Sustainable forestry in India for carbon mitigation

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Combustion of fossil fuels is one of the main contributors of increase in CO_2 concentration in the earth's atmosphere. The current carbon emission from fossil fuel burning and cement manufacturing in India is estimated at about 0.272 Giga tonnes (Gt). This increase in CO_2 concentration can be sequestered through massive afforestation programmes. The current rate of afforestration in India is about 2 million hectare (mha) per annum which is sufficient to sustain the growing needs of increasing population, but has only marginal CO_2 sequestration potential. According to recent land-use/land cover statistics of India generated by remote-sensing techniques, the areas under non-forest degraded lands and forest degraded lands are currently 93.68 mha and 35.89 mha, respectively, totalling to 129.57 mha. If a conservative managed forest productivity of 5.5 tonnes per hectare per year could be attained on only 40 mha of the available surplus degraded land in India through managed forestry programmes such as short rotation forestry plantation, it is possible to obtain carbon mitigation of about 3.32 Gt in the next 50 years, with an annual reduction of about 0.072 Gt of carbon.

ANTHROPOGENIC pressures resulting from increasing demand of bio-resources have led to a higher rate of deforestation all over the world in recent decades. According to the United Nations Food and Agricultural Organization (FAO), the world has lost approximately 40% of the original forest area of 6000 million hectares (mha) over a period of 150 years[1]. Most of this deforestation has occurred in the later half of the 20th century. About 70% of wood products from deforestation have been used for generating energy. Coal, oil, natural gas or bio-fuels provide energy for most of our everyday activities. The burning of these fuels is responsible for about 80% of the current global CO_2 emission. The increase in energy demand from industrial activities, the generation of electricity, transportation and an increasingly energy-intensive standard of living are likely to continue with increase in population.

According to recent estimates reported in a scientific assessment of the Intergovernmental Panel on Climate Change[2], anthropogenic emissions of CO_2 and other greenhouse gases (GHGs) have begun to affect the world's climate. CO_2 is the largest single greenhouse gas currently trapping about half of the total heat contributing to global warming. In order to find a solution to arrest the global warming, the industrialized countries (ICs) agreed to commit themselves to a legally binding schedule for reduction in the emissions of greenhouse gases in the atmosphere at the Conference Of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) held at Kyoto in 1997. However, at the Buenos Aires Conference in 1998, they (ICs) argued that India and China, which have the highest current growth rate for CO_2 emission among the DC countries (the future emissions of GHGs by these countries could neutralize any tangible reductions by ICs), should also take steps for simultaneous curbs on CO_2 emission.

Carbon emissions are strongly, though not entirely, related to economic growth and standard of living, and given the fact that developing countries whose participation is being sought are amongst the poorest countries in the world who need the 'maximum economic space' and 'environmental space' to grow, sharing the economic space and environmental space for combating climate change becomes a critical issue. At the current stage of development, India cannot afford to reduce its energy consumption. A potential option for mitigating the accumulation of CO_2 in the atmosphere is the enhanced cycling of carbon by the terrestrial biosphere through massive reforestation or sustainable afforestation programmes. This paper examines the possibility of reducing the threat of global warming by supplementing plantation forest management in India in order to offset the carbon emissions.

Role of forests in carbon mitigation

The world's forests contain about 830 Peta grams (Pg) carbon in their vegetation and soil, with about 1.5 times as

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much in the soil as in the vegetation[2]. A large amount of CO_2 is released due to leaf litter decomposition in forests every year, but that does not necessarily contribute to increasing CO_2 as it is again taken away by the growing vegetation. The net release of CO_2 to the atmosphere from deforestation is estimated to be between 1 and 2 billion metric tonnes (bmt) in 1980 and between 1.5 and 3 bmt in 1990 (ref. 3). The total release from global deforestation between 1850 and 1985 is calculated to have been about 120 bmt (refs 3 and 4; Figure 1).

Forests play an essential role in storing and recycling the earth's carbon. The cycling of carbon by the terrestrial biosphere is controlled by photosynthesis, respiration and decomposition. The managed forests have the potential to conserve and sequester carbon and thus mitigate emissions of CO_2 by an amount equivalent to 11–15% of the fossil fuel emission. According to preliminary estimates by IPCC[2], about 60 to 90 Giga tonnes (Gt) of carbon emission could be reduced or sequestered by slowing deforestation, establishing plantations, agroforestry and forest regeneration between the period 1995 and 2050.

Present status of Indian forests and their future potential

The recorded forest area in India is currently about 76.52 mha (ref. 5). The actual forest cover is, however, only 63.34 mha. This has been classified into reserved, protected and unclassed forests each of which covers fractional areas of about 54.44%, 29.18%, and 16.38%, respectively. Almost 58% of the Indian forest is dense (with crown density more than 40%), 41% is open (crown density is less than 40%) and the rest is covered by mangrove forests (about 0.78%). The growing stock of the country has been estimated[6] to be about 4740 million cubic meters (mm^3) with an average volume of 74.42 m^3/ha. The total annual increment of growing stock is estimated at 87.62% mm^3. The contribution of forestry and logging to the national gross domestic product (GDP) was reported[7] to be Rs 293,000 million in the year 1996–1997. Almost 50% of forest area is reserved with a view to preserving the diversity of Indian flora and fauna, which is considered to be unique in the world.

In India, plantations are being established both in the forest area and in the village farmlands to fulfil the growing demands for fuel wood by the local people. In 1978–1979, as many rural households were collecting fuel wood from the forests as those from farmlands in their own villages. In a span of 15 years, the proportion of households collecting fuel wood from forests has decreased from 35% to only 17% during 1992–1993 (ref. 8). The share of fuel wood consumption for total energy generation has also declined[8] in India from 30% in 1980 to 20% in 1994. It has been projected that short rotation plantations will be able to fulfil the demands of industrial wood and fuel wood requirements in the coming years[8]. Energy consumption pattern has been changing in recent years and is shifting towards other conventional energy sources, i.e. fossil fuels.

Energy resources and carbon emissions

Carbon emission is mainly governed by the economic status and energy consumption pattern of any country. The carbon emissions from fossil fuel combustion, cement manufacturing and gas flaring in India have almost doubled from 1985 to 1995 and recent trends indicate[9] a further increase in these emissions. The carbon emissions in India (significantly lower than those reported for USA or China) are estimated[9] at approximately 272 mt for the year 1996 (Figure 2). India's recoverable fossil fuel reserves include 186 Gt of coal, 5060 mt of lignite, 728 mt of crude oil and 686 billion cubic meters (bm^3) of natural gas[10]. These reserves have a CO_2 emission potential of about 350 Gt and, under a 'business-as-usual' scenario, most of it would be released to the atmosphere by the end of 21st century. India also has to import petroleum products to fulfil its energy demands. As an alternative

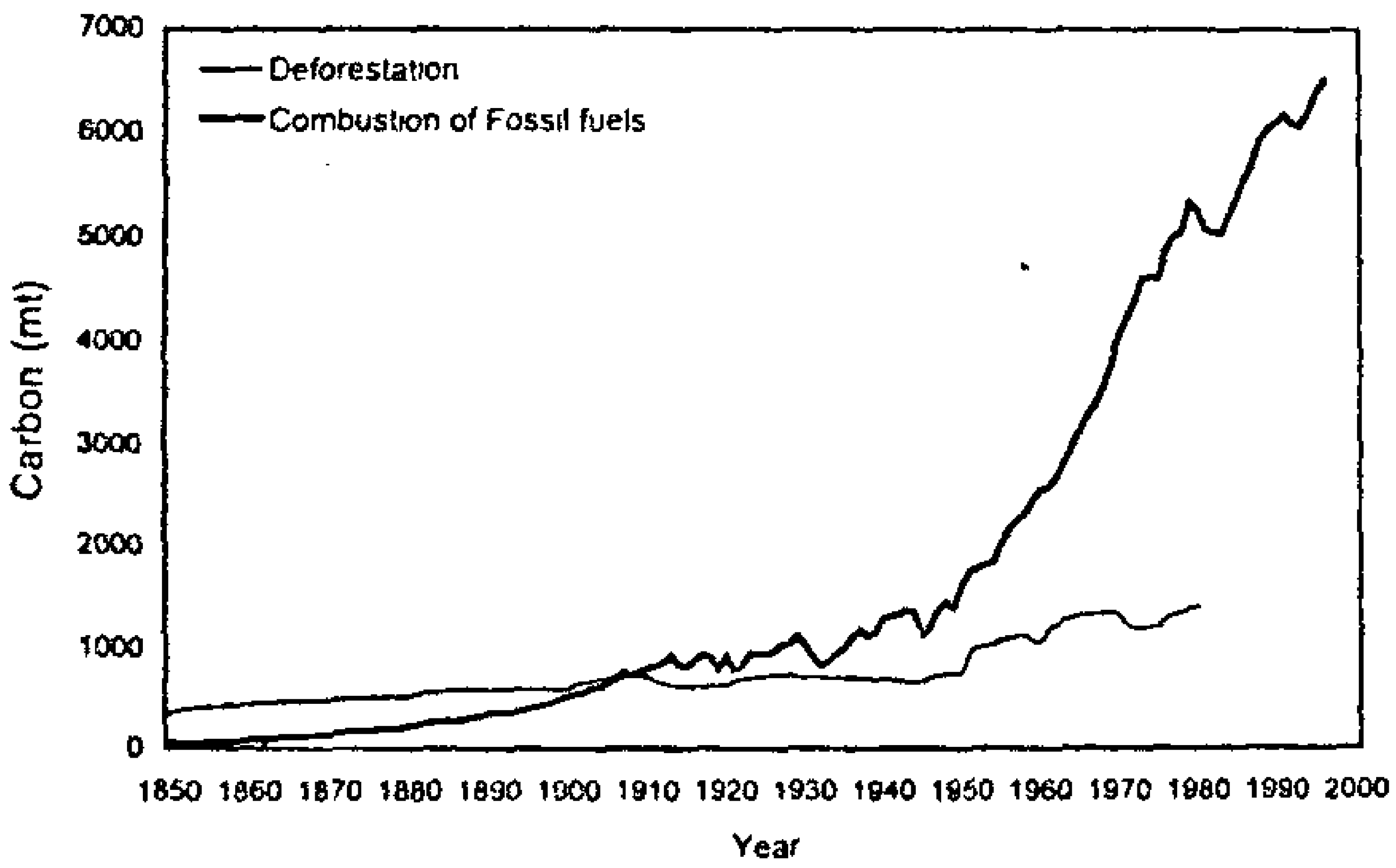

Figure 1. Global emissions of carbon from fossil fuels and deforestation.

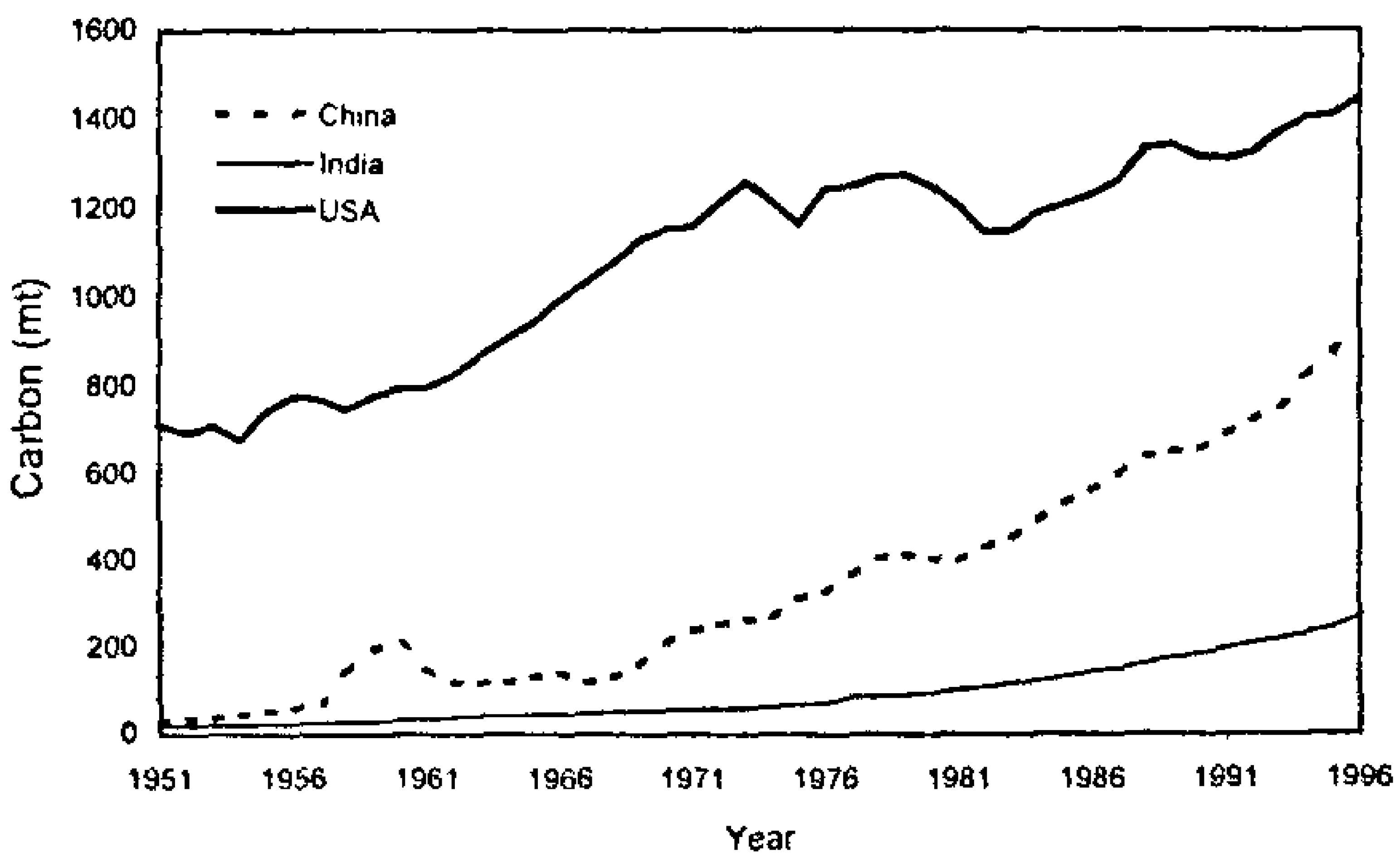

Figure 2. Total carbon emissions for China, India and USA (1951–1996).

energy future, a shift towards renewable energy resources with increased efficiency in India should provide a viable option towards mitigating the CO_2 emission.

Renewable energy options and their carbon reduction potential

Renewable energy technologies draw energy from the sun, wind, water and plant and have the advantage of restricting the emission of air pollutants. Their development and use would not only decrease CO_2 emission but also lessen our dependence on oil imports, improve air quality and create rural employment. These energy options can be decentralized and adopted to specific local needs. Eventually the supply of a substantial portion of the country's need of energy resources could be met from renewables thus minimizing carbon emissions. Some of the potential renewable energy options and their potential and achievements are given in Table 1. These options, if fully exploited, can avoid CO_2 emission by a significant amount. Establishment of biogas plants and improved cooking stoves in rural areas are among the few priorities of the Indian government. If only biogas plants and improved cooking stoves are exploited to their full potential, this would avoid the combined carbon emission of 43 mt per year.

Among the renewable energy options, biomass has the maximum potential. This is a priority option to meet the growing demands of power for both the rural and the urban population in India. Biomass power can be generated from gasification of either the agricultural residues or through energy plantations. The amount of main agricultural crop residues has increased[11] from 88.6 mt in 1950–1951 to 341.9 mt in 1996–1997, which is more than the total amount of fuel wood consumed in India during the year 1996–1997. The current predominant use of agricultural crop residues in India is for cattle feed. In some cases, crop residues are left in fields as they help in restoring soil productivity and in retention of rainwater. For better crop management, crop residues must be fed to livestock, which in turn provide dung to be used as manure. Hence, agricultural residues are not the best potential source of bio-energy for commercial purposes. On the other hand, energy plantations can be grown and harvested for decentralized power generation in India.

Table 1. Renewable energy potential and achievements[7]

Source	Approximate potential	Status (as on 31 March 1998)
Biogas plants	12 million	2.71 million
Improved wood stoves	120 million	28.49 million
Biomass power and gasifiers	17,000 MW	29.50 MW
Biogas-based cogeneration	3500 MW	84 MW
Solar photovoltaic	20 MW/km^2	32 MW
Solar water heating systems	35 MW/km^2 (30 mm^2 collector area)	0.38 mm^2 collector area (13.3 MW)
Wind power	20,000 MW	970 MW
Small hydro power (up to 16 megawatt (MW))	10,000 MW	155.38 MW

CO_2 mitigation options through activities in forestry sector

Activities in the forestry sector provide a large range of options to reduce the increasing CO_2 concentrations in the atmosphere. Options like afforestation and regeneration of degraded forests and plantations for timber are being practised in India since the 1950s. Plantation for power generation is, however, a relatively new potential option and should be quite efficient in sequestering the carbon from the atmosphere, if used to replace the energy obtained from fossil fuels. There continues to be a large potential for expanding energy plantations in India. Some of the basic requirements for the sustainable energy plantations include land, technology and plant species with high biomass yields. The land available in India for reforestation or development of forest plantations is rather limited, thus relative merits of various mitigation strategies must be considered. Sustainable production of wood requires a permanent land area on which biomass can be grown and harvested in rotation. The land categories that can be conveniently exploited for plantation are the degraded forests, marginal croplands, wastelands and the area under shifting cultivation. According to an estimate[12], the available wasteland from non-forest degraded and forest degraded land is 93.68 mha and 35.89 mha, respectively, totalling about 129.57 mha. Almost 50% of this land is, however, highly degraded and not suitable for afforestation. Moreover, due to high cost of raising plantations and maintaining them, we will consider only 40 mha of the land area for energy plantations and examine the mitigation potential of carbon storage in this study.

The selected land for plantations may not be available in a single stretch, and the selection of plant species would entirely depend on the agro-climatic conditions of the region. The Ministry of Non-conventional Energy Sources has set up biomass research centres in eleven agro-climatic regions in India[12]. In these centres, productivity of selected plant species is analysed under different ecological conditions. The mean productivity at different age groups of plantations of high-yielding species seems to increase up to a certain age and then decreases (Table 2). These findings offer a viable choice in selection of species and rotation time for plantation projects.

Biomass can be converted into a combustible gas called producer gas through the gasification process. For this, two main technologies used in India are steam turbine cycle technology and gas turbine cycle technology. Reddy *et al.*[11] have conducted a detailed financial analysis of decentralized power generation, conventional centralized power generation and conservation options for India. Installed cost of power for other bio-energy options, namely biogas and producer gas is estimated to be almost 10% lower than the dominant coal and large hydro-electric options. Besides electricity, biomass from energy plantations can also provide energy forms such as fuels, heat, liquid fuel, etc. Biomass-based power generation in India has already proven to be economically viable and is being practised in some remote villages.

In this study, 40 mha of land is considered for plantation in 20 years at the rate of 2 mha/yr. After 20 years, these plantation plots can be harvested and grown in rotation at the rate of 2 mha/yr. Productivity of these plots governs the amount of biomass available for energy production. With a marginal above ground productivity of 5 tonnes per hectare per year (t/ha/yr), we can get 200 mt of biomass each year after 20 years from the start of the project. This wood can be used to replace 124 mt of coal, if used for electricity generation in place of coal (about

Table 2. Biomass productivity of selected plant species obtained in different ecological regions in India[12]

Region	Species	Age (years)	Yield (tonnes/ hectare/ year)
Himalayan region	*Prunus cerasoides*	7.0	18.0
	Albizzia stipulata	5.0	14.0
	Alnus nepalensis	6.0	20.0
	Leucaena leucocephala	6.0	36.8
Central India	*Samanea saman*	5.0	26.7
	Cassia siamea	3.0	20.7
	Erythrina indica	3.0	26.7
	Prosopis juliflora	8.0	12.1
South-east India	*Cassia siamea*	3.5	16.9
	Leucaena leucocephala	3.5	11.3
	Casuarina equisetifolia	3.5	06.3
	Acacia auriculiformis	3.5	10.8
South-west India	*Terminalia arjuna*	6.0	07.0
	Acacia nilotica	8.0	07.4
	Acacia auriculiformis	8.0	06.8
	Prosopis juliflora	8.5	22.0

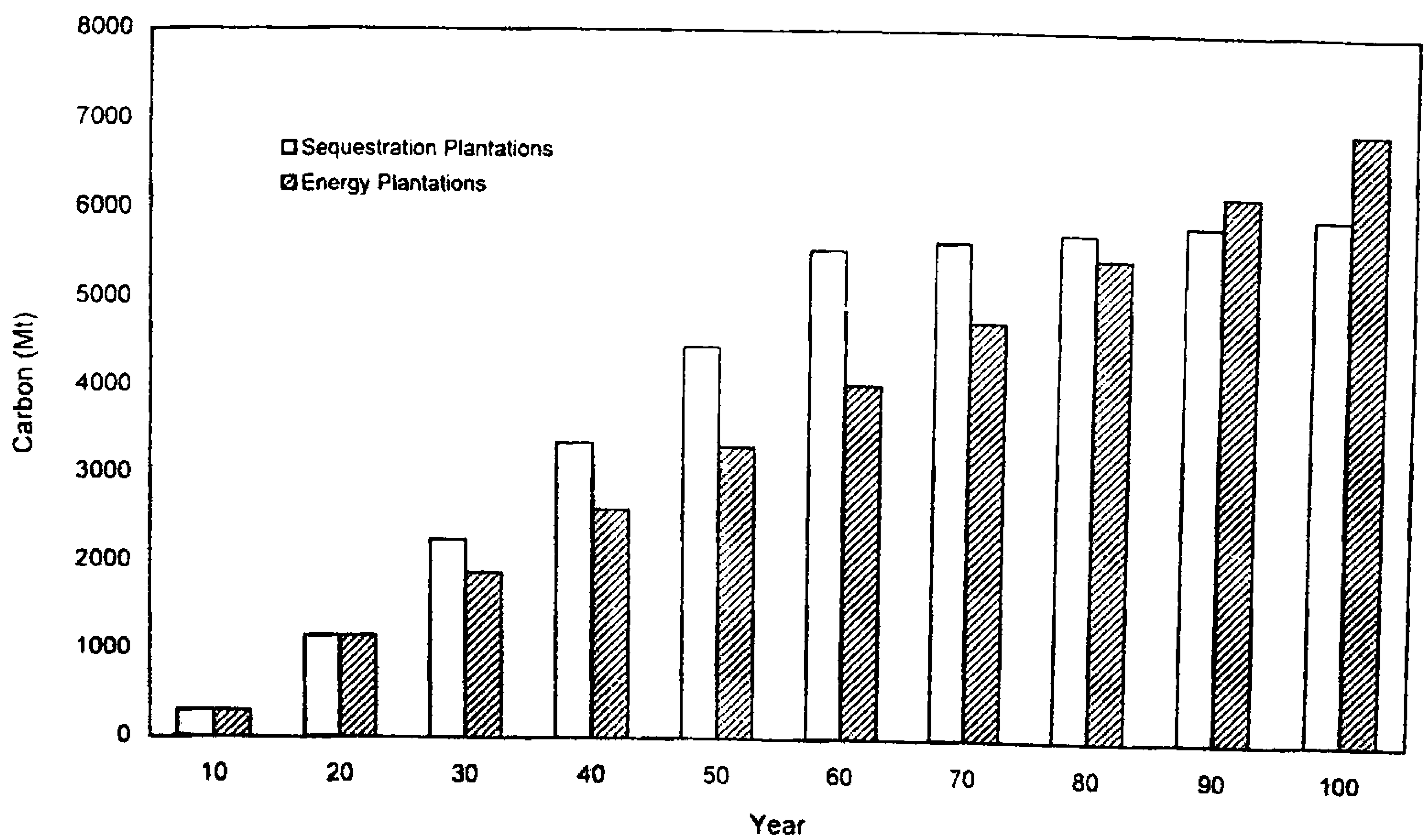

Figure 3. Carbon sequestered/substituted through plantations.

0.62 tonnes of coal generates as much power as is generated by 1 tonne of wood[14]).

We consider the coal replacement option as it has the highest displacement factor. Biomass fuel energy can avoid emission of 0.62 units of fossil fuel carbon for each unit of biomass burnt. If the biomass fuel is used to replace oil or natural gas, the displacement factor drops down and the avoided carbon emission is reduced. The avoided carbon emission for coal replacement energy plantation in this case is 0.062 Gt annually after 20 years from the start of the project. In addition to this, about 0.010 Gt of carbon would be stored in the soil annually[15], increasing the annual carbon reduction up to 0.072 Gt.

If used only for carbon conservation and sequestration, the amount of carbon stored by plantations in this land area would be the same during the first 20 years but they would absorb more carbon thereafter (this land would sequester approximately 0.11 Gt annually) than the energy plantations but only up to about 60 years of plant age (Figure 3). The amount of carbon stored would slow down with the maturation of these plantations. Therefore, for long-term carbon mitigation, energy plantations are the best suited options as they provide for energy along with reducing carbon emissions from fossil fuels.

Conclusions

Our estimates suggest that if we can use 40 mha of degraded land for short rotation forestry plantations with a marginal productivity of 5.5 mha per year, it could sequester at least 1.46 Gt of carbon in the soil, litter and biomass and could avoid 1.86 Gt of carbon emission by substituting coal with bio-energy (a total of about 3.32 Gt of carbon) in the next 50 years. This emission reduction could be continued for hundreds of years with an annual carbon reduction of 0.072 Gt. For a constant long-term carbon emission reduction, short rotation forestry for bio-energy is the best option.

The leftover treetops, twigs and branches of the energy plantations not used in gasifiers should fulfill the needs of fuel wood in rural areas. Small shrubs and grass can be grown between energy plantations and can be used for cattle feeds. This will help in reducing the pressure on natural forests and conserving biodiversity of flora and fauna. With a shift in the government policy towards sustainable bio-energy plantations as part of the afforestation programme, the rural mass in India could also be provided with employment opportunities which would improve their social and economic conditions.

The biomass energy plantation programme is further expected to have a significant positive effect on rainfall pattern, retention and recharging of underground water resources, arresting soil erosion and nitrogen run-off and raising habitat diversity in addition to being effective towards CO_2 emission abatement strategies. This study does not include the effects of increasing CO_2 levels in the atmosphere on forest productivity. Future increases in CO_2 concentration may further enhance the carbon sequestration potential of the forests.

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