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Carbon Sequestration and Economic Potential of the Selected Medicinal Tree Species: Evidence From Sikkim, India

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Medicinal plants are widely used in India for various livelihood and health benefits. However, there is a lack of awareness and research on their carbon sequestration and economical potential, which constrains their use in various ongoing carbon forestry schemes precluding farmers from potential carbon revenue opportunities. The present study seeks to fill this knowledge gap by assessing the carbon sequestration and economic potential of three extensively used medicinal tree species of Emblica officinalis *(Amla),* Terminalia belerica *(Bahera), and* Terminalia chebula *(Harar) in the state of Sikkim with the help of the project-based comprehensive mitigation assessment process (PROCOMAP) model. The findings of this research suggest that the selected species of Amla, Bahera, and Harar have significant carbon sequestration rates of 1, 2.64, and 1.42 tC ha^{-1} yr^{-1}, which could generate Indian National Rupees (INR) 844, 1,198, and 2,228 ha^{-1} yr^{-1}, respectively from carbon revenues in a \$5/tCO_2 scenario through various ongoing carbon forestry schemes.*

KEYWORDS medicinal trees, carbon forestry, carbon sequestration, Sikkim, India

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INTRODUCTION

Medicinal plants provide a range of social, cultural, and economic benefits to a large part of the Indian population (Ved & Goraya, 2007; Vaidya & Devasagayam, 2007). It is estimated that around 70% of the population in the country meets its health care needs from herbal medicines (Vaidya & Devasagayam, 2007; Sheng-Ji, 2001; Hamilton, 2004). Medicinal plants also contribute to the country's internal and external trade. The estimated annual trade of the herbal industry in the country is between Indian National Rupees (INR) 80 to 90 billion out of which INR 10 billion worth of products are exported (National Medicinal Plants Board [NMPB], n.d.). The global trade of medicinal plants is expected to rise to US$7 trillion by 2050, which offers good opportunities for the country (Vaidya & Devasagayam, 2007; NMPB, n.d.).

But along with these opportunities, there are many constraints, especially with the supply of the medicinal plants. It has been estimated that 80 to 90% of the medicinal plant products are derived from wild in the country (Planning Commission, 2000). Seventy percent (70%) of these collections involve unsustainable harvesting practices hence endangering their diversity and existence, which have livelihood and economic implications as well (Hamilton, 2004). Only 20% of the medicinal plant species are cultivated in India due to issues related to awareness, knowledge, quality, and economic returns (Planning Commission, 2000; Uniyal, Uniyal, & Jain, 2000; Schippmann, Leaman, & Cunningham, 2002). The Government of India is trying to promote cultivation, use, and trade of medicinal plants among the farmers through various scientific and management interventions to mitigate these issues (NMPB, n.d.).

The economic return is one of the main criteria that affects farmers' decision to cultivate a particular medicinal plant (Planning Commission, 2000). In addition to the regular benefits, the new economic opportunities such as carbon benefits could affect farmers' decisions about the cultivation of medicinal tree species (Planning Commission, 2000). It could potentially provide the twin benefits of livelihood improvement and climate mitigation under various carbon forestry options. There are various mechanisms at the national and international levels that are being operationalized for facilitating forestry mitigation options. These schemes include afforestation/reforestation clean development mechanism (A/R CDM) and reducing emissions from deforestation and degradation in developing countries (REDD+). A/R CDM is already operational while REDD+ is being negotiated under the new climate regime. Besides, these regulated mechanisms which constitute part of the climate deal; there are many similar opportunities in the voluntary sector. India has in fact initiated a program known as National Mission for a Green India (Green India Mission or GIM henceforth) for climate mitigation through the forestry sector on the lines of REDD+ (Ministry of Environment and Forests

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[MoEF], 2010). Hence, there are opportunities for the farmers to cultivate and benefit from carbon revenues in the country.

But a review of the existing carbon forestry projects of the country suggests that medicinal tree species have largely been neglected (Aggarwal, 2012). The medicinal tree species like *Emblica officinalis* (Amla), *Terminalia chebula* (Harar), *Terminalia bellerica* (Bahera), *Azadiracta indica* (Neem), and *Terminal arjuna* (Arjun)—which are commonly used for vitality and various ailments such as allergy, digestive disorder, and heart disease—have largely been out of focus (The Energy and Resources Institute [TERI], 2010). It could be attributed to lack of awareness and knowledge among the stakeholders and dearth of research on carbon assessment studies of medicinal tree species and their potential role in climate change mitigation (TERI, 2010).

This knowledge gap led the National Medicinal Plants Board (NMPB), an agency of the Government of India, and TERI, an autonomous research institute, to initiate national project titled "feasibility study on carbon sequestration benefits from growing tree species of medicinal value in India" during the year 2009–2010 (TERI, 2010). The major objective of the project was to assess carbon sequestration potential and study the scope of carbon benefits for selected medicinal tree species across various states of the country (TERI, 2010). The article focuses on the assessment of the three important species of *Emblica officinalis* (Amla), *Terminalia chebula* (Harar), and *Terminalia bellerica* (Bahera) studied in the state of Sikkim.

The article has been divided into four sections. After the introduction in this section, the second section deals with the methodological aspects of the study. It elaborates on the study sites and the process of data collection and analysis. It also gives the brief geographical and socioeconomic context of the state. The third section discusses the results of the study. It also presents the constraints and opportunities of realizing carbon benefits in the present context. The fourth section presents a brief summary of the results and concludes the article.

METHODOLOGY

Study Area Context

Sikkim is situated in the eastern Himalayan region of India and shares international borders with the countries of Nepal, Bhutan, and China. The altitude of the state varies from 300 to 8,586 m, which explains diversity in its climate, plant, and animal life (Forest Survey of India [FSI], 2008). The state could be divided into the tropical, temperate, and alpine zones based on its climate (Department of Forests, Environment and Wildlife Management [DoFEWL], 2007). The state experiences a high average annual rainfall of 500 cm due to its proximity to the Bay of Bengal, which is one of the highest in the Eastern Himalayas (DoFEWL, 2007).

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The state is divided into four administrative districts of North, South, West, and East. The large part of the North district remains covered with snow throughout the year. About 64% of the population is dependent on agriculture for their livelihoods in the state (Government of Sikkim [GoS], 2011). But most of the farming is subsistence based, as the average landholding is only 0.24 ha (GoS, 2011). Tourism is another important economic mainstay in the state (GoS, 2011).

Eighty-two percent (82%) of the total geographical area of the state has been classified as forest, but only 46.35% of it is under forest and tree cover (DoFEWL, 2007). The state forest area is managed into forest divisions that coincide with East, West, North, and South districts.

The state has a rich depository of 424 species of medicinal plants but many of them have declined sharply in the wild (DoFEWL, 2010). The State Medicinal Plant Board (SMPB), which was established in 2002–2003, is focusing on promoting the sustainable cultivation of these tree species for a decade. The traditional medicines constitute an important part of the health system in the state. An herbal medicine fund known as *Jari Buti Kosh* has been started to rejuvenate traditional knowledge of medicinal plants in the state (DoFEWL, 2010).

Selection of the Field Sites

After discussions with the State Forest Department (FD), NMPB, and SMPB staff, it was realized that plantations of the selected species of Amla, Harar, and Bahera were available only at lower altitudes ranging from 300 to 500 m with tropical and subtropical climate in the forest areas in the East, West, and South districts of the state. Due to the high altitude, temperate climate, and low rainfall, the North district is not suitable for growing these medicinal tree species. These plantations were scattered in the forestland with approximately 30 to 40% density. Very few farmers had planted these trees on the private lands because of low awareness and market linkages. Hence, it was decided to study these species in the forest areas for their carbon sequestration and economic potential. The details of the plantations—such as area, year of plantation, and number of saplings—were taken from the FD. An effort was made to select plantations from different age classes and geographical locations in order to assess their carbon sequestration potential and cost benefits in different conditions.

Data Collection

The present study includes four out of the five carbon pools defined by Penman et al. (2003), which include aboveground biomass, belowground biomass, woody litter, and organic soil carbon. Dead organic matter, which is the fifth eligible carbon pool, has not been included in this study because

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of the low volume and complexities involved in collection and estimation. So, data were collected to assess carbon in the above-mentioned four pools.

First of all, secondary data on the selected species were collected from the Sikkim Forest Department (SFD) and National Medicinal Plant Board (NMPB), New Delhi. These data were used to understand the distribution pattern and plantation models of the species in different agro-climatic zones. This was further followed by preparation of two structured data formats: the first to assess biomass through data on height, girth, canopy cover, age, and slopes; and the second to estimate the costs and benefits of different species. In the cost and benefit format, costs included plantation, maintenance, and fencing costs; while the benefits included benefits from fruits, seeds, leaves, timber, and fuelwood.

The field survey was conducted in the month of November 2009. During the field data collection, a minimum of three quadrats of the size 25 m × 20 m for the selected species covering different age classes were laid. The researchers use various quadrat sizes for herbs, shrubs, and tree populations depending upon the objectives of study, sample size, and topography of the terrain (see Krebs, 1999). In this case, the size of 25 m × 20 m was chosen because of its medium dimensions and ease of analysis of the data as 20 plots of this size make a 1-ha area. The crown cover of five representative trees for different species was recorded at every location to study the crown density of the species.

The measurements were recorded for all trees of the above-mentioned species within the sample plots. The diameter at breast height (dbh) of the tree at 1.37 m was measured with a tape and the height of each tree was measured with the help of a Ravi multimeter instrument (Ravi Viganik Kendra, Dehra Dun). The established procedures for these kinds of measurements were followed. The trees on the slope were measured from the uphill side. The case where trees were forked much below the dbh, were taken as two separate trees. Before taking the height of the tree, the slope correction was taken into account (Ravindranath & Premnath, 1997).

The field data were used to estimate the mean annual increment (MAI) for all the plantation interventions (Table 1). The volume of each species was calculated through site specific volume equations and biomass was calculated by multiplying the volume with species specific wood density. The following volume equations were taken from the published work of the Forest Survey of India (FSI, 1996):

$$V\,(\text{Amla}) = 0.137 - 2.490\,D + 15.595\,D^2 - 11.06205\,D^3,$$

$$V\,(\text{Bahera}) = 0.264 - 3.0524\,D + 12.357\,D^2,$$

$$V\,(\text{Harar}) = -0.05004 - 0.344\,D + 6.3571\,D^2,$$

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TABLE 1 Brief Silvicultural Details of Selected Plantations

S. no.	Plantation	Av. crown spread of mature tree (m)	Number (trees/ha)	Rotation (yr)
1	Amla	8 × 8	94	30
2	Harar	10 × 12	50	50
3	Bahera	17 × 14	25	50

Source: Field survey.

where D is diameter at breast height (dbh).

The wood density was taken at the default value of 0.67 from the Intergovernmental Panel on Climate Change (IPCC) good practice guidelines (Penman et al., 2003). The aboveground and belowground biomass of selected species was calculated as per the IPCC guidelines (Penman et al., 2003). The woody litter was estimated by laying out 1 m × 1 m quadrats, collecting the freshly fallen woody litter, and extrapolating the values in terms of t ha^{-1}.

As the organic carbon changes in the soil take place up to 45 cm, three soil samples at three different depths—viz. 0–15, 0–30, and 0–45 cm—were collected and mixed from each plantation as well as control sites (Ravindranath & Ostwald, 2007; Environmental Protection Agency [EPA], 2010). These soil samples were carefully labeled and transferred to a soil testing laboratory in Delhi, which analyzed organic carbon in the soils. The data on the costs and benefits were collected from the SFD in consultation with the local people and took into account the present prevailing market rates.

Carbon Mitigation and Economic Potential

The carbon mitigation potential and cost benefit analysis of the selected plantation interventions were calculated using the Excel™ sheet-based model, known as project comprehensive mitigation assessment process (PROCOMAP), developed by Sathaye, Makundi, and Andrasko (1995) and Makundi and Sathaye (2001). This model is designed specifically to undertake a comprehensive assessment of the role of the plantations in climate change mitigation.

Many studies assessing mitigation potential of carbon forestry in India have used different versions of PROCOMAP. Some studies have looked into the methodological issues, mitigation, and economic potential of carbon forestry at the regional and country levels (Sathaye et al., 2001; Ravindranath et al., 2007b). A few others have assessed the impact of carbon prices on the availability of land for mitigation (Khatun, Valdes, Knorr, & Chaturvedi, 2010; Ravindranath, Murthy, Chaturvedi, Andrasko, & Sathaye, 2007a). A limited number of studies have even assessed carbon sequestration and economic potential of various forestry species under different plantation models at the

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TABLE 2 Species Wise Key Input Data to PROCOMAP

Parameter	Amla	Harar	Bahera
Baseline soil carbon (tC/ha)	53.55	20.7	17.55
MAI for aboveground biomass (t/ha/yr)	3.53	1.97	2.49
Rotation (yr)	30	50	50
Soil carbon uptake (tC/ha/yr)	5.025	1.67	2.89
Woody litter (t/ha/yr)	0.25	1.0	1.2
Main products	Fruits & fuelwood	Fruits & fuelwood	Fruits & fuelwood

Note. PROCOMAP = project comprehensive mitigation assessment process; MAI = mean annual increment.
Source: Field survey and analysis.

local level using this model (Hooda et al., 2007). Hence PROCOMAP is a useful and widely accepted model to study the carbon mitigation potential of forestry species.

The cost effectiveness of the selected plantation interventions was estimated using three different discount rates—i.e., 6, 8, and 10% for Amla; and 8, 10, and 12% for Harar and Bahera plantations. The lower discount rate of 6% has been considered for Amla plantations because of the relatively smaller rotation period of 30 yr. The analysis period selected for the present study was 2009 to 2038 for Amla and 2009 to 2058 for Harar and Bahera (for the rotation periods of 30 and 50 yr, respectively). The output of the model consists of annual incremental carbon sequestration, values on economic indicators, and expected benefits under the selected carbon price scenarios for each plantation intervention. The relevant field data, which was provided as input to the model, is presented in Table 2.

RESULTS AND DISCUSSION

In Sikkim, initial cost of establishment of the plantations for Bahera and Harar is INR 15,187 ha^{-1} whereas it is INR 17,100 ha^{-1} for Amla. The initial cost includes planting, seedling, labor, transportation, fertilizer, silviculture operations, and fencing, etc. These costs have been worked out in discussion with the SFD. The cost of Amla plantations per hectare is higher than Bahera and Harar plantations because of higher cost of saplings and higher number of saplings planted per hectare.

Economic Potential Without Carbon Benefits

The economic viability of these plantations has been calculated by using the PROCOMAP model. The economic indicators such as internal rate of return (IRR) and net present value (NPV) have been calculated for this purpose.

The plantations of all three species are economically viable and will provide good returns on investments (Table 3). Amla, Harar, and Bahera

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TABLE 3 Economic Viability for Selected Species

Species	Discount rates (%)	NPV (INR/ha)	IRR (%)
Amla	6	520,980	42.7
	8	392,001	
	10	297,918	
Bahera	8	267,461	34.1
	10	197,251	
	12	146,288	
Harar	8	257,157	34.7
	10	190,917	
	12	142,544	

Note. NPV = net present value; INR = Indian National Rupees; IRR = internal rate of return.
Source: Field survey and analysis.

plantations have IRR of 42.7, 34.7, and 34.1%, respectively. The relatively high IRR of Amla could be explained by the fact that its rotation period is relatively less (30 yr) than Harar and Bahera (50 yr). Amla has been studied at lower discount rates as compared to other two species due to this reason. NPV ranges from INR 142,544 for Harar at 12% to INR 520,980 for Amla at 6% discount rate. It again reflects that Amla plantations are economically more attractive because of quick returns from fruits and a short rotation period.

Economic Potential With Carbon Benefits

The carbon sequestration potential and average annual incremental carbon stock of selected species for Sikkim is given in Table 4 and Figure 1. Bahera has maximum sequestration potential of 132 tC ha^{-1}, followed by Harar and Amla with sequestration potentials of 71 and 30 tC ha^{-1}, respectively. As the samples were taken from different aged plantations, these figures represent the average sequestration rates over the rotation period of the species. But the difference in sequestration potential of these species, especially with Amla, becomes less stark if we compare their net annual carbon increments. Again, this is due to the shorter rotation period of Amla. The net annual carbon increments of Bahera, Harar, and Amla are 2.64, 1.42, and 1 tC ha^{-1} yr^{-1}, respectively (Table 5).

Likely Carbon Benefits

The likely benefits of selected species in Sikkim were calculated under two carbon price scenarios priced at 5 and \$10 per ton of CO_2. The exchange value of US\$1 was taken at INR 46, prevalent at the time of study. At \$5/tCO_2, benefits range from INR 844 ha^{-1} yr^{-1} for Amla to INR 2,228 ha^{-1} yr^{-1} for Bahera. Similarly, these benefits range between 1,688 and INR 4,456 at a price of \$10/tCO_2 for these two species (Table 4).

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TABLE 4 Initial Cost, Sequestration Potential, and Annual Carbon Benefits for Selected Species

Plantation	Initial cost (INR/ha)	Carbon sequestration potential during 2009–2038 & 2009–2058 (tC)	Annual carbon incremental (tC/ha/yr)	Likely benefit with carbon price \$5/tCO_2 (INR/ha/yr)	Likely benefit with carbon price \$10/tCO_2 (INR/ha/yr)
Amla	17,100	30	1	844	1,688
Bahera	15,187	132	2.64	2, 228	4,456
Harar	15,187	71	1.42	1, 198	2,397

Note. INR = Indian National Rupees.
Source: Field survey and analysis.

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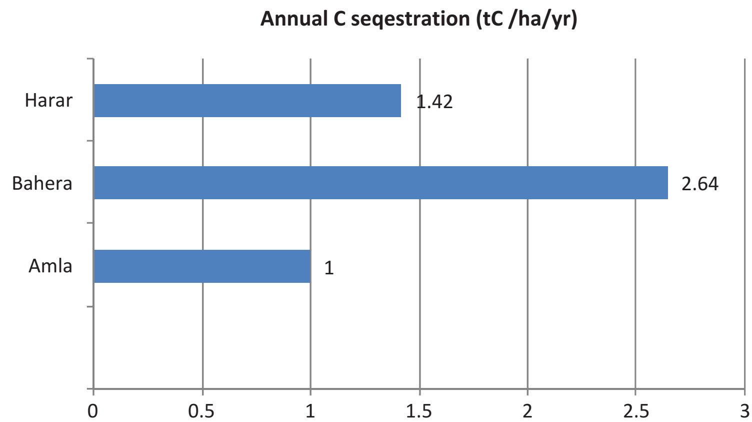

FIGURE 1 Carbon sequestration rates of the selected species (source: Field survey and analysis; color figure available online).

TABLE 5 IRR With and Without Carbon Benefits Under Two Carbon Price Scenarios

Species	Annual incremental CO_2 (tCO_2/ha/yr)	IRR without carbon benefit (%)	IRR with carbon benefits at \$5/tCO_2 (%)	IRR with carbon benefitsat \$10/tCO_2 (%)
Amla	3.67	42.70	45.00	48.60
Bahera	9.68	34.10	40.30	51.00
Harar	5.21	34.70	38.10	42.20

Note. IRR = internal rate of return.
Source: Field survey and analysis.

It is observed that the IRR significantly increases for all the species when the carbon benefits are included. Again, these changes have been calculated for two carbon price scenarios priced at 5 and \$10 per ton of CO_2. There is a significant increase for Bahera as IRR changes from 34.1 to 40.30 and 51% at 5 and \$10/tCO_2 prices, respectively (Table 5). The relative sharp increase in the IRR of Bahera is because of higher carbon sequestration rate than the other two species (Figure 2). It suggests that Bahera plantations are likely to be most profitable with carbon benefits at the \$10/tCO_2 scenario. Amla could be the species of choice in the case of no carbon benefits and with carbon at \$5/tCO_2.

Realizing Carbon Benefits: Constraints and Opportunities

The carbon benefits of the three species could be realized through voluntary or regulated mechanisms. The regulated mechanisms are part of the international climate regime and offer mandatory emission reductions whereas voluntary are self-initiated efforts. At present only one regulated mechanism—i.e., afforestation/reforestation clean development mechanism

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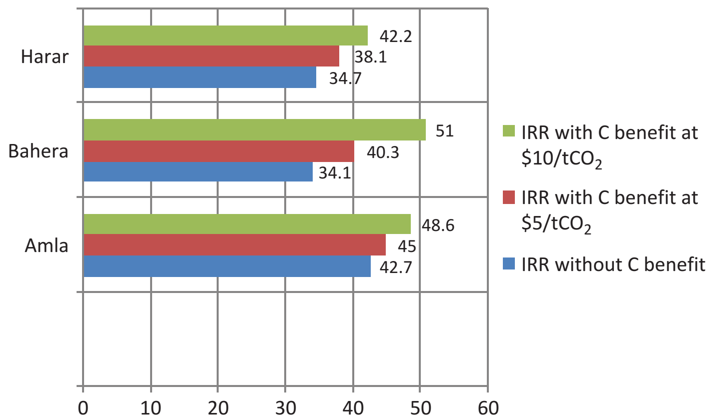

FIGURE 2 Internal rate of return (IRR) with and without carbon benefits under different carbon price scenarios (source: Field survey and analysis; color figure available online).

(A/R CDM)—is operational. But REDD+, which is a more comprehensive and large-scale effort, is one of the most advanced mechanisms in the climate change negotiations (International Institute for Sustainable Development [IISD], 2012).

With the closing down of Chicago Climate Exchange (CCX) in December 2010, the opportunities in the voluntary carbon markets have reduced for forestry projects (Gronewold, 2011). However, these species could be mixed and planted under A/R CDM projects. Though these projects have a complex cycle with high transaction costs, still India has the highest number of registered A/R CDM projects (Michaelowa & Jotzo, 2005; Jindal, Swallow, & Kerr, 2008; Thomas, Dargusch, Harrison, & Herbohn, 2010).

There are other opportunities for exploiting the multiple benefits of medicinal plants. India has launched a National Mission for a Green India (Green India Mission or GIM henceforth), under its National Action Plan for Climate Change (NAPCC) to address issues related to climate change (GOI, n.d.). The GIM aims to treat an additional forest and nonforest area of 10 Mha over a period of next 10 yr (MoEF, 2010). It involves public, private, and community lands. The estimated budget of GIM for a period of 10 yr is INR 460 billion (MoEF, 2010). The planning and implementation of this program has already started. The government is trying to get part of GIM financed from the international community through REDD+ (Sharma, 2010). The GIM and REDD+ mechanisms propose to transfer the carbon benefits to the local communities (MoEF, n.d.). The farmers in Sikkim and other states could avail carbon and other benefits from planting these species on the available lands.

There are opportunities under REDD+ projects in the nongovernment and voluntary sector as well. Community Forestry International, an international NGO, is implementing a REDD+ project in the northeastern state of

Meghalaya (Community Forestry International [CFI], 2011). There are other projects in the pipeline as well. If the civil society or the private sector takes the initiative, such programs could be operationalized in Sikkim as well.

CONCLUSION

All three medicinal tree species of Amla, Bahera, and Harar have significant carbon sequestration potential of 1, 2.64, and 1.42 tC ha^{-1}, respectively. Plantations of these species are economically viable for the farmers with and without carbon benefits. Amla, Bahera, and Harar plantations could fetch 844, 1,198, and INR 2,228 ha^{-1} in a $5 per carbon credit scenario, which is a good additional income for the farmers. These species have internal rates of return of 42.70, 34.10, and 34.70%, respectively, without carbon benefits. However, the rate of return increases significantly with carbon revenues to 45, 40.30, and 38.10% in a $\$5/tCO_2$ scenario; and to 48.60, 51, and 42.20% in a $\$10/tCO_2$ scenario, respectively. Amla is the most profitable species in the zero carbon benefits scenario and with carbon benefits at $\$5/tCO_2$, whereas Bahera becomes the most profitable species in a $\$10/tCO_2$ scenario. Thus, carbon prices could affect the choice of species.

The multiple benefits of medicinal trees could be realized through carbon forestry projects in voluntary or regulated carbon markets. Despite many constraints with A/R CDM, India has the largest number of registered projects. There are other programs such as Green India Mission and REDD+ under which the potential of medicinal tree species could be explored in Sikkim and other states of the country.

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