network*	Forest size**	CFBZ area*	Protected area**	Political factor***
Mean	1990-99	0.26	2.94	2.33	9.93	48.94	2.68	64.76	0.13
	1999-09	-0.21	1.87	3.82	5.55	48.07	3.32	70.46	5.73
Median	1990-99	0.25	3.28	1.85	8.94	50.54	2.39	71.06	0.04
	1999-09	0.26	2.29	2.70	5.62	51.22	3.25	72.51	4.40
SD	1990-99	0.80	1.31	4.59	9.40	15.12	2.52	31.24	0.24
	1999-09	1.08	0.97	3.69	3.21	15.77	2.70	21.35	3.71
Max	1990-99	1.36	4.84	10.16	39.66	69.50	7.67	95.55	0.89
	1999-09	0.75	2.89	12.54	10.35	70.87	8.29	94.18	14.28
Min	1990-99	-1.58	-0.39	-6.34	1.88	17.10	0.05	21.38	0.00
	1999-09	-3.02	-0.15	0.20	0.85	15.64	0.26	42.66	1.88

*Note: * % change (annual), **% at the beginning of the period, ***No. of persons killed per 100 thousands per year*

Fixed and random effects as well as OLS models were tested for the selected to estimate parameter values. *Table 2.2* displays the results and relevant statistics of all models. The parameter estimates are reported as elasticities, in order to make effects of different variables with different units of measurement comparable.

Preliminary result suggested that fixed effect model was rejected in favour of the random effect model by the Hausman test. Hausman test shows whether the unique errors were correlated with the regressors. A not significant test result indicates that they were not correlated; hence, a random effects model fits better than a fixed effects model. At second stage; a Breusch and Pagan Lagrangian multiplier (LM) test was conducted to determine an appropriate model out of random effects and OLS. Therefore, the OLS model is appropriate for the given data set.

Notably, population growth has the highest positive coefficient followed by effects of agricultural yield and community forests and buffer zone on deforestation. Property rights variables; area under community forest and buffer zone and protected areas appear to be significant underlying causes of deforestation in the landscape. Agricultural growth is the most important explanatory factor under both the OLS and random effects models. Population growth is significant at 5% and 10% level in random effects and OLS models respectively. Contrary to our expectation, both road and political instability variables are not statistically significant even at 10% level. Similarly, the not significant effect of forest size on deforestation leads to rejection of the 'free common good attitude (FCGA)' hypothesis which postulates that larger absolute forest areas will reflect higher FCGA, with higher consumption of forest products at lower prices, and hence more deforestation.

The large coefficient (0.258) estimated in the preferred deforestation model confirmed that population growth is a major determining factor of deforestation in the landscape, as demonstrated in other developing countries by Kothke, et al. (2013); Mahapatr and Kant (2005); Palo at al. (1996); Rudel and Roper (1996); and Southgate (1991). The Terai Arc Landscape harbours one third of Nepal's total population, with growth rate higher than those in hilly regions. The Terai populations are dependent on agriculture and forests for their livelihoods. Meeting the demand of a growing population for food and other commodities has caused much deforestation in the Terai Arc Landscape.

Table 2.2 Panel analysis of deforestation in the Terai Arc Landscape of Nepal, 1990-1999 and 1999-2009

Dependant Variable: deforestation (% annual change in deforested area)[a]			
Explanatory Variables	Fixed Effects Estimates (FE)	Random Effects Estimates (RE)	OLS
Population growth (% change annual)	-.009 (-0.02)	.258 (1.88)**	.258 (1.88)*
Agriculture growth (% change annual)	-.044 (-0.73)	-.113 (-3.08)***	-.113 (-3.08)***
Road network (% change annual)	-.026 (-0.68)	-.035 (-1.45)	-.035 (-1.45)
Size of forest (% of forest area)	.333 (2.64)**	.015 (1.30)	.015 (1.30)
Community forest and buffer zone(% change annual)	-.034 (-0.05)	-.166 (-2.23)**	-.166 (-2.23)**
Protected area (% of Protected area)	-.031 (-0.48)	.012 (2.01)**	.012 (2.01)*
Political assassinations (person killed per '00,000 population/yr)	-.030 (-0.30)	-.004 (-0.08)	-.003 (-0.08)
Constant	-15.006 (-2.15)	-.425 (-0.61)	-.425 (-0.61)
R^2 (overall/adjusted)	0.002	0.479	0.314
Prob> F	0.045		0.027
Prob> chi2		0.005	
No of observations	30	30	30
Hausman test (Prob>Chi2)	0.115		
Breusch and Pagan Lagrangian multiplier test for random effects(Prob>Chi2)		0.025	

[a] Mean for all districts are 0.26% for period 1990-99 and -0.21% for period 1999-09
t-ratios are indicated in parentheses
*** Significant at 1% level; ** significant at 5% level ; *significant at 10% level

The study demonstrated that the net effect of agriculture yield on deforestation is negative. The result confirmed the argument of Coxhead et al. (2002) that higher agricultural yield achieved through crop intensification retards deforestation. Mean increase in crop yield in a later period (1999-09) is higher (5.74%) than in an earlier period 1990-1999 (5.00%), likely due to improved irrigation facilities, introduction of improved varieties, use of pesticides and fertilizers among other intensification practices. Subsistence farming is a common agricultural practice in the landscape which is neither shifting cultivation as discussed by Rowe et al. (1992) nor commercial agriculture as mentioned by Barraclough and Ghimire (1995) among others. Conversion to agricultural land from subsistence farming (Rijal, Bansal, & Grover, 1991) is, however, permanent in nature. A distinct feature of such farming is that household consumption is the primary objective followed by sale of surplus products. In such situation, increasing agricultural yields may have provided no motivation to further clear forest as that requires more investment.

In line with the body of literature that supports security of tenure and negative relation with deforestation, the study found evidence of significant correlation of various property rights and management regimes with deforestation. Pagdee, Kim, and Daugherty (2006) enumerated the variables for success of community forestry as tenure security, clear ownership, effective enforcement of rules and regulations, monitoring, sanctioning, strong leadership with capable local organization, expectation of benefits, local authority among others. These attributes of institutional arrangements under community forestry and buffer zones have contributed to retarding deforestation. Our result confirmed the earlier studies of Deacon (1995), Bhattarai et al.(2001), Culas (2007), Nguyen-Van et al. (2007) and Southgate et al. (1991) that security of tenure is negatively related to deforestation. In contrast, increased sizes of protected areas have facilitated more deforestation. Strict protection in such areas may have resulted in increased pressure on remaining government-managed forest hence causing more deforestation.

In contrast, the net effects of the road network, size of forest area, and political assassination as a political instability variable were each found to be statistically insignificant. The not significant effect of road network may be due to its lack of account of forest roads or tractor trails in the dataset if these are used to extract forest products from the forest. Inclusion of more complete road data may produce a different result. Similarly, other variables like general strikes, riots, anti-government demonstrations, revolutions, among others as studied by Deacon (1995) to measure political instability can provide better insight on the effect of such institutional variable on deforestation. The statistically not significant result of net effect of size of forest on deforestation refutes the FCGA hypothesis argued by Kant et al. (1997) that the vastness of a forest area facilitates higher consumption of round wood with lower prices, resulting in more deforestation.

2.5.2 Forest degradation

For forest degradation analysis, we derived annual forest biomass degradation (%) from year 1990 to 1999 and 1999 to 2009 as the dependant variable. Summary statistics of forest degradation variables are presented in Table 2.3.

Table 2.3 Descriptive statistics of forest degradation variables (% change per annum) selected in the study, by period 1990-99 and 1999-09

	Period	Biomass	Agri_expan	Timb_extrac	Live_popu	Fuel_extrac
Mean	1990-99	0.50	1.06	125.08	4.56	153.35
	1999-09	-0.23	1.17	32.64	2.51	31.61
Median	1990-99	0.49	1.40	79.58	3.49	48.64
	1999-09	0.17	0.43	-17.14	2.54	-21.07
SD	1990-99	1.05	2.47	192.84	3.57	198.88
	1999-09	1.24	3.18	116.79	2.73	133.66
Max	1990-99	1.26	12.01	264.80	7.79	359.43
	1999-09	2.37	4.14	633.36	10.70	465.14
Min	1990-99	-3.53	-2.05	-85.50	-3.64	-99.10
	1999-09	-1.79	-6.06	-90.01	0.37	-69.15

All explanatory variables were also expressed in annual change in percentage form. Parameter estimates of all three models are presented in table 2. All three models provided more or less similar results. However, a Hausman test revealed that coefficient estimates were more efficient under a random effect model than in a fixed effects model. It means individual heterogeneity of the districts is not correlated with the explanatory variables. Hence, the random effects model produced better estimates. LM test result showed that there is a panel effect; hence, random effect model is preferred over OLS.

Table 2.4 Panel analysis of forest degradation in TAL, 1990-99 and 1999-09, using Fixed Effects, Random Effects and OLS Models

Dependant Variable: Forest Biomass degradation (% annual change)[a]			
Explanatory Variables	Fixed Effects Estimates (FE)	Random Effects Estimates (RE)	OLS
Agricultural land expansion(% annual change)	-.107 (-1.43)	-.089 (-1.52)	-.089 (-1.52)
Timber extraction (% annual change)	.003 (2.08)*	.002 (2.40)**	.002 (2.40)**
Livestock Population growth(%annual change)	.046 (0.68)	.055 (1.14)	.055 (1.14)
Fuel wood extraction(% annual change)	.004 (2.86)**	.003 (3.23)***	.003 (3.23)***
Constant	-.535 (-1.49)	-.438 (-1.74)	-.438 (-1.74)
R^2 (overall/adjusted)	0.568	0.571	0.502
Prob> F	0.009		0.000
Prob> chi2		0.000	
No of observations	30	30	30
Hausman test (Prob>Chi2)	0.805		
Breusch and Pagan Lagrangian multiplier (LM)test for random effects(Prob>Chi2)		0.272	

[a] Mean for all districts are 0.50 % for period 1990-99 and -0.23 % for period 1999-09
t-ratios are indicated in parentheses
*** Significant at 1% level; ** significant at 5% level ; *significant at 10% level

Both timber and fuel wood extractions are significant under all three models but at different levels. The variable timber extraction is significant at 10 % level in the fixed effects model and fuel wood extraction at 5% level. The random effects and OLS models produced the same result. Timber and fuel wood extraction are significant at 5 % and 1% level respectively under random effects and OLS. Both variables have net positive relation with forest biomass degradation indicating that these are the two major drivers of forest biomass degradation in the landscape. Unexpectedly, the parameter estimate for fuel wood is higher than the parameter for timber extraction. On the other hand, livestock population and agricultural land extension are statistically insignificant despite their larger coefficients than those for timber and fuel wood extractions.

A notable result of the study is the identification of key drivers of forest degradation. The result is consistent with the findings of earlier studies in the case of timber extraction and fuel wood collection. However, the study found no evidence of effects of livestock population and agricultural expansion on forest degradation. Acharya et al. (2011) stated that cattle grazing have effects on surface soil, natural regeneration and habitat destruction rather than on biomass. Econometric evidence of no effect of livestock population growth in forest biomass degradation might be due to grazing on annual herbs or grasses rather than browsing on tree species.

Similarly, shifting cultivation is not a common practice in the landscape, as observed in the hilly region of Nepal. The agricultural practice in the landscape is different to shifting cultivation. Expansion of agricultural land for paddy cultivation, which is one of the major crops of the landscape, requires clear felling of trees rather than intercropping or mixed cropping inside the forest, or agro-forestry. Deforestation covers such conversion of land from forest to clear-felled agriculture land. A relationship between forest degradation and agricultural land expansion can be observed in agro-forestry, shifting cultivation and taungya agricultural practices where forest remains forest, but changes occur in level of forest biomass. This might be the reason behind the lack of evidence in the landscape of effects of agricultural expansion on forest degradation.

2.5.3 Implications for REDD+ policy

REDD+ requires complete or near complete reporting of emissions by sources and removals by sink. Therefore, policy and management interventions require addressing both problems in order to reduce net emissions. The study incorporates both deforestation and degradation components of REDD+. Our attempt is to address these intertwined problems while earlier studies have done very little to establish root causes of these phenomena. Identification of important underlying and proximate causes of deforestation and forest degradation is the prerequisite to address the emissions from the forests. The parameter estimates of the underlying and proximate causes of deforestation and forest degradation will be helpful to determine reference emissions levels in the landscape. In addition, the findings of this study will provide an evidence-base to facilitate on-going debate on appropriate institutional arrangement (Agrawal & Gupta, 2005; Agrawal & Ostrom, 2001; Chakraborty, 2001; Shrestha & Budhathoki, 1993) for such a commercially exploitable forest of the region to be managed in a sustainable way.

The biologically rich landscape harbours five protected areas including one recently established in Banke district. Conventional wisdom dictates that local people's utilization of resources in areas where biodiversity is high is in conflict with biodiversity targets. Limiting access and a strict control policy as promoted by stakeholders has implications not only for conservation, but critically for the livelihoods and welfare of the people (Brown, 1998). Evidence from this study also supports this statement and such policy may not help to achieve desired outcome of REDD+. Allendorf (2007) studied the perceptions of local people towards protected areas and found that their negative perception towards protected areas were shaped by size of the area, people's access to them, and management objectives amongst other factors. Each of those factors may have contributed to deforestation in the region and requires further research.

The results highlight the most important drivers of deforestation and forest degradation in the landscape. In addition to policy reconciliation focussing on property rights and management regime, halting rapidly growing population is a significant challenge in the region. According to the population census, 2011; the landscape has 8 million populations which is almost one third of the total population of the country. Population growth rate in the landscape is also higher than in hilly regions due to migration. Increasing agricultural product prices may motivate agricultural expansion, while increased yields through agricultural intensification not only helps meet the food requirements of a growing population, but also retards deforestation. Therefore, without technological advancement in the agriculture sector in the region, the challenge remains to reduce emissions from deforestation in the landscape.

The subsistence forest-based livelihood of more than 80% of the inhabitants of the landscape is another challenge. Fuel wood is the main source of energy used for cooking. As discussed earlier, heavy pressure on forests due to fuel wood collection is reflected as forest biomass degradation. Since there is no sign the country's electricity demands will be met in the immediate future, alternative energy sources like solar, and biogas can be substituted for fuel wood. But this may also require huge amount of implementation cost as well as funding from REDD+. Sustainable harvesting of timber is another area to focus on in order to reduce emissions from forest degradation. Active management of old-growth forest such as introducing silvicultural operations and promoting and protecting natural regeneration is vital for sustainable supply of timber in the country's timber market, while impeding forest degradation.

The research provides an evidence basis for REDD+ strategy formulation and current policy reconciliation. While the desired outcome of REDD+ appears uncertain under the current focus on expansion of protected areas in the landscape, it demands reform of current forest governance in favour of strong, effective and efficient forest institutions supported by clearly defined property rights. Attention is also required to intensify farming practices, adopt technological advancement in agriculture and switch from forest-based livelihoods to alternative livelihood options. Active and intensive management of such a commercially exploitable forest is required to meet the timber demands of the country. Substitution or alternatives for fuel wood and promotion of energy efficient improved cooking stoves should be targeted interventions in the Terai landscape to stop further degradation of the forest resources. All these interventions have significant influence on implementation costs of REDD+ in the landscape.

2.6 Conclusion

Tropical deforestation occurs in diverse circumstances and has multiple causes. Those circumstances and causes vary from place to place making it difficult to generalise about causality. The intent of this study was to present statistical results of modelling of the underlying and proximate causes of deforestation and forest degradation for the purpose of REDD+ in the Terai Arc Landscape of Nepal. We identified the main underlying causes of deforestation based on tests of significance. To facilitate fresh discussion on the under-researched topic of forest degradation with its intertwined relationship with deforestation, we studied proximate causes of degradation using an econometric model. The study analysed the determinants by estimating a panel data model using the most recent dataset available. The dataset combines extensive review and compilation of progress reports, census data, biomass data and forest cover data derived from analysis of satellite imageries available from multiple sources.

The results suggested that population growth; agricultural yield and property right variables were the dominant underlying causes of deforestation in the study area. Similarly, timber and fuel wood extraction were the most important proximate causes of forest degradation. While most of our results were consistent with earlier studies in developing countries, no statistically significant effects of road network, size of forest and political instability variable on deforestation were found. Similarly, no evidence was found on effects of livestock population and agricultural land expansion on forest degradation. Data constraints are very often a limiting factor in forest degradation research. Inclusion of some other important causes like Gross Domestic Product (GDP) as an Environmental Kuznets Curve (EKC) variable in deforestation analysis and forest fire in the degradation analysis were constrained by the lack of historic data for the districts studied.

To operationalize the incentives under REDD+ mechanism, reporting of net emission reductions by sources and removal by sink is required. The study incorporated both deforestation and degradation components; the latter was largely overlooked in earlier studies. Identification of important drivers of deforestation and forest degradation is the first key step. Because the desired outcome of REDD+ under the current policy of limiting access and strict control of expanding protected areas in the landscape appears elusive, this demands reform of current forest governance in favour of strong, effective and efficient forest institutions supported by clearly defined property rights. Reconciliation of current forest policy is essential, targeting reform of forest governance, agricultural intensification and switching of forest-dependent communities to alternative livelihoods. Significant amounts of REDD+ implementation costs may be required to implement more intensive management of forest for sustainable timber extraction and substitution for fuel wood in order to stop further degradation of forest resources.