Economic Model to Forecast Future Rates of Deforestation and forest Degradation in Nepal

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1 Executive Summary

This report describes the development of two important models for analyzing the impacts of REDD policy in Nepal: A dynamic land use model and a Computable General Equilibrium Model (CGE). The dynamic land use model provides projections of distribution of land use change and forest management change. The CGE model provides projections of the demand for wood and agricultural products as well as the resulting demand for land. The models are designed to estimate the effects of REDD policy spatially within Nepal and to illustrate how the resulting financial flows and land use changes will interact within the economy. Both models are developed with Nepal specific most recent available data.

The dynamic land use model is a dynamic optimization approach that models land use in three categories namely forests, crops, and livestock. Payments are made directly within the model for carbon and the model re-allocates land among uses and regions to optimally store carbon and produce crop, livestock, and forest outputs. The CGE model is a standard approach that relies on a recently developed social accounting matrix for the country of Nepal.

The dynamic land use model suggests that forestland is increasing modestly in the baseline case, by around 2000 hectares per year over the next 60 years. The change is not the same in all regions. The Mid-hill region experiences more afforestation over the next 60 years, while Terai and Churia experience modest deforestation of around 1800 hectares per year in total as land converts to croplands. Some of the increase in croplands in Terai and Churia is derived from pastureland, albeit a small amount.

When carbon prices are added to the dynamic land use model, the model suggests that for around $10 per ton CO_2, deforestation will largely be stopped. Interestingly, deforestation continues to occur in Churia in all of the scenarios examined, suggesting the relatively high value of crop production there. The largest changes in land-use occur in the least productive area, the Mid-Hill region.

The CGE model is stimulated with a REDD policy that induces 2617 additional hectares each year to be maintained in agricultural production for a payment of 2761 million Nepalese Rupees each year. Under this policy, the effects are initially positive for Nepal, but over time, the removal of land from agricultural production reduces rate of growth in overall economic activity in Nepal although the overall such effects are small.

2 Introduction

Reducing Emissions from Deforestation and forest Degradation (REDD) is evolving as a means to reduce forest sector carbon emissions through forest management and enhanced forest governance in forestry and related sectors. The World Bank's Forest Carbon Partnership Facility (FCPF) is assisting Nepal to develop and apply strategies to address the drivers of deforestation and forest degradation. This study is an input to assess the strategic options and developing a model to forecast future rates of deforestation and forest degradation.

A REDD scheme exchanges payment, to a developing country, for a promise to reduce forest clearing and/or forest degradation. The payment and the restrictions on forest use will affect various sectors of the economy, and the effects will vary over time. Thus a multi-period, multi-sectoral economic model is needed to flesh out these effects in detail. The objective of this project is to develop a dynamic land use model and a computable general equilibrium economic simulation model to project the future land use in Nepal and assess the carbon payment impacts on land use changes and the potential of carbon sequestration in Nepal. Generally, any carbon policies that result in positive carbon prices would alter land rents and land uses across forest, crop, and pasture land.

The report provides some general background on REDD schemes and on forests in Nepal. The models used to project land use and attendant economic impacts are then described along with the results of several alternate policy scenarios. Two models are developed, a dynamic land use model of the entire country and a Computable General Equilibrium model (CGE model) focused on the Terai and Churia areas of the country.

Carbon taxes, REDD schemes and forests in Nepal

From 1880 until 2012 world temperatures rose[1] by 0.8°C. During the last 30 years a consensus has developed that this temperature rise (a) is largely due to CO_2 emissions caused by humans, and (b) may cause serious problems. The CO_2 damage, which affects all regions, is due to the accumulated level of atmospheric CO_2 (not the current emision rate) and may[2] persist for decades, even if emissions cease. The main emission sources are burning of fossil fuels and deforestation. Deforestation accounts for perhaps 6–17% of all emissions worldwide (Werf et al, 2009), and accounts for a much larger share of emissions in some countries. Deforestation emissions arise because a forest is a carbon store (even though a mature forest absorbs little net CO_2). Conversion of forest to, say, cropland, releases this carbon as CO_2.

[1] source: NASA-GISS Global mean land-ocean temperature
[2] Estimates of the half-life of atmospheric CO_2 range from 5 to 200 years (IPCC, 2001).

To reduce atmospheric CO_2, emissions taxes have been proposed -- but not widely adopted. If applied uniformly, such taxes would raise enormous revenue -- most of it from richer countries. Politically acceptable schemes are usually far more limited in scope. For example:

- They may apply to one country only, or a group of countries.
- 'Grandfathering' arrangements may exempt from taxation emissions below a stipulated (often historical) level.
- Whole sectors, such as agriculture, may be exempt. Often export-oriented sectors are exempt.

A variation on the tax scheme is a payment not to pollute. For example, a poorer country may be paid to replace older, dirtier, power stations with more efficient modern generators. The payment would reflect the emissions saved by the upgrade.

REDD (Reducing Emissions from Deforestation and forest Degradation in developing countries) schemes fall within this category. First, the schemes focus on forests only. A country must establish a 'reference level' of forest-related emissions that do or might occur in the absence of a REDD payment. REDD payments will be made in proportion to the extent that future emissions fall below this reference level.

There are many practical difficulties with such schemes. Establishment of the reference levels, and subsequent emissions monitoring impose complex requirements. A basic REDD scheme does not reward previous progress in reducing deforestation or forest degradation. There is no payment for forest stewardship that merely maintains the status quo. Thus international discussions continue, which may result in agreement about modified REDD schemes.

Nevertheless the CGE modelling focusses on a basic REDD scheme, where payments from abroad are in proportion to the reduction in emissions below a reference level. As explained below, the CGE analysis (a) focus only on the Terai/Churia part of Nepal; and (b) base the reference level on the average rate of deforestation during recent decades.

Forests in Nepal[3]

Forest still covers much of the non-alpine regions of Nepal, although much has been cleared in the most cultivable plains areas. Many forests are owned and managed ultimately by the state; although management has been delegated in some places to the local level. There is selective logging of old/mature trees but rather little active forest management (such as planting, thinning, and optimized timing of cutting). Often, the stock of trees is older than would be deemed optimal. Illegal logging also occurs.

[3] The brief survey in this and the next section draws on material found at the excelllent www.forestrynepal.org

As well as providing sawlogs, forests and their products support Nepalese agriculture and poorer people. Firewood, used for cooking and heating, is gathered from the ground, from low branches and from coppiced stumps, filling perhaps half of Nepal's energy needs. Much firewood gathering is illegal or uncontrolled. Forage for livestock is gathered similarly. Livestock may graze in the forest; their dung and litter from the forest floor are used to fertilize fields. All of these activities are often pursued above a sustainable level, leading to forest thinning and degradation.

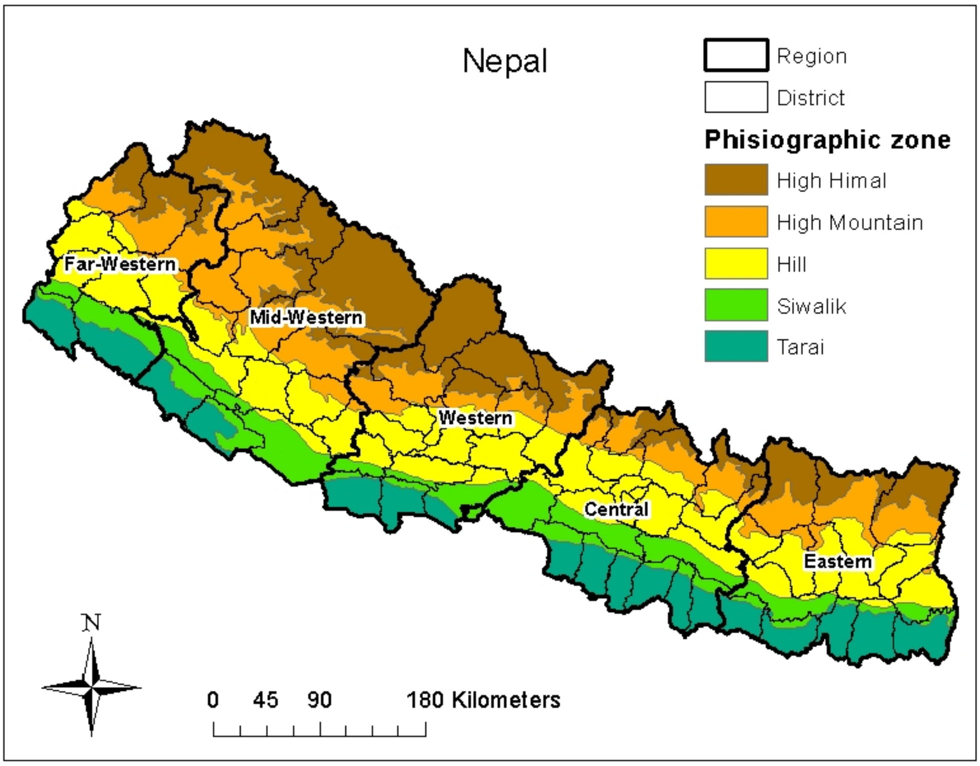


Figure 1. Physiographic Zones in Nepal (taken from FRA/DFRS, 2014)

The Hills area of Nepal (Figure 1) has historically suffered from poor communications, poverty and over-population. Deforestation and forest degradation (caused by over-harvesting of firewood and fodder) are long-standing problems. Yet since the 1970s considerable progress has been made to combat these problems, especially through Community Forestry schemes, whereby local communities are encouraged to manage and protect local forest resources. Two Hills-specific factors underlying the success of such schemes are that (a) it is usually possible to associate particular forest areas with particular villages; and (b) villages tend to be fairly ethnically homogenous. These factors assist in creating and enforcing local forest management plans (which are embedded in wider schemes for community development). Deforestation and forest degradation have been slowed, and sometimes reversed. Another factor helping to preserve the Hills forests is outmigration to the Terai area (see next subsection). Although the Community Forestry schemes were very successful, it is expected that there is little scope to greatly expand the schemes (personal communication). Consequently the CGE modelling of this study assumes that a REDD scheme will not affect Hills forest management.

While mostly hills and mountains, Nepal includes also a fertile low-lying plains region along its southern border, called the Terai (Figure 1). The Churia or Siwalik is generally composed of the first range of foothills. Historically the Terai/Churia region was forested, with the iconic Sal tree as the dominant species. High prevalence of malaria resulted historically in low population levels, although export logging took place from the 1920s. In the 1950s malaria was eradicated using DDT. The government encouraged forest clearing and migration from the overcrowded hills. Migrants from India arrived too. Today much of the Terai forest has been converted to cropland, and deforestation continues. The Terai/Churia region now accounts for most of Nepal's agriculture and GDP, and about half the population. Deforestation causes CO_2 emissions (see below) but the loss of the unique Terai/Churia habitat has equally raised international concerns. For various reasons Community Forestry schemes have been less successful in the Terai than in the hills (Nagendra et. al., 2005). Better roads, the proximity of the Indian border, and the high value of Sal timber make it harder to protect against illegal logging. Compared to the hills, it is less easy to assign particular forest areas to particular communities, and local populations (often migrants from elsewhere) are more divided by ethnicity and caste. Finally, the greater fertility of the Terai increases the pressure to convert forests to cropland.

Deforestation and forest degradation

Forest clearing causes emissions because the above-ground carbon content of forest is greater than than of the replacement use (eg, crops). Yet forest degradation is also noted as a cause of emissions. The degraded forest has fewer, smaller trees, and sequesters less carbon.

The calculations presented later in this report ignore emissions from degradation; that is, they are assumed to be unchanged by a REDD scheme. We use Figure 2 to explain this assumption.

The top panel A of Figure 2 graphs the 2015 above ground carbon per hectare of the Terai/Churia, with the least-carbon land (crops) at the left, and the most-carbon land (healthy forest) at the right. In between is an area of degraded forest, with a range of carbon contents. We may imagine, as the diagram suggests, that the degraded forest forms a fringe between cropland and healthy forests. The area under the graph is the total amount of sequestered carbon (shown as zero for crops).

Panel B of Figure 2 shows the situation in 2045 with no REDD scheme. Crop area has increased, and forest area has fallen by the same amount. The area of (and carbon stored in) degraded forest does not change. So emissions can be estimated merely by measuring the change in forest area. In effect, the degraded forest fringe simply moves right over time.

To an observer on the ground, it could well appear as if degradation were the main cause of emissions. Imagine a forest resident who lived initially at the border between healthy and degraded forest (shown by a house symbol). Over the period 2015-45 he would see his forest surroundings steadily degraded by grazing, litter removal and excessive harvesting of firewood and forage -- all leading to emissions. There would be little above-ground carbon around his house in 2044 -- so that emissions from the final conversion to cropland might be small.

Panel C depicts an alternate scenario for 2045 -- where forest area has again shrunk, but crop area has not expanded. Instead, the area of degraded land has grown. This scenario is also possible, but is not simulated here.

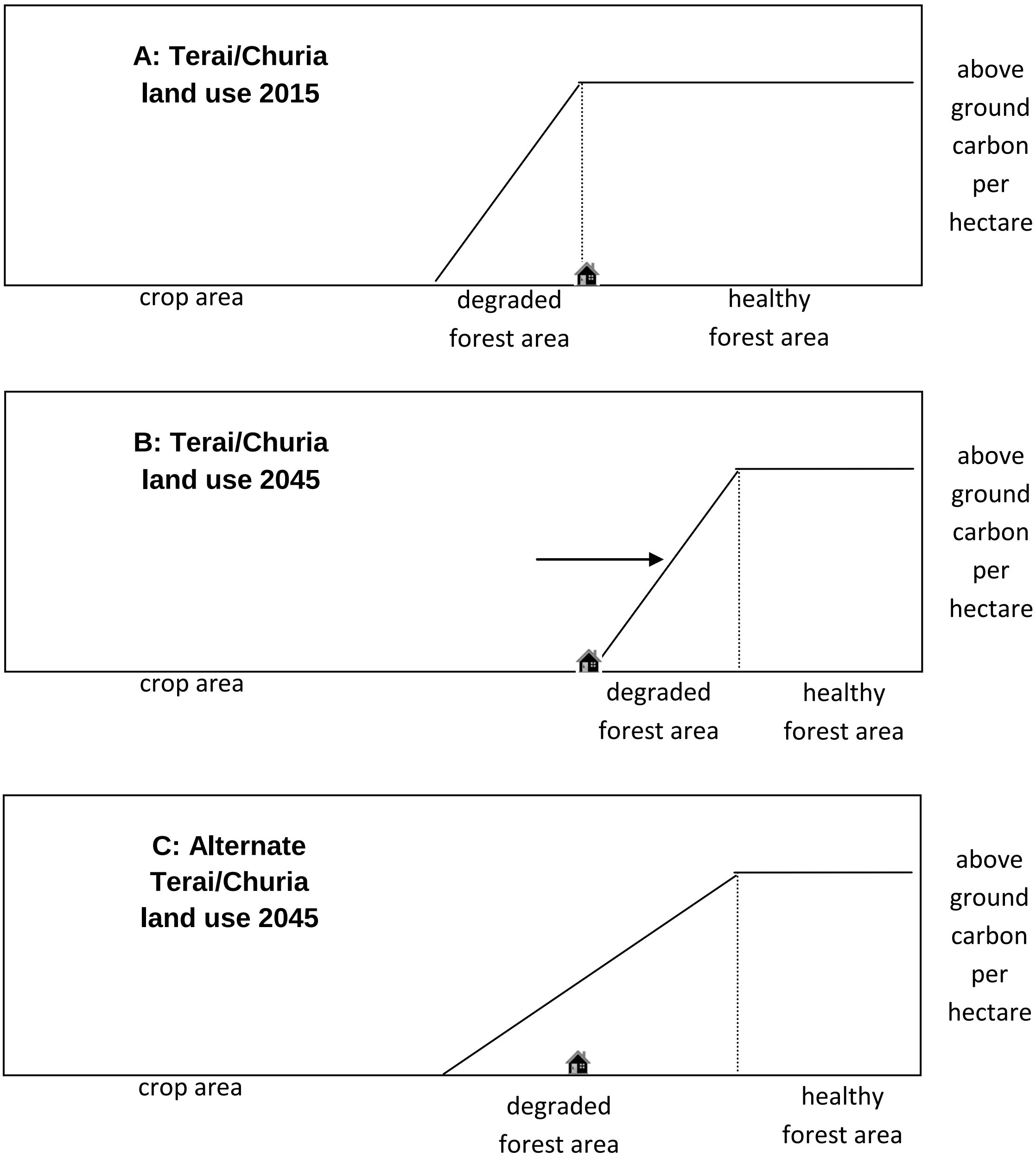


Figure 2. Deforestation and forest Degradation

In the REDD policy scenario presented in CGE modelling we assume that Terai deforestation ceases from 2015, so that Panel A also depicts the 2045 situation. Thus, each part of the fringe area must retain over time the same carbon content. By contrast, in the base scenario, each spot in the fringe area steadily loses carbon. In other words, while the base scenario assumes over-use of the fringe, the policy scenario scenario assumes sustainable use of the fringe. The sustainability might be achieved by more careful management or by simply harvesting less firewood and forage -- which would have costs. Our REDD policy simulation ignores most of these costs, so that the costs of a REDD scheme are somewhat underestimated.[4]

Is REDD a cheap way for richer countries to purchase emissions credits?

The argument is sometimes made that emission control by preventing forest clearing and degradation may be much cheaper for the world as a whole than other approaches, such as burying CO2 or using renewable energy. For example, after the Brazilian forest has been plundered for timber and charcoal, the cleared land may be used as beef pasture which raises little revenue. In such a case, a small REDD payment might be enough to preserve the forest. On the other hand, a large REDD payment might be insufficient to prevent Indonesian rainforest from being converted to profitable oilpalm plantations. Clearly, within Nepal local conditions vary greatly, so that some places resemble Brazil, others Indonesia. There might be particular areas where a localized REDD scheme was attractive even with a low carbon price.

The data used in this study for CGE modelling does not allow for such fine-grained geographical detail. Broad averages are used. Hence we overlook the possibility of some local "low-hanging fruit". On the other hand we assume a rather generous REDD payment ($US 50 per tonne of CO2).

[4] Appendix 5 explores this aspect further, building on useful comments by Dr Hom Pant, Senior Advisor, National Planning Commission, Kathmandu, Nepal.

3 Analysis Methods

This analysis is conducted in two stages. First a dynamic optimization model of land use in Nepal is developed. This model maximizes the sum of the net present value of market welfare in the forestry, crop, and livestock sectors in Nepal. This model and the resulting analysis are developed for the entire country. Second, a Computable General Equilibrium (CGE) analysis of two most deforested regions (i.e. Terai and Churia) in the country is developed.

3.1 Dynamic Optimization Model

The model in this study is based on the global-level land use model described in Choi et al. (2011). That model has been modified extensively to examine forest, crop, and pasture land use within Nepal for this study. The regions analyzed in this study are five physiographic zones, and include the entire area of Nepal (Terai, Churia, Mid-Hills, Mid-Mountain, and High-Mountain). For analysis purposes, the Mid-Mountain and High-Mountain physiographic zones are combined together and presented as the Mountain zone in this report[5]. A number of important input variables were missing or unavailable when constructing the model, so a number of key input variables have been derived from other sources, or assumed. These include information on timber growth and yield, the age distribution of tree species, land rents, and agricultural inputs in physiographic zones. Despite these data limitation, the model provides robust results and can be easily accommodated with additional data if new data becomes available for Nepal. The model optimally chooses inputs to production, such as land, capital, and labor, in order to produce outputs like wood products, crops, and livestock. The model can be described mathematically as a constrained optimization problem (see Appendix 1). The key data inputs required for the model include:

- Total land area in forestry, crop, and livestock sector (000 ha)
- Capital inputs for crop and livestock
- Labor inputs for crop and livestock
- Productivity factor for capital, labor, and land composite
- Land rents for forestry, crop, and livestock
- Timber yield (growth) function

The model optimizes production and land use for 150 years with 10-year time steps beginning in 2010. The reason for running the model over such a long time period is to minimize the effects of

[5] Land use changes in High-Mountain region is insignificant compare to the other regions and there are little activities in crop production. Total agricultural production in Mid Mountain and High Mountain region is about 6% out of total production in Nepal (SINA, 2014). Therefore, combining the two Mountain zones will not have large impacts on the analysis results.

the terminal conditions on current policy results.[6] We are interested only in the results for the first 60 years, and present those below. The annual discount rate is 5%. The model is solved using a General Algebraic Modeling System (GAMS) program with the CONOPT solver (Rosenthal, 2015).

One of the critical issues of this analysis is to assess whether carbon policies could be used to reduce deforestation. To simulate these types of policies with the model, we incorporate carbon prices into the objective function. For our model, we rent carbon stored in the forest and pay for carbon that is stored in wood products for the time it is stored there. This provides an estimation of the implications of an efficient carbon policy. Other policies could be explored as well, although we expect that they would be more expensive. For additional details on the model, see Appendix 1.

We have conducted the analysis for three development scenarios, a base case and two alternative demand scenarios. For the forestry sector, demand is assumed to increase relatively slowly in the baseline, following recent historical trends. Crop demands and livestock demands are assumed to increase more rapidly.

1. Base Scenario: crop demand assumed to increase at 5% annually for the first 6 decades (i.e. until 2070); forest product demand rises at 3% annually for the first 6 decades, and livestock product demand increases at 4% annually for the first 6 decade. After 6 decades all demands are held constant.

2. High Demand Scenario (HDS): crop demand assumed to increase twice as quickly as in the Base Scenario, 10% annually, and stabilizes. Forest and livestock rates remain the same as the Base Scenario.

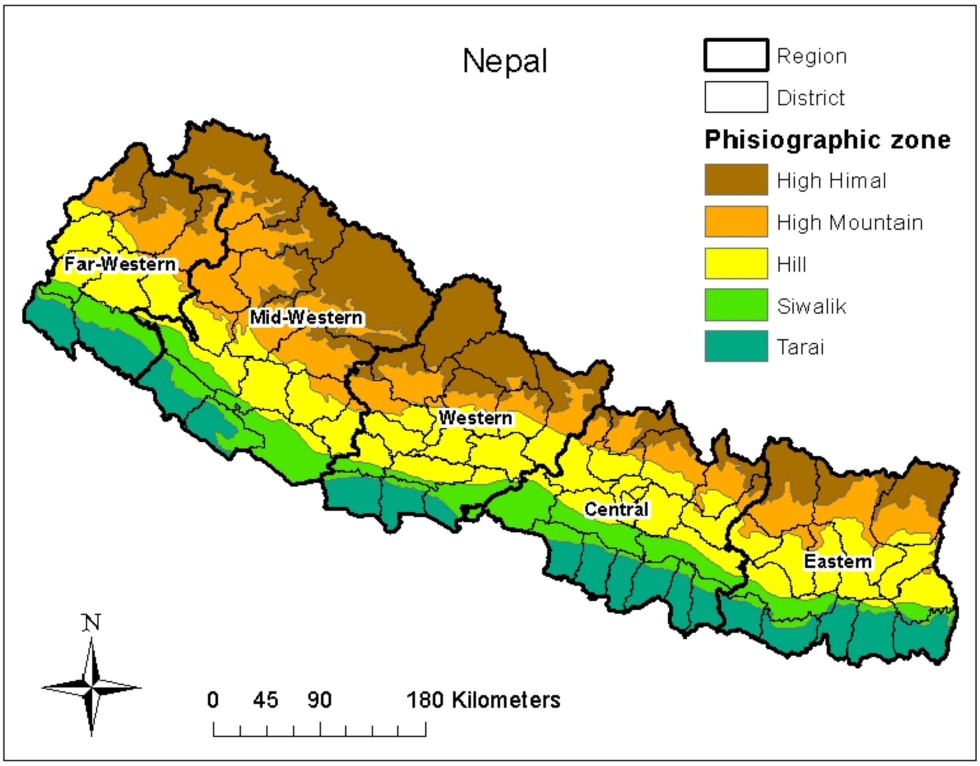
3. Low Demand Scenario (LDS): crop demand assumed to stay constant at the initial level in 2010 while other product demands rise as the "Base Scenario" (see Appendix 2 for the elasticity values).

When carbon payments are introduced, deforestation will decline and afforestation will increase. The scenario with higher (lower) crop demand will require more (less) cropland usage, and should be more (less) costly to reduce the deforestation with carbon payments.

3.1.1 Source of model inputs

This analysis is based on the most recent available land use data (FRA/DFRS, 2014) for all 5 physiographic zones (Terai, Churia, Mid-Hill, Mid Mountain, and High Mountain) in Nepal. In each physiographic zone, there are 5 regions (Eastern, Central, Western, Mid-Western, and Far-Western) (Figure 3). This FRA data provides our initial land use distribution of forest, grassland, and agricultural land use for 2010 (Table 1).

[6] In dynamic optimization models, long time horizons for solutions minimize the impact of selecting terminal conditions on the results of interest, i.e., the policy projections over the next 50 years.



A Regions in FRA data

B Regions in Census data

Figure 3. Comparison of regional definitions between FRA and Census

Table 1. Land use area (000 hectares)

Physiographic zone	Region	Crop	Grass	Forest
Terai	Eastern	478.6	13.76	58.55
	Central	402.25	0.23	107.64
	Western	131.41	0.26	87.42
	Mid-Western	229.42	0.00	39.44
	Far-Western	161.85	4.08	116.94
Churia	Eastern	64.07	5.38	180.92
	Central	151.65	1.15	448.25
	Western	160.61	0.71	371.20
	Mid-Western	64.63	0.07	169.20
	Far-Western	31.29	1.98	169.23
Mid-Hill	Eastern	466.32	19.69	470.25
	Central	410.42	5.82	494.68
	Western	365.63	4.38	417.97
	Mid-Western	465.95	11.58	459.16
	Far-Western	272.40	5.16	377.59
Mountains	Eastern	58.89	164.13	386.89
	Central	61.42	101.37	283.55
	Western	211.33	432.64	630.00
	Mid-Western	73.25	229.67	329.92
	Far-Western	127.45	163.55	281.80

Source: FRA/DFRS (2014)

We performed a data approximation process for agricultural inputs, agricultural outputs, and parameters for crop and livestock production function because there is discrepancy in regional definitions between the FRA land use data and the agricultural census data (SINA, 2014 & CBS, 2014) which provides agricultural labor inputs and outputs (Table 3). Land rents from GTAP (2015) also are composed of a different regional definition (based on 18 Agro Ecological Zones) so we approximate the land rent data as well. While there are 5 physiographic zones in FRA data, the agricultural census data (SINA, 2014 & CBS, 2014) is divided into 3 Ecological zones (Eco-Terai, Eco-Hill, Eco-Mountain) with the same regions (Eastern, Central, Western, Mid-Western, and Far-Western) (See comparison of maps in figure 3). We divided agricultural census data in each Ecological zone into each physiographic zone by applying proportion of labor uses for inputs and proportion of crop outputs for land rent and output production function.

Table 2. Summary of model inputs and data source

Model Input	Source
Total land area in forestry, crop, and livestock sector (000 ha)	FRA/DFRS (2014)
Capital inputs for crop and livestock	GTAP, SINA (2014), CBS (2014)
Labor inputs for crop and livestock	GTAP, SINA (2014), CBS (2014)
Productivity factor for capital, labor, and land composite	Ludena et al (2007)
Land rents for forestry, crop, and livestock in each district	GTAP, SINA (2014), CBS (2014)
Timber yield (growth) function	DFRS (1993) & DFRS (1999)

The process for getting physiographic zone data from census data is performed with the following steps.

1. Calculate the proportion of labor inputs and crop output in 15 regional Ecological zones (5 regions X 3 Ecological zones) (Table 3). This calculation provides the proportion of labor use and total crop output in Nepal. For example, Eastern Terai region produces 14% of total crop production in 2014.
2. Calculate the proportion of physiographic zone in each regional Ecological zone (Table 4). Since FRA data is based on GIS data, combining FRA GIS data with district map, the proportion of cropland for each physiographic zone in each district could be calculated[7]. By doing this to all the regions, we can obtain the total physiographic zone in each Eco-development zone. For example, Eastern Eco-Terai region is composed of 95% Terai physiological zone and 5 % Churia physiographic zone.
3. Multiplying each proportion of labor usage and output in each Ecological zone (Table 3) to physiographic zone ratio (Table 4) generates the labor input and crop output data for each regional physiographic zone (5 regions X 5 physiographic zones).

[7] The underlying assumption of this procedure is that crop inputs and output are proportion to cropland area. It might not reflect regional productivity differences in each physiographic zone originating from soil productivity or ecological conditions and it could be a strong assumption but this is the only available agricultural data for physiographic zone at this point.

Table 3. Proportion of labor use and total crop outputs from census

Regional Eco-development zone	Labor proportion	Output proportion
Eastern Terai	15%	14%
Eastern Hills	8%	8%
Eastern Mountain	2%	2%
Eastern Total	25%	25%
Central Terai	19%	24%
Central Hills	10%	10%
Central Mountain	2%	2%
Central Total	30%	36%
Western Terai	10%	11%
Western Hills	11%	9%
Western Mountain	0.2%	0.1%
Western Total	21%	20%
Mid-western Terai	8%	6%
Mid-western Hills	5%	4%
Mid-western Mountain	1%	1%
Mid-Western Total	14%	11%
Far-western Terai	6%	5%
Far-western Hills	2%	2%
Far-western Mountain	1%	1%
Far-Western Total	9%	8%
Grand Total	100%	100%

Source: SINA (2014) & CBS (2014)

Table 4. Percent of Physiographic zone in each Ecological zone calculated with cropland area

Eastern						
	Terai	Churia	Mid-Hill	Mid-Mountain	High-Mountain	Total
Eco Terai	95%	5%				100%
Eco Hills	1%	8%	88%	2%		100%
Eco Mountain	0%	0%	51%	48%	1%	100%
Central						
	Terai	Churia	Mid-Hill	Mid-Mountain	High-Mountain	Total
Eco Terai	82%	16%	1%			100%
Eco Hills	0%	17%	80%	3%		100%
Eco Mountain			60%	40%		100%

	Terai	Churia	Mid-Hill	Mid-Mountain	High-Mountain	Total
Western						
Eco Terai	77%	17%	6%			100%
Eco Hills		3%	82%	15%		100%
Eco Mountain				20%	80%	100%
Mid-Western						
	Terai	Churia	Mid-Hill	Mid-Mountain	High-Mountain	Total
Eco Terai	48%	45%	8%			100%
Eco Hills		8%	73%	19%		100%
Eco Mountain				100%		100%
Far-Western						
	Terai	Churia	Mid-Hill	Mid-Mountain	High-Mountain	Total
Eco Terai	87%	12%				100%
Eco Hills		3%	92%	4%		100%
Eco Mountain			25%	75%		100%

Total labor and capital input data for physiographic zones is calculated using GTAP data that provides the total usage in Nepal. Although census data provides labor inputs (CBS, 2014), it doesn't have capital input while GTAP provides the both. To have consistent data for inputs, we used GTAP labor and capital input data for the whole Nepal and applied the regional information from the census data (CBS, 2014). In addition, livestock sector input data is not available from the census data so we apply the same ratio used for the crop sector with total input for livestock from GTAP.

Similar as labor input calculation process, land rent in physiographical zone is obtained using GTAP land input data and above steps (Table 3 and Table 4). While labor usage proportion is used for labor input data, output proportion is used for rent data calculation (Table 3). Land input in US dollar term is available from GTAP land use data for Agro Ecological Zones (AEZ) in Nepal. The AEZ distribution, however, is not correlated with the districts used in this model, so we sum land use inputs from GTAP across the AEZs to derive total land rent for each sector in Nepal. We then disaggregate this proportionally to the regions used in this model. Table 5 presents the resulting land rents, labor inputs, and capital inputs used in this study.

Table 5. Calculated data

Regional land rent (US million dollars)

Physiographic zone	Region	Crop	Grass	Forest
Terai	Eastern	87.3	20.8	8.3
	Central	126.1	30.0	11.9
	Western	18.8	4.5	1.8
	Mid-Western	51.7	12.3	4.9
	Far-Western	30.0	7.1	2.8
Churia	Eastern	8.8	2.1	0.8
	Central	35.9	8.5	3.4
	Western	19.8	4.7	1.9
	Mid-Western	13.0	3.1	1.2
	Far-Western	4.6	1.1	0.4
Mid-Hill	Eastern	52.5	12.5	5.0
	Central	59.0	14.0	5.6
	Western	23.1	5.5	2.2
	Mid-Western	51.2	12.2	4.8
	Far-Western	13.7	3.2	1.3
Mountain	Eastern	8.31	1.98	0.79
	Central	6.65	1.58	0.63
	Western	11.12	2.65	1.05
	Mid-Western	9.48	2.26	0.90
	Far-Western	5.01	1.19	0.47
Total in 3 regions		636.06	151.39	60.20
Nepal Total in GTAP[8]		636.06	151.39	60.20

[8] GTAP land use data version 8. The land rent, labor and capital input data are Value of Firms' purchases of endowments at Market prices (VFM).

A) Regional labor and capital inputs (US million dollars)

	Crop		Livestock	
	Labor	Capital	Labor	Capital
Terai	376.1	92.7	24.7	6.1
Churia	106.7	26.3	7	1.7
Mid-Hill	279.7	69	18	4.5
Mountain*	58.5	14.4	3.8	0.9
Nepal total	821.1	202.4	54	13.3

*Mountain includes Mid Mountain and High Mountain physiographic zones.

Timber yield is calibrated using the global timber model parameters as a starting point and available volume data obtained from in Nepal (DFRS, 1993 & DFRS, 1999). Since there is not available timber age information, we assume that the maximum timber age is 110 years. We also assume that all the timber in Nepal is at maximum age. Timber yield (growth) function defined as $V = \exp(\alpha - \beta / age)$, age is timber age, *α* and *β* is parameter. Adjusting the parameter α and β, we approximate the volume at age 110 to match the available data from DFRS (1993) and DFRS (1999). Figure 4 presents the timber yield by age in each district and Table 6 presents the calibrated yield function parameters and Table 7 shows the carbon content (CO_2e) per hectare by timber ages. For the presentation purpose, we show results in 20 year bins, but the model uses decadal data.

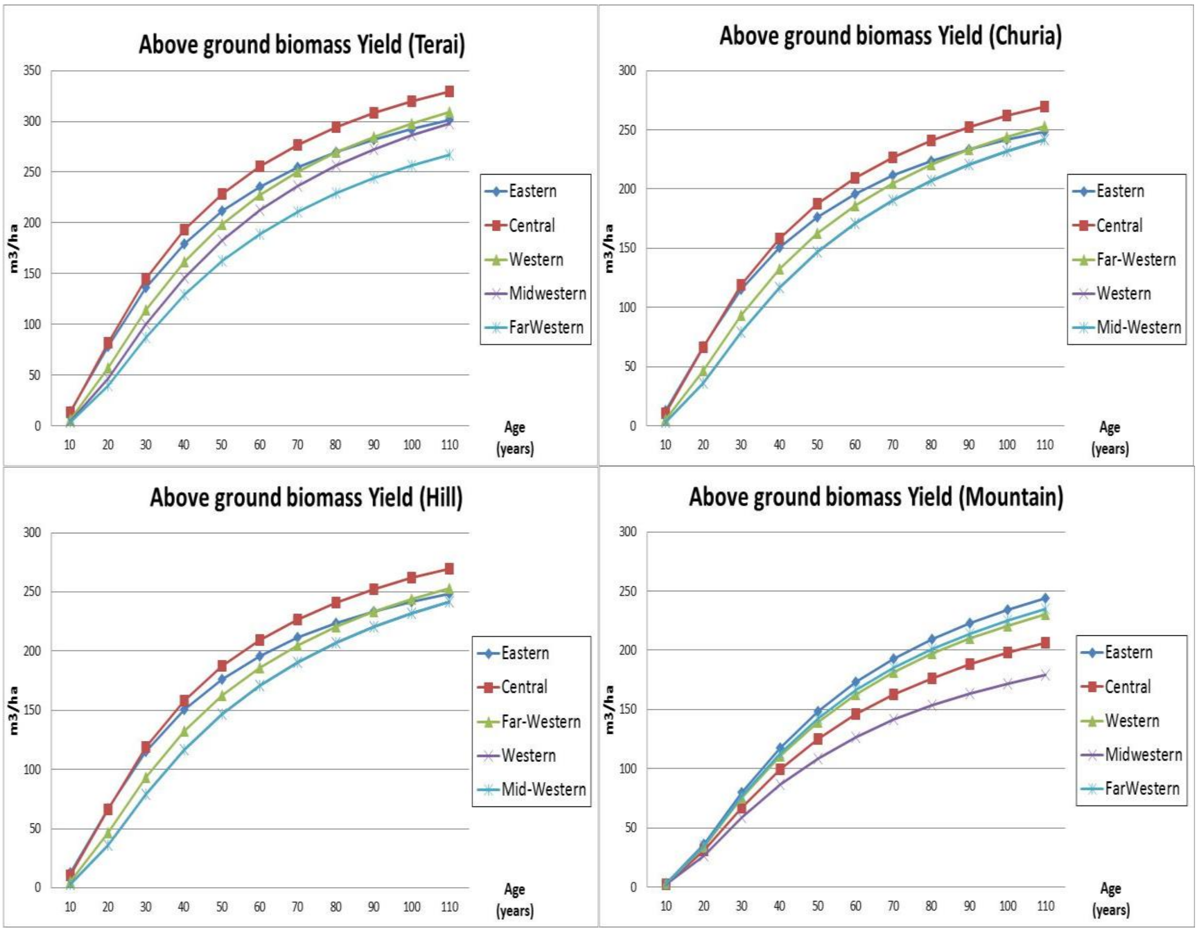


Figure 4. Total aboveground biomass yield (growth) in each region

Table 6. Calibrated parameters of timber yield function.

	Terai timber yield	
	Parameter (α)	Parameter (β)
Eastern	6.1	32
Central	6.1	33
Western	6.1	40
Mid-Western	6.1	44
Far-Western	6.1	45
	Churia timber yield	
	Parameter (α)	Parameter (β)
Eastern	5.8	31
Central	5.9	33
Western	5.9	40
Mid-Western	5.9	45
Far-Western	5.9	45
	Mid-Hill timber yield	
	Parameter (α)	Parameter (β)
Eastern	5.8	31
Central	5.9	33
Western	5.9	40
Mid-Western	5.9	45
Far-Western	5.9	45
	Mountain timber yield	
	Parameter (α)	Parameter (β)
Eastern	5.81	45
Central	5.64	45
Western	5.75	45
Mid-Western	5.5	45
Far-Western	5.77	45

* Yield function defined as $V = \exp(\alpha - \beta / age)$, *age* is timber age, *α* and *β* is parameter.

Table 7. Carbon amount per hectare by timber ages (ton CO_2e/ha)*

		Timber ages (years)					
		10	30	50	70	90	110
	Eastern	0.5	138.0	248.4	309.4	347.4	373.3
	Central	0.5	145.4	266.4	334.1	376.5	405.4
Terai	Mid-Western	0.11	109.9	228.0	300.0	346.8	379.3
	Western	0.05	93.6	208.6	282.1	330.8	365.1
	Far-Western	0.04	81.4	184.6	251.4	295.8	327.2
		10	30	50	70	90	110
	Eastern	0.5	117.6	207.9	257.3	287.8	308.5
	Central	0.3	107.7	197.3	247.5	278.9	300.4
Churia	Mid-Western	0.08	81.4	168.9	222.3	256.9	281.0
	Western	0.03	66.6	151.1	205.8	242.2	267.9
	Far-Western	0.03	66.6	151.1	205.8	242.2	267.9
		10	30	50	70	90	110
	Eastern	0.5	117.6	207.9	257.3	287.8	308.5
	Central	0.3	107.7	197.3	247.5	278.9	300.4
Mid-Hill	Mid-Western	0.1	81.4	168.9	222.3	256.9	281.0
	Western	0.03	66.6	151.1	205.8	242.2	267.9
	Far-Western	0.03	66.6	151.1	205.8	242.2	267.9
		10	30	50	70	90	110
	Eastern	0.03	65.7	149.0	202.9	238.8	264.1
	Central	0.03	55.4	125.7	171.2	201.5	222.8
Mountain	Mid-Western	0.03	63.1	143.2	194.9	229.4	253.8
	Western	0.02	48.2	109.3	148.8	175.1	193.7
	Far-Western	0.03	63.1	143.2	194.9	229.4	253.8

*Carbon numbers in this table are only for the above ground carbon.

3.1.2 Development Scenarios Modeled

To address the uncertainty in future demand for agricultural outputs and wood products, the model was run under three demand scenarios. Income and population both are drivers of future demand for wood products. We start with a set of baseline assumptions about future demand based on historical rates of change. This is our "base scenario." In all cases, we assume that demand growth stabilizes after 60 years and is constant. The high demand scenario then assumes that the demand for crops increases more rapidly over time. This could occur if income and population increase within Nepal or if exports increase dramatically. The low demand scenario holds the crop demand constant while allow livestock and forest demands to increase.

For the carbon analysis, we calculate the effects of a series of carbon payment scenarios, ranges from \$1/ton CO_2e (\$5/ton C) to \$41/ton CO_2e (\$150/ton C). By applying this, we can derive the supply (marginal cost) curve of carbon from forestland in 5 physiographic zones. We assume that the carbon price is constant over time. We apply the series of carbon payment scenarios on each 3 different food demand scenarios[9].

3.1.3 Results and Discussion

Under Base Scenario, the model projects that there will be over 115 thousand new hectares of forestland over the next 60 years (Figure 5 and Appendix 2). At the same time, less land is used for crops and more land is used for pasture. Although overall land use trends in Nepal suggest an increase in forests, the model projects that deforestation occurs in the Terai and Churia regions, accounting 53 thousand hectares and 50 thousand hectares respectively (Table 8). In both regions, deforested hectares are mostly shifted into cropland uses. Churia region is projected to get 51 thousand of new cropland and Terai region is projected to gain 56 thousand hectares of new cropland. The census data suggest that these regions are the most productive agricultural regions in Nepal, accounting more than 60% of crop production (Table 3). The results show the opposite trend in Mid-Hill region, with 218 thousand hectares of afforestation mainly from cropland conversion.

[9] It is absolutely possible to apply other carbon price schemes such as IPCC's Assessment Report results. The reason for applying this method is to focus on the potential of carbon supply in Nepal. Moreover, given the various uncertainties in parameters and data, this simplifies the analysis and provides more straightforward implications of carbon sequestration potential.

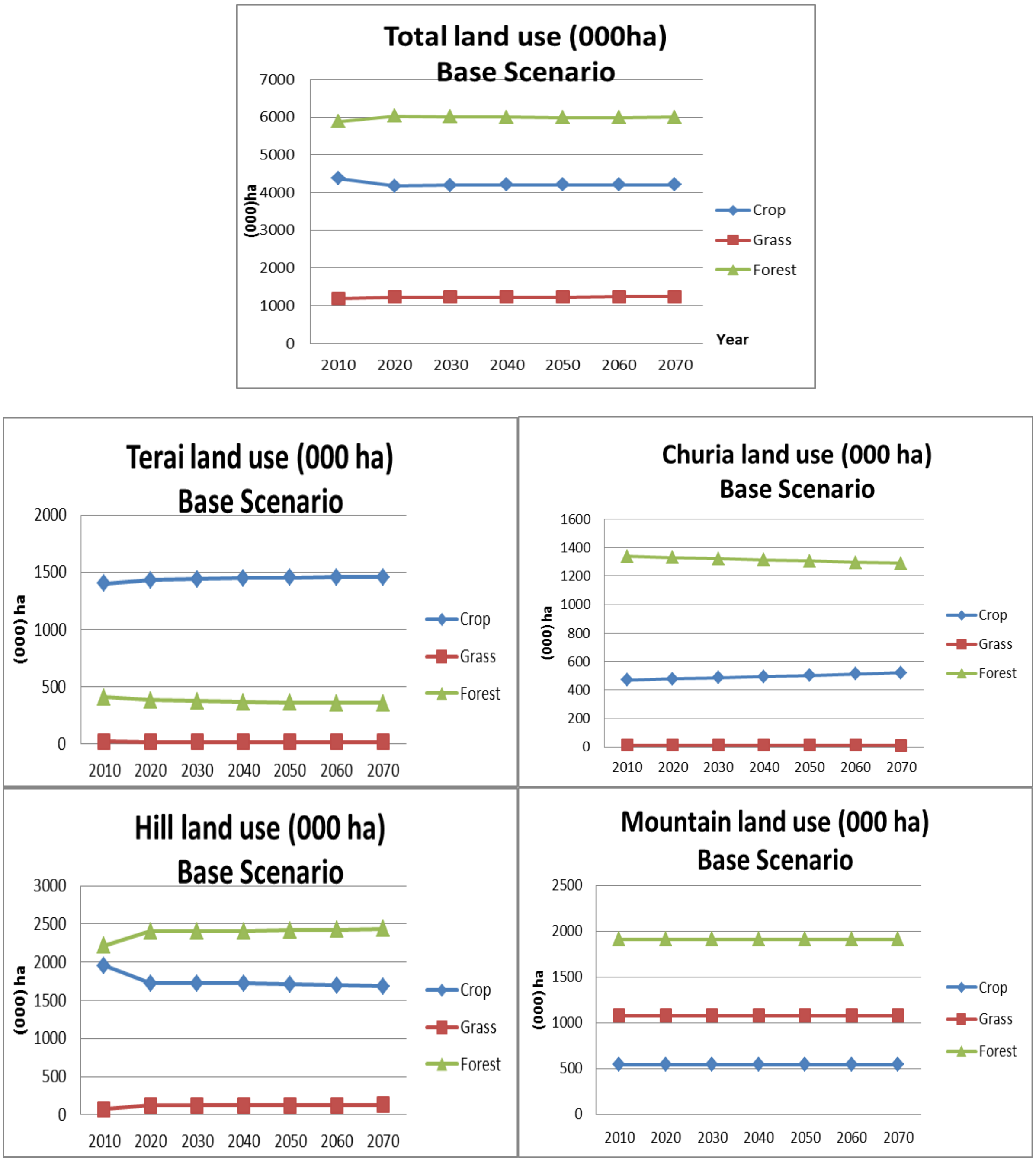


Figure 5. Total land use results under Base Scenario (000 ha)

Table 8 presents total land use changes under 3 different demand scenarios for the year 2070 relative to 2010. With higher crop demand, more cropland is required to meet the higher demand. As a result, over 300 thousand additional hectares compare to the base scenario are converted to cropland (Increasing 133 thousand hectares under High Crop demand versus decreasing 169 thousand hectares under the Base). Most of this increased cropland shifts from forestland, 250 thousand hectares, although some also comes from pastures (around 53 thousand hectares).

Under the Low Demand Scenario, model projects that there will be major land use shift away from cropland to other uses. Lower crop demand assumption requires less land use in crop and it results in 637 thousand hectares of cropland shift to other land uses. Among these shifts, 496 thousand hectares are transferred to forestland by 2070, an additional 381 thousand hectares compared to the Base scenario. Compared to forest and cropland, pasture does not change as much. Under the High Demand Scenario, it is projected that there will be around 50 thousand hectares of loss compared to the Base Scenario and an additional 87 thousand hectares under Low Crop Demand. While this may seem surprising, the low demand scenario significantly reduces the demand in the sector that requires most of the land use change, the crop sector.

Table 8. Modeled total land use changes under different demand scenarios between 2010 and 2070 in Nepal (000 hectares)

		Base	High Crop Demand	Low Crop Demand
Forest	Terai	-53	-78	19
	Churia	-50	-62	-36
	Mid-Hill	218	5	513
	Mountain	0	2	0
	Total	115	-135	496
Crop	Terai	56	81	-26
	Churia	51	63	36
	Mid-Hill	-275	-11	-603
	Mountain	0	0	-44
	Total	-169	133	-637
Pasture	Terai	-2	-2	8
	Churia	-1	-2	0
	Mid-Hill	57	6	90
	Mountain	0	-2	44
	Total	54	1	141

Carbon payment reduces the deforestation and increases the afforestation as the carbon price increases (Table 9). Under the Base Scenario, the $11 per ton CO_2e payment increases forestland area over 1.5 million hectares, and at $41 per ton CO_2e carbon payment, forestland area increases 3.6 million hectares by 2070. Higher crop demand requires more cropland usage and it is thus more costly to reduce the deforestation with carbon payment. Lower crop demand scenario requires less land use in crop thus forestland is projected to increase the most across the different carbon prices.

For the most part, additional land in forests under the carbon price scenarios is derived from crop land. The high carbon price scenarios imply large changes in land use. For example, under the Base Case, cropland declines by about 2/3rds by 2070. Impacts on pastureland are smaller, but that is mainly because less land is used overall for pasture.

Table 9. Modeled land changes for 60 years under 3 different modeled demand scenarios with carbon payment (Appendix 5 shows detailed regional results)

	\$0/ ton CO_2e	\$3/ ton CO_2e	\$5/ ton CO_2e	\$11/ ton CO_2e	\$27/ ton CO_2e	\$41/ ton CO_2e
Forestland (000 ha)						
Base	115	488.8	864.2	1591.5	3160.1	3675.0
High Crop Demand	-135	-126.8	384.3	800.6	2022.2	2696.8
Low Crop Demand	495.9	1016.1	1471.5	2284.3	3569.4	4248.3
Cropland (000 ha)						
Base	-168.6	-266.8	-423.1	-1034.4	-2503.1	-2975.1
High Crop Demand	132.9	120.8	68.1	-75.8	-1287.4	-1949.4
Low Crop Demand	-637	-861.8	-1121.9	-1797.3	-2903.0	-3546.8
Pastureland (000 ha)						
Base	53.6	-222.0	-441.1	-557.1	-657.0	-699.9
High Crop Demand	0.9	6.0	-452.5	-724.7	-734.7	-747.4
Low Crop Demand	141.4	-154.3	-349.6	-487.0	-666.4	-701.5

The sum of carbon gain above the Baseline (\$0 per ton CO_2e) is calculated to the annual equivalent of carbon gain using 5% discount rate (Table 10). It ranges from 32 thousand tons per year to 3.2 million tons per year under Base Scenario depending on the carbon price. As expected, the carbon gain is the largest under Low crop Demand Scenario, up to over 3.4 million tons per year. In Figure 6, marginal cost curve (carbon supply**)** is plotted for the 3 Scenarios, basically presenting Table 10. It is evident that the marginal cost curve (or carbon sequestration supply curve) under Low crop Demand Scenario is the lowest (cheapest). Since we cannot have definite information about the future demand changes, this range of carbon sequestration supply curves can provide at least inferences on the carbon sequestration potential range given the scope of demand change assumptions in Nepal.

Table 10. Annual equivalent of carbon gains for 60 years (000 tons CO_2e/year) under 3 different modeled demand scenarios

	\$1/ ton CO_2e	\$3/ ton CO_2e	\$5/ ton CO_2e	\$11/ ton CO_2e	\$27/ ton CO_2e	\$41/ ton CO_2e
BASE	32.6	274.0	626.9	1281.1	2642.4	3239.1
High Crop Demand	10.2	13.1	384.1	672.4	1928.4	2595.6

Low Crop Demand	113.7	406.2	816.8	1587.3	2875.7	3434.3

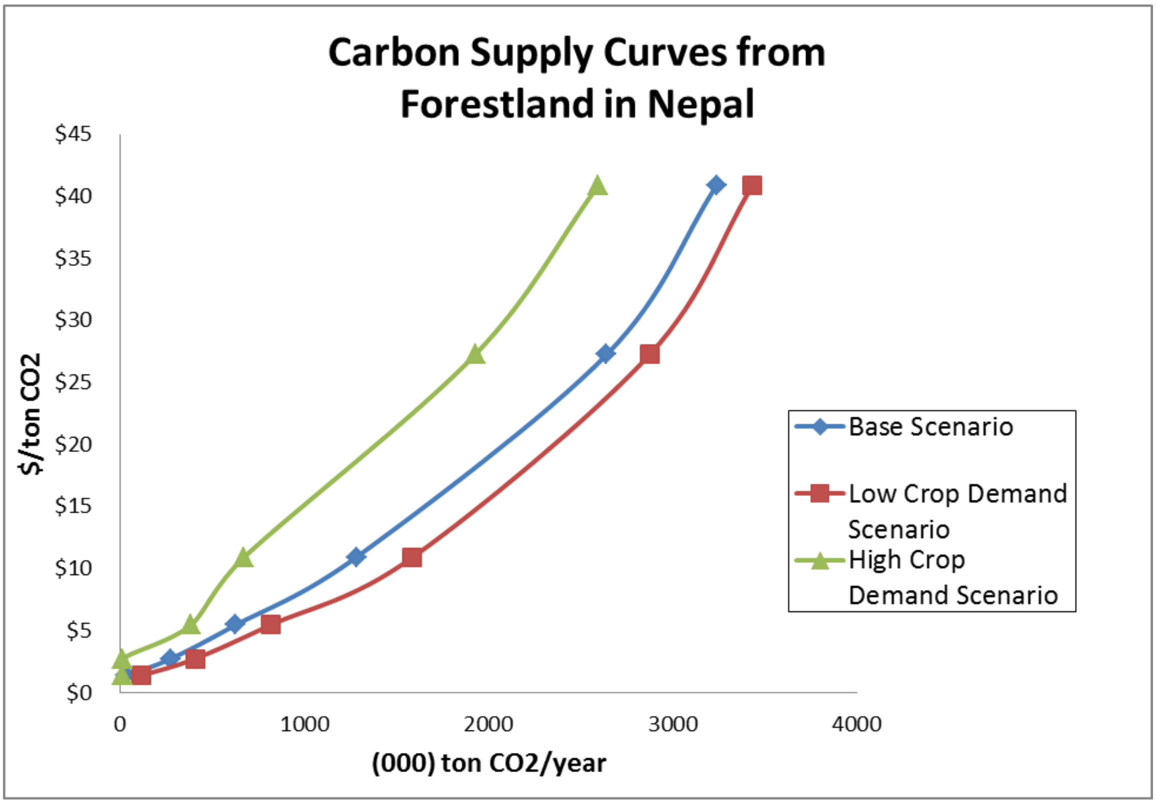


Figure 6. Marginal cost curves under 3 different demand scenarios

3.2 Computable General Equilibrium model[10]

A fairly simple Computable General Equilibrium (CGE) model has been constructed specifically for this project. Like other CGE models[11] the model consists of equations describing:

- Demands by industries and final demanders for commodities are influenced by prices.
- Demands by industries for capital, land and labour are again influenced by prices.
- Commodity taxes affecting user prices are explicitly modeled.
- Market clearing: prices adjust to equate supply and demand for each commodity.
- How factor income is distributed and the system of transfer payments between households, government and the rest-of-the-world (ROW) is clearly embodied in the model.
- Various macro indicators, such as GDP, GNP, CPI, etc. are generated in the model.

Production technology is structured by a series of "nests", shown in Figure 7 below. In more detail:

- 62 industries are distinguished, each producing one commodity. These are listed underneath Table 11. They include 13 agricultural industries: Paddy, Maize, Wheat, OthGrain, VegetFruit, Oilseed, Sugarcane, PlantFiber, OthCrops, Cattle, OthAnmlPrd, RawMilk, Wool; and 4 forest industries: Firewood, Timbers, GrassFoddr, OForestPrd.
- Each industry and non-export final demander use 62 composite commodities -- each of which is a CES combination of a domestic good and its imported equivalent. Commodity prices and import/domestic shares are the same for all local users.
- For intermediate (industry) demand the 62 composite commodities are combined (via CES) into an aggregate "Intermediate goods" input, which is demanded in proportion to output.
- Industries also require, in proportion to output, a composite primary factor which is a CES aggregate of capital, land and labour used by that industry. Only agricultural and forest industries have a land input.
- Some local output goes directly to export; the rest is combined with imports to form the composite good.

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[10] Market clearing mechanism is the building block of the CGE model and hence quite often questions are raised on the suitability of such a model in an economy with less well developed market system. However, for the present nature of exercise, similar model is recommended and used widely and hence such a model was proposed for the present exercise. The model is reliable and applied in other big REDD+ countries such as Brazil, Indonesia.

[11] The model is solved using GEMPACK. It is very similar to the PhilGem model described in Corong and Horridge (2012) and to the standard IFPRI GAMS CGE model (Lofgren et al, 2002), except that trade and transport margins are treated as direct demands. To compute and compare 40-year base and policy scenarios takes about 5 minutes. Archive Item TPMH0151 at http://www.copsmodels.com/archivep.htm contains materials sufficient to replicate the simulation reported here.

- Each of the 7 household types demand the 62 composite commodities following the Linear Expenditure System (LES).
- The commodity mixes of investment and of government demands are exogenous.
- Exporters face foreign demand curves of constant elasticity -- typical values 4-8.
- Most of the CES, expenditure, and export demand elasticities are taken from the GTAP database[12]. The figure shows some typical values.
- The supply of agricultural land is distributed between agricultural industries using a CET function with transformation elasticity 0.25. The total supply of agricultural land to all agricultural industries is exogenous, as is the total supply of land to all forest industries. Land inputs to forest industries move together (they are sharing the same land).
- Although not used in this project, the model allows for several types of labour, and for industries to produce a range of commodities.

[12] GTAP data base is relatively most reliable and used extensively for global, regional and country specific models.

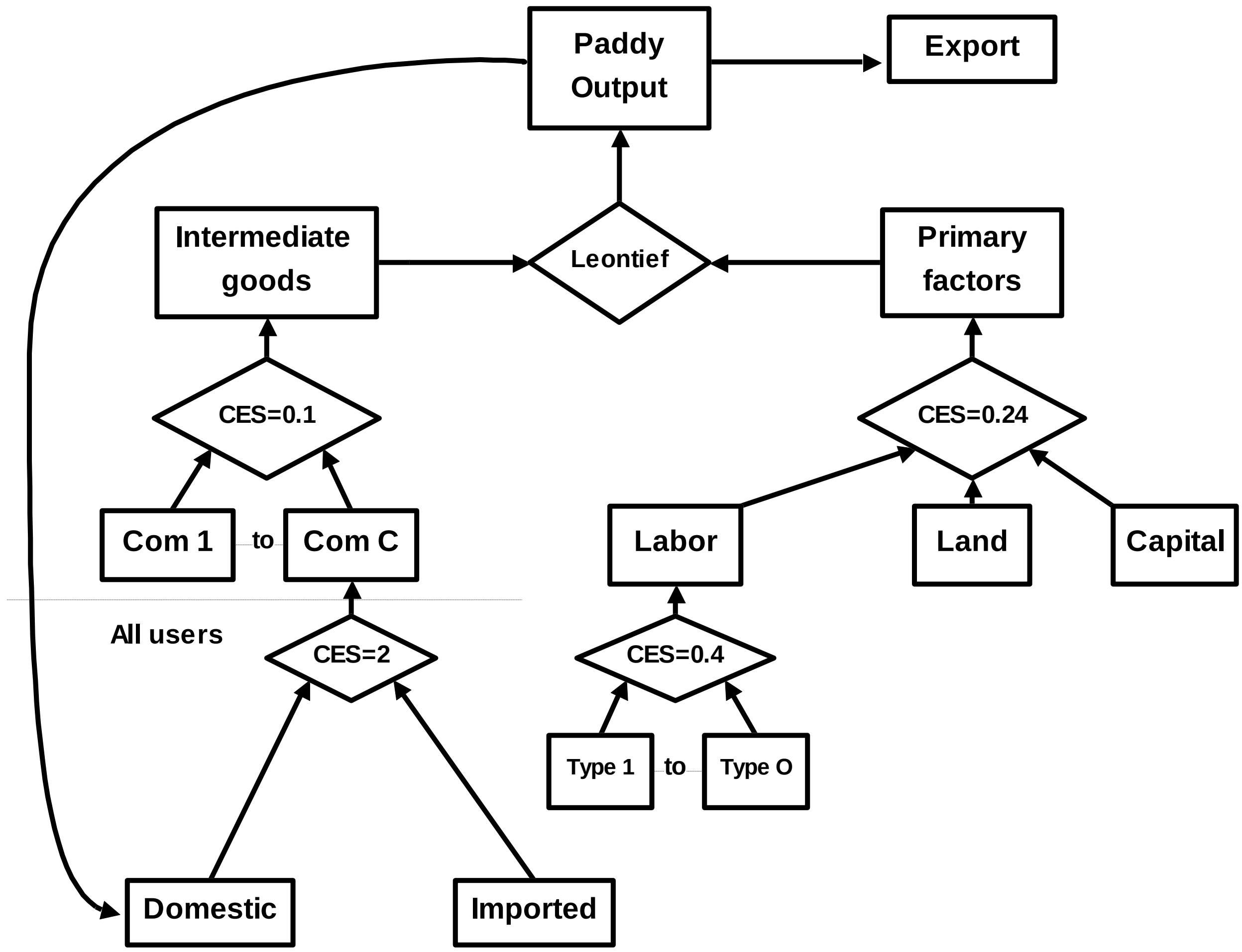

Figure 7. Production Technology

The model is a multiperiod; of the recursive-dynamic type. The only dynamic mechanism is that which sets next-period sector-specific industry capital stocks to last-period stocks less depreciation plus last-period investment. Investment for each industry is positively related to that industry's rate of return on capital. Investors are myopic, but investment in each sector changes so that, after some time, capital earns an exogenous industry-specific rate of return. An open capital market is assumed, so that investment is not limited by Nepali saving.

3.2.1 Model Database

The initial model database consists mainly of a Social Accounting Matrix (SAM) with 139 rows and columns (Table 11). The data sources and methods used to construct SAM are presented in the Appendix 4. As exhaustively discussed there, apart from using supply and use table of CBS, other numerous sources had to be used for fulfilling the data gaps. For further breaking down of forestry and other few sectors, new estimates had to be made based on the data available from the national accounts. As well known, for SAM which is a building block of CGE huge data sources that too providing information on supply and use of inputs, factor distribution and final demand vectors as per distinguished sectors is needed. Such a data set is hardly produced in Nepal despite regular annual and periodic surveys covering different sectors of the economy. From that perspective, data gap in forestry sector is equally high and hence for further exercise as per REDD+ requirement by avoiding or minimizing bold assumptions, there is a need of fulfilling the data gaps in a standard input and output framework.

A SAM shows all monies received or spent by each sector and final demander [a cell in row i, column j shows funds flowing from j to i]. A summary appears in Table 11. Apart from the SAM, the database contains:

- Various elasticities (like those shown in Figure 7).
- For each of Terai/Churia agriculture and forestry: land use in hectares, and share in value of national output.
- Investment in, and capital stock of, each of 62 sectors defined in the SAM.
- The proportion of consumption of each good by each household that is regarded as "subsistence" in the Linear Expenditure System (LES).

Table 11. Summary of the Social Accounting Matrix (SAM), Nepal, 2007, aggregated million rupees. Yellow-highlighted cells show flows of goods and primary factors (as seen in an input-output table), while other cells show transfer payments or subtotals. (ROW = Rest of World)

	Industries	Commodities	Labour	Capital	Land	Households	ComTax	Tariff	Government	ROW	Investment	Total
62 Industries	0	1126303	0	0	0	0	0	0	0	0	0	1126303
62 Commod.	393986	0	0	0	0	741903	0	0	57642	70703	172120	1436354
Labour	285158	0	0	0	0	0	0	0	0	0	0	285158
Capital	375500	0	0	0	0	0	0	0	0	0	0	375500
Land	71658	0	0	0	0	0	0	0	0	0	0	71658
7 Households	0	0	285158	375500	71658	0	0	0	9985	91978	0	834280
ComTax	0	70425	0	0	0	0	0	0	0	0	0	70425
Tariff	0	12627	0	0	0	0	0	0	0	0	0	12627
Government	0	0	0	0	0	16000	70425	12627	0	25854	0	124906
ROW	0	227000	0	0	0	0	0	0	0	0	0	227000
Investment	0	0	0	0	0	76377	0	0	57279	38464	0	172120
Total	1126303	1436354	285158	375500	71658	834280	70425	12627	124906	227000	172120	4736331

Note: A 2007 SAM of Nepal was prepared by Dr D.R. Khanal, as described in Appendix 4. His SAM has 139 rows and columns; in the summary above rows and column for the 62 sectors and 7 household types have each been combined. The original 62 sectors are: Paddy, Maize, Wheat, OthGrain, VegetFruit, Oilseed, SugarCane, PlantFiber, OthCrops, Cattle, OthAnmlPrd, RawMilk, Wool, Firewood, Timbers, GrassFoddr, OForestPrd, Fishing, Coal, Oil, GasMining, OthMining, Meat, MeatPrd, VegetblOil, DairyPrd, GrainMill, Sugar, OthFoodPrd, DrinkTobac, Textile, Clothing, LeatherPrd, Lumber, Paper, Petroleum, ChemRubber, MineralPrd, IronSteel, NonFerrMtl, FabricMetl, MotorVehcl, OthTrnsEqp, ElctrncEqp, OthMechEqp, Furniture, OthManuf, Electricty, Gas, Water, Construct, Trade, OthTrnsprt, WtrTrnsprt, AirTrnsprt, Communictn, Finance, Insurance, OthBusSvc, RecOthSvc, GovSvc and Dwelling. The 7 household types have different patterns of income and expenditure: the table below shows source shares in disposable income.

The main components of Nepal's GDP and GNP are summarized in Tables 11 and 12. A feature of Nepal's economy is the importance of non-export income from overseas. The sum of first five components of GNP labour, capital, land and commodity taxes) in Table 11 equates to the total GDP shown in Table 12. The last 2 components of GNP in Table 12 represent income from overseas: 'remittances' are mainly the earnings of Nepali migrant workers, and 'aid' shows transfers to the government from the rest of the world. Together these account for 13% of total GNP, relatively a high share. Table 13 shows the main components of expenditure-side GDP. Imports are triple exports; the trade deficit is funded by income from the rest of the world. Also notable is the low share of government spending in GDP (just 7%).

Table 12. Components of GNP; from Nepal SAM, 2007, million rupees

GNP	Labour	Capital	Land	Commodity Taxes	Tariffs	Remittances	Aid	GNP Total
Values	285158	375500	71658	70425	12627	91978	25854	933201
% Shares	31	40	8	8	1	10	3	100

Table 13. Components of GDP; from Nepal SAM, 2007, million rupees

GDP	Households	Investment	Government	Exports	- Imports	GDP Total
Values	741903	172120	57642	70703	-227000	815368
% Shares	91	21	7	9	-28	100

Income is derived from various sources, depending on whether households are located in urban or rural areas (Table 14). In rural areas, households with no or little land derive most of their annual income from labor (i.e., from working). Households with greater landholdings derive more and more income from both land and capital sources. In all cases, rural households derive a significant proportion of their income (8% to 18%) from the rest of world, either through remittances or other international transfers. Less educated urban households derive much income from labor. With higher income levels a comparatively higher level of income is derived from capital.

Table 14. Income sources by household type, percentages of after-tax income

	Labour	Capital	Land	Government	ROW	LessTax	Total
RurLndNone	64.0	22.5	0.0	1.4	12.1	0.0	100
RurLndSmall	62.5	16.8	1.6	1.6	17.5	0.0	100
RurLndMedium	26.0	50.8	10.4	0.4	12.5	-0.1	100
RurLnLarge	3.7	62.9	28.3	0.7	8.2	-3.8	100
UrbLowEduc	64.8	17.8	3.8	4.2	10.6	-1.1	100
UrbMedEduc	24.7	68.4	5.4	3.3	4.0	-5.8	100
UrbHighEduc	4.2	97.0	4.3	1.1	5.3	-11.8	100

RurLndNone = rural households with no land; RurLndSmall= rural households with small landholdings; RurLndMedium= rural households with medium landholdings; RurLnLarge = rural households with large landholdings; UrbLowEduc= urban households with low education levels; UrbMedEduc=urban households with medium education levels; UrbHighEduc=urban households with high education levels;

3.2.2 The Closure

Most CGE model contains more variables than equations. Hence some variables have to be exogenous -- set by the model user. There is some flexibility in the choice of exogenous variables: the chosen set is called the *closure*. Here the same closure is used in both base and policy simulations. The following variables are exogenous:

- Tax rates, and rates of technological changes
- Import prices, and the positions of export demand curves
- ROW transfers to Nepal households and government (including REDD payments)
- Employment; and land available for forestry and agriculture
- Target rates of return to capital: investment in each industry goes up or down according to whether the current rate of return is above or below the target rate.
- The exchange rate (acting as numeraire).
- External balance (= exports + ROW transfers to Nepal Households and government - imports).

Household spending follows household income, and government spending on goods follows GNP. But in each case the propensity to consume is adjusted by a single scale factor that allows the external balance conditions to be met. The effect of this is that REDD payments allow both government and household spending to increase (implicitly the REDD payment is shared between households and government). Obviously the question of how the REDD payments are distributed is important; we simulate a neutral scheme.

3.2.3 Scenario Analysis

Two scenarios were modeled. The base scenario is designed to serve as a plausible scenario for the future path of the Nepalese economy in the absence of a REDD scheme. Its main function is to serve as a point of comparison for an alternate, policy, scenario which does include a REDD scheme. The difference between the two scenarios is interpreted as the effect of the REDD scheme.

- Obviously the future paths of foreign prices, technological change, foreign demand for Nepalese labour, etc, are unknown and have to be guessed. The same guesses are used for base and policy forecasts.
- Plausible variations in the set of assumptions which are common to base and policy forecasts usually have only a small effect on the difference in results between base and policy scenarios.

Hence, details of the base forecast are not strongly relevant to analysis of effects of the REDD policy. Nonetheless the base forecast is of considerable interest in its own right, so the main features are described below.

Base Scenario

The base scenario assumes the Nepalese economy is taking place in absence of a REDD scheme. The following exogenous changes were imposed for each year of the base scenario:

- 2% annual productivity increases for all labour and land inputs used by industries
- 1.4% annual population increase (reflecting recent history) and a 2% annual increase in the labour force (the difference between these two reflecting the 'demographic dividend' associated with a reduced birth rate).
- An increase in demand for Nepalese exports of 3.5% per annum (p.a.)

The above assumptions reflect an expectation that the future annual rate of real GDP growth will be about 3.7% per year -- similar to the average of the last decade[13]. They imply that per-capita GDP will rise by about 2% per year -- more than doubling in 40 years. This suggests that Nepal may become less dependent on non-export income from abroad. The next three assumptions reflect this idea:

- An increase in foreign currency remittances to Nepalese households from the ROW of 3% per year -- these mainly comprise the earnings of Nepalese working abroad. Thus foreign labour earnings as a fraction of GDP are assumed to fall slowly.

- No increase in (non-REDD) donations by the ROW to the Nepalese government (Aid frozen at 2007 levels).

[13] See for example: http://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG/countries/NP?display=graph

- A gradual movement towards external balance, ensuring that the value of exports, plus remittances from the ROW to households and government, are sufficient to pay the import bill. That is, the 2007 excess of imports over foreign income is gradually reduced (by 10% per year).

Lastly we assume, in the base forecast only:

- Annual conversion of 2617 hectares of Terai/Churia land from forest to agriculture. That translates to an increase of 0.1% p.a. in the national supply of agricultural land, with a corresponding decrease of 0.1% p.a. in the forest area.

Policy forecast

The policy scenario follows the same assumptions as the base scenario, except with two differences:

- From 2015 there is no further annual conversion of 2617 hectares of Terai/Churia land from forest to agriculture.

- From 2015 there is an annual REDD payment of 2716 million NPR paid from ROW to Nepal. The amount is calculated in Appendix 3, and corresponds to a $US 50 / t CO_2e price[14]. The REDD payment allows both household and government spending to expand by an equal percentage[15].

[14] We assume that other foreign aid payments are not reduced -- although it is of course possible that aid could be 'relabelled' as REDD funds, without increasing the total amount.

[15] Conceivably, a wisely-directed increase in government spending might increase future productivity -- but we did not include such a mechanism.

3.2.4 Results and Discussion

Base Scenario

Table 15 and 16 show results of the base forcast. Table 15 shows changes in selected macro aggregates, both as total changes over the simulated period; and as annual percent changes. Under the base scenario real GDP grows at an average rate of 3.7%, but real GNP and real household and government consumption grow at a slightly lesser speed (Table 15). This reflects our assumption of a gradual movement towards external balance. Similarly, exports grow more than imports.

The aggregate land variable (xlnd_i) is an average of land used by different sectors, weighted by the rental value of land in each sector. This variable grows at a small rate, even though the total hectares allocated to Agriculture or forestry remains unchanged, because forest (which has a low per-hectare rental) is being turned into agricultural land (which earns more). This causes the aggregate land variable to increase slightly, and contributes slightly to increase GDP.

Table 15. Base forecast, total and average annual percent changes 2007-2047, selected macro variables

Description	Model variable name	total % change	average annual % change
Real household consumption	xhoutot	265.7	3.29
Real investment	xinv_c	353.5	3.85
Real government consumption	xgov_c	282.0	3.41
Real GNE (absorption)	xgne	281.7	3.41
Real exports	xexptot	664.0	5.21
Real imports	ximptot	251.8	3.19
Real GDP	xgdpexp	323.3	3.67
Aggregate capital	xcap_i	336.5	3.75
Aggregate labour	xlab_oi	120.8	2.00
Aggregate Land	xlnd_i	3.6	0.09
Total factor inputs	xgdpfac	185.5	2.66
Real GNP	xgnp	308.6	3.58
Real GDP per capita	xgdppc	134.3	2.24
Real GNP per capita	xgnppc	134.3	2.15

Table 16 shows some broad sectoral results: to save space we have aggregated these results from the model's 62 sectors down to 13 broad sectors. Three mechanisms drive these sectoral results:

- Unit land rents rise steeply, reflecting the fixity of land supplies. The higher rents cause price rises for local Crops, Livestock, Forest and (indirectly) Food. Imports grow most (and exports and output least) for these sectors.
- In the "Local Use" column, rising household incomes and higher expenditure elasticities for manufacturing and service outputs cause local demand for those goods to raise more.

- Exports increase sharply, except in the forest sector, where exports decline.

Table 16. Base scenario, average annual percent changes 2007-2047 (Model's 62 sectors aggregated into 13 broader categories)

	Output	Exports	Imports	Local Use	Price (dom)	Land rent
Model variable→ Broad Sector ↓	Aggxtot	aggxexp	aggximp	aggxcmp	aggpdom	aggplnd
Crops	2.46	2.13	3.06	2.54	0.30	3.94
Livestock	2.69	1.13	4.52	2.86	0.58	4.61
Forest	2.87	-1.03	4.28	2.90	0.49	7.51
Fishing	3.42	4.02	3.12	3.37	-0.20	
Mining	4.44	5.65	3.48	3.83	-0.41	
Food	2.93	3.27	2.98	2.90	0.05	
Manufact	4.44	5.85	3.37	3.70	-0.29	
Utilities	4.04	0.00	2.78	3.87	-0.44	
Construction	3.99	0.00	2.94	3.85	-0.53	
TradeTrans	4.17	5.39	3.07	3.96	-0.47	
Services	4.21	5.55	3.13	4.04	-0.49	
GovSvc	4.21	5.96	2.71	3.69	-0.62	
Dwellings	4.08	0.00	0.00	4.08	-0.50	

Policy Scenario

The policy forecast is the same as the base forecast but with two differences:

- From 2015 there is no further annual conversion of 2617 hectares of Terai/Churia land from forest to agriculture.
- From 2015 there is an annual REDD payment of 2716 million NPR paid from ROW to Nepal. The amount is calculated in Appendix 3, and corresponds to a $US 50 CO2 price[16]. The REDD payment allows both household and government spending to expand by an equal percentage[17].

For this analysis we report policy results as differences from the base scenario. For example, a 2047 0.5% GDP decrease should be interpreted to mean that in 2047 GDP in the policy scenario is 0.5%

[16] We assume that other foreign aid payments are not reduced -- although it is of course possible that aid could be 'relabelled' as REDD funds, without increasing the total amount. Both the $50 CO2 price and the 2617 hectares p.a. change in land use change are simply illustrative assumptions. A much smaller CO2 price, say $5, would yield very gloomy results. Estimates of the CO2 price needed to hugely reduce rich-world emissions are normally in the $30-$100 range. The CO2 price could also change over time.

[17] Conceivably, a wisely-directed increase in government spending might increase future productivity -- but we did not include such a mechanism.

less than in 2047 in the base scenario. In other words, we report cumulative percentage deviations from base (Figure 8).

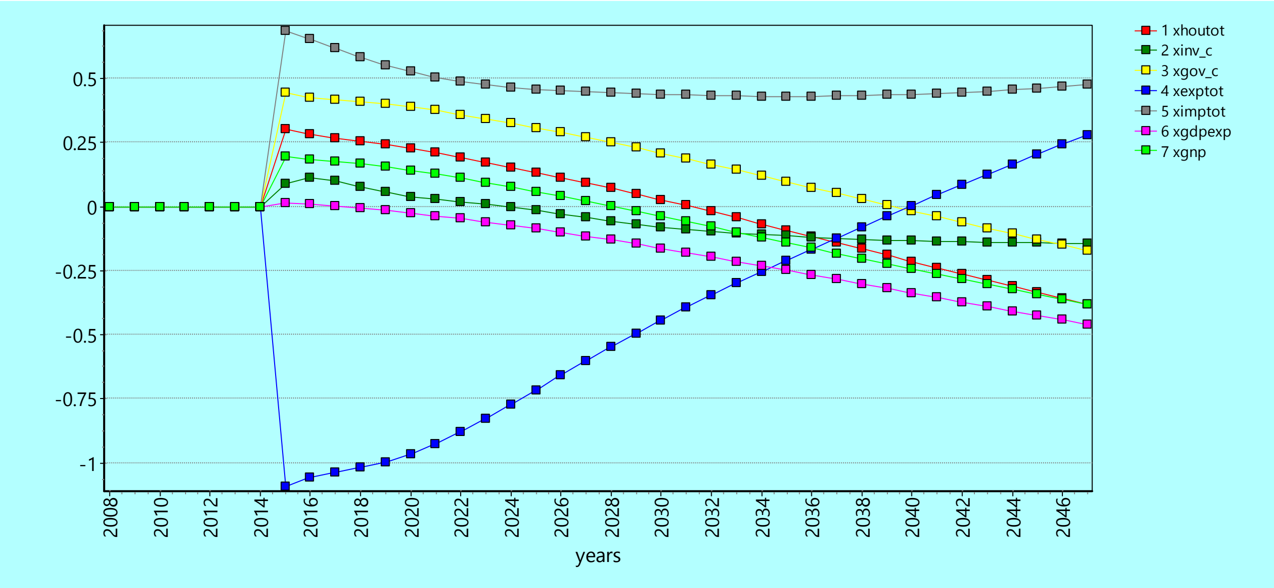

Figure 8. Macro variables, cumulative percentage deviations from base scenario

(1. Real household consumption = xhoutot, 2. Real investment = xinv_c, 3. Real government consumption = xgov_c, 4. Real exports = xexptot, 5. Real imports = ximptot, 6. Real GDP = xgdpexp, 7. Real GNP = xgnp)

Based on model results, when the REDD scheme is introduced in 2015, real household consumption (xhoutot, in red) increases by about 0.3%, but the increase declines over time. By 2032 consumption returns to its base level, and after that consumption is lower than in the base scenario. Real GNP (xgnp, in limegreen) follows a similar path. By contrast, real GDP (xgdpexp, in purple) jumps very slightly initially, and then steadily declines to nearly 0.5% below base by 2047. Based on these three measures, the REDD scheme leaves Nepal worse off in 2047.

To understand these results, we should bear in mind that:

- Macro effects are small, since the size of the scheme simulated here is small relative to GDP.
- Compared to the base scenario, the REDD scheme consists of two components:

A. a 2015 increase in payments from ROW to Nepal of 2716 million NPR, continuing at that level thereafter.

B. an annual transfer of 2617 hectares of Terai/Churia land from high-rent agriculture to low-rent forests. This causes a continuing, cumulative, reduction in agricultural output and GDP.

Thus this REDD scheme front-loads the REDD's benefits and defers the costs. Each year, Nepal receives 2716 million NPR, and in return loses a further 2617 hectares of agricultural land forever. Eventually the costs exceed the benefits[18].

To understand the interaction of mechanisms A and B above, it is helpful to simulate their effects separately. The total effect is approximately the sum of the two individual effects. Figure 9 shows the effect of only A -- the 2716 million NPR annual payment (with no change in forest clearing) from REDD. The gift of foreign exchange has little effect on Nepal's output or real GDP (xgdpexp, in purple). With fixed endowments of labour and land and a fixed rate of return to capital[19], we should not expect real GDP to change much. Rather the gift allows Nepalese to consume more without producing more. The trade balance worsens by the amount of the REDD payment. Imports (ximptot, grey) rise and exports (xexptot, blue) decrease. With the payment fixed, the percentage effects get smaller over time, since GDP is growing over the period.

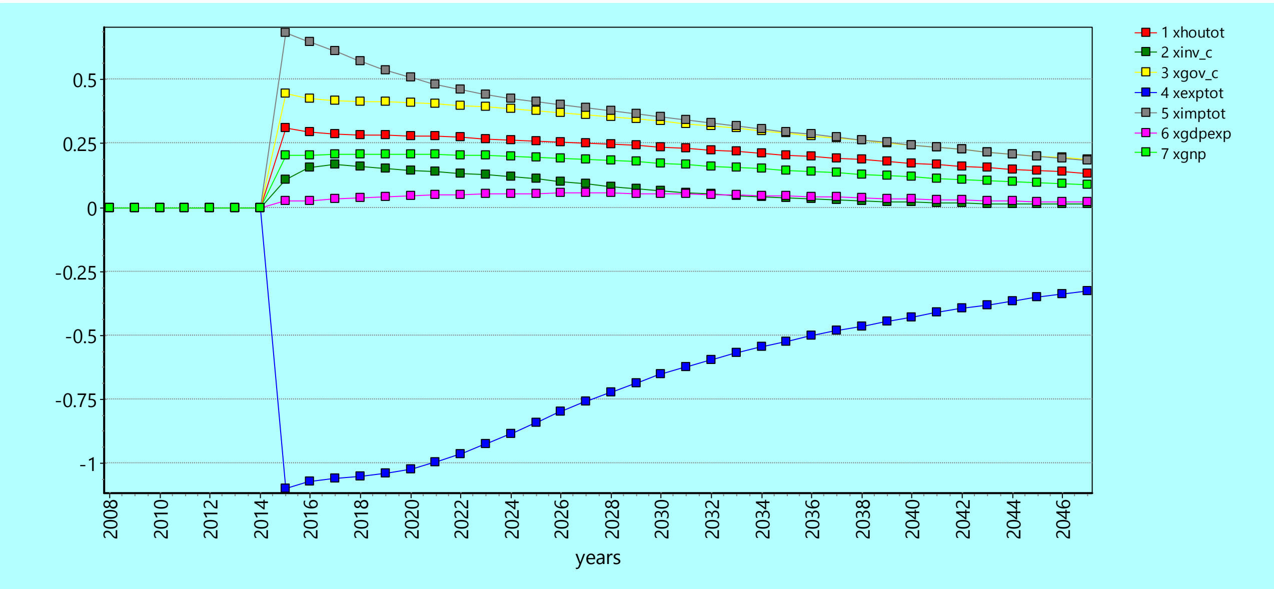

Figure 9. Macro variables, REDD payment only

(1. Real household consumption = xhoutot, 2. Real investment = xinv_c, 3. Real government consumption = xgov_c, 4. Real exports = xexptot, 5. Real imports = ximptot, 6. Real GDP = xgdpexp, 7. Real GNP = xgnp)

Figure 10 shows the effect of only B -- the annual loss of agricultural land without a compensating payment. GDP, GNP, and household consumption fall steadily, until in 2047 they are about 0.5% less than in the base scenario. Imports (especially of food) rise, so to preserve the trade balance exports must also rise. Initially, exports are much smaller than imports (Table 13), so the trade-balancing percent export rise is larger than the percent import increase.

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[18] Implicitly we assume a zero discount rate here. With a high enough discount rate, 2716 million NPR today could compensate for the perpetual loss of 2617 hectares of agricultural land.

[19] In the model, rates of return to capital vary in the short run, but tend to return to normal levels over time.

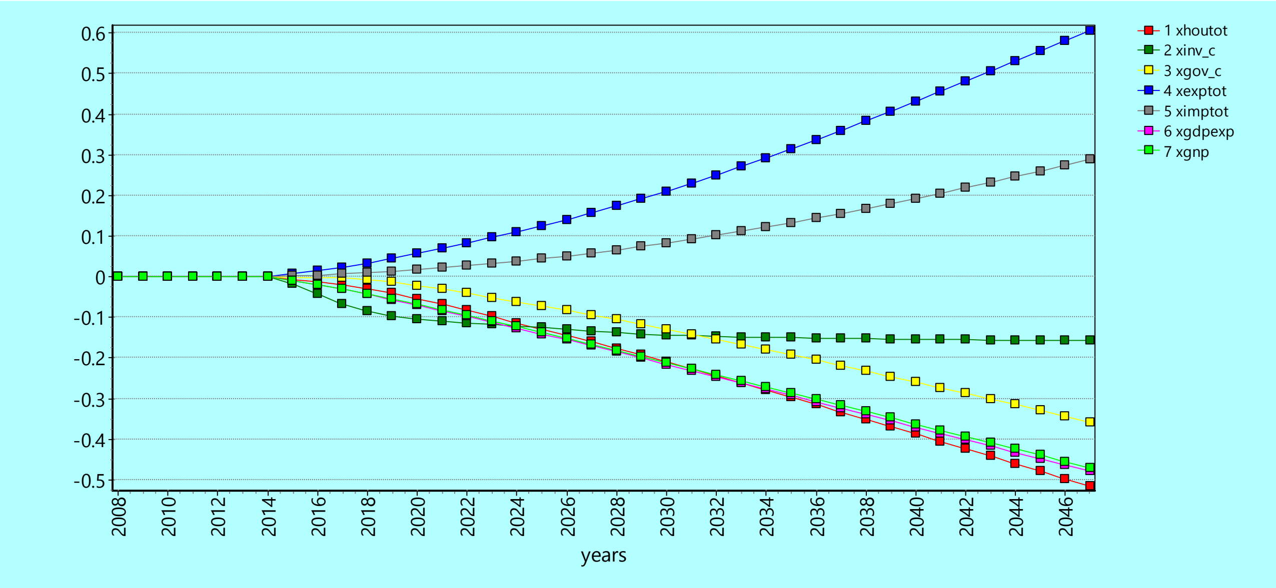

Figure 10. Macro variables, stop deforestation only

(1. Real household consumption = xhoutot, 2. Real investment = xinv_c, 3. Real government consumption = xgov_c, 4. Real exports = xexptot, 5. Real imports = ximptot, 6. Real GDP = xgdpexp, 7. Real GNP = xgnp)

The combined effect, shown in Figure 8, is that initial benefits of the REDD scheme are eroded and reversing by steadily increasing costs.

Broad sectoral effects

The table below (Table 17) shows end-period effects of the REDD scheme for broad industry sectors. Less land for agriculture means higher land rents, reduced output, and higher crop (and food) prices. The opposite applies to the Forest sector, which has more land available -- but because the forest sector is much smaller than agriculture, this good news does not outweigh the bad. Increased food imports are balanced by export increases for Manufacturing and Services.

It should be emphazied that these effects are fairly small. The REDD may cause 2047 Crops output to fall by 2.37% relative to the base scenario, but in the base scenario Crops output grows by more than that each year (see Table 16).

Table 17. Broad sectoral effects, percent deviation from 2047 Base scenario

	Output	Exports	Imports	Local Use	Price (dom)	Land rent
Model variable→ Broad Sector ↓	aggxtot	aggxexp	aggximp	aggxcmp	aggpdom	aggplnd
Crops	-2.37	-9.67	3.17	-1.56	2.61	6.05
Livestock	-2.68	-8.82	3.96	-1.93	2.68	5.51
Forest	1.90	15.31	-5.01	1.81	-2.72	-7.72
Fishing	-0.22	-0.35	-0.03	-0.21	0.14	
Mining	0.13	0.63	-0.21	-0.11	-0.15	
Food	-2.33	-5.13	0.83	-0.71	1.18	
Manufact	0.43	1.54	-0.07	-0.05	-0.18	
Utilities	0.05	0.00	-0.46	-0.01	-0.18	
Construction	-0.08	0.00	-0.58	-0.14	-0.26	
TradeTrans	0.32	0.79	-0.16	0.22	-0.21	
Services	0.19	0.97	-0.30	0.09	-0.21	
GovSvc	0.14	0.71	-0.35	-0.06	-0.19	
Dwellings	0.12	0.00	0.00	0.12	-0.24	

Effects on different households

The table below (Table 18) compares end-period nominal and real effects of the REDD scheme between different household groups. The several household types distinguished by the SAM have different income (see Table 14) expenditure patterns, leading to differential incidence of income and price effects. The first column shows effects on post-tax nominal factor income -- which on average are small (last row). However, labour's share of GDP is falling, whilst the land share is rising. So the poor, who depend most on labour income, do worse, while larger landowners do best.

The second column shows effects on living costs -- which on average rise by 0.6%. But high land rents cause high food prices; and the poorer groups spend more on food, so for the poor, CPI rises more. The net effect, which is doubly regressive, is shown in column 3.

Neither nominal nor real factor incomes shown below take into account the redistribution of REDD payments from the ROW. As explained earlier, this redistribution is neutral in effect: the closure ensures that REDD funds allow for each household and the government to increase goods purchases by the same percentage amount. Hence real consumption by household (the last column) is uniformly 0.21% greater than the previous column. Still, the only winners are the large landowners.

Table 18. Nominal and real effects by household type, percent deviation from 2047 Base scenario

	Nominal Income	CPI	Real Income	Real Consumption
RurLndNone	-0.35	0.83	-1.17	-0.96
RurLndSmall	-0.27	0.70	-0.96	-0.75
RurLndMedium	0.08	0.61	-0.52	-0.31
RurLnLarge	0.60	0.51	0.09	0.30
UrbLowEduc	-0.19	0.33	-0.52	-0.31
UrbMedEduc	-0.07	0.24	-0.32	-0.11
UrbHighEduc	-0.09	0.21	-0.30	-0.10
All households	0.01	0.58	-0.56	-0.38

RurLndNone = rural households with no land; RurLndSmall= rural households with small landholdings; RurLndMedium= rural households with medium landholdings; RurLnLarge = rural households with large landholdings; UrbLowEduc= urban households with low education levels; UrbMedEduc=urban households with medium education levels; UrbHighEduc=urban households with high education levels;

The regressive direct effects of the REDD scheme, shown above, point to the need for a targeted distribution of REDD funds, favouring those harmed most: the poor and landless.

4 Conclusions and Policy Implications

The study develops an analysis of the economic costs and benefits of carbon payments for changing land use in Nepal. Two models are developed and employed. First, a dynamic land use model is developed which illustrates the change in land use and change in carbon for various levels of REDD payments. Second, a computable general equilibrium model (CGE) is developed to assess the interaction of the payments and resulting land use changes on the Nepalese economy.

The dynamic land use model examines the interaction between forest, crop, and pasture land use in Nepal. All regions in the country are considered, with the country broken into 5 physiographic zones, Terai, Churia, Mid-Hill, Mid Mountain, and High Mountain regions.

Three different scenarios are developed with no carbon payments, a base case, a high crop demand case and a low crop demand case. The results suggest that

- There will be deforestation in Terai and Churia physiographic zone ranging from 50 thousand to 78 thousand hectares over a 60 year period while 218 thousand hectares of new forests will be established in the Mid-Hill zone. The deforestation in Terai and Churia is projected to shift land to from forests to cropland, at a rate of 1770 hectares per year. Several fixed carbon price scenarios ($1 per ton CO_2e to $41 per ton CO_2e) are applied for each of these demand scenarios.

- At the high carbon price of $41 per ton CO_2e, afforestation will occur under Base (3.6 million hectares) and Low crop Demand Scenario (4.2 million hectares).

- Under the High crop Demand Scenario at $41 per ton of CO_2e, there will be additional 2.6 million hectares by 2070. Cropland will decrease about 2.9 million hectares under Base Scenario and 3.5 million hectares under Low crop Demand Scenario. Carbon gains are calculated as annual equivalent gains and it ranges from 10.2 thousand tons per year (High Crop Demand scenario with $1/ton CO_2e) to 3.4 million tons per year (Low Crop Demand scenario with $41/ton CO_2e) in Nepal forestland.

The results, however, should be interpreted more cautiously as these are based on certain bold assumptions. First, in the model only a single timber type in each region is assumed and hence carbon changes may not be fully accurate. Second, in the absence of land rental cost data to assist in the calibration phase, data available from GTAP have been used. Therefore, better data would provide better starting point for the model. Introduction of regional differences in crop productivity more explicitly affecting future crop production potential differently would have differential impact on land use changes. Third, consideration on the development of infrastructures such as highways and facilities would have shown large impacts on land use conversions in the long run but it could not be considered in the model. Fourth, availability of more detailed information on land use categories in agriculture including fallow land would have provided more reasonable insights on the understanding of future land use projections in Nepal. Such limitations of the model indicate on the need of fulfilling data gaps for more detailed robust policy analysis in future based on the land use model developed here which is a pioneering contribution in the Nepalese context. The second analysis conducted is based on a Computable General Equilibrium (CGE) model that takes land use change and REDD payments as given. The model explores how the payments and the resulting changes in land use interact in the economy. The model has examined the effects of one possible REDD scheme, finding that initial benefits to Nepal's economy are in time reversed by the loss of agricultural land. Different REDD schemes could have been simulated, including those with a higher carbon price. Those might have proved more advantageous to Nepal. A higher (or lower) future growth rate for the Nepalese economy could have been assumed-- but this probably would not much affect the judgment of any particular REDD scheme.

The simulation results draw on data computed based on some brave assumptions in some of the sectors. Like any forecast about the future, they should, therefore, be treated with caution. Some of the broad conclusions derived from the model are:

- A fairly high carbon price is needed to entice Nepal into a REDD scheme.
- The 'front-loading' feature of REDD -- payments are received now to compensate for future non-use of agricultural land -- could be tempting for the Nepalese government, but offers the potential to steal from future generations of Nepalese. As well, ROW funders of the scheme may worry that REDD payments may reward a cessation of forest clearing, but will not be repaid if clearing later resumed.
- A REDD scheme is not naturally pro-poor. Special measures would be needed including progressive benefit sharing mechanism to undo regressive income and price effects. The major conclusions suggest that hard bargaining, and careful design of the basic REDD scheme may be needed for ensuring benefits for Nepal from REDD scheme. More attractive schemes, which might reward Nepal for forest stewardship rather than for emissions saved, have been proposed (often called REDD+). For example, REDD+ revenue might cover the cost of planting and nurturing new trees in mountain areas unsuitable for farming. Possibly, the recent earthquake may accelerate the depopulation of the Hills areas, opening up new possibilities for replanting degraded forests or abandoned agricultural land. Here too REDD+ revenue might cover the costs of restoration.

The study has evaluated a basic REDD scheme according to a rather narrow, national, economic focus. By contrast, REDD+ schemes are usually judged according to wider social and environmental criteria, taking into account local opportunities for community involvement and for the preservation of biodiversity. To explore such options would require a separate in-depth study.

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Appendix 1: Land Use Model

This appendix illustrates the dynamic optimization model used for this project. The model maximizes the sum of the net present value of market welfare in the forestry, crop, and livestock sectors in Nepal. As noted above, this model is based on the Global Forest and Agricultural Model (GFAM) described in Choi et al., (2011). The model optimally chooses inputs to production, such as land, capital, and labor, in order to produce outputs like wood products, crops, and livestock. The model can be described mathematically as a constrained optimization problem. The objective function for the model is:

$$(1) \qquad Max\sum_{t=0}^{T-1}\rho^{t}\left\{\begin{aligned}&\int_{0}^{QFt}DF_{t}(QF)dQF+\int_{0}^{QCt}DC_{t}(QC)dQC+\int_{0}^{QLvt}DLV_{t}(QLV)dQLV\\&-\sum_{r=1}^{2}\sum_{j=1}^{5}R_{F,r,j,t}X_{r,j,t}^{F}-\sum_{r=1}^{2}\sum_{j=1}^{5}R_{Cr,j,t}X_{r,j,t}^{C}-\sum_{r=1}^{2}\sum_{j=1}^{5}R_{r,j,t}X_{r,j,t}^{lv}\end{aligned}\right\}+\rho^{T}S^{T}$$

The first 3 terms in the bracket denote the integral of demand in forestry (*DF*), crop (*DC*), and livestock (*DLV*) and the last 3 terms in the bracket are associated land rent costs for each sector. The last term outside the bracket is the terminal value, indicating the value of production in the last period. Based on the data availability, we examine 3 physiographic zones, Churia, Terai, and Mid-Hill in Nepal (index r). In each physiographic zone, there are 5 regions, Eastern, Central, Western, Mid-Western, and Far-Western (index j).

The constraint for the forest sector is shown in Equation (2). The index *r, j, a*, and *t* denotes region, districts, timber age, and time period in each region. Importantly, the model tracks forest age classes in order to facilitate the calculation of carbon stocks and carbon stock changes over time. Note that the subscript for region r is omitted in constraints for brevity.

$$(2) \qquad X_{j,a+1,t+1}^{F}=X_{j,a,t}^{F}-h_{j,a,t}+g_{j,a=0,t}$$

Let the first term of equation (1) be W and combining with equation of motion (2), we can define the current value Hamiltonian at time t as

$$\mathrm{H}_{t}=W_{t}+\rho\lambda_{t+1}(X_{t}^{F}-h_{t}+g_{t})$$

Further we can set up Lagrangian function of the optimization problem as,

(3) $$L = \mathrm{H}_0 + \sum_{1}^{T-1} \rho^t [\mathrm{H}_t - \lambda_t (X_t^F) - R_{F,t} X_t^F] - \rho^T \lambda_T X_T^F + \rho^T S^T$$

The necessary Kuhn-Tucker conditions are:

(4-a) $$\frac{\partial L}{\partial h_t} = \rho^t \frac{\partial H_t}{\partial h_t} = W_{ht} - \rho\lambda_{t+1} \leq 0,\ h_t \geq 0 \text{ and } (W_{ht} - \rho\lambda_{t+1}) h_t = 0$$

(4-b) $$\frac{\partial L}{\partial X_t} = \rho^t \frac{\partial H_t}{\partial X_t} = \rho\lambda_{t+1} - \lambda_t - R_{F,t} \leq 0,\ X_t^F \geq 0 \text{ and } (\rho\lambda_{t+1} - \lambda_t - R_{F,t}) X_t^F = 0$$

(4-c) $$\lambda_T \geq 0, X_T^F \geq 0, \text{ and } \lambda_T X_T^F = 0$$

We assume that there will be no remaining forestland at the terminal year (*T*) and equation (4-c) indicates that the co-state variable value λ_T is positive.

Equation (4-a) indicates that the marginal benefit of timber harvest is equal to the discounted value of opportunity cost in the following period. Combine equation (4-a) and (4-b) with 1/ρ=(1+r),

(5) $$\frac{W_{h,t+1}}{W_{h,t}} = (1+r) + \frac{R_{F.t+1}}{W_{h,t}}$$

We are using constant elasticity demand function such as $Q=P^e$ so the market welfare is

$$W = k + \left(\frac{1}{\frac{1}{e} + 1} \right) (h \cdot V)^{\frac{1}{e}+1} - c \cdot h \cdot V$$

k is constant and *e* is demand elasticity. Timber production is harvest hectare (*h*) multiplied by volume (*V*), and the last term *c* indicates the cost of harvest. The derivative of market welfare with respect to harvest is $\left(h^{\frac{1}{e}} \cdot V^{\frac{1}{e}} - c \right) \cdot V$. The inside bracket is the marginal benefit minus marginal cost, in turn market stumpage price under perfect competition assumption. Then equation (5) can be shown as

(6) $$\frac{P_{t+1} \cdot V_{a+1,t+1}}{P_t \cdot V_{a,t}} = (1+r) + \frac{R_{F.t+1}}{P_t \cdot V_{a,t}}$$

The implication of equation (6) is that optimal harvest between time periods occurs until the marginal benefit of holding timber (on the left hand side) equals the marginal cost of holding timber (on the right hand side). Marginal benefit of holding timber comes from the combination of timber stumpage price change and timber growth rate. One important new element in this model is the last term *R*, forestland rent endogenously determined in the model. So if forest rent rises higher, then timber harvest will happen faster because cost of holding timber is more expensive and vice versa.

Production in the forest sector is based on the dynamic optimization approach in Sedjo and Lyon (1990), Sohngen et al. (1999), and Sohngen and Mendelsohn (2003; 2007). Management intensity influences the yield of timber. Forest sector costs are the sum of harvest costs, management costs in regeneration for each timber types, and rental costs on the area of land in each timber type. The quantity of forestry outputs are calculated as the sum of regional timber harvest (*h*) multiplied by yield of trees (*V*), timber yield being a function of timber age (*a*), and management input of timber (*m*). The model therefore optimizes the age of timber harvested, and the inputs used to manage timber over the production cycle (10 to ≥110 year timber rotations). Equation (7-a) shows the total timber harvested each period:

(7-a) $$QF = \sum_{r=1}^{2}\sum_{j=1}^{5}\sum_{a}^{a*}\left(H_{r,j,a}\right)V_{r,j,a}(m_{r,j}),$$

(7-b) $V = \exp(\alpha - \beta / a)$ *a* is timber age, *α* and *β* is parameter

Production for crop and livestock outputs is adopted from the GTAP model (Hertel, 1997). We utilize a nested constant elasticity of substitution (CES) production structure. The CES functions are continuous, differentiable, monotonic, and strictly quasi-concave, and they represent a constant return to scale technology. For this study, the production function of crop and livestock for each region is CES functional form with inputs such as capital, labor, and land in each sector (Equation 8). Note that the index for time (*t*) is omitted for presentation purposes.

(8) $$Q = \sum_{r=1}^{2}\Big(\sum_{i=K,L,Land}(\delta_{i,r}^{\frac{1}{\sigma}}(A_{i,r}XL_{i,r})^{\frac{\sigma-1}{\sigma}}\Big)^{\frac{\sigma}{\sigma-1}}$$

The parameter δ_i is share for each input (capital, labor, and land) in each region. The input shares δ_is sum to 1 in each region. The term *σ* is the elasticity of substitution parameter for the inputs into the production function (see Appendix 1 for elasticity values).

There are several uncertainties in terms of parameters and assumptions and particularly one important element could be the assumption on future changes in food demand.

We apply three different scenarios on the future crop output demand:

1. "Base Scenario", we assume that crop demand increases at 0.2% annually for the first 6 decades and stays constant. Forest product demand rises at 0.1% annually for the first 6

decades and livestock product demand increases at 0.3% annually for the first 6 decade. Both income elasticity values are assumed to be stabilized after 6 decades.

2. "High Demand Scenario (HDS)", crop demand increases higher rate at 0.4% annually and stabilizes. Forest and livestock rates remain the same as the Base Scenario.

3. "Low Demand Scenario (LDS)" assumes that crop demand stays constant while other product demands rise as the "Base Scenario" (see Appendix 1 for the elasticity values).

For the carbon analysis, we hypothesize a series of carbon payment scenarios, ranges from \$5 per ton of Carbon (C) to \$150 per ton C, and introduce a carbon valuation function into the model. Specifically, we price the stock of carbon (above ground carbon only in this project) relative to the Baseline, when there is no carbon price (i.e. \$0). We assume that the carbon price is constant over time. Assuming interest rate at 5%, carbon values for each scenario is simply multiplying 0.05 to each carbon price per ton. We apply the series of carbon payment scenarios on each 3 different food demand scenarios. The objective function for carbon payment scenario is shown as follows:

$$Max\sum_{t=0}^{T-1}\rho^t\left\{\begin{array}{l}\int_0^{QFt} DF_t(QF)dQF+\int_0^{QCt} DC_t(QC)dQC+\int_0^{QLvt} DLV_t(QLV)dQLV \\ -\sum_{r=1}^{2}\sum_{j=1}^{5}R_{F,r,j,t}X_{r,j,t}^{F}-\sum_{r=1}^{2}\sum_{j=1}^{5}R_{Cr,j,t}X_{r,j,t}^{C}-\sum_{r=1}^{2}\sum_{j=1}^{5}R_{r,j,t}X_{r,j,t}^{lv} \\ +RC*CB(X_{r,j,k.a}^{F},v,m_{r,j,k}) \end{array}\right\}+\rho^T S^T$$

The model optimizes production and land use for 150 years with 10-year time steps beginning in 2010, and results are considered for the first 60 years to minimize terminal period effects. The annual discount rate is 5%. The model is solved using a General Algebraic Modeling System (GAMS) program with the CONOPT solver.

Table A-1 Variables and Parameters for the Land Use Model

Notation	Definition
$DF_, DC_,, DLV$	Demand function for forestry, crop, and livestock sector
$QF_, QC_,, QLV$	Production function for forestry, crop, and livestock products
$XL_,, XF$	Composite land inputs for crop and livestock
$X^F_, X^c_,, X^{lv}$	Total land area in forestry, crop, and livestock sector (000 ha)
K_{Cr}, K_{Lv}	Capital inputs for crop and livestock
L_{Cr}, L_{Lv}	Labor inputs for crop and livestock
r, *j*	Index for Physiographic zones (*r*= Churia & Terai), Regions (*j*= Eastern, Central, Western, Mid-western, and Far-Western)
i	Index for inputs capital, labor, and land composite
V	Timber yield function
m	Timber management intensity input
h	Timber harvest area
g	Timber replant area
A	Productivity factor for capital, labor, and land composite
$\delta_{i=land,capital,labor}$	Shares of land, capital, and labor for production function
σ	Elasticity of production function (0.2391)
$\alpha_F, \alpha_{Cr}, \alpha_{Lv}$	Shares of land for timber, crop, and livestock
$P_{i=K,L,Land}$	Input price for capital, labor, and land composite in crop and livestock
R_F, R_{Cr}, R_{Lv}	Land rents for forestry, crop, and livestock in each district
γ	Land shares for crop and livestock land composite in each region
XE	Land endowment as composite of all land uses by CET function
τ	Elasticity in CET function for land supply (-0.9)
β	Elasticity in CES function for composite land inputs to production (20)
ρ	Discount rate (0.05)
S^T	Terminal value
RC	Carbon rental payment
CB	Carbon stock
Income elasticity	Forest:0 .8 Crop: 0.6 Livestock: 0.65 (Yu et al, 2002)[1]

[1]We use the 'Rest of World' region data in their study and average value for 1985,1990, and 2020 projection for this study. In addition, we assume that income elasticity in Nepal is lower than the average value of 'Rest of World' so we scaled down by 0.2.

Land demand component

Land demand in each region is described below. The output price and input prices are given and each sectors representative firms maximization problem is solved.

(1) $\Pi = PQ - \sum_{i=K,L} p_i X_i - \sum_{j} R_j XL_j - \sum_{n=1}^{N} p_n Z_n$

s.t. $Q = (\sum_{i=K,L,Land} \delta_i^{1/\sigma} (A_i \cdot XL_i)^{(\sigma-1)/\sigma})^{\sigma/(\sigma-1)}$

$XL = (\sum_{j=1}^{5} \gamma_j X_j^{(\beta-1)/\beta})^{\beta/(\beta-1)}$

$Q = \alpha_n Z_n$

The profit maximization problem for a representative industry firm in the crop sector chooses inputs to maximize profit where *Q* is the output, XL_i is capital and labor inputs and P_i is the unit input cost. R_j is unit input cost (rent) for land (*X*) and *Z* is the intermediate inputs.

After setting up maximization problem and taking the first order conditions with respect to the capital, labor, and land composite and arranging the ratios of the first order conditions for inputs *i* and capital (*K*) gives following condition (2).

(2) $$\frac{\delta_i}{\delta_K} = \left(\frac{p_i}{p_K}\right)^{\sigma} \frac{X_i}{X_K}$$

The share parameter δs sum to 1, δs could be obtained for capital, labor and land. Rearrange equation (A-2) for other inputs (capital and labor) expressed as land composite inputs and substitute into the production function gives the input demand for land.

(3) $$XL_i = \frac{\delta_i \cdot Q}{p_i^{\sigma}} (\sum_{i=L,K,Land} \delta_i A_i^{\frac{\sigma-1}{\sigma}} p_i^{1-\sigma})^{-\frac{\sigma}{\sigma-1}}$$

The first order conditions with respect to land in each region gives

(4) $$\frac{R_j}{R_l} = \frac{\left(\gamma_j X_j^{-1/\beta}\right)}{\left(\gamma_l X_l^{-1/\beta}\right)}$$

Because γ are sum to 1, γ_j could be calculated for all *j*. Take the ratios in (4) and substitute into the land composite equation constraint in (2) gives land demand in each 5 region (Eastern, Central, Western, Mid-Western, Far-Western).

(5) $$X_j = XL\left(\frac{\gamma_j p_{i=Land}}{R_j}\right)^{\beta}$$

Land supply

This section illustrates land supply problems for representative land owner in each region. Rent maximization problem for land supply for each land use categories could be expressed as (1), where to choose land X_{Cr}, X_{Lv} , and X_F given rental rates for crop, livestock, and forestry respectively, R_{Cr}, R_{Lv}, and R_F.

(1) Max $R_{Cr} Xcr + R_{LV} X_{LV} + R_F X_F$

s.t. $XE = (\alpha_{Cr} X_{Cr}^{\frac{(\tau-1)}{\tau}} + \alpha_{Lv} X_{Lv}^{\frac{(\tau-1)}{\tau}} + \alpha_{F,k} X_{F,k}^{\frac{(\tau-1)}{\tau}})^{\frac{\tau}{(\tau-1)}}$

The composite land *XE* is expressed in constant elasticity of transformation (CET) function and *α* is the share for each land use sum up to 1.Taking the first order conditions for each choice variable will give series of ratios as following.

(2) $$\frac{R_{Cr}}{R_F} = \frac{\alpha_{Cr}}{\alpha_F}\left(\frac{X_F}{X_{Cr}}\right)^{\frac{1}{\tau}};\ \frac{R_{Cr}}{R_{Lv}} = \frac{\alpha_{Cr}}{\alpha_{Lv}}\left(\frac{X_{Lv}}{X_{Cr}}\right)^{\frac{1}{\tau}};\ \frac{R_{Lv}}{R_F} = \frac{\alpha_{Lv}}{\alpha_F}\left(\frac{X_F}{X_{Lv}}\right)^{\frac{1}{\tau}}$$

Since the sums of *α* is 1 and with equations in (2) will give each share of *α*. If these first order conditions in (2) substitute into the constraint in (1), the supply function could be obtained such as in (3).

(3) $$X_{j,t}^F = \frac{XE_j\left(\alpha_F^\tau / R_{F,j,,t}^\tau\right)}{\left[\alpha_{Cr,j}^\tau R_{Cr,j,t}^{1-\tau} + \alpha_{Lv,j}^\tau R_{Lv,j,t}^{1-\tau} + \alpha_{F,j}^\tau R_{F,j,t}^{1-\tau}\right]^{\left(\frac{\tau}{\tau-1}\right)}}$$

Appendix 2: Land Use Model - Regional modeled land use results between 2010-2070

		$0/ ton CO_2e	$1/ ton CO_2e	$3/ ton CO_2e	$5/ ton CO_2e	$11/ ton CO_2e	$27/ ton CO_2e	$41/ ton CO_2e
				Forestland				
	Terai	-53.2	-53.1	-52.3	-41.6	41.5	335.8	522.5
Base	Churia	-50.2	-49.3	-48.8	-47.6	-45.8	-41.2	-35.8
	Mid-Hill	218.4	240.5	298.3	419.2	892.0	1599.7	1807.4
	Mountain	0.0	1.4	291.6	534.2	703.8	1265.9	1380.8
	Total	115.0	139.5	488.9	864.2	1591.5	3160.1	3675.0
	Terai	-78.4	-78.3	-78.2	-77.9	-77.4	17.3	94.4
High	Churia	-62.0	-61.8	-61.8	-61.6	-61.2	-60.6	-59.9
	Mid-Hill	5.1	11.8	11.8	43.7	155.9	1184.3	1644.5
	Mountain	1.4	1.4	1.4	480.2	783.3	881.1	1017.8
	Total	-133.8	-126.9	-126.7	384.4	800.6	2022.2	2696.8
	Terai	18.6	27.5	32.3	45.9	137.3	479.8	590.7
Low	Churia	-36.1	-33.2	-30.6	-26.8	-22.7	72.5	455.3
	Mid-Hill	513.4	619.9	735.2	933.4	1247.6	1716.7	1807.4
	Mountain	0.0	19.3	279.3	519.0	922.1	1300.4	1394.8
	Total	495.9	633.5	1016.1	1471.5	2284.3	3569.4	4248.3
				Cropland				
	Terai	55.6	55.3	54.1	41.6	-44.7	-335.3	-520.7
Base	Churia	51.0	50.1	49.5	48.3	46.4	41.5	35.8
	Mid-Hill	-275.3	-300.5	-365.8	-500.2	-1007.2	-1742.4	-1961.0
	Mountain	0.0	0.2	-4.6	-12.8	-28.9	-466.9	-529.2
	Total	-168.6	-194.9	-266.8	-423.1	-1034.4	-2503.0	-2975.1
	Terai	80.6	80.3	80.1	79.4	78.3	-16.7	-92.1
High	Churia	63.5	63.4	63.3	63.1	62.7	62.0	61.4
	Mid-Hill	-11.3	-22.8	-22.8	-67.8	-201.0	-1289.9	-1787.1
	Mountain	0.2	0.2	0.2	-6.6	-15.9	-42.8	-131.6
	Total	132.9	121.1	120.8	68.1	-75.9	-1287.4	-1949.4
	Terai	-26.2	-35.8	-41.0	-57.6	-149.9	-478.1	-587.5
Low	Churia	36.1	33.1	30.4	26.4	22.0	-74.0	-462.5
	Mid-Hill	-603.3	-718.5	-841.9	-1051.7	-1379.2	-1865.6	-1960.1
	Mountain	-44.0	-18.7	-9.3	-39.0	-290.3	-485.4	-536.7
	Total	-637.3	-740.0	-861.8	-1121.9	-1797.3	-2903.0	-3546.8

		\$0/ ton CO_2e	\$1/ ton CO_2e	\$3/ ton CO_2e	\$5/ ton CO_2e	\$11/ ton CO_2e	\$27/ ton CO_2e	\$41/ ton CO_2e
					Pastureland			
	Terai	-2.4	-2.2	-1.8	0.1	3.2	-0.4	-1.8
Base	Churia	-0.8	-0.8	-0.7	-0.7	-0.6	-0.3	0.0
	Mid-Hill	56.9	60.0	67.5	81.0	115.1	142.7	153.6
	Mountain	0.0	-1.6	-287.0	-521.5	-674.9	-799.0	-851.7
	Total	53.7	55.5	-222.1	-441.1	-557.1	-657.0	-699.8
	Terai	-2.2	-2.1	-1.9	-1.5	-0.9	-0.6	-2.3
High	Churia	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.4
	Mid-Hill	6.2	11.0	11.0	24.1	45.1	105.7	142.6
	Mountain	-1.6	-1.6	-1.6	-473.5	-767.4	-838.4	-886.2
	Total	0.9	5.8	6.0	-452.5	-724.7	-734.7	-747.4
	Terai	7.6	8.3	8.7	11.7	12.6	-1.7	-3.3
Low	Churia	0.0	0.1	0.3	0.5	0.7	1.5	7.2
	Mid-Hill	89.9	98.6	106.7	118.3	131.6	148.9	152.7
	Mountain	43.9	-0.5	-270.0	-480.0	-631.8	-815.0	-858.1
	Total	141.4	106.5	-154.3	-349.6	-487.0	-666.4	-701.5

Appendix 3: CGE Calculations underlying the simulations

In this section we detail some data sources and calculations used to estimate:

(a) the annual economic benefit to Nepal of Terai/Churia deforestation in the absence of a REDD scheme.

(b) the annual REDD payments if Terai/Churia deforestation were to cease.

These values, which drive model results, are estimated outside the model, via simple (but tedious) calculations. We start with some forest areas drawn from FRA surveys:

Table A1. Historical area change calculations

	Start year	Initial area	End year	Final area	N year	Change	Annual change	2007 estimate
TERAI	1991	440100	2010	408100	19	-32000	-1684	403047
CHURIA	1995	1411790	2010	1373740	15	-38050	-2537	1366130
				1781840			-4221	1769177

The estimates of 2007 areas are interpolated.

We assumed that 62% of the disappearing forest became cropland (source: FRA/DFRS 2014).

62% of 4221 is 2617 = annual cropland taken from forest.

We use this figure to estimate Terai/Churia agricultural area in 2007:

Agriculture area 2010 FRA TERIA + CHURIA = 1397000+472000 = 1869000.

Assuming it grew by 2617 ha/pa during 2007-2010, Terai/Churia agriculture in 2007 was 1861149 ha

Emissions

According to the latest FRA reports, the Terai forests contained 89 tonne/ha of above-ground carbon, while the Churia forests contained 85 t/ha. We assumed the average was 87 t/ha of above-ground Carbon. We multiply 87 by 3.67 to convert to CO_2e, getting 319.29 t/ha of CO_2e (which, we assume, = CO_2ee).

So we assume turning a hectare of TERIA/CHURIA forest into cropland releases 319.29 tons of CO_2e.

Thus annual conversion of 2617 ha of forest to agriculture would annually emit 835582 tons of CO_2e (=2617*319.29).

The value units for the initial model database are 2007 million Nepalese.

Rupees (NPR). In 2007 one $US exchanged for 65 NPR. So a $US 50 CO_2e price = 0.00325 (=50*65/1000000) million NPR per tonne.

Hence the REDD reward for NOT turning a hectare of TERIA/CHURIA forest into cropland is a one-off payment 319.29*0.00325 = 1.0376925 million NPR per hectare. To eliminate annual forest loss of 2617 ha would earn 2716 million NPR pa.

Figures from the model database imply that land's economic contribution per hectare is far less for Forestry than for Agriculture.

Table A2. Area and rent calculations

	1	2	3	4	5	6	7	8
Value-added	Labour	Capital	Land	Total	Terai share[20]	Terai land rent	Terai area	Terai rent per ha
Agr	93598	53138	70086	216822	0.7	49060.2	1860136	0.026374521
For	7066	10179	1572	18818	0.6	943.2	1794503	0.000525605
Other	184494	312182		496676				
Total	285158	375500	71658	732316				

Hence the economic reward for turning a hectare of TERIA/CHURIA forest into cropland is a perpetual annual payment of 0.025848916 million NPR (=0.026374521-0.000525605), if rents remained at 2007 levels. In fact, land rents increase sharply in our base scenario, so the reward increases over time.

Sources:

FRA/DFRS. 2014. Terai Forests of Nepal (2010 – 2012). Babarmahal, Kathmandu: Forest Resource Assessment Nepal Project/Department of Forest Research and Survey. Available at http://www.franepal.org/wp-content/uploads/downloads/publications/TeraiForestsofNepal_23April2014_LowResolution.pdf

DFRS. 2014. Churia Forests of Nepal. Forest Resource Assessment Nepal Project/Department of Forest Research and Survey. Babarmahal, Kathmandu, Nepal. Available at http://www.franepal.org/wp-content/uploads/downloads/publications/Chure_report.pdf

[20] Estimates provided via D.R.Khanal. In this table "Terai" includes also Churia.

Table A3. Extract from base-period SAM: primary factor payments by sector

Note: the original SAM, supplied by D.R.Khanal, included no land contribution to Forestry. That SAM was adjusted so that land shares in value-added for Agriculture and Forestry sectors approximated those in the GTAP database, while row and column totals in table below remained unchanged.

Sector	Labour	Capital	Land	Total
1 a_Paddy	15894	12571	12916	41381
2 a_Maize	6113	3092	4420	13625
3 a_Wheat	8508	2203	5491	16203
4 a_OthGrain	6800	3440	4916	15156
5 a_VegetFruit	23017	22818	20154	65988
6 a_Oilseed	2084	1761	1729	5574
7 a_SugarCane	1657	1070	1271	3997
8 a_PlantFiber	219	97.2	120	437
9 a_OthCrops	3318	1822	2451	7591
10 a_Cattle	2954	1619	1939	6511
11 a_OthAnmlPrd	6488	458	5279	12226
12 a_RawMilk	16406	2180	9326	27912
13 a_Wool	142	6.22	74	222
14 a_Firewood	4119	5926	916	10961
15 a_Timbers	1046	1292	213	2551
16 a_GrassFoddr	1866	2911	435	5213
17 a_OForestPrd	35.1	50.6	7.82	93.6
18 a_Fishing	264	1690	0	1955
19 a_Coal	15	36.1	0	51.1
20 a_Oil	26.1	138	0	164
21 a_GasMining	48.5	186	0	234
22 a_OthMining	609	2735	0	3344
23 a_Meat	168	240	0	408
24 a_MeatPrd	185	282	0	467
25 a_VegetblOil	395	817	0	1212
26 a_DairyPrd	348	1491	0	1839
27 a_GrainMill	1338	5732	0	7069
28 a_Sugar	227	545	0	772
29 a_OthFoodPrd	489	869	0	1358
30 a_DrinkTobac	1147	3565	0	4712
31 a_Textile	830	691	0	1521
32 a_Clothing	548	1652	0	2200
33 a_LeatherPrd	215	819	0	1034
34 a_Lumber	25.8	175	0	201
35 a_Paper	346	1101	0	1447
36 a_Petroleum	11.2	73.2	0	84.4
37 a_ChemRubber	773	7022	0	7796
38 a_MineralPrd	538	2227	0	2765

39 a_IronSteel	205	1482	0	1687
40 a_NonFerrMtl	289	5639	0	5928
41 a_FabricMetl	726	12585	0	13311
42 a_MotorVehcl	83.8	5.68	0	89.5
43 a_OthTrnsEqp	36	13.8	0	49.8
44 a_ElctrncEqp	124	38.1	0	162
45 a_OthMechEqp	491	4380	0	4871
46 a_Furniture	58.6	398	0	457
47 a_OthManuf	268	310	0	578
48 a_Electricty	2006	11011	0	13016
49 a_Gas	214	610	0	824
50 a_Water	76.9	460	0	537
51 a_Construct	22866	10228	0	33093
52 a_Trade	25476	76565	0	102041
53 a_OthTrnsprt	17589	59874	0	77463
54 a_WtrTrnsprt	0	33	0	33
55 a_AirTrnsprt	2706	7507	0	10213
56 a_Communictn	2227	3095	0	5322
57 a_Finance	2420	1111	0	3531
58 a_Insurance	6035	9542	0	15577
59 a_OthBusSvc	8884	12365	0	21249
60 a_RecOthSvc	11162	11368	0	22531
61 a_GovSvc	53319	7600	0	60919
62 a_Dwelling	18686	43875	0	62560
Total	285158	375500	71658	732316

Appendix 4: CGE Data Sources and Methods Used in Updated and Extended 2007 SAM

Social accounting matrices (SAMs) are the most comprehensive and consistent data systems with disaggregated information on production, aggregate demand components and factor distribution by different industries, institutions and agents including similar information on external balances and imbalances through coverage on exports and imports of goods and services, transfers and capital flows, among others. Based on the level of disaggregation, SAMs enable to get comprehensive idea on the structure of an economy or economies including production and distribution relations in a consistent manner by bringing together both macro and micro level data (Pyatt and Thorbecke, 1976). For these reasons, the accounting matrix of a SAM requires portraying economic relations by distinguishing (1) total domestic supply of commodities (2) activity accounts for producing sectors (3) main factors of production such as land, labor and capital (4) current account transaction between main institutional agents such as households, corporate enterprises, government and the rest of the world (5) the rest of the world and (6) at least a consolidated capital account (domestic and rest of the world) to capture the flows of savings and investment by institutions and the rest of the world. They, in turn, are the building blocks of computable general equilibrium models (CGEs), immensely useful in policy simulation exercise (Dervis et al., 1982).

Thus, construction of a disaggregated input/output table and SAM requires detailed information on domestic supplies by industries/firms added by similar information on imports to represent total supplies of an economy. As a counterpart, it also needs similar detailed information on the uses side in terms of intermediate consumption, final consumption, gross capital formation and exports. The factor distribution in terms of, among others, labor and capital share must be an integral part of a SAM. Besides detailed information on taxes, transfers and subsidies, special treatment of trade, transport and financial services margins is also required for avoidance of double counting and take price factor into account. This is the reason why a huge macro and micro level reliable data with information on inputs and outputs including information on external trade and payments and factor distribution is required for such exercises.

Paucity or lack of such reliable data and information has constrained construction and institutionalization of more robust disaggregated input output tables in Nepal to be useful for policy modeling or simulation exercises despite such an initiative from the late 1980s and continued efforts thereafter. Today, a disaggregated 57 *57 input/ output table with base year 2000/2001 is available but it has very aggregative SAM (IPRAD, 2007). Although a more disaggregated 57*57 sector SAM 2007 is available, it has only one forestry sector (Raihan and Khondker, 2011) and hence, despite being important benchmark, it does not allow more detailed exercise for this sector from the point of view of exploring alternative mitigating policy measures. Moreover, a closer review of data sources and derived levels at both macro and sectoral level show some inconsistencies in the SAM 2007. This was due to numerous data sources with different formats and many bold assumptions for generating the required data or fulfilling the data gaps.

An important recent development is that based on huge data sources and information, Central Bureau of Statistics has compiled a comprehensive 51 sector supply and 51 sector use table for the year 2004/05 (CBS, 2013). A quick review shows that in the table over all consistency in terms of supply and corresponding uses has been maintained. Such a supply and use table has been taken as a benchmark to construct a new SAM for the year 2007[21].

A quick review of the tables shows that numerous data sources were used for the estimation of tables. Around 35 bench mark surveys carried out in 2004/05 by the CBS were the primary data sources. Likewise, administrative records of enterprise financial statements were extensively used for estimating the inter-industry domestic supply of major inputs. Censuses of manufacturing establishment 2001/02 and 2006/07 were the major sources for the manufacturing sector. These Censuses provide detailed information on input purchase and supplies at a disaggregated level as per ISIC classification helping to trace out the total supply and corresponding uses. Nepal's first distributive trade survey 2007/08 was used to estimate both transport cost and trade margins. The survey gives the detail layout of the trade margin in dealer, wholesale and retail level trade for domestically produced and imported goods. The intermediate costs associated with freight charges are also reported there facilitating to derive the transport cost share.

For the import matrix of goods, Department of Customs was the basic data source. It maintains the international trade statistics in HS classification scheme. HS classification was used to transform to CPC by using correspondence mechanism. Matrix of imports of services was based on BOP statistics. Such data are available from the Central Bank of Nepal which publishes in a monthly basis. Information on the insurance and freight services incurred by non-resident from BOP statement was used to adjust CIF/FOB. Freight and insurance services were proportionally apportioned to imports. Export matrix was prepared for both exports of good and exports of services using the similar source and methods. Separate vectors for government expenditure were computed based on the government finance statistics.

The matrix in the table consisted of value added tax on domestic production, excise duty on some selected commodities and value added tax on imports. Information on taxes was based on the information provided by the Department of Inland Revenue and Department of Customs. In such calculations, domestic production including VAT exemptions was also taken into consideration. Information on subsidies was based on the government finance statistics.

The gross fixed capital formation was estimated by using commodity flow method. For this, two basic mechanisms of supply i.e. domestic supply (adjusted for exports) and imports were analyzed. Output

[21] Details on the data sources and methodology used in the preparation of Supply and Use Tables of Nepal 2004/05 are found in CBS Occasional Paper (CBS, 2013).

of the construction was also adjusted accordingly. The new independent method was used to estimate the change in stock based on the information provided by government owned trading and other corporations, balance sheets and benchmark surveys.

Compensation of employees was estimated by using government financial statistics to administrative records and enterprise financial statements. Beside these secondary sources, the bench mark surveys and censuses of manufacturing establishment of 2001/02 and 2006/07 were used. For some subsectors of manufacturing, trade and business, the compensation was apportioned by the output. For taxes less subsidies, government financial statistics was the major data source. Depreciation was not calculated separately in the absence of required minimum data. The operating surplus representing the profit or retained earnings was derived residually by deducting the compensation and taxes less subsidies from value added.

In addition to deriving the coefficients from both supply and use tables prepared based on the above mentioned sources , a number of additional works were carried out to extend the sectors to be useful for more detailed forestry related exercise and introduce various additional elements that were essential to construct a standard SAM.

In the beginning, detailed data sheet prepared and used for the 51 sector supply and 51 sector use table were used to disaggregate sectors like forestry, agriculture and manufacturing. In the new table, forestry sector has been disaggregated into four, viz, firewood, timbers, grass/fodders and other forestry products. Similarly, a new furniture sector has been created to find out particularly the extent of its linkages with the forestry sector. Given the importance, maize has been separated from other grains. Altogether, the supply and use table was extended to 62 sectors.

Another important feature is that at least eight household's type viz, rural landless, rural land small, rural land medium, rural land large as well as urban lower education, urban medium education and urban higher education are distinguished in the new SAM. Both income sources and expenses are shown accordingly in the SAM. For such calculations, information contained in the NLSS 003/04 has been used. By examining the income and expenditure structure, the share distribution has been made among 7 representative household groups and 62 SAM commodities. Foreign aid has been introduced more specifically as this is the major source of government funding which is also a possible major source of REDD+ in future.

After deriving the coefficients within comprehensive and consistent SAM framework, the table was transferred into 2006/07 bases by multiplying the coefficients with the control totals available from the national accounts, government budgetary sources and central bank BOP data, among others, for the fiscal year 2006/07. The intermediate input totals and factor distribution numbers were derived from the working sheets of national accounts.

Appendix 5: Revenue from Forest Destruction

The analysis presented in the main text assumes that replacing a hectare of forest with cropland has the following costs and benefits:

(a) adding a stream of agricultural rent which continues into the future;

(b) foregoing a stream of forest rent which continues into the future. We assume that this income derives from sustainable use of the forest (the forest does not degrade).

(c) paying (if a REDD scheme is in operation) a fine based on emissions caused by forest clearing. This is a one-off payment.

Since per hectare rentals are less for forest than for crops, the REDD penalty is needed to discourage forest clearing.

Dr. Hom Pant, The Senior Advisor to the NPC, has pointed out that this calculation ignores an important economic benefit of forest clearing: the revenue from selling logs harvested during clearing. More generally (as pointed out in the main text) some log, forage and firewood output that exceeds sustainable levels would be unavailable if forest clearing were halted. To analyse this with precision, we would need to know what proportion of say, logs, came from clearing land (as opposed to logs from selective, sustainable harvesting). Although we do not have data to support this, we can make some approximate calculations.

The Terai native forest is fairly mature; and current (official) harvesting permits only the removal of mature (say 80-year old) trees. If the usable timber in a tree increased linearly over time, the timber gained by chopping down a whole area of forest might (in that year only!) be 40 times the timber gained annually by sustainable harvesting. A 2.5% discount rate would be low enough to make the continued revenue from sustainable use seem as attractive as the immediate reward from destruction (here we are ignoring both the environmental benefits of forest preservation, and the possible revenues yielded by alternative crop use).

Table A2 of Appendix 3 suggests that Terai/Churia forest rentals are 0.000525605 million NPR per ha. Multiplying this by 40 we may estimate that 0.0210242 million NPR per ha might be yielded by clearing a hectare and selling the logs. But we calculated that the REDD reward for NOT doing this was 1.0376925 million NPR -- 50 times larger. Hence the REDD payment need not be significantly increased to offset the potential log revenue from clearing forest.

On the other hand, Dr Pant's observation points to a second source of error. The figures presented in Table A1 of Appendix 3 suggest that Terai forest has been disappearing at the rate of 0.4% p.a. That suggests that 13.8%[22] of log output may have arisen from forest clearing rather than from

[22] Imagine that 0.4 cleared hectares yields 16 (=40*0.4) logs, while 99.6 remaining hectares yield 99.6 logs.

sustainable harvesting. That is, for the Terai, we may have over-estimated the income from sustainable harvesting by 13.8%. If appropriate adjustments[23] were made to our CGE model database, the cost of preserving forest (or the REDD payment needed to discourage forest clearing) would be higher.

However, our Social Accounting Matrix, together with FRA data, suggests that a hectare used for crops earns 50 times more than a hectare used for forestry. This dominates the results of the CGE simulations. Small errors in measuring the contribution of forestry are almost irrelevant in this context.

[23] The "appropriate adjustments" would need to take into account that the Churia forest is larger, and disappearing at a slower rate, and that in the Hills the deforestation rate is lower still. So our over-estimate of the sustainable contibution of forests is probably less than 13.8%.

Appendix 6: List of participants of national stakeholder workshops

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Final Workshop

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