CARBON FLOWS
IN
INDIAN FORESTS

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Deforestation in the tropics has contributed to the rise in atmospheric concentration of CO_2 (Houghton, 1990). Thus at the global level, forestry options are considered as a cost effective method of sequestration of carbon for mitigation of potential climate change (Andrasko, 1990). Further, bioenergy from forests and tree plantations is also being considered for its potential to replace fossil - fuels (Hall et. al, 1991) for the same reason. In developing countries like India, forestry is important for conserving biological diversity, for its watershed role and for meeting the diverse biomass needs of local communities. There may not be any conflict regarding the role of forestry for local, national and global benefits. In the context of greenhouse warming there is a need to understand clearly both of the contribution of the forestry sector to greenhouse gases, particularly CO_2, and of its potential for coping with greenhouse warming. Several estimates are available on carbon emission from forestry at global level (Houghton, 1991, Hao et.al., 1990 and

Myers, 1990) and they are in the range of 1.5 - 3 G.t. annually. These uncertainties in estimates are due to difficulties in obtaining accurate data on rates of deforestation, extent of conversion of deforested area to various purposes, rates of degradation of forests, standing biomass and soil carbon in different forest types and their rates of change,and the extent of dependence on forests for various biomass needs in different countries.

In this situation there is a need for individual country level studies on carbon flow in forests to arrive at global values. Local researchers using their first hand knowledge of the forest situation would be generally in a better position to make more meaningful estimates of carbon flows. This study aims at understanding the carbon flows in Indian forests, its contribution to global CO_2 build up, the factors that influence the carbon flows and finally considers some policy options for considering forestry options for local and global benefits. The study specifically aims at estimating the following:

1. The standing biomass, biomass productivity and carbon storage given the area under different forest types.

2. The carbon releases through various conversions given the rates of deforestation as well as forest degradation and the dependence on forests for meeting various biomass needs.

3. The accumulation of biomass and carbon in Indian forests.

4. The net carbon emissions from forestry sector.

5. The net carbon emissions from Indian forests in future using different scenarios. And finally we consider,

6. Some forestry strategies for promoting local and global benefits to environment and communities.

Carbon flows from Indian forests is estimated for the reference year 1986. The methodology is based mainly on the COPATH model of Makundi et.al. (1991). Several additions and modifications however are incorporated into the model.

LAND USE PATTERN IN INDIA

India with a population of 843 million (1991) has a geographic area of 328.8 m. ha. The land use pattern is given in Table-1. In India 47% of geographic area is under cropping and 23% of the area is classified as forest land. The area under various categories other than forests and croplands accounts for 22.7% (74.8 m.ha.) and this land is highly degraded with poor vegetation cover. No official record exists for the remaining 7.3% of the land.

AREA UNDER FORESTS

Area actually under forests was one of the highly contested figures in the past. However, with access to satellite imagery data, area under forests has been estimated and it is given in Table - 2 (State of Forest Report, 1989). The satellite assessments carried out during 1981-83 and 1985-87 are used in this study. According to the recent assessment (1985-87) 64.01

m.ha. or 19.5% of geographic area is under forests with over 10% crown cover.

Further, area under dense forest cover (with a crown cover of over 40%) is only 37.8 m.ha. or 11.5% of geographic area. The area under forest includes the area under natural forests, plantations raised over the years as well as plantation crops like rubber and apple. It has to be noted here that the forest or plantation area with crown cover of less than 10% is not considered as forest area in Table - 2 or in this study.

AREA UNDER FOREST TYPES

Indian forests have been classified into four major groups based on climate (State of Forest Report, 1987).

1. Tropical
2. Montane subtropical
3. Montane temperate
4. Alpine

Each of these major groups is further classified into different sub-types based on vegetation and the areas under each forest type are given in Table - 3. Tropical moist deciduous and tropical dry deciduous forests dominate by accounting for 36% and 28.2% of the total forest area respectively.

AREA DEFORESTED

A figure commonly quoted for area deforested in India is 0.4 m.ha. annually, comes from Myers (1990). It is not clear how this figure was estimated and whether area afforested is considered. The satellite imagery at two periods separated by a gap of 4 years includes area brought under tree plntations. These changes in area under forest in different states are given in Table - 2. Total area under forest has declined by 1,90,900 ha during the period of 4 years. Thus when both deforestation and afforestation are considered the net area deforested annually is only 47,725 ha compared to 0.4 m.ha quoted in literature (Myers,1990). The reference year for the carbon flow is 1986 (the mid-year of the imagery assessment 1985-87). The following procedure is adopted for estimating the area deforested for carbon flow calculations.

All the states where there was a decline in area under forest between the years 1982 and 1986 from the two satellite assessments given in Table - 2 are considered. The net decline in forest area of only the states where there was reduction in area between 1982 and 1986 was estimated and further it was divided by 4 years to obtain the mean annual area deforested in each state.

$$\text{Net area deforested in a year} = \sum_{i=1}^{27} (A\ 82_i - A\ 86_i)/4 \text{ years},$$

of only states where $A\ 82_i > A\ 86_i$.

$A\ 82_i$ = Area under forest in 1982 assessment in State 'i'

$A\ 86_i$ = Area under forest in 1986 assessment in State 'i'

i = 1 to 27 states and union territories.

A sum of all such states is considered as the area deforested during the reference year 1986. It has to be noted that the area brought under plantations is included as forest area. Thus the area declined in each state is over and above the area replanted with trees having over 10% crown cover. The standing biomass or carbon storage in afforested areas is going to be different from forests. To overcome this problem carbon storage is estimated by considering the crown cover of the forests and plantations.

The area deforested for each state and its total is given in Table - 2 (last column). Thus the area deforested in the reference year is estimated to be 4,98,250 ha. The states where area under forest in 1986 was higher than in 1982 are considered only while estimating carbon uptake.

CONVERSION OF DEFORESTED AREA FOR DIFFERENT PURPOSES

Details of the conversion of deforested area for different purposes for the states are available only for the period 1951 - 1975 (Central Forestry Commission, 1981). Using this state level data, it is possible to obtain the details of deforested area for different purposes under each forest type. The same proportion of total deforested area diverted for different purposes available for the period 1951 - 75 (Table - 4) is assumed for 1986,the reference year of this study. Conversion of deforested area to agriculture is considered as agriculture, conversion to river valley projects and roads is considered as clear cutting, conversion to industry as selective cutting and conversion to other purposes as conversion to pasture lands.

By considering the rates of conversion of deforested area to different uses at state level and the area under different forest types in that state, the proportion of deforested area diverted to each of the four purposes is calculated for each forest type and at national level for the COPATH model. The proportions are given in Table - 3. Nationally conversion to agriculture dominates by accounting for 62.6% of the area deforested, followed by conversion to pasture and clear cutting .

BIOMASS DEMANDS ON INDIAN FORESTS

In accordance with the COPATH model, the biomass demands on forests are considered under three heads namely - combustion, long term use and short term use. It is very difficult to estimate the quantity of different types of biomass removed from different forest types, as well as the contribution of deforested area in meeting various demands. Thus the current consumption levels are considered and are given in Table - 5 (combustion or firewood) and Table - 6 (short term and long term use).

Combustion (Firewood)

Firewood is the dominant source of fuel for cooking in rural areas (as 95% of households depend on biomass - firewood, crop residues and dung) and for about 16% of households in urban areas (Reddy and Reddy, 1983). According to State of Forest Report (1987) the total firewood demand in 1987 was 157 m.t., or a per capita demand of 286 kgs/annum. This is in addition to the use of crop residues and cattle dung. Combustion is important as it leads to release of CO_2 and other greenhouse gases during the reference year. The different sources of firewood are; forests, village trees, shrubs and weeds like Prosopis juliflora, and plantation tree crops like coconut, areca nut, tea, rubber and Eucalyptus, Casuarina etc. Firewood in the form of twigs and branches or even full trees if harvested in a sustainable way, will not make any net CO_2 contribution. However if trees or branches are felled for fuel in a non-sustainable way and burnt, there would be net CO_2 emissions.

It is difficult to estimate the proportion of 157 m.t. of firewood coming from forests and further how much of it is harvested in a non-sustainable way. The sources of firewood considered in the study are, deforestation, current year's production, felling from existing forests and shifting cultivation. Wood harvested for fuel purpose in sustainable as well as non-sustainable mode is considerd here. Some details of calculations are given in Appendix - I.

Short Term Use

Wood used for pulp, paper, packaging, match industry, etc., is considered as short term use and the demand was officially estimated to be 13.82 $m.m^3$ for the reference year (State of Forest Report, 1987). The sources of timber for short term uses are forests and tree plantations.

Long Term Use

Long term use consists of timber use for housing, agricultural implements, plywood, mining pit props, railway sleepers, etc. The total long term use according to State of Forest Report (1987) was 13.76 $m.m^3$ and the same value is taken for the reference year. The sources of timber for long term use are, forests, tree plantations and trees in the village ecosystems (not considered as forest). The forest is the dominant source of timber for structural materials (urban), plywood and mining pit props. The actual quantity used may be higher than what is officially recorded as coming from clear felled areas. This higher quantity is accounted by considering the source of forest degradation.

STANDING BIOMASS IN FORESTS

Standing biomass data for different forest types was obtained from the literature (references and values given in Appendix II). For each forest type, among the various estimates the maximum standing biomass recorded, is taken for the study and further it is taken to hold maximum crown cover of say 100%.

The State of Forest Report 1989 gives the crown cover of forests in different states. Tiwari and Singh (1987) provide estimates of biomass under 5 different crown cover levels for some forest types. This was extrapolated to other forest types. Using the data on standing forest biomass under full crown cover (from literature) and estimated mean crown cover for each forest type, the total standing biomass was calculated for each forest type (Table - 7). The total standing biomass in Indian forests is estimated to be 8357.9 m.t. with a mean per ha standing biomass of 130.5 t.

CARBON STORAGE

Carbon storage in the vegetation and soil is given in Table - 8. Carbon storage in forests is estimated by taking 50% of the standing biomass as carbon. Carbon storage in forest soil is considered based on the soil organic carbon content in the soils of different forest types from the literature (references and values are given in Appendix - III).

The total carbon stored in Indian forests is estimated to be 9578 m.t. out of which vegetation and soil account for 44% and 56% respectively.

CARBON UPTAKE IN FORESTS

While considering net carbon release, the carbon uptake and storage in forests, perennial plantation crops (like rubber, apple, tea, coffee, coconut), and tree plantations (like *Eucalyptus, Casuarina equisetifolia*) should be considered.

Only in mature or climax forests, all gross primary productivity is either used up in respiration or returned to soil as litter and there will be no net addition to the standing biomass. At all other stages of succession there would be net addition to the standing biomass or in other words carbon accumulation. Further the 64.01 m. ha. of forest considered in the study also includes 11.4 m. ha. of cumulative area afforested from 1952 to 1986 (Ministry of Environment and Forests, 1989) and several plantation crops like rubber, coffee and tea. Large tracts of forests in India have been subjected to anthropogenic interventions over centuries and thus are at various stages of succession. Net annual accumulation for the reference year is calculated using data on net primary productivity (NPP) and standing biomass from various studies. The NPP is taken as a per cent of standing biomass from studies which are listed along with references in Appendix - IV. Further only a part of NPP resulting in the accumulation of biomass in main trunk and large branches is considered for calculating carbon uptake. Productivity in the form of leaf litter and micro wood litter is not considered as it comes from current years production and is likely to end up in decomposition. The net accumulation of woody biomass considered for the study is in the range of 1.28 to 2.84 t/ha/year.

Thus the net accumulation of carbon in Indian forests is estimated to be 69 m.t. for the year 1986 (Table - 8).

CARBON EMISSIONS

Carbon emissions from forests could be from deforested areas as well as from unrecorded depletion plus degradation in the existing forest areas. The carbon emission values are given in Table - 9.

Clear Felled Forest

The combustion or firewood component of 27 m.t. of annual recorded removal from forests as given in State of Forest Report 1987 is taken to be coming from deforested area during the year. Thus 13.5 m. t. of carbon is estimated to be released from combustion from deforested area. When the release of carbon from long term use is considered, a life of 30 years is taken for the timber used. Accordingly the quantity of timber used for long term purposes 30 years earlier to the reference year is assumed to decompose and release carbon during the reference year. Due to this factor there is no balance between the total carbon stored in the felled vegetation (of 28.59 m.t. from Table - 3) and the total carbon released from deforested area (of 27.65 m.t. from Table - 9). Regarding the short term use the quantity of wood or timber used is expected to last for only 3 years. Accordingly the biomass used for short term purposes during the previous 3 years which is assumed to release carbon annually plus one-third of the reference year's use is taken for carbon release during the reference year. Release of carbon from soil was calculated based on Ayanaba et. al (1976) while biomass decomposition was calculated based on the values of FRI (1970).

The total carbon release from various conversions (like combustion, short and long term use and decomposition) is estimated to be 27.6 m.t. (Table 9).

From Current Year's Production

Total NPP was estimated by taking the measured NPP for different forest types (Appendix IV). Out of the total net primary productivity of 137.7 m.t.,69% was considered as getting accumulated in bole and big branches for long term storage. Out of the remaining current year's production (43 m.t.), 50% is considered to be used as firewood and the remaining 50% is assumed as left for decomposition.

The total carbon released from the current (reference) year's production in forests for combustion and decomposition is estimated to be 21.5 m.t. (Table 9).

From Forest Degradation and Illegal Removal

In addition to the carbon release from deforestation or clear-felling, degradation of existing forests also contributes to carbon release. Degradation could result from grazing, fire, death due to disease and pest attack, illegal removal of timber and over harvest of firewood, etc. Evidence is available from several studies (Brown et.al, 1991 and Flint and Richards, 1991). The analysis carried out by Flint and Richards (1991) for South Asia (including Northern parts of India) indicates a degradation ratio of 1.54 for the period 1950 - 80. One interpretation according to Houghton (1991) is that for every ton of carbon released to atmosphere through deforestation, an additional 0.54 t of carbon is released from degradation of the standing forests. Thus out of total carbon emission of 27.65 m.t. from clear felling (Table 9) and taking a degradation ratio of 1.54 the total quantity of carbon involved due to degradation factors is 15 m. t. Out of this about 50% is assumed to be used as firewood (7.72 m.t.), 25% is assumed to be used for short term (or possibly for long term purposes) and 25% is assumed to end up in decomposition (3.86 m.t.).

The carbon release due to degradation and unaccounted removal is estimated to be 12.87 m.t. for the reference year (Table 9).

Shifting Cultivation

About 0.99 m. ha. are annually subjected to shifting cultivation (State of Forest Report, 1987). The fallow period is getting shortened. Considering the shortened fallow period a net carbon emission of 1.56 m.t. (Table 9). is estimated after accounting for new accumulation in areas left fallow and degradation or burning of new areas.

The total carbon emission from all the natural and anthropogenic factors in the forest is estimated to be 63.58 m.t.

NET CARBON RELEASE

When the net carbon flow in Indian forest ecosystem is considered (carbon uptake - carbon release) a marginal net carbon sequestration of 5.29 m.t. could be observed for the reference year (Table - 8). Thus our estimate differs from the estimates of Myers (1990) as well as of Ahuja (1991). This study has not considered the CO_2 fertilization effect on the remaining forest, which contributes to net CO_2 sequestration.

At global level, deforestation and land use changes are estimated to contribute 1.5-3 G.t. of carbon annually (Houghton, 1990). It is not clear whether carbon sequestered in the existing forest area annually and in the new forest plantations are considered in such estimations. For example Myers (1990) considers a deforestation rate of 0.4 m. ha. annually for India and correspondingly 41 m.t. of carbon is estimated to be released to the atmosphere. Ahuja (1991) has made an estimate of the net carbon emission, based on values of global flux of 700 m.t. of carbon (from Lashof and Tirpak, 1989) and by considering the share of India in global deforestation, as 20.2 m.t / year. If Indian forestry is considered as an ecosystem, what is of consequence to climate change is the net carbon release after accounting for total emission from forests from deforestation and forest degradation annually and total long term sequestration (or annual accumulation due to net primary productivity in bole and large branches) in forests and tree plantations

EXPLANATION FOR NO NET CARBON RELEASE

The present study has established that in the Indian forest ecosystem the carbon flux may be balanced and Indian forestry sector might not make any net contribution to global CO_2 build up. Though this may look surprising there are strong reasons to support the case.

(i) The forest conservation Act, 1980 prescribes that no land should be alienated from control by state forest departments without consent of the central government. Obtaining permission from central government is an onerous task. This has largely halted all such alienation.

(ii) Beginning with the Fifth Five Year Plan of 1975 - 80, it is compulsory for all major development projects to carefully prepare an Environmental Impact Statement and to provide for compensatory afforestation in the event of loss of any forest cover.

(iii) Beginning in the late 1970's, the subsidies enjoyed by the forest-based industry have been gradually reduced, thereby helping to motivate the industry to use the resources more carefully.

(iv) Beginning in 1970's, the farmers have been encouraged to take to tree crop production and many industries and farmers have developed healthy links for fulfilling the needs of forest based industries.

(v) Beginning in 1970's with the village Forest Protection Committees of West Bengal, local tribals and villagers are being given an economic stake in the well being of local forest resources. The response has been most encouraging. Other states like Haryana and Gujarat have initiated measures to create village community based management systems for involving the local people positively in sustainable use and restoration of the local forest resources.

(vi) Beginning in late 1970's with the state of West Bengal and mid 1980's with Karnataka many state governments are decentralizing political decision making. The village and district level political authorities that have thus been created are far more motivated to ensure prudent use of local resources - including forest resources. Other states are expected to follow suit in decentralization of power, creating more favourable conditions for better management of forest resources. Further, the National Wastelands Development Board created in 1985 has taken novel initiatives in decentralizing integrated planning of the use of natural resources and is spearheading efforts at restoring the vegetation cover of vast stretches of degraded lands by meaningfully involving the local people.

(vii) Large afforestation programme : India has launched a very large afforestation programme. The area afforested in the recent years is given below (Ministry of Environment and Forests, 1989).

Years	Area afforested
1985 - 86	1.51 m.ha.
1986 - 87	1.76 m.ha.
1987 - 88	1.77 m.ha.
1988 - 89	2.12 m.ha.

The above data indicates that large areas are brought under tree vegetation and the area brought under vegetation could be in deforested area or degraded community land or degraded private land. Studies of plantations raised by the forest department as well as farmers have shown a productivity in the range of 1.3 to 8.3 t/ha/yr (Ravindranath et.al, 1992).

(viii) Above all these factors, the strong environmental movements in different parts of the country, with the very active support of mass-media, have contributed significantly to reduce large scale legal as well as illegal conversion of reserve forest land.

(ix) Biomass fuel conservation programmes like biogas and efficient stoves are being implemented in all the states.

(x) A large section of area under forests (with less than 40% crown cover) is under disturbed and successional state. Thus there would be accumulation of biomass (and carbon) in such forests.

Thus it is possible to support the findings of the carbon flow analysis that Indian forests may not be making any net contribution to CO_2 build up in the atmosphere.

FUTURE SCENARIOS OF CARBON FLOW

To get an idea of the possible future carbon emissions a medium term scenario for the year 2011, which is 25 years from the reference year is considered. Future scenario is considered at two levels. The carbon flux values for the scenarios are given in Table - 8.

Scenario - I : Current rates of deforestation , afforestation , firewood consumption, productivity, long term and short term timber uses , etc. are considered. Area under plantations and perennials (coffee, tea, rubber, etc.) is expected to increase at current rates.

Scenario - II : A favourable scenario is considered assuming the following changes.

- Short term forestry (firewood and soft wood) : 2.5 m.ha/year.
- Long term forestry (fruit and timber trees): 2 m.ha/year.
- Area to be brought under natural regeneration : 1 m.ha/year.
- Productivity of plantations : 3t/ha/year.

- Productivity under natural regeneration : 0.75 t/ha/year.
- Biogas plants for cooking : 0.5 m/year.
- Efficient cook stoves for all houses (at a saving of 33% in fuel use).
- Area under forest would remain unchanged, but area under plantation crops (like rubber, coconut, tea, coffee) would increase at current rates.

Scenario - I : The `business - as - usual' scenario for the year 2011 shows that with increase in population there would be a relative increase in demands for biomass from forests and plantations. If the current proportion of demands for firewood, short term and long term timber which are being met from the forests is assumed for 2011 also, Indian forests would be making a total carbon emission of 99.42 m.t. during the year. Thus the `business - as - usual' scenario is not environmentally sound given a large increase in the population.

Such a scenario is not likely to be realised because of several factors like,

i) Biomass fuel conservation programmes are being implemented more rigorously.

ii) Area afforested annually is likely to go up from the assumed rate of 1.8 m. ha. and even farmers are likely to shift from marginal cropping to tree cropping.

iii) Shift from wood to other materials like steel, plastics and reinforced cement concrete for structral purposes, and also for packaging, railway sleepers and other purposes.

iv) Increased participation of community in management of forests and community plantations leading to sustainable harvests.

Scenario - II : The favourable assumptions made for this scenario do not look unrealistic. It is possible to bring in 4.5 m. ha. under tree vegetation/year apart from bringing 1 m. ha. under natural regeneration, or to build 0.5 million biogas plants or to build two million fuel efficeint stoves annually. Under this scenario a net carbon sequestration of 121.1 m.t. is possible. This highlights the potentiality of the forestry sector in India for achieving global as well as local benefits.

FORESTRY OPTION FOR GLOBAL AND LOCAL BENEFITS

The present study has shown that forestry sector in India may not be making any net contribution to global CO_2 build up. The favourable Scenario - II has further shown the large potential for carbon sequestration for global benefits. The primary goals of forestry options in India would be for its role in promoting biological diversity, watershed development and for meeting the local diverse biomass needs in a sustainable way. However carbon sequestration for global benefit would be a very important outcome of any good forest strategy. It is possible to promote the forestry strategy which provides local as well as global benefits. Such a strategy would include the following important components. A full consideration of the forestry strategy is beyond the scope of the present study.

1. All the wood requirement for commercial purposes (mainly for short term use) should be met from plantations on privately owned degraded crop lands. Appropriate incentives have to be provided to farmers to shift from marginal cropping to tree farming on such degraded crop lands.

2. Subsistence biomass needs of tribal and rural populations could be met in a sustainable way from a network of community lands near their habitats.

3. The reserve forest lands including the degraded forest areas should be brought under a regime of production restricted to non-wood forest produce for employment and income generation to tribal and rural communities.

4. Empowering of the local communities to sustainably manage the common lands as well as the reserved forests is necessary.

5. Biomass fuel conservation programmes like biogas and efficient stoves should be implemented more rigorously. Such programmes would lead to reduction in pressure on forests, plantations and village trees.

6. Exploring the potentiality of bio-energy technologies and options for power generation at decentralized level to meet village energy needs in a sustainable way. Substitution of fossil-fuel based energy with bio-energy systems would lead to net reduction in green house gases (Hall et.al.,1991).

All these strategies which have a strong local benefit bias lead to increased stocking or accumulation of carbon in the existing forests and new sequestration of carbon in currently degraded areas leading to significant carbon sequestration for global benefits. Thus the forestry strategy for global and local benefits would include prevention of deforestation and degradation of forests, afforestation on all degraded lands, implementation of biomass conservation programmes, substitution of fossil-fuel energy with bio-energy technologies at decentralized levels and above all a sustainable management of forestry and energy systems through community participation. The economic, social and political implications of such a strategy have to be carefully analysed.

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TABLE 1 : LAND USE PATTERN IN INDIA

(x 10^6 ha)

Sl. No.	Land Use	Area	% of total area
1.	Agriculture/area cropped	154.70	47.0
2.	Forests (Area officially recorded as forests)	75.18	22.8
3.	Permanent pastures and other grazing land	12.15	3.7
4.	Land under cultivable tree crop and groves	3.91	1.3
5.	Cultivable wasteland	16.64	5.1
6.	Land under other non-agricultural uses	17.53	5.3
7.	Barren and waste land	24.60	7.5
8.	Area for which no records exist	24.09	7.3
		328.80	100.0

Source : The State of Forest Report 1987.

TABLE 2 : AREA UNDER FORESTS - STATEWISE (1981-83 and 1985 - 87)

($\times 10^3$ ha)

State/ Union territories	1987 Assessment based on imagery 1981-83	1989 Assessment based on imagery 1985-87 *	1989 Assessment Dense forest (Crown cover above 40%)	1989 Assessment Open forest (Crown cover 10% to 40%)	Mean net area deforested per year
Andhra Pradesh	5019.4	4791.1	2553.5	2197.1	57.1
Arunachal Pradesh	6050.0	6876.3	5427.2	1449.1	-
Assam	2638.6	2605.8	1668.8	937.0	8.2
Bihar	2874.8	2693.4	1341.2	1352.2	45.4
Goa (including Daman & Diu)	128.5	130.0	97.5	32.2	-
Gujarat	1357.0	1167.0	525.9	599.9	47.5
Haryana	64.4	56.3	13.0	43.3	2.0
Himachal Pradesh	1288.2	1337.7	710.0	627.7	-
Jammu & Kashmir	2088.0	2042.4	1082.4	960.0	11.4
Karnataka	3226.4	3210.0	2474.9	735.1	4.1
Kerala	1040.0	1014.7	831.2	183.7	6.3
Madhya Pradesh	12774.9	13319.1	9144.8	4174.3	-
Maharashtra	4741.6	4405.8	2617.7	1776.7	84.0
Manipur	1767.9	1788.5	506.0	1282.5	-
Meghalaya	1651.1	1569.0	342.7	1226.3	20.5
Mizoram	1909.2	1817.8	388.3	1429.5	23.0
Nagaland	1435.1	1435.6	463.2	972.4	-
Orissa	5316.3	4713.7	2756.1	1938.4	150.6
Punjab	76.6	116.1	9.7	106.4	-
Rajasthan	1247.8	1296.6	290.2	1006.4	-
Sikkim	283.9	312.4	241.0	71.4	-
Tamilnadu	1838.0	1771.5	975.9	790.9	16.6
Tripura	574.3	532.5	121.4	411.1	10.4
Uttara Pradesh	3144.3	3384.4	2263.2	1121.2	-
West Bengal	881.1	839.4	333.2	295.3	10.4
Andaman & Nicobar	760.3	762.4	651.8	13.3	0.8
Other territories	26.2	23.5	16.2	7.5	-
Total	64203.9	64013.0	37847.0	25740.9	498.2

Source : The State of Forest Report 1989.

* includes an area of 425.5 x 10 3 ha under mangroves.

TABLE 3 : AREA UNDER DIFFERENT FOREST TYPES, AREA DEFORESTED ACCORDING TO FOREST TYPE, CONVERSION OF DEFORESTED AREA FOR DIFFERENT PURPOSES (PERCENTAGES) AND MAXIMUM RELEASABLE CARBON.

(area = $x\ 10^3$ ha and quantity = $x\ 10^6$ t)

Sl. No.	Forest type	Area occupied	Area deforested	Conversion rate (% of the total deforested area): Agri.	Pasture	Clear cut	Sel. cut	Maximum releasable carbon from the vegetation of the deforested area
1.	Tropical wet evergreen	5289	7.48	44.8	24.7	19.9	10.57	1.00
2	Tropical semi evergreen	2576	16.77	44.4	22.3	22.4	10.9	1.77
3.	Tropical moist deciduous	23054	240.45	68.0	16.3	12.0	3.7	20.57
4.	Littoral and swamp	384	5.35	89.5	6.2	3.3	1.0	0.25
5.	Tropical dry deciduous	18083	172.49	67.8	18.1	11.0	3.1	3.43
6.	Tropical thorn	1573	25.81	29.9	46.0	21.0	3.1	0.20
7.	Tropical dry evergreen	134	1.36	31.4	14.5	52.2	1.9	0.01
8.	Sub tropical broad leaved hill	268	2.57	80.5	8.7	9.1	1.7	0.05
9.	Sub tropical pine	4567	3.27	34.4	28.7	29.2	7.7	0.15
10.	Sub tropical dry evergreen	1201	13.68	8.6	85.4	6.0	-	0.32
11.	Montane wet temperate	2582	.89	49.9	13.7	19.6	16.8	0.05
12.	Himalayan moist temperate	2243	6.09	20.8	52.8	22.6	3.8	0.72
13.	Himalayan dry temperate	30	.17	-	100.0	-	-	0.006
14.	Sub alpine and alpine	2028	1.87	26.3	57.2	10.7	5.8	0.06
		64013	498.25	62.8	21.3	12.2	3.7	28.59

TABLE 4 : DIVERSION OF FOREST AREA FOR VARIOUS PURPOSES

Causes	Conversion taken in the present study	Area lost during 1951-75	Proportion of area lost to total (1951-75)	Area lost annually during 1981-83 & 1985-87	% loss to the total forest area 1981-83 & 1985-87
Agriculture	Agriculture	2520	0.625	313.02	0.4879
River valley projects and roads	Clear cutting	479 57	0.119 0.014	60.61	0.0946
Industries	Selective cutting	168	0.042	18.53	0.0289
Miscellaneous purposes	Pasture	803	0.199	106.08	0.1657
Total		4028	1.000	498.24	0.7783

Source : Since statewise details of deforestation for various purposes were available only for the years 1951-75 (Central Forestry Commission, 1981) the same proportions have been used as the basis while allocating the area deforested for various purposes in different states between 1982 and 1986.

TABLE 5 : FIREWOOD, CROP RESIDUES AND DUNG USE AS FUEL

(x 10^6 t)

Year	Fuelwood (air dry)	Crop residues (air dry)	Dung (fresh)
1953-54[a]	86.3	26.4	46.4
1960-61[b]	99.6	30.6	54.6
1965-66[c]	109.3	33.6	59.9
1970-71[d]	117.9	36.3	64.6
1975-76[e]	133.1	41.0	73.0
1986[f]	157.0	-	-
2011[g]	191.0	-	-

Note : a – e : Department of Environment, Forests and Wildlife, 1986.

f : The State of Forest Report 1987.

g : Projected figure

Projected population for 2011 is 1287.18 million, calculated using a decinnial growth rate of 23.50 between 1981-91 (74.3% rural and 25.7% urban). Entire rural and 16.1% (Reddy and Reddy, 1989) of urban people are dependent on fuelwood. Using a demand of 286 kgs wood / capita / year (obtained by dividing 157 m.t. by the population depending on firewood) and, a 33% saving due to improved efficiency, a value of per capita wood requirement of 189 kgs/year is obtained.

TABLE 6 : LONG TERM AND SHORT TERM USE CATEGORY DEMAND

(x 10^6 m^3)

Description	1986*	2011** projections
For long term use		
Plywood and veneer	1.71	
Fibreboard, Particle and chip board	0.23	
Sports goods	0.03	
Railway sleepers	0.50	
Agricultural implements bullock carts and temporary rural constructions	5.43	
Furniture and panelling	0.36	
Housing	2.50	
Others (mining pitprops truck and bus bodies)	3.00	
Total LT use	13.76	25.85
For short term use		
Pulp and paper	6.57	
Match industry	0.44	
Packaging	6.81	
Total ST Use	13.82	25.96
Total	27.58	51.81

* The State of Forest Report 1987.

** Timber demand: Population and demand ratio of 1981 was calculated. This ratio was multiplied with the projected population of 2011 to estimate the projected demand assuming current rate of consumption.

TABLE 7: PRODUCTION AND STANDING BIOMASS IN FORESTS 1986

Forest type	Area occupied ($\times 10^3$ ha)	Standing Biomass t/ha	Average crown cover	Total standing biomass ($\times 10^6$ t)
1. Tropical wet evergreen	5289.3	607.7	0.47	1496.6
2. Tropical semi evergreen	2575.7	468.0	0.48	576.5
3. Tropical moist deciduous	23054.7	409.3	0.43	4018.6
4. Littoral and swamp	383.4	213.8	0.44	36.3
5. Tropical dry deciduous	18083.3	93.8	0.43	731.5
6. Tropical thorn	1573.0	40.0	0.40	25.1
7. Tropical dry evergreen	134.2	40.0	0.42	2.2
8. Sub tropical broad leaved hill	267.8	108.7	0.38	11.1
9. Sub tropical pine	4567.5	210.8	0.46	441.1
10. Sub tropical dry evergreen	1201.0	159.7	0.29	55.6
11. Montane wet temperate	2581.9	237.67	0.49	299.2
12. Himalayan moist temperate	2242.8	562.2	0.43	537.5
13. Himalayan dry temperate	30.5	169.1	0.41	2.1
14. Sub alpine and alpine	2027.7	127.4	0.48	124.6
	64013.0	--	--	8358

* Average crown cover and standing biomass were calculated using data on standing biomass under five different crown covers from Tiwari and Singh (1987).

* See Appendix II for references on standing biomass.

TABLE 8 : CARBON FLOWS - CURRENT AND FUTURE SCENARIOS

(x 10^6 t for the reference year)

CARBON FLUX	1986	2011 (at current rates)	2011 (at favourable rates)
CARBON STORAGE			
Forest - vegetation	4178.95	4178.95	4178.95
- soil	5399.33	5399.33	5399.33
Plantation	--	850.50	1181.25
Perennials	--	75.00	3000.00
Natural regeneration	--	--	1096.87
Total	9578.28	10503.78	14856.40
CARBON RELEASE			
- Shifting cultivation	1.56	1.56	1.56
- Combustion	31.97	61.66	31.85
- Past LT use	1.38	4.61	4.61
- Past ST use	3.10	5.91	5.91
- Current ST use	2.84	2.95	2.95
- Release from soil	3.91	3.91	3.91
- Biomass decomposition (surface and underground)	18.82	18.82	18.82
Total	63.58	99.42	69.61
CARBON UPTAKE			
- Forests*	68.87	68.87	68.87
- Natural regeneration	--	0.23	9.38
-Afforestation (short rotation forestry)	--	27.00	37.50
-Reforestation	--	--	75.00
Total	68.87	96.10	190.75

TABLE 9 : CARBON EMISSIONS FROM FORESTS - 1986

(x 10 t)

End use	From clear felled area for					From the NPP in the forest	From degradation of existing stock	From shifting cultivation	Total
	Agriculture	Pasture	Clear cutting	Selective cutting	Total				
1. Combustion	8.15	2.92	2.03	0.40	13.50	10.75	7.72	1.56	33.53
2. Past LT use	—	—	1.38	—	1.38	—	—	—	1.38
3. Past ST use	—	—	1.30	0.25	3.10	—	—	—	3.10
4. Current ST	—	—	1.30	0.25	1.55	—	1.29	—	2.84
5. Root decomposition	—	—	0.16	0.05	0.21	—	—	—	0.21
6. Soil	2.41	0.83	0.50	0.17	3.91	—	—	—	3.91
7. Other surface decomposition	—	—	—	—	4.00	10.75	3.86	—	18.61
Total	10.56	3.75	6.67	1.12	27.65	21.50	12.87	1.56	63.58

LT = Long term, ST = Short Term, NPP = Net Primary Productivity.

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APPENDIX I : SOURCES OF FIREWOOD

1. From deforestation

Since the area deforested is officially recorded, it is assumed that, all the recorded production of firewood (27 m.t.) would come from this recorded deforested area (Ministry of Environment and Forests, 1988). Out of this, 17.7 m.t. would come from the area deforested for agriculture, while 5.3 m.t., 3.4 m.t. and 0.6 m.t. would come respectively from the areas deforested for pasture, clear cutting and selective cutting.

2. From the Net Primary Productivity (NPP) of woody biomass in the forest

Biomass accumulated annually in the forest through NPP is 137.7 m.t. Studies (Rai, 1981; Rana, 1985; Sharma et.al, 1990) have shown that about 48-74% of the NPP gets accumulated in the bole. Thus about 94.7 m.t. would remain in the bole fraction and about 43 m.t. would be available in the form of small twigs and branches. Out of this, only 50% (21.5 m.t.) is assumed to be in the form of extractable firewood and the remaining microlitter is likely to end up for decomposition (table 9).

3. From the degradation of existing stock

At a degradation ratio of 1.54 the biomass that would come from degraded source is estimated to be 30.88 m.t. out of which 15.44 m.t. (50%) would be available as firewood and the remaining part may end up partly for short term or long term use and partly for decomposition (table 9).

4. From shifting cultivation

From an annual area of 0.99 m.ha under shifting cultivation wood equivalent to 3.12 m.t. is considered to be burnt (table 9).

Altogether firewood from forests account for 67.06 m.t. The rest of the firewood (89.94 m.t.) may come from (i) trees in the village ecosystems, (ii) shrubs like Prosopis juliflora, Lantana camara and Cassia auriculata, (iii) plantation crops like tea, coffee, rubber, coconut.

APPENDIX II : MAXIMUM STANDING BIOMASS OF DIFFERENT FOREST TYPES

	Forest type	Standing biomass (t/ha)	Reference
1.	Trop. wet evergreen	607.7	Rai, 1981
2.	Trop. semi evergreen	468.0	Swamy, 1989
3.	Trop. moist deciduous	409.3	Swamy, 1989
4.	Littoral & swamp	213.8	Singh, 1989
5.	Trop. dry deciduous	93.8	Singh, 1990
6.	Trop. thorn[1]	40.0	-
7.	Trop. dry evergreen[2]	40.0	-
8.	Sub trop. broad leaved hill	108.7	Toky & Ramakrishnan, 1982
9.	Sub trop. pine	210.8	Chaturvedi & Singh, 1984
10.	Sub trop. dry evergreen[3]	159.7	-
11.	Montane wet temp.	237.67	Yadava, 1986
12.	Himalayan moist temp.	562.2	Rana, 1985
13.	Himalayan dry temp.[4]	169.1	-
14-16	Subalpine & alpine	127.4	Yoda, 1968

1. Tropical thorn forests were assumed to have 40% crown cover of tropical dry deciduous forests as they appear along side the tropical dry deciduous forests; 40% of the standing biomass of deciduous forests was assumed to be the standing biomass of tropical thorn forests, which is 37.52 t/ha further rounded off to 40 t/ha.

2. Same as tropical thorn forests.

3. Since it occurs between subtropical pine and tropical dry deciduous forests a mid value between the standing biomass values of these two forest types is taken.

4. Since it occurs between sub tropical pine and sub alpine forests, a mid value between the standing biomass values of these two forest types is taken.

APPENDIX III : SOIL CARBON IN DIFFERENT FOREST TYPES

Forest type	Soil carbon (t/ha)	Reference
1. Tropical wet evergreen	125.19	Singh, 1968
	140.4	Rajamannar & Krishna moorthy, 1978
Mean	132.79	
2. Tropical semi evergreen	152.9	Singh, 1968
	190.6	Swamy, 1989
Mean	171.75	
3. Tropical moist deciduous	40.17	Das, 1975
	42.12	Rajamannar & Krishna moorthy, 1978
	67.08	Banerjee et.al, 1986
	79.17	Jha et.al, 1979
Mean	57.135	
4. Littoral & swamp	26.52	Sahoo et.al, 1989
	29.25	Sahoo et.al, 1989
	34.90	Sahoo et.al, 1989
Mean	30.22	
5. Tropical dry deciduous	51.87	Kumar et.al, 1987
	54.21	Sachan et.al, 1980
	61.16	Singh et.al, 1990
	64.74	Singhal & Sharma, 1983
Mean	57.99	
6. Tropical thorn	44.0	Since no studies were available it was assumed that soil carbon in this forest type would be equivalent to 75% of soil carbon of tropical dry deciduous forests.
7. Tropical dry evergreen	33.0	Since no studies were available, it was assumed that soil in this forest would contain carbon equi valent to 75% of soil carbon of tropical thorn forest.

APPENDIX IV : NPP (t/ha/year) IN DIFFERENT FORESTS

Forest type number	Forest type	Standing biomass	NPP of stem, branch and twig	% NPP (% to the standing biomass)	Reference
1.	Tropical wet evergreen	607.7	7.806	1.28	Rai, 1981
3.	Tropical moist deciduous	588.9	8.59	1.46	Rana, 1985
5.	Tropical dry deciduous	115.5	3.28	2.84	Sharma et al, 1990
9.	Sub tropical pine	198.96	4.12	2.07	Rana, 1985
12	Himalayan moist temperate	432.8	8.98	2.07	Rana, 1985

* Apart from the above studies, data were not available for the remaining forest types. Thus the above values were used for the other forest types. 1.28% (type 1) was used for forest type 2; 1.46% (type 3) was used for forest type 4; 2.84% (type 5) was used for forest types 6 & 7; 2.07 (from type 9 & 12) was used for forest types 8, 10, 11, 13 & 14-16.

APPENDIX III : SOIL CARBON IN DIFFERENT FOREST TYPES (contd.)

Forest type	Soil carbon (t/ha)	Reference
8. Sub tropical broad leaved hill	94.37	Mandal et.al, 1990
	111.93	Banerjee et.al, 1986
	119.70	Mandal et.al, 1990
Mean	108.66	
9. Sub tropical pine	73.9	Singh et.al, 1990
	85.0	Sachan et.al, 1981
	88.14	-
	114.66	Nair & Chamuah, 1988
Mean	90.425	
10. Subtropical dry evergreen	33.0	Since no studies were available, it was assumed that soil carbon content would be be similar to a value equivalent to 75% Tropical thorn forest.
11. Montane wet temperate	170.0	Singh, 1990
	206.7	Banerjee, 1986
Mean	188.35	
12. Himalayan moist temperate	132.6	Banerjee & Badola, 1980
	132.6	Sachan et.al, 1981
	144.3	Rawat & Kumar, 1989
	152.1	Dhar & Jha, 1983
Mean	140.4	
13. Himalayan dry temperate	71.4	Singh & Gupta, 1990
	78.0	Negi & Ghosh, 1980
Mean	74.7	
14-16. Sub alpine and alpine	255.0	Das et al, 1988
	259.7	Datta et al, 1989
	259.7	Gangopadhyaya,1990
Mean	258.13	

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