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GREENHOUSE GAS INVENTORY IN THE FORESTRY SECTOR

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OVERVIEW

Forestry and land use change are important sources/sinks of greenhouse gases. When trees are growing, CO_2 from the atmosphere is absorbed by the plants through the process of photosynthesis. When forests are cleared, the carbon content of the biomass is released to the atmosphere instantaneously by burning, or slowly through decay. When the land is abandoned for twenty years or more, substantial sequestration can be realized due to regrowth. The need to include the historical perspective of this sector makes the estimation of greenhouse gas emission/sinks quite complex. Furthermore, there are many uncertainties concerning the factors used in the methodology. Although the methodology may not be the most accurate, it was agreed upon by consensus among experts in the field.

In 1981, the forest covered more than 12 million hectares of the country. The forested area was reduced by half to about 6 million hectares in 1990. From the rate of clearing alone, the enormous amount of CO_2 released to the atmosphere can be deduced since half of the dry biomass is carbon. Land use change is a very important source of CO_2 among developing countries. Forested areas are converted to agricultural lands by burning and/or cutting trees. Unburnt biomass are left to rot. In addition, carbon is released when soils are disturbed. From tropical deforestation, the Intergovernmental

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Panel on Climate Change (IPCC, 1994) estimated the average annual flux of C as CO_2 for the decade 1980–89 at 1.6 + 1.0 Gt C.

The following activities are covered in this inventory:

- changes in forests and other woody biomass stocks — include commercial management, harvest of industrial roundwood and fuelwood, production and use of wood commodities and establishment and operation of forest plantations as well as planting of trees in urban, village and other non-forest locations.
- forest and grassland conversion — the conversion of forests and grasslands to pasture, cropland or other managed uses can significantly change carbon stored in vegetation and soil.
- abandonment of croplands, pastures, plantation forests or other managed lands — lands which regrow into their prior natural grasslands or forest conditions.

To illustrate the complex relationships among the different components of Forestry and land use change, the linkages among these categories are shown in Figure 1.

DATA AND METHODOLOGY

The forestry data were taken from the Philippine Forestry Statistics published by the Forestry Management Bureau (FMB) of the Department of Environment and Natural Resources (DENR). For non-forest plantations, however, data were obtained from the Bureau of Agricultural Statistics of the Department of Agriculture. In cases where there are data gaps like in the case of biomass density of mangrove forests and non-forest plantations, experts' judgment is relied upon.

The methodology is generally based upon the IPCC guidelines (IPCC, 1996). The following are the bases for the methodology:

- the flux of CO_2 to or from the atmosphere is assumed to be equal to changes in carbon stocks in existing biomass and soils
- changes in carbon stocks can be estimated by first establishing rates of change in land use and the practice used to bring about the change (e.g., burning, clear-cutting, selective, cut, etc.)

CHANGES IN FOREST AND OTHER WOODY BIOMASS STOCKS

This category covers not only changes in forests but also non-forest trees which may not be considered traditionally part of forests.

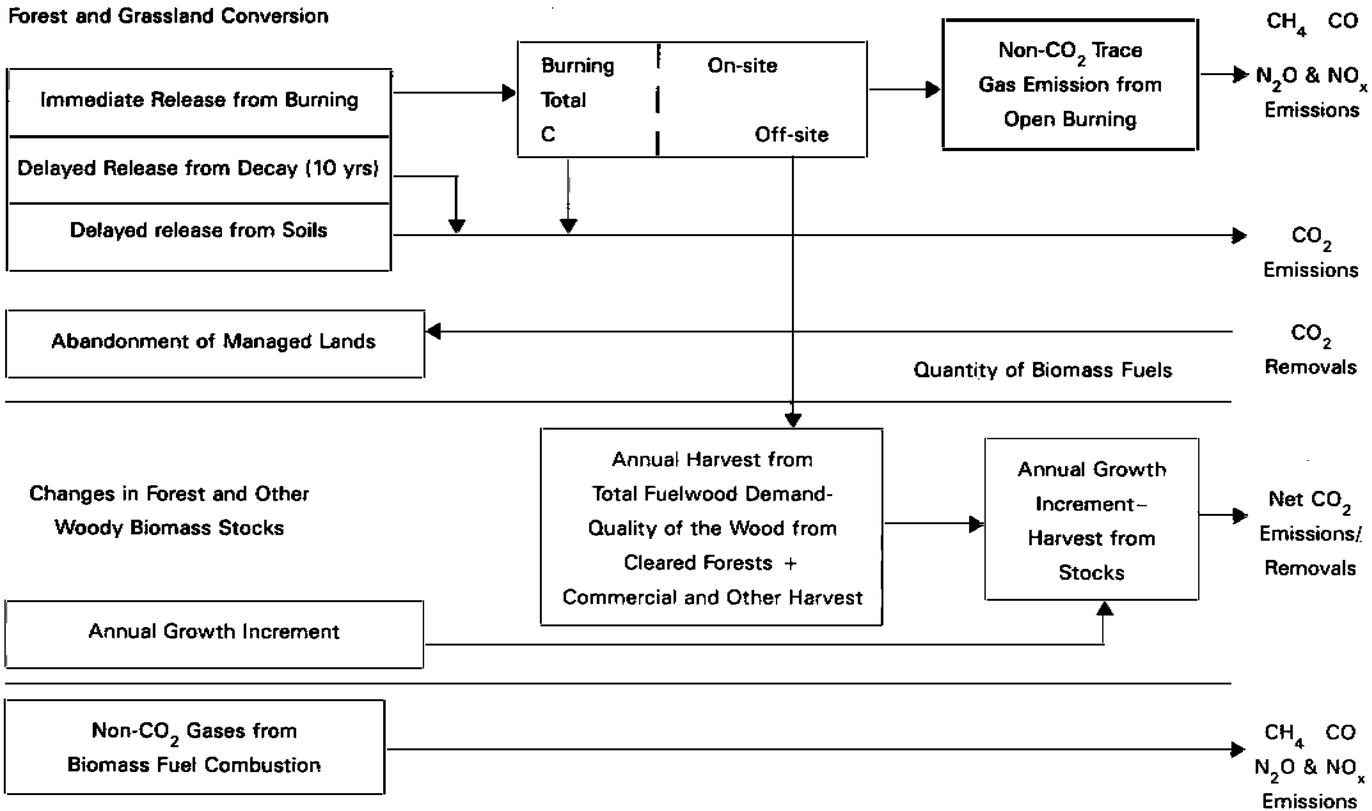

Figure 1. Relationship among categories

The following assumptions were made in estimating greenhouse emission/ sinks:

- old growth forests are natural, undisturbed forests and are considered in equilibrium, i.e, whatever CO_2 is removed from the atmosphere by photosynthesis is emitted through respiration
- the average annual growth by forest types in terms of t dm/ha/yr are given in Table 1.

Table 1. Annual aboveground biomass uptake

Land Type	Annual Increment in Biomass (t dm/ha/yr)	Source/Comment
Dipterocarp		
• Old Growth	0	• no net uptake nor emission
• Residual	10	• derived from Table 3-5, under mixed hardwood and softwook (IPCC, 1996)
Pine		
• Close	11.5	• IPCC (1996)
• Open	5.8	• half of close pine forest
Submarginal	3.2	• Expert's judgment
Mossy	1.0	• Expert's judgment
Mangrove	3.0	• Expert's judgment
Brushland	1.0	• Expert's judgment
Forest Plantations		
• <25 yrs. old	4	• Expert's judgment
• 26-30 yrs. old	3	• Expert's judgment
• 31-40 yrs. old	2	• Expert's judgment
Non-Forest Trees		
• Coconut	3	• Expert's judgment
• Fruit Trees	2	• Expert's judgment
• Rubber	4	• Expert's judgment
• Coffee/Cacao	2	• Expert's judgment

- half or 50% of the dry matter is carbon
- all carbon removed in wood and other biomass from forests is oxidized in the year of removal, though not strictly accurate, this is based on the perception that stocks of forest products in most countries are not increasing significantly on an annual basis

Biomass Growth in Forests and Non-Forest Trees

The area covered by each land type is known (Table 2). These land types differ from those recommended by IPCC which classified the

Table 2. Uptake of CO_2 by different land types

Land Type (FMB Data)	A Area of Forest Biomass Stocks (kha)	B Annual Growth Rate (t dm/ha)	C Total CO_2 Uptake (Gg) (AxBx5x44/12)
Forest	6158.8		
Dipterocarp			
Old Growth	861.2	0.0	0
Residual	3287.6	10.0	60273
Pine			
Closed	128.3	11.5	2705
Open	108.1	5.8	1149
Submarginal	527.4	3.2	3094
Mossy	1113.7	1.0	2042
Mangrove	132.5	3.0	729
Brushland	2455.6	1.0	4502
Forest Plantation			0
<25 yrs old	672.5	4.0	4932
26–30 yrs	28.4	3.0	156
31–40 yrs	32.7	2.0	120
Sub-Total			79701
Non-Forest Trees			
Cocnut	3112	3	17116
Fruit Trees	68	2	249
Rubber	86	4	631
Coffee/Cacao	162	2	594
Sub-Total			18590
Total			**99450**

forests into: wet/very moist, moist, dry, montane moist and moist dry. The land type as shown in the Table is adapted from the classification of the Philippine Forest Management Bureau.

The formula used to determine the amount of CO_2 absorbed from the atmosphere is:

Q_{uptake} (Gg CO_2) = Area ('000 ha) x Biomass growth (t dm /ha) x 0.5 t C/ t biomass x 10-3) (kt /t) x 44/12 (ratio of molecular weight of (CO_2 to C)

Table 2 shows also the total CO_2 uptake which amounted to 99,450 Gg CO_2. The main sink came from the residual dipterocarp forests which occupy the largest area of more than three million hectares and the high annual growth rate of 10.0 among the different land types. This annual growth rate is derived from the value recommended by the IPCC (1996) for mixed hardwood and softwood. The estimated uptake of residual forests was 60,273 Gg CO_2 or 61% of the total uptake. As discussed, earlier, the old growth forests have zero growth; the rate of photosynthesis is assumed to be equal to respiration. Although the pine trees have a relatively high biomass growth rate, the trees covered only a total of 236.4 thousand hectares. The CO_2 uptake was estimated at 2,705 for closed pine forests and 1,130 for open pine forests or a total of 3,835 Gg CO_2 or about 4% of the total uptake. Submarginal forests are dominated by leguminosae and lesser utilized species mainly restricted to shallow and excessively drained limestone soils. The uptake of CO_2 from these submarginal forests was estimated at 3,094 Gg. Mossy forests or mid-mountain forests have trees which are mostly dwarf with stems and branches usually covered by moss. There are still more than 1 million hectares of mossy forests, and they account for 2,042 Gg CO_2 uptake. As for mangrove forests, only about 132.5 thousand hectares existed in 1990. About 729 Gg CO_2 was absorbed by the mangrove forests. Lastly, brushlands are degraded areas dominated by a discontinuous cover of shrubby vegetation. There were still about 2,455 thousand hectares of brushlands in 1990. Despite the small annual growth uptake of 1.0, the sink accounted for 4,502 Gg CO_2 or 4%.

Among the non-forest trees, coconut plantations are a major source of livelihood. The plantations cover more than 3 million hectares. However, the growth of coconuts is much smaller than the residual forests and is assumed to be 3 t dm/ha. The estimated uptake of coconuts was 17,116 kt, a poor second to the uptake of the residual forests which was 60,273 kt CO_2 . The rest of the non-forest trees seem insignificant compared with those of coconuts.

Forest plantations were mostly less than 25 years olds, hence the high growth rate. The sink accounted for more than 5,000 Gg CO_2 (Table 2).

Biomass Removals

Biomass is removed from forests through commercial harvests or for other reasons (e.g., thinning). Biomass damaged or killed during logging release CO_2 through decay or burning.

According to the IPCC (1996), harvested wood releases its C at rates dependent upon the method of processing and end-use; waste wood is usually burned immediately or within a couple of years, paper usually decays in 5 years, and lumber decays in 100 or more years. Long-term forest products such as building lumber and furniture are stored carbon; and rapid forest regrowth can become a response strategy.

For the initial calculations of CO_2 emissions from this activity, IPCC recommends that all carbon in biomass harvested is oxidized in the removal year. This is based on the perception that stocks of forest products in most countries are not increasing significantly on an annual basis. It is the net change in stocks of forest products which should be the best indicator of a net removal of carbon from the atmosphere, rather than the gross amount of forest products produced in a given year.

The equation used in estimated CO_2 released from harvest is:

$Q_{harvest}$ (Gg CO_2) = Harvest (Gg dm) x expansion ratio to treat slash x 0.5 t C/t dm x dm x 44/1w (ratio of molecular weight of CO_2 to C)

It is important to differentiate between harvests from standing forests and harvests associated with forest conversion (forest clearing) which is discussed in the next section. When forests are cleared, harvestable products such as lumber and fuelwood are taken advantage of. These harvests under the forest conversion activity can be estimated by partitioning the biomass harvested. The biomass burned off-site are used as fuelwood. The harvested fuelwood and lumber are deducted from the total harvest which can be obtained from FAO (1993). According to FAO, about 38,442 thousand m^3 of roundwood, 33,422 thousand m^3 of fuelwood and 4 thousand of charcoal were harvested in 1990. The roundwood harvests from clearing of forests were 11,162 Gg dm (see action on Forest and Grassland Conversion). At the conversion ratio of 2 M^3/t dm, the harvests were 22,324 m^3. This is subtracted from the total roundwood harvests of 38,442 thousand m^3 and the difference of 16,118 m^3 is now the harvests from standing forests and non-forests. This is equivalent to 15,312 Gg dm of total biomass when the combined conversion and expansion ratio of 0.95 t dm/m^3 commercial roundwood for logged forests is used (IPCC, 1996). This value is applied to account for the non-commercial biomass (limbs, small trees, etc.) harvested with the commercial roundwood and left to decay.

With regards to fuelwood and charcoal, the study by the UNDP/ ESMAP (1992) showed that the household consumption was 18,317 and 1,565 Gg, respectively. According to the study, only 15% of the total woodfuels harvested came from forested areas. The rest came from agricultural and even urban lands. Assuming that 85% was dry matter, the amount of woodfuels was 15,569 Gg dm.

Further, the UNDP/ESMAP (1992) study showed that, 70% of the charcoal came from wood; the rest from coconut shells. Hence, only 1,095.5 Gg charcoal was produced from wood. The amount of wood to produce charcoal was estimated at 3,286 Gg using the conversion factor of 3 Gg dm of wood/Gg of charcoal. Adding this value to 15,569 totalled 18,855 Gg dm which is the total fuelwood from the forests. The fuelwood harvest of 1,562 Gg dm from biomass clearing under off-site burning is subtracted from 18,855 Gg. The difference of 17,293 Gg dm is now the total fuelwood harvest from existing forests and non-forests.

Net Uptake

Substantial sinks of CO_2 can occur under the category Changes in Forest and Other Woody Biomass Stocks through biomass growth. A total of 99,450 Gg CO_2 (Table 2) was estimated to be absorbed by the trees in 1990. Forest harvests such as roundwood and fuelwood released CO_2 either by burning or decay. All CO_2 are assumed to be released in the inventory year in the case of roundwood. Roundwood and fuelwood harvests accounted for 50,796 Gg CO_2. Subtracting this value from the CO_2 uptake would still result in a net uptake of 48,655 Gg CO_2 (Table 3).

FOREST AND GRASSLAND CONVERSION

Forest and grassland conversion includes conversion of existing forests and natural grasslands to other land uses such as agriculture, highways, urban development, etc. Among the different sources, forest

Table 3. Emission/uptake summary from changes in forest and other woody biomass stocks

	CO_2 Released	CO_2 Uptake	Net Uptake
Biomass Growth		99,450	
Roundwood Harvests	19,092		
Fuelwook	31,704		
Total	50,796	99,450	
Net Uptake			**48,655**

and grassland conversion is the most complex because of the involvement of different time scales of its components, e.g., instantaneous release in the case of biomass burning, decades for decomposition of wood, and several decades for loss of soil carbon. In order to have a clearer picture of what happens when the forests are cleared, the percentage share of burning, decomposition and harvest of biomass for each forest type must be known (Table 4). First, initial cutting of undergrowth and felling of trees occur. Harvestable products are utilized like roundwood (considered long-term product in Table 5 and fuelwood (considered under off-site burning). On-site burning then occur, and the remaining unburnt biomass is left on the ground to decompose. Forestry experts were consulted in determining the different fates of the biomass of cleared forests.

To know how much biomass is cleared, the biomass density of the different types of forests before and after clearing must be determined, as well as the area cleared in order to know the net change in biomass.

IPCC provides a range of values for aboveground biomass prior to clearing. Only old growth dipterocarp and logged dipterocarp forest were given values of 370–520 and 300–370 tonnes dm/ha, respectively. The middle values of 445 for old-growth dipterocarp and 335 for logged dipterocarp will be used in the computations.

For evergreens, IPCC provided a range of 60–200 tonnes dm/ha for Myannaar, 85 for dry evergreens in Thailand. A value of 120 tonnes dm/ha will be used for pine trees. For the rest of the forest types, experts' judgment was used. Table 5 provides the values for biomass density before and after clearing together with the hectarage of cleared forests in 1990 and the 10-year average annual clearing from 1981 to 1990.

Table 4. Fates of biomass cleared from forests

Forest Type	Burning: On-Site	Burning: Off-Site	Decay	Long-term Products
Dipterocarp				
• Old Growth	0	5%	30%	65%
• Residual	20%	5%	30%	45%
Pine	20%	5%	30%	45%
Submarginal	15%	5%	35%	45%
Mossy	20%	0%	80%	0
Mangrove	0%	50%	50%	0
Non-forest Brushland	75%	15%	10%	0

Table 5. Rates of clearing and biomass densities for each land type

Land Type	Area Converted Annually (kha)	Area Converted (10–Yr Ave) (Kha)	Biomass Before Conversion (t dm/ha)	Biomass After Conversion (t dm/ha)
Forest				
Dipterocarp				
Old Growth	60.8	193.3	445	335
Residual	63.3	398	335	10
Pine	1.2	–4.5	120	10
Submarginal	8.4	–19.81	30	10
Mossy	11.7	31.8	30	10
Mangrove	3.2	10.7	50	0
Brushland	34.5	34.5	30	10
Total	**183.1**	**644.0**		

The latter factor was used to estimate CO_2 released from decay. IPCC (1996) recommends the 10-year period to be a reasonable historical horizon to capture all the decay. It is assumed that 10% of the total decay is cleared in each historical year.

The amount of CO_2 release from on-site and off-site burning, roundwood harvests and decay are shown in Table 6. The residual forests are the most important source of CO_2 due to high clearing rate of 63.3 kha in 1990 and 398 kha/yr from 1981–90. The biomass cleared is assumed to be 325 t/ha with 335 as the original biomass and 10 t/ha as the leftover living biomass after clearing. Although the dipterocarp forests have a high clearing rate in 1990 (60.8 kha, Table 5), the forests were converted to residual forests; the biomass content was originally 445, decreased to 335 after conversion.

Biomass decay.released a total of 84,450 Gg CO_2 (Table 6), and as emphasized, this is mostly due to a high clearing rate during the decade prior to 1990 in residual forests. The same can also be said for other land types except pine and submarginal forests. On-site burning only released 7,807 Gg CO_2 and 2,575 Gg CO_2 from off-site burning, while roundwood harvests accounted for 25,194 Gg CO_2. The latter should be considered as stored carbon but for the purpose of this study, all of the carbon is assumed to be released in the inventory year. A total of 120,026 Gg CO_2 was emitted due to on-site and off-site burning, decay and harvests from forest conversion.

Table 6. Emissions summary from forests and grassland conversion

Land Type	CO_2 Released (from on-site burning) (kt CO_2)	CO_2 Released (from biomass burned) (kt CO_2)	CO_2 Released from round-wood harvests (kt CO_2)	CO_2 Released from decay (kt CO_2)	Total CO_2 Release (kt CO_2)
Forest					
Dipterocarp					
Old Growth	0	550	7971	11693	20214
Residual	6791	1698	16973	71144	96606
Pine	44	11	110	0	164
Submarginal	42	14	139	0	195
Mossy	77	0	0	933	1010
Mangrove	0	132	0	490	622
Brushland	854	171	0	190	1214
Total	7807	2575	25194	84450	120026

Non-CO_2 Emissions

Biomass burning is a significant source of CH_4, N_2O, CO and NO_x. For on-site burning of forests, the method of calculation for non-CO_2 trace gases is based on the carbon content of biomass. The emission ratio approach is followed wherein CH_4 and CO emissions are treated as direct rations to total C released. Likewise with N_2O and NO_x which are based on ratios to total N release. The ratio of N to C in biomass is used to determine the total N released from burning. The estimated N/C ratio is 0.01. This is multiplied with the C released to yield the amount of N released. Table 7 shows the emission ratios used and the estimated emissions. The amount of trace gases emitted from on-site burning are 34.06 Gg CH_4, 298.06 Gg CO, 0.23 Gg N_2O and 8.46 Gg NO_x.

Table 7. Emission ratios for open burning of cleared forests (as cited from IPCC, 1996)

Compound	Emission Ratios	Emission (Gg)
CH_4	0.012 (0.009–0.015)	34.06
CO	0.06 (0.04–0.08)	298.06
N_2O	0.007 (0.005–0.009)	0.23
NO_x	0.121 (0.094–0.148)	8.46

ABANDONMENT OF MANAGED LANDS

Managed lands include cultivated lands and pastures. If managed lands are abandoned, carbon may reaccumulate on the land and in the soil as it returns to its previous natural state. On the other hand, it can be a net source of CO_2 when the land continues to degrade.

A 20–year historical time horizon is suggested to capture the more rapid growth expected after abandonment. A second time period from 20 years after abandonment up to roughly 100 years may be considered if data are available.

In the Philippines, abandoned lands have been considered under the brushland category. Report of increases in the area of the pine and submarginal forests during the preceding 20 years before 1990 can be considered under this category. Such regrowth was responsible for the uptake of 363 Gg C or 1,331 CO_2 (Table 8).

No estimates were made for lands abandoned by more than 20 years due to lack of data.

Table 8. CO2 Uptake from Abandonment of Managed Lands

	A	B	C	D	E	F	G
Land Types	20–Yr Total Area Abandoned & Regrowing (kha)	Annual Rate of Above-ground Biomass Growth (t dm/ha)	Annual Carbon Uptake in Above-ground Biomass (kt C) (CxD)	Annual Rate of Uptake of Carbon in Soils (t C/ha)	Total Annual Carbon Uptake in Soils (<20 yrs) (kt C) AxD	Total Carbon Uptake from Abandoned Lands (kt C) C+E	Total Carbon Dioxide Uptake Growth (kt CO_2) Ox44/12
Pine Forest	44	2	44	0.5	22	66	242
Submarginal	198	1	99	1.0	198	297	1089
Total			143		220	363	1331

CO_2 EMISSION/UPTAKE BY SOIL FROM LAND USE CHANGE AND MANAGEMENT

Soils are sources/sinks of CO_2. To estimate the next fluxes, changes in the amount of the organic carbon stored in soils should be known. Inorganic carbon in soils is not a significant source of carbon in most agricultural soils. Data are needed for the inventory year and will include those of 20 years ago. Estimates of soil carbon stocks are based on the top 30 cm of the soil profile only.

The current method employs an accounting approach based on estimating carbon stocks and area for major categories of agricultural land-use/management system. This is based upon the assumption that after many years under a particular form of landuse, soil carbon levels tend toward an equilibrium state where carbon inputs from plant residues and losses of carbon through decomposition roughly balance.

Up to this writing, no estimations were made under this activity, except for the carbon uptake considered under abandonment of managed lands.

CONCLUSIONS

Among the components in the inventory of greenhouse gas sources and sinks, forestry and land use are the most complex. Comprehensive and systematic information is not available. Ideally, data on land use changes over the past 40 to 50 years are needed to include delayed emissions and uptake due to activities in prior years. Emissions/sinks are sensitive to biomass density. For each forest type, there should also be an inventory of the carbon contents in soils in order to determine the extent of emission/uptake of CO_2 in soils.

Nevertheless, this inventory was undertaken using whatever data available. The methodology has undergone much improvement since the IPCC guidelines released in 1991, 1995, and 1996. With these changes, the inventory of emissions/sinks from Philippine Forestry and Land Use Change correspondingly changed. The methodology has been agreed upon by consensus among experts from different countries in order to provide a standard approach among countries for intercomparison and for assessments of global emissions/sinks of greenhouse gases.

The summarized results of the present study are shown in Table 9. The uptake of CO_2 due to growth of existing trees totalled 99,450 Gg.

Table 9. National inventory for the forestry and land use sector

	C Emissions (+)/ Uptake (–) Gg	CO2 Emissions (+)/ Uptake (–) Gg	CH4 Gg	N2O Gg	CO2 Equivalent Gg
Changes in fuel in other woody biomass stocks					
Biomass growth	–28180	–99450			–99450
Roundwood harvests	5207	19092			19092
Fuelwood harvests	8647	31704			31704
Forests and Grassland Conversion					
Onsite burning	2129	7806	30.86	0.21	8519
Offsite burning	703	2578			2578
Roundwood harvests	6870	25190			84451
Decay	23032	84451			–1331
Abandonment of Managed Lands	–363	–1331			
Total		70041	30.86	0.21	70754

Most of the uptake came from residual forest which occupied about half of the total forests.

The roundwood harvests from standing forests and cleared forests were combined. About 5,207 Gg C or 19,092 Gg CO_2 was emitted from roundwood harvest from existing forests and 6,870 Gg C or 25,190 Gg CO_2 from cleared forests. Biomass decay from cleared forests was the largest source of CO_2. This is due to the large deforestation rate that occurred during the 10 years preceding 1990 which was 644 kha (Table 5). Fuelwood harvests from existing forests and agricultural lands accounted for 31,704 Gg CO_2. On-site burning was not much in 1990 because to the government policy to conserve forests. The rate of clearing in 1990 was 183 kha. Off-site burning is also considered in fuelwood harvest from cleared forests.

The net emissions of greenhouse gases from the forestry and land use sectors amounted to 70,754 Gg. This value already includes the contribution of trace gases using the principle of global warming potential of 21 for methane and 310 for nitrous oxide.

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