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Competing Demands on Land: Implications for Carbon Sink Enhancement and Potential of Forest Sector in Karnataka to Contribute to the INDC Forest Goal of India

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Indu K Murthy,[ρ] Vinisha Varghese [α,*] & K V Devi Prasad [ρ]

I. Introduction

The land is a critical resource that provides food for a burgeoning population of about 7 billion, supports livelihoods and is important for sustainable development. Growing demands for food, feed, fuel, fiber, and raw materials create local as well as remote pressures for land-use change (Lambin and Meyfroidt, 2011). The cascade of outcomes resulting from these demands is complicated by urbanization and globalization (Barles 2010; Kissinger and Rees 2010). Climate change is an additional stress that will exacerbate the pressure on land as there is a conflict between goals related to production and those related to conservation and climate change mitigation. In light of this, the Sustainable Development Goals of the United Nations (UNDP, 2015) have recognized the need for integration of human development and the environment as mutually reinforcing development goals.

The main goal of the forestry sector in India is to meet the current and projected biomass demands sustainably and conserve the existing natural forest for biodiversity and watershed protection (Ravindranath et al., 2001). India has a long-term goal of enhancing its forest cover to 33% of the geographic area (MoEF, 1999). It has the Forest Conservation Act, 1980, which regulates the conversion of forest land to non-forest uses, and further, there is a ban on logging in reserve forests (Ravindranath and Hall, 1994). Thus, the only option for meeting India's biomass demands is through afforestation and reforestation, coupled with sustainable plantation forestry management practices. Added to this demand and need is creation of carbon sinks to mitigate climate change, as indicated in the Intended Nationally Determined Contribution (INDC), submitted to the UNFCCC by the Government of India. Karnataka is one of the forested states in India and its potential to contribute to the INDC goals and targets is assessed by estimating the mitigation potential of land-based sectors. This study makes a model-based assessment of mitigation potential.

The state of Karnataka, with a total land area of 1,91,791 sq. km accounts for 5.83% of the total area of India and as per the 2011 Census, the state's population was approximately 61 million with a population density of 319 persons/sq. km. Karnataka is prone to disasters due to cyclones and rainfall and is highly susceptible to floods, droughts, and coastal erosion. Land-use strategies will have implications for food security, self-sufficiency, the economy, and the contribution to climate change will be profound. In this study, an assessment is conducted to elucidate the following:

1. What are the trends in area under different land uses in Karnataka?
2. What land categories, and to what extent is land potentially available for climate change mitigation through forestry?
3. What is the mitigation potential of forest sector in Karnataka and its percentage contribution to INDC?

II. Trends in Land use in Karnataka

Land use in Karnataka, like elsewhere in the country, is driven by human and livestock pressure, availability of irrigation facilities, expanding urbanization, industrial growth, diversion of forest land to other uses, the law of inheritance, and natural calamities such as flood and drought. In the following sections, the current land use pattern and trends in land use in Karnataka are discussed. Trends in area under different land use categories help gain an understanding of the dynamics of land use over the decades, which gives a broad understanding of the direction of change in the future as well.

a) *Trends in the Area under Agriculture Land Categories in Karnataka*

Table 1 presents the area under different agriculture land categories for the period 1960-61 to 2012-13. The percentage area under crops was highest in 1990-91, after which, it shows a declining trend.

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i) Land under cultivation: The gross cropped area recorded in 2012-13 was about 12 Mha (Table 1) as reported by the Agricultural Department and the Directorate of Economics and Statistics (2012-13). The area increased marginally from 10.39 Mha in 1960-61 to 11.75 Mha in 2012-13, only a 1.35% increase over more than 50 years. The net sown area has decreased over the long-term period of 1960-61 to 2012-13 and even during the last decade, by about 3%. Over this period, the area sown more than once has increased by almost 83% while the cropping intensity has increased from 103.31% to 120%, an increase of 16% (Figure 1). Further, it is to be noted that although the population of Karnataka has been increasing steadily, the net sown area has remained almost stable (Figure 1).

An analysis of the area under cereals, pulses and oil seeds shows that the overall area under cereals has reduced by about 26%, and area under pulses and oil seeds have also decreased by 37% and 40%, respectively (Figure 2).

ii) Land not available for cultivation: The trend of land put to non-agricultural use is an important indicator of the extent of urbanization if it does not involve afforestation and reforestation activities. As seen from Figure 3, the land put to non-agricultural use increased significantly during the period 1960-61 to up till the year 2000-01. In the past decade (2002-03 to 2012-13), the increase is only 8%. The land area under the other category - barren and uncultivable has stabilized over the past decade.

iii) Uncultivated land excluding fallow land: The area under permanent pastures saw a sharp decline before early 2000s (Figure 3). The decline in area under permanent pastures could be because of agricultural and industrial expansion and lesser importance given to grazing land when compared to land for food crops (FAO, 2012). The area under permanent pastures and other grazing land in 2013 is 48% lesser than the area reported during 1960-61 (Figure 3). However, in the recent past – over the past decade, this area has stabilized.

iv) Fallow land: The area under current fallow land category although fluctuating, shows an overall increasing trend (Figure 4).

From 0.6 Mha in 1960-61, current fallow land increased to an all-time high of 1.83 Mha in 2002-03 (2.05% increase in area). Post this period, the area under current fallow land showed a decreasing trend till 2010-11. During the 3-year period of 2010-11 and 2012-13, there has been an increase of about 52% in the area under current fallow. The other fallow land category shows a marginal increase of about 4% during the decade of 2003-03 to 2012-13.

It is evident from the trends in the area under agriculture land use category that the land under cultivation i.e., the net sown area has decreased over the decades. Further, the area under cereals, pulses, and oil seeds have all decreased. Over this period, an increase in cropping intensity is recorded, which is in concurrence with an increase in area irrigated in the state. This period also witnessed an increase in the area under the fallow land category, an indication of more and more land being left uncultivated.

- Trends in the area under rainfed agriculture and crop yields in Karnataka: The area under rainfed agriculture in Karnataka is 68%. The presence of rainfed/dryland regions is compounded by frequent climatic aberrations and not so frequent but devastating floods. Failure of technology to meet these challenges has resulted in low average productivity and consequently, low income. Rainfed areas confront harsh environment and economic hardship. The basic problem of rainfed areas is one of a vicious cycle that starts with low water availability, degradation of natural resource base because of poor management, which ultimately results in low productivity leading to over-exploitation of the existing natural resources causing further degradation.

It can be seen from Figure 5 that the area under majority of the cereals such as Jowar, Ragi, Maize, Bajra and, Minor Millets is predominantly rainfed. In the case of pulses, the area is almost completely rainfed, except for a small percentage of area under Bengal Gram. Similarly, oil seeds are also grown principally as a rainfed crop.

Figure 6 presents the yield of rainfed crops – cereals and pulses. In the case of cereals, the yield per hectare is consistently low in the rainfed regions, as compared to irrigated regions. There is no comparison in the case of pulses as they are predominantly rainfed.

A close look at the area under cereals, which are predominantly rainfed shows that not only the area but the yield of cereals such as Ragi, Jowar and, Bajra have declined over the decades (Figure 7). In the case of pulses, the area under Green Gram, Horse Gram and, Black Gram have reduced substantially and, their yields are variable and, in the recent decades, a decline is recorded (Figure 7).

- Comparative analysis of yield of major rainfed crops with states recording highest yield in India: An analysis of the trends in yield of minor millets and some pulses shows that the yield per hectare is very low at 0.5 to 1 t/ha. Further, there has been no significant increase in yields over the last two to three decades, and in the case of Ragi, the yields have even declined. Further, the yields of these rainfed crops are highly variable across the decades. Comparison of the yield of some of the major crops of Karnataka with average yield of states reporting highest yield in India shows that Karnataka has a large gap in yield, particularly rainfed crops such as Jowar, Bajra, Tur and Soybean (Table 2).

While production of food grains across India is steadily increasing, in Karnataka, the production of food grains is not only highly fluctuating but also has declined substantially over the decades (Figure 8). It is evident from the analysis that there are issues concerning food production in Karnataka, as evident from the decreasing area and declining yield of cereals and pulses. There also exists a huge yield gap when compared with the highest yield reported for the different crops, particularly in the case of cereals. There has also been stagnation in crop yields both in the case of rainfed and irrigated crops. All these point to the fact that there is no great demand for land for agriculture purposes and that it is possible to sustain food production even without expanding land under agriculture, as indicated by the increase in cropping intensity over the decades.

b) *Trends in Area under Forests in Karnataka*

Karnataka has 41.97 Mha of forest and tree cover, which is 21.88% of the state's geographical area (FSI, 2015). During the period 1983 to 2015, the area under forest increased from 30.30 Mha in 1983 to 41.97 Mha as reported by the State Forest Department in 2015, which is a 43.09% increase in area under forests. During the 1986-2003 period, reforestation has been significant and more than deforestation, resulting in an overall increase in forest cover. However, industrial plantations do not have high biodiversity as did the natural forests, but they are often planted on degraded lands and therefore represent an improvement in vegetation cover over what has existed for the past few decades (Virk and King, 2006).

The State of Forest Reports published by the Forest Survey of India (1987–2015) categorizes forests based on crown density as (i) Very dense forest – All lands with tree canopy density of 70 percent and above; (ii) Moderately dense forest – All lands with tree canopy density of 40 percent and more but less than 70 percent, and (iii) Open forest – All lands with tree canopy density of 10 percent and more but less than 40 percent. Figure 9 presents the trends in area under forests across the crown density classes. Dense forests saw an increase from 1987 to 2001. The Open Forests initially saw a nearly 50% decline from 1987 till 2001 where it increased again. Post-2001, the area under open forests, has been continuously increasing.

Area under forests in Karnataka has stabilized. But, there is degradation of forests, as indicated by the decrease in area under dense forest cover between 2001 and 2015 and the consequent increase in area under open forest.

c) *Trends in Area under Wastelands in Karnataka*

Wasteland in India is described as ''degraded land which can be brought under vegetative cover with reasonable effort (and cost), and which is currently under-utilized or land which is deteriorating for lack of appropriate water and soil management or because of natural causes''(NRSC, 2011). Wastelands are divided into two categories namely; (i) cultivable wastelands comprising various land categories such as shifting cultivation areas, degraded forestland, degraded pastures and mining wastelands which can be brought under tree cover, and (ii) uncultivable wastelands. The extent of wastelands in Karnataka is 1.44 Mha, accounting for 7.53% of the geographical area (NRSC, 2011).

The area under wastelands in Karnataka has marginally decreased during the period 1986 to 2009. The reduction in area under wastelands could be due to various wasteland reclamation and watershed development projects being implemented in the state. However, there remains 1.44 Mha of wastelands, with many of the wasteland categories potentially available for forestry mitigation options.

d) *Summary of Analysis of Trends in Land Use*

The key findings of this analysis include:

- The area under agriculture is decreasing but cropping intensity is increasing.
- The area as well as yield of rainfed crops has decreased substantially and there exists a large yield gap in cereals and pulses, compared to states reporting highest yields in India.
- Fallow land area is increasing – indicating lesser area being cultivated over the years and failure of agriculture, particularly rainfed agriculture in Karnataka.
- Area under forests has stabilized but there is pressure on forests, as indicated by the increase in area under open forest.
- Area under wastelands show a net marginal reduction in area, and the state is undertaking afforestation on these lands over the decades.

This analysis gives us an indication on the demand for land for multiple purposes and the extent of land that could potentially become available for climate change mitigation purposes, to implement forestry mitigation options on these land categories.

III. Need for Tree and Forest Plantations on Marginal Croplands

It is evident from the discussion in the previous section that significant area under croplands in Karnataka is rainfed with very low productivity. The return on investment and labor on such lands to farmers is meager and therefore, putting such lands under multifunctional tree plantations or agroforestry systems or fruit orchards is an option.

Agroforestry systems are designed and managed for maximizing positive interactions between tree and non-tree components. The fundamental idea behind agroforestry is that trees are an essential part of natural ecosystems, and their presence in agricultural systems will provide a range of benefits. Agroforestry is also increasingly gaining recognition as a tool for mitigating climate change and building resilience in farming communities to cope with climate change impacts.

Cnversion of marginal croplands with low productivity to tree plantations will help rehabilitate nutrient-depleted cropland soils, promote carbon sequestration, and improve livelihoods (Murthy et al., 2016). Tree farming on marginal croplands can increase the productive potential of land, increase the efficiency of irrigation water use, contribute to climate change mitigation, and rural incomes (Djanibekov *et al*., 2012; Khamzina *et al*., 2012; Castro *et al*., 2012). Further, such tree plantations have been reported to serve as adaptation measures during crop failure, particularly in rainfed dryland agriculture areas (Kattumuri *et al*., 2015).

Agroforestry is thus one of the key strategies that will help design multifunctional landscapes that can deliver multiple ecosystem services. Given its potential to contribute positively to climate change mitigation as well as adaptation synergistically, it is gaining importance as a land-based mitigation option and as a reliable coping strategy or adaptation measure, particularly in regions with rainfed agriculture dependent farming communities, because of the potential of agroforestry to generate income during drought or rainfall deficit years.

India is one of the pioneering nations to have formulated an agroforestry policy. India's National Action Plan on Climate Change has also included agroforestry as one of the mitigation and adaptation measures. In this context, considering agroforestry for the greening of marginal croplands in Karnataka has multiple co-benefits in addition to being a climate change mitigation-adaptation measure.

IV. Demand for Land in Karnataka: Implications for Forestry Mitigation

The population in Karnataka during 1901 was about 13 million, and it has grown exponentially to about 61 million during 2011. The net addition in population over the decades has steadily increased during this period. However, from 1981-1991, the decadal growth rates have shown a declining trend, which implies that although the population is steadily growing, the rate of growth is on the decline. The increase in population has implications for food security as well as infrastructure and settlement expansion and development. Similarly, when the forest land category is considered, the issues are forest degradation, encroachment, and conversion of forest for non-forestry purposes. Wasteland reclamation has been underway for decades. Despite such aggressive measure, there is still area under wastelands, requiring reclamation. In the following section, the pressures and demands on agriculture land, forestland, and wasteland are discussed, and finally, their implications for land availability for forestry mitigation are highlighted.

- o *Agriculture land:* Discussions in Section 2 highlighted decreasing area under agriculture in India and the yield gap, particularly concerning cereals and pulses grown in Karnataka. Section 3 highlighted the need for promoting tree crops on the marginal croplands, given the returns for investment and labor to the farmer under the current conditions is meager. Further, increase in area under agriculture, population, and per capita income are not significantly corelated (R^2 = 0.25 and 0.35, respectively). also, there is potential to increase food production in currently cultivated areas to bridge the yield gap that exists. This could help meet the food demands of a growing population, rather than expanding the area under agriculture.
- o *Forestland:* The overall area under forests in Karnataka is increasing, but the transition across tree crown cover classes is a cause of concern as dense forests are dwindling, and the area under open forests are increasing. This requires measures to halt degradation and promote conservation of the existing forests.
- o *Wastelands:* There is a significant area under wastelands, requiring reclamation. There are also potential alternate uses such as land required for infrastructure development, for wind and solar projects, and road development.

Competing demands for the land include land needed for infrastructure development with urbanization and other developmental needs. The total urban population of Karnataka is projected to be 35.14 Mha by 2025, which will constitute about 42.29% of the total population. This would require an additional 2.96% of the total geographical area to support the growing population (GoK, 2009). The land requirement for urban use in Karnataka is estimated to be 0.57 Mha by the year 2025, the estimated additional land requirement to be 0.14 Mha. However, what is of consequence here is the fact that area under urban and infrastructure in Karnataka is only about 7.5% of the geographic area and has not undergone much change over the decades.

The area under settlements is only about 12%, and the growth in this land category has been only about 0.8% per annum during the period 1995 to 2010.

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Thus, the demand for land for urbanization and infrastructure is unlikely to limit land available for forestry mitigation. Infact, urbanization could be accompanied by greening programs such as the establishment of parks, gardens, multi-rows of avenue trees to have >10% tree cover, qualifying them as 'Forest'. Even the Greening India Mission, recognizing the importance of greening urban areas, has a sub-mission for peri-urban areas.

As a progressive state, Karnataka envisionsed job-oriented, inclusive economic growth through sustainable industrialization and accelerated urbanization. These transitions are likely to increase the demand for resources and energy significantly. Promotion of renewable energy to meet the energy demands of the state is given prominence by Karnataka as evident from formulation and rolling out of renewable energy policy at the state level. These again place demands on land. In this section, two such renewable energy sources – solar and wind power, and the demand for land for these are discussed.

Solar power: Karnataka is among the states with the highest consumption of electrical energy with an annual consumption of 36,975 million kWh (2010-11). Per capita, annual consumption is around 604 kWh and despite a total installed plant capacity of 13,490 MW, Karnataka is an electrical energy deficit state. Karnataka currently has a 6 MWp grid interactive system and 29.41 kWp capacity stand alone solar power plants. The state receives an annual average solar insolation of 5.55 kWh/m^2/day (Ramachandra, 2003 & 2011). It is one of the states with good solar potential and favorable government policies towards solar energy utilization. Ganesh and Ramachandra (2012) assess the potential for generating solar energy from wastelands and estimate the wasteland requirement for the generation of 42,233 MU to be 2% of the total area under wastelands, which is 26,061 ha.

Wind power: A study by CSTEP (2014) analyzing the key green growth opportunities for the state outlays increasing the energy efficiency in industry, reducing T & D losses, intensifying public transport, and generating more electricity from wind power as the options. The study analyses the land requirement of the power sector and concludes that wind power could increase land requirement primarily because of 3 GW of additional installed capacity of wind (from 8 GW in BAU to 11 GW). The estimated land requirement for the generation of wind power as a source of renewable energy is 0.04 to 0.19 Mha and 0.05 to 0.25 Mha for windmills of 80 m and 120 m hub, respectively. This is an important strategy in the light of the INDC, wherein increasing the installed capacity of wind energy to achieve a target of 60 GW by 2022 from the current capacity of 23.76 GW is one of the targets.

It is clear from the discussion above, there will be population increase and therefore demand for development. However, trends in the past show that this demand is not likely to place immense pressure on land. Given this understanding, land availability for an emerging demand on land – climate change mitigation is analyzed.

V. Assessment of Forestry Mitigation Potential in Karnataka

The overall methodological approach and framework for the assessment of mitigation potential are presented in Figure 10.

a) *Scale, Land Categories and Area Considered for Assessment of Forestry Mitigation Potential*

The scale of assessment pertains to both spatial and temporal. In this study, the spatial scale of assessment is the state of Karnataka. The temporal scale of assessment is one that coincides with the INDC commitment period of 2016-2030.Three key land categories are considered, to be potentially available for implementing forestry mitigation options; they include forestland, wasteland, and agriculture land sub-categories. Table 3 presents land category-wise area considered for assessment.

i) *Forestland:* The forests in Karnataka are under pressure as indicated by the decrease in area under dense forest cover between 2001 and 2013 and the consequent increase in area under open forest. In all, 3.44 Mha of forestland, spanning 2.018 Mha of moderately dense forest and 1.418 Mha of open forest are considered for this assessment for the purposes of conserving carbon sinks as well as enhancing the carbon sink capacity of forestland category.

ii) *Wasteland:* Wastelands are 'degraded lands which can be brought under vegetative cover with reasonable effort (and cost), and which is currently under-utilized' (NRSC, 2011). The wastelands are categorized into 23 categories, of which only 15 categories are distributed in Karnataka (NRSC, 2011). For this assessment, wasteland categories including, land with dense and open scrub, under-utilized/degraded forest – both scrub dominated and agriculture, mining wastelands, and gullied and ravinous land and riverine and coastal sands are included. This spans a total area of 1.31 Mha.

iii) *Agriculture:* There are several sub-categories of land under agriculture. Among these sub-categories, the assessment considers permanent pasture and grazing land, long fallow lands and marginal croplands, which are currently under low productive agriculture with meager returns on investment and labor, and which could benefit from growing trees or promoting multi-functional forestry. The total area

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considered for forestry mitigation in agriculture land category is 3.20 Mha.

b) *Mitigation Scenarios and Models for Assessment of Forestry Mitigation Potential*

The mitigation scenarios considered for this assessment are "Technical Potential" scenario and "Economic Potential" scenario. Under the "Technical Potential" scenario, all lands potentially available under forestland, wasteland and, some of the agriculture land sub-categories are included for the assessment (Table 3). In all, 7.94 Mha of land encompassing wastelands, forestland, and agriculture land categories, is considered. Of the total 7.94 Mha, 43% is forestland category, 40% is agriculture, and the remaining is wasteland.

In the "Economic Potential" scenario, competing demands for urbanization and infrastructure development such as renewable energy projects of solar and wind are accounted for in the wasteland category.

- In the agriculture land category, the area under both long fallow and permanent pasture land is included, but all area under marginal cropland is excluded, considering the shift from annual crops to tree farming may require awareness building and institutional mechanisms.
- In the forestland category, only 50% of the total land available under the two forest cover classes – moderately dense and open forests are considered, factoring in the limited organizational capacity of forest personnel that may currently exist in the state.
- The total area considered for forestry mitigation under the "Economic Potential" scenario is 3.86 Mha (Table 6), including 0.91 Mha (24% of total area) of wastelands, 1.65 Mha (39% of total area) of forestland and 1.45 Mha (38% of total area) of agriculture land categories.

Model: PROCOMAP model is used in this study. PROCOMAP model scored the highest when a decision criteria framework was applied.

It is clear from Section 4 that there is a demand for land for multiple purposes, particularly agriculture, urban infrastructure, and generation of renewable power such as wind and solar. These competing demands are taken into consideration to obtain area potentially available for mitigation under the "Economic Potential" scenario. The rationale for the same is as follows:

- Demands for infrastructure and power generation place direct demands on the wasteland category. These demands require about 0.44 Mha and these could be met from the wasteland area of 1.3 Mha, leaving a total of about 0.864 Mha for forestry mitigation activities.
- When agriculture is considered, it is to be noted that the area under agriculture has not increased in proportion with population (R^2 = 0.25) nor has it done so with increasing per capita income (R^2 = 0.35) over the decades. Further, there is potential to increase food production in currently cultivated areas to bridge the yield gap that exists, which could help meet the food demands of a growing population. Based on an assumption that an increase in extent of area under agriculture is not a path that Karnataka is likely to follow, long fallow (currently uncultivated for long periods) and degrading pasture lands are considered. Additionally, a percentage of the marginal croplands which are under low-productive agriculture is also considered, without compromising on food production demands of an increasing population. Further, agro forestry as a forestry option will help promote synergistically the twin goals of mitigation and adaptation, in addition to improving soil fertility and improving livelihoods.
- Forestland category, despite conservation and aggressive afforestation by the Karnataka Forest Department, is experiencing degradation. This land category needs to be protected for maintaining, increasing, and improving carbon stocks.

Thus, under the "Technical Potential" scenario, all land available under the three land categories, without considering the competition for land, are potentially available. In the "Economic Potential" scenario, the competing demands on land are considered, and land apportioned for alternate uses before land availability for forestry mitigation activities is assessed. In this scenario, economic incentives are envisaged to promote forestry along with appropriate policies and forestry practices.

VI. Mitigation Potential Estimates for Forestry Mitigation Scenarios and Options

The mitigation potential of forestry options for the three land categories in Karnataka - forestland, wasteland, and agriculture is estimated. The model was run for each of the land categories and sub-categories, and for the identified mitigation option. There were two runs to estimate the mitigation potential under "Technical" and "Economic" Potential scenarios

a) *Mitigation Potential Estimates*

The forestry mitigation potential estimates per hectare, incremental as well as cumulative up till 2050 are presented in this section. In Figure 11, land category-wise carbon mitigation potential under baseline and mitigation scenarios – corresponding to the technical potential and economic potential land area (scenarios) are presented.

As can be seen from Figure 11, the aggregate carbon flow under the mitigation interventions during

2015-2050, for the three land categories considered for mitigation assessment is highest on forestland, followed by agriculture lands and finally wastelands. This is because, on the forest lands, there is substantial baseline carbon stocks which are conserved and (or) enhanced through protection in the case of moderately dense forests or enhanced through natural regeneration on open forests. Wastelands, on the other hand have very poor soil quality and low baseline biomass, therefore leading to slower rates of carbon accumulation over the years.

Table 4 provides the baseline, mitigation, and incremental mitigation potential estimates for the different forestry mitigation options for every 5-year interval spanning 2015 to 2050. The baseline assumed for all land categories and forestry mitigation options is static. It is evident from Table 4 that the highest mitigation potential is realized on forestlands (forest protection and natural regeneration options), followed by agriculture lands (agroforestry) and then finally wastelands (afforestation option).

By 2030, which is the NDC target year, the overall mitigation potential achieved, considering all the options is 2887 Mt CO_2-e, which increases to 3572 Mt CO_2-e by 2050. Maximum mitigation potential of 1452 Mt CO_2-e is realized through forest protection option, followed by agroforestry (646 Mt CO_2-e), natural regeneration (615 Mt CO_2-e) and afforestation (173 Mt CO_2-e) options. Table 5 provides mitigation potential estimates for the different forestry mitigation options under the "Economic Potential" scenario. By 2030, highest mitigation potential of 692 Mt $CO_{2\text{-e}}$ is achieved through forest protection option, followed by agroforestry (321 Mt $CO_{2\text{-e}}$), natural regeneration (308 Mt $CO_{2\text{-e}}$), and afforestation (122 Mt $CO_{2\text{-e}}$) options. By 2030, in the "Economic Potential" scenario, the mitigation potential of all options together is 1341 Mt $CO_{2\text{-e}}$ and this increases to 1650 Mt $CO_{2\text{-e}}$ by 2050.

Between the two scenarios, by 2030, the realized mitigation potential is about 50% lesser in the "Economic Potential" scenario, as compared to the "Technical Potential" scenario, area is about half of what is considered in the "Technical Potential" scenario.

b) *Mitigation potential per hectare of different forestry mitigation options*

The mitigation potential for the period 2015–2030 (on a per hectare basis) is lowest for the afforestation option (at 132 Mt $CO_{2\text{-e}}$/ha) and highest for forest protection option (at 729 Mt $CO_{2\text{-e}}$/ha). The mitigation potential per hectare for the natural regeneration option is 434 Mt $CO_{2\text{-e}}$/ha, and under the agroforestry option, it is 351 Mt $CO_{2\text{-e}}$/ha (Figure 12). Under natural regeneration and forest protection, no harvesting is considered for two reasons – (i) there is a ban on logging, and (ii) the goal is biodiversity conservation. Woody litter, however, is often collected for use as fuelwood by local communities for subsistence needs. The annual mitigation potential on a per hectare basis ranges from 9 Mt $CO_{2\text{-e}}$/ha/year for the afforestation option to 49 Mt $CO_{2\text{-e}}$/ha/year for the forest protection option (Figure 13).

c) *Cumulative forestry mitigation potential of different mitigation options*

The cumulative mitigation potential of options implemented on forestland namely, forest protection on moderately dense forests and natural regeneration on open forests is highest, and in the year 2030, it is cumulatively about 395 Mt CO_2-e. The next highest mitigation potential is of agroforestry on agricultural land, encompassing degrading pasture and grazing as well as long fallow and marginal croplands (253.7 Mt $CO_{2\text{-e}}$). Least mitigation potential is realized on wastelands wherein afforestation through short and long-rotation plantations are the mitigation options (Table 6).The cumulative mitigation potential achieved by 2030 through all the options under the "Technical Potential" scenario is 710.3 Mt CO_2-e. It is 405 Mt CO_2-e under the "Economic Potential" scenario - 57% of the potential realized under the "Technical Potential" scenario.

VII. Role of Karnataka Forest Sector in Meeting the NDC Targets

Karnataka has about 22% of its geographic area under forest. The National Forest Policy target is to have 33% of the geographic area of the country under forest and tree cover. Karnataka needs to bring an additional 11% of its area under forest cover, if the same target is to be achieved in the states. The current area under forests is 3.6 Mha. The average annual afforestation rate in Karnataka is about 47,000 ha. The additional area that will be brought under tree cover considering only the "Economic Potential" scenario is 1.1 Mha. The forest cover may increase from 3.6 Mha to 4.7 Mha, therein increasing the forest cover of Karnataka to 24.5% of the geographic area, against the national goal.

As part of its INDC, India has envisaged a massive afforestation drive to sequester an additional 2.5-3.0GtCO_2 by 2030. Globally, the COP 21 agreement relies heavily on forests to achieve zero carbon emissions in the next half of this century – which is a pre-requisite for limiting warming below 2°C. In this context, the potential of Karnataka to contribute to the NDC target becomes relevant. The cumulative mitigation potential achieved by 2030 through forestry mitigation in Karnataka is about 710 Mt CO_2 and 405 Mt CO_2, respectively under the "Technical Potential" and "Economic Potential" scenarios. This can help India meet 24% to 28% and 14% to 16% of the NDC forestry

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sink creation commitment, considering the "Technical Potential" and "Economic Potential" scenarios.

To conclude, it is evident from this assessment that land availability for climate change mitigation through forestry is not a constraint in Karnataka. It is possible to achieve this without compromising on the competing demands of food production, infrastructure, and urban settlement requirements. Forestry mitigation potential is significant, provided forestland, agriculture lands and wastelands are all included, as promotion of tree plantations on these lands would create forests– that is in line with the definition adopted by India and submitted to the UNFCCC, and create or enhance carbon sinks, as envisaged in the INDC. These mitigation activities further promote mitigation-adaptation synergy in addition to the delivery of several co-benefits. However, for the realization of forestry mitigation potential in Karnataka, barriers need to be overcome.

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Table 1: Trends in area (Mha) under different land use categories in Karnataka

Category	1960-61	1970-71	1980-81	1990-91	2001-02	2011-12	2012-13
Land under Cultivation							
Net Sown Area	10.065	10.248	9.899	10.381	10.031	9.941	9.773
Gross Cropped Area	10.398	10.887	10.660	11.759	11.670	12.059	11.748
Area Sown More Than Once	0.333	0.639	0.761	1.378	1.638	2.118	1.955
Cropping Intensity (%)	103.310	106.240	107.690	113.270	116.340	121.310	120.000
Land not Available for Cultivation							
Land put to non-agricultural use	0.853	0.937	1.066	1.189	1.325	1.433	1.436
Barren and uncultivable land	0.844	0.839	0.844	0.799	0.788	0.787	0.787
Uncultivated Land Excluding Fallow Land							
Permanent Pastures and Other Grazing Land	1.744	1.619	1.346	1.098	0.956	0.908	0.908
Miscellaneous Tree Crops and Groves not included in Net Sown Area	0.374	0.311	0.342	0.316	0.302	0.285	0.283
Cultivable Waste	0.621	0.615	0.502	0.446	0.423	0.413	0.413
Fallow Land							
Current Fallow	0.669	0.811	1.459	1.29	1.728	1.672	1.822
Other Fallow	0.665	0.672	0.558	0.457	0.426	0.539	0.535

Source: PPM & SD, 2014-15

Table 2: Comparative yield estimates of major rainfed crops of Karnataka with National average and states reporting highest yield (kg/ha)

Crop	Highest - State	Yield of crops in Karnataka
Jowar	1433 – Madhya Pradesh	1183
Bajra	1938 – Madhya Pradesh	1082
Maize	5351 – Andhra Pradesh	3442
Tur	1333 - Bihar	596
Bengal gram	1241 – Andhra Pradesh	656
Groundnut	2308 - Tamilnadu	871
Sunflower	2500 – Uttar Pradesh	610
Soyabean	1692 – Andhra Pradesh	882

Source: Agriculture Statistics at a Glance 2012, GoI, MoA, New Delhi

Table 3: Land category-wise area considered for mitigation assessment under "Technical and "Economic Potential" scenarios

Land category	Area (Mha)	
	Technical potential	Economic potential
Wasteland	*1.30*	*0.86*
Wasteland – multiple categories	1.304	0.860
Mining wastelands	0.003	0.003
Forestland	*3.44*	*1.65*
Moderately dense forest	2.018	0.939
Open forest	1.418	0.709
Agriculture land	*3.20*	*1.45*
Long fallow lands	0.539	0.539
Permanent pastures and grazing land	0.908	0.908
Marginal croplands	1.754	-
Total (Wasteland+Forestland+Agriculture)	7.94	3.86

Table 4: Carbon stocks ($MtCO_{2\text{-}e}$) under baseline, cumulative and incremental mitigation under "Technical Potential" scenario for different mitigation options

Option		2015	2020	2025	2030	2035	2040	2045	2050
Afforestation *(Wastelands)*	Baseline	112	112	112	112	112	112	112	112
	Cumulative mitigation	113	131	157	173	192	202	211	230
	Incremental mitigation	1	19	44	61	80	89	99	118
Forest protection *(Forestland)*	Baseline	1241	1241	1241	1241	1241	1241	1241	1241
	Cumulative mitigation	1242	1276	1356	1452	1547	1619	1658	1686
	Incremental mitigation	1.0	34.5	114.9	210.7	305.8	377.8	416.7	444.8
Natural regeneration *(Forestland)*	Baseline	431	431	431	431	431	431	431	431
	Cumulative mitigation	432	461	531	615	699	764	804	835
	Incremental mitigation	0.8	30.2	100.8	184.7	268.2	333.6	373.0	403.9
Agroforestry *(Agriculture land)*	Baseline	392	392	392	392	392	392	392	392
	Cumulative mitigation	431	448	555	646	732	773	790	821
	Incremental mitigation	39	56	162	254	339	381	398	429
Total	Baseline	2176	2176	2176	2176	2176	2176	2176	2176
	Cumulative mitigation	2218	2316	2599	2887	3169	3358	3463	3572
	Incremental mitigation	41.1	139.5	422.3	710.3	992.9	1181.8	1286.9	1395.2

Table 5: Carbon accumulation (Mt $CO_{2\text{-}e}$) under baseline, mitigation and the increment under "Economic Potential" scenario for different mitigation options for the period 2015 to 2050

Option		2015	2020	2025	2030	2035	2040	2045	2050
Afforestation *(Wastelands)*	Baseline	79	79	79	79	79	79	79	79
	Cumulative mitigation	79	92	110	122	135	142	148	161
	Incremental mitigation	0.4	13.2	31.0	42.8	55.8	62.6	69.3	82.2
Forest protection *(Forestland)*	Baseline	590	590	590	590	590	590	590	590
	Cumulative mitigation	591	607	646	692	738	773	792	805
	Incremental mitigation	0.5	16.7	55.6	102.0	148.0	182.8	201.5	214.9
Natural regeneration *(Forestland)*	Baseline	215	215	215	215	215	215	215	215
	Cumulative mitigation	216	230	266	308	349	382	402	417
	Incremental mitigation	0.4	15.1	50.4	92.4	134.1	166.8	186.5	201.9
Agroforestry *(Agriculture land)*	Baseline	203	203	203	203	203	203	203	203
	Cumulative mitigation	204	239	312	371	426	459	474	491
	Incremental mitigation	1.0	36.1	108.3	167.8	222.9	255.3	270.4	287.8
Total	Baseline	1088	1088	1088	1088	1088	1088	1088	1088
	Cumulative mitigation	1090	1169	1333	1493	1649	1755	1816	1875
	Incremental mitigation	2.3	81.1	245.4	405.0	560.7	667.5	727.7	786.9

Table 6: Cumulative mitigation potential (Mt $CO_{2\text{-}e}$) of forestry mitigation options during 2015 to 2030

Land category	Mitigation option	Mitigation potential (Mt CO_2-e)							
		2015		2020		2025		2030	
		Tech[1]	Eco[2]	Tech	Eco	Tech	Eco	Tech	Eco
Forestland	Forest protection	1.0	0.5	34	16.7	114.9	55.6	210.7	102.0
	Natural regeneration	0.8	0.4	30	15.1	100.8	50.4	184.7	92.4
Wasteland	Afforestation	0.5	0.4	19	13.2	44.3	31.0	61.2	42.8
Agriculture land	Agroforestry	1.6	1.0	56	36.1	162.3	108.3	253.7	167.8
Total		3.9	2.3	139.5	81.1	422.3	245.4	710.3	405.0

[1]*Afforestation includes short rotation and long rotation plantations, agroforestry option includes block and bund plantations*

[2]*"Technical Potential" scenario, considering a total land area of 7.94 Mha*

[3]*"Economic Potential" scenario considering a land area of 4 Mha.*

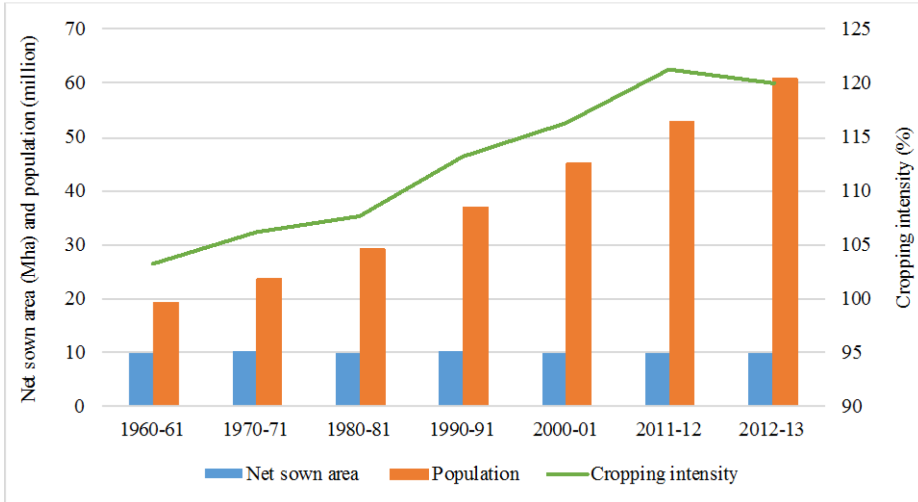

Figure 1: Trends in land under cultivation (Mha), population and cropping intensity (%)

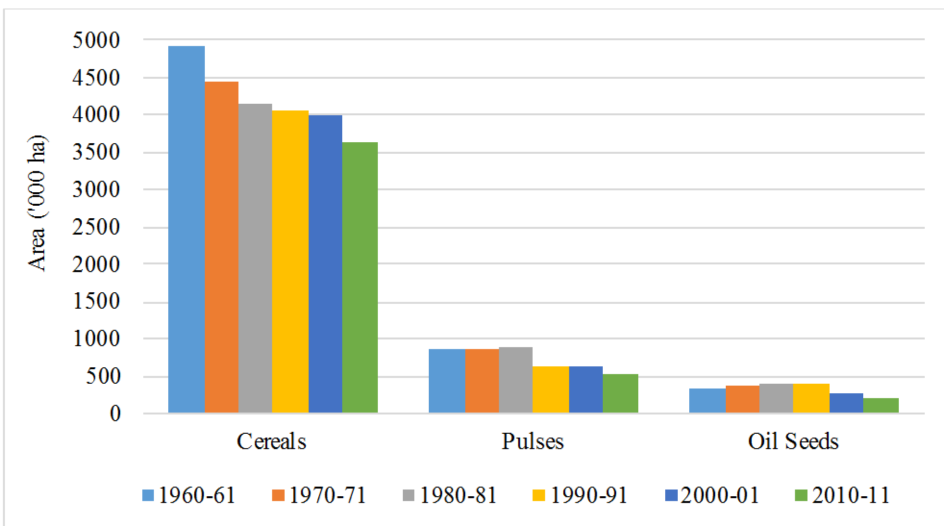

Figure 2: Trends in total area under cereals, pulses and oilseeds

Figure 3: Trends in land not available for cultivation (left panel) and area under permanent pastures and other grazing land, miscellaneous tree crops and groves and cultivable waste

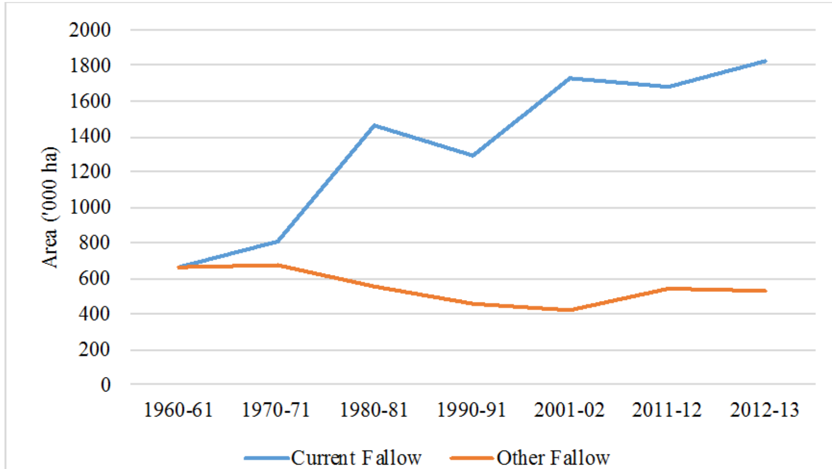

Figure 4: Trends in area under fallow land category

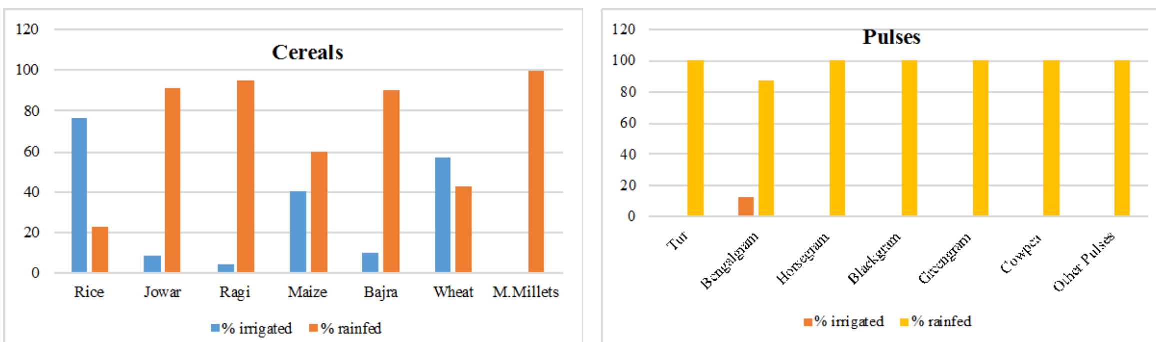

Figure 5: Area under major irrigated and rainfed crops in Karnataka during 2011-12

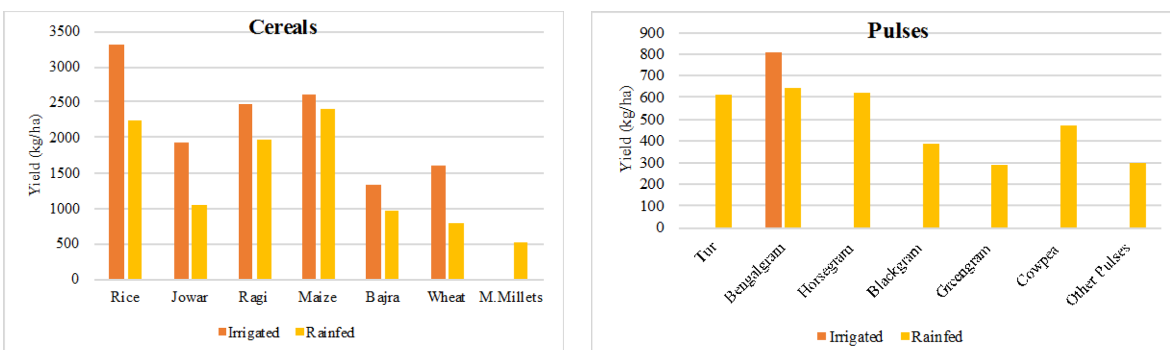

Figure 6: Yield of major irrigated and rainfed crops in Karnataka during 2011-12

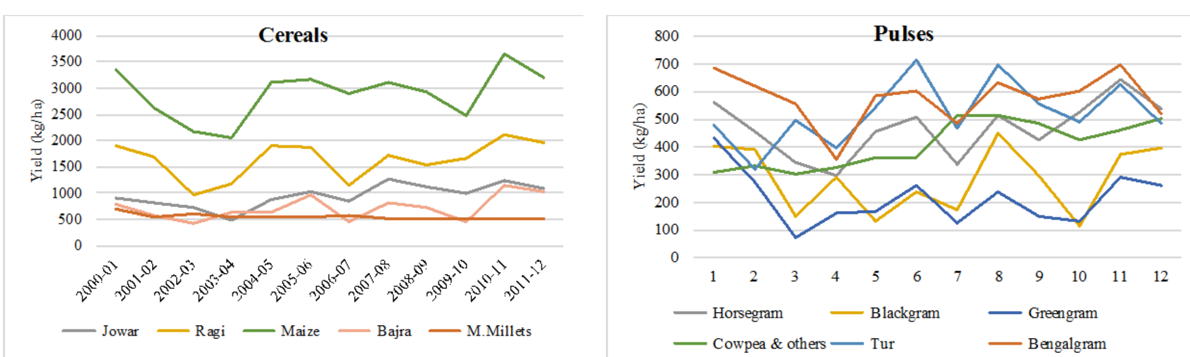

Figure 7: Trends in yield of major cereals and pulses in Karnataka

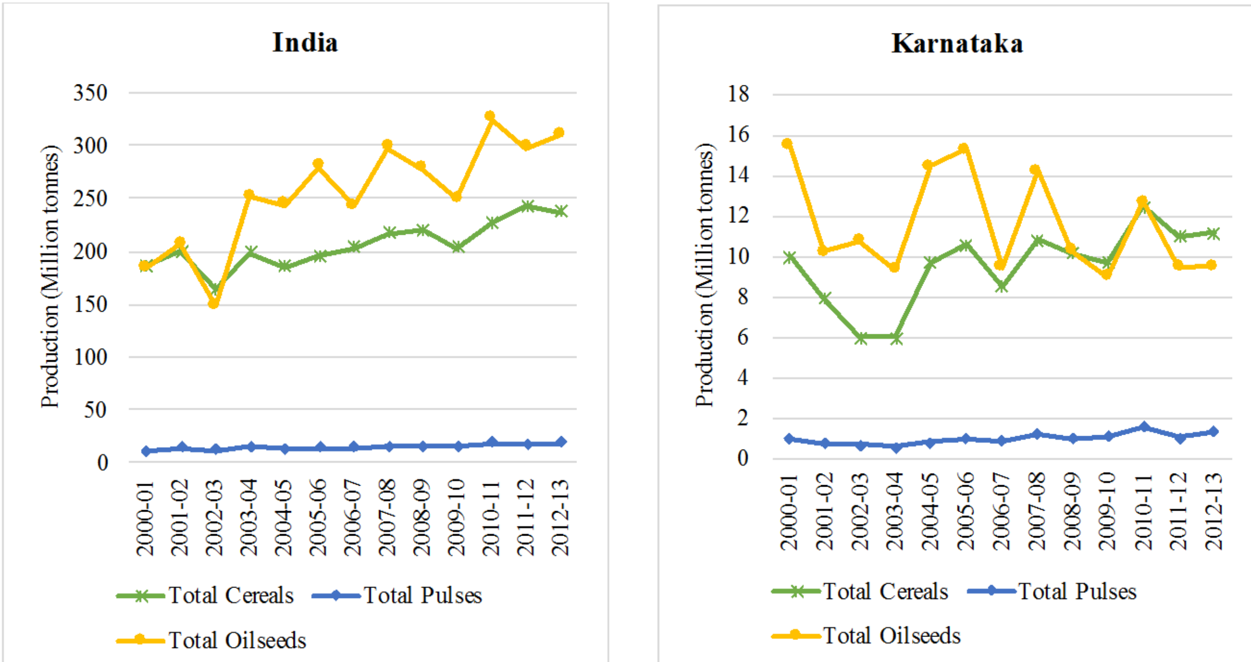

Figure 8: Trends in food grain production in Karnataka and India

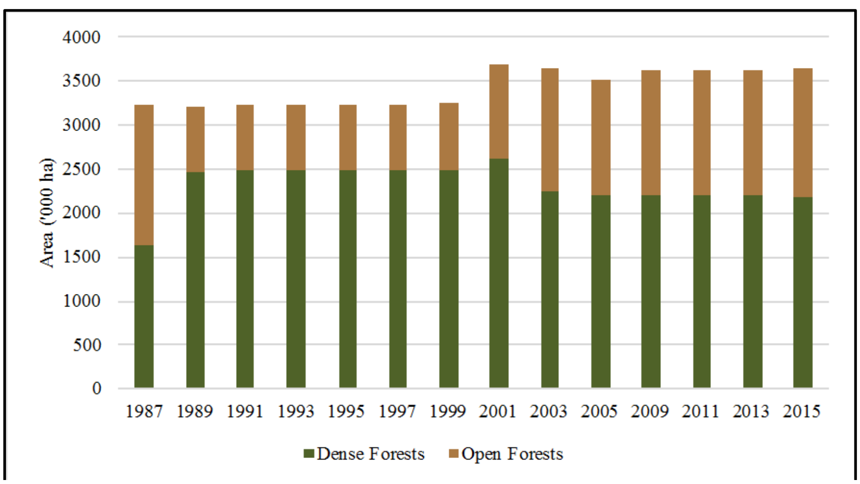

Figure 9: Trends in area under forests in Karnataka ('000 ha) during 1987 to 2015

Step 1	Selection of scale of assessment
Step 2	Selection of land categories and estimation of area available for mitigation purposes
Step 3	Selection of mitigation scenarios
Step 4	Selection of model for assessment of mitigation potential assessment
Step 5	Selection of mitigation options and matching of options to identified land categories
Step 6	Selection of carbon pools

Step 7	Generation of data for inputting into the model
Step 8	Model runs for estimating the mitigation potential

Figure 10: Approach to assessment of mitigation potential of forest sector

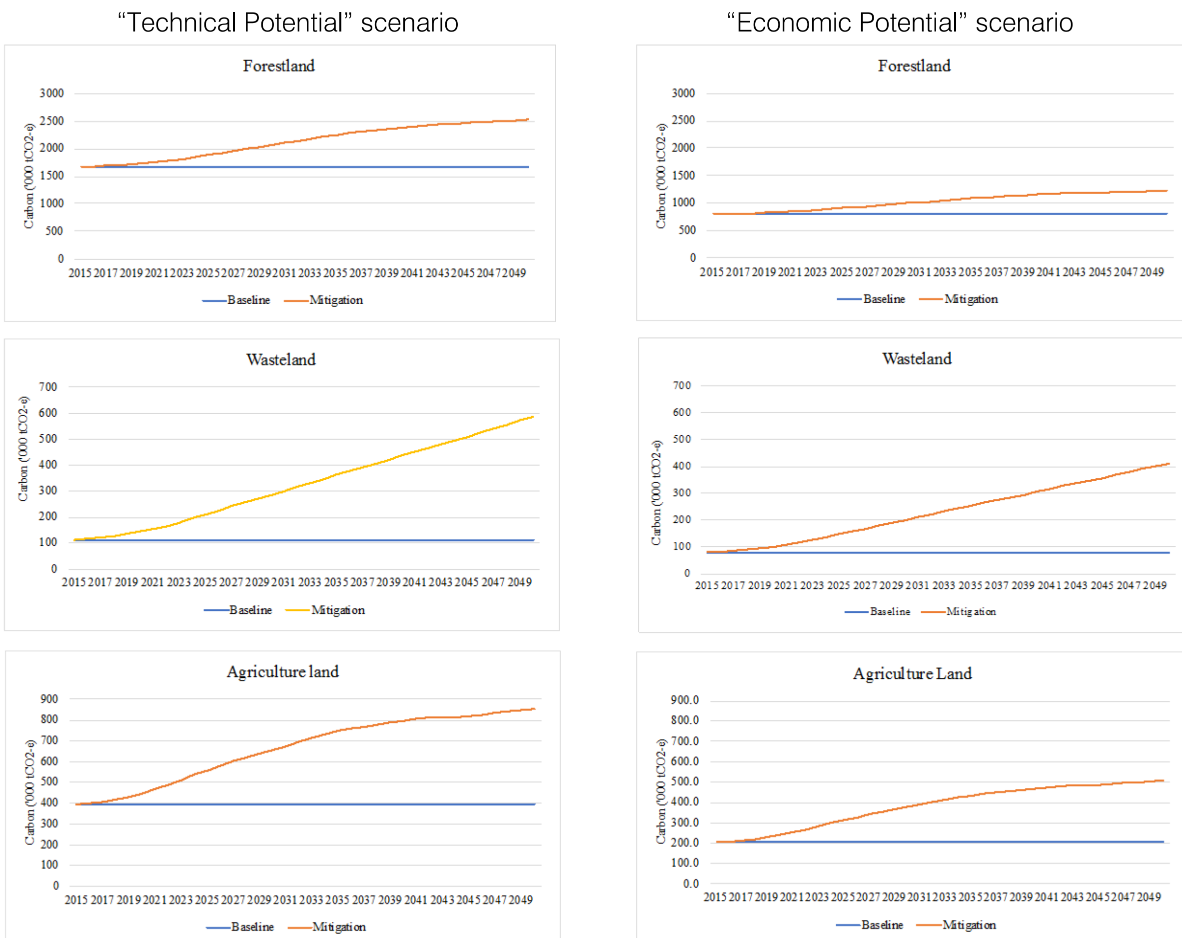

Figure 11: Cumulative carbon stock accumulation across land categories during 2015-2030 under "Technical Potential" (left panel) and "Economic Potential" (right panel) scenarios

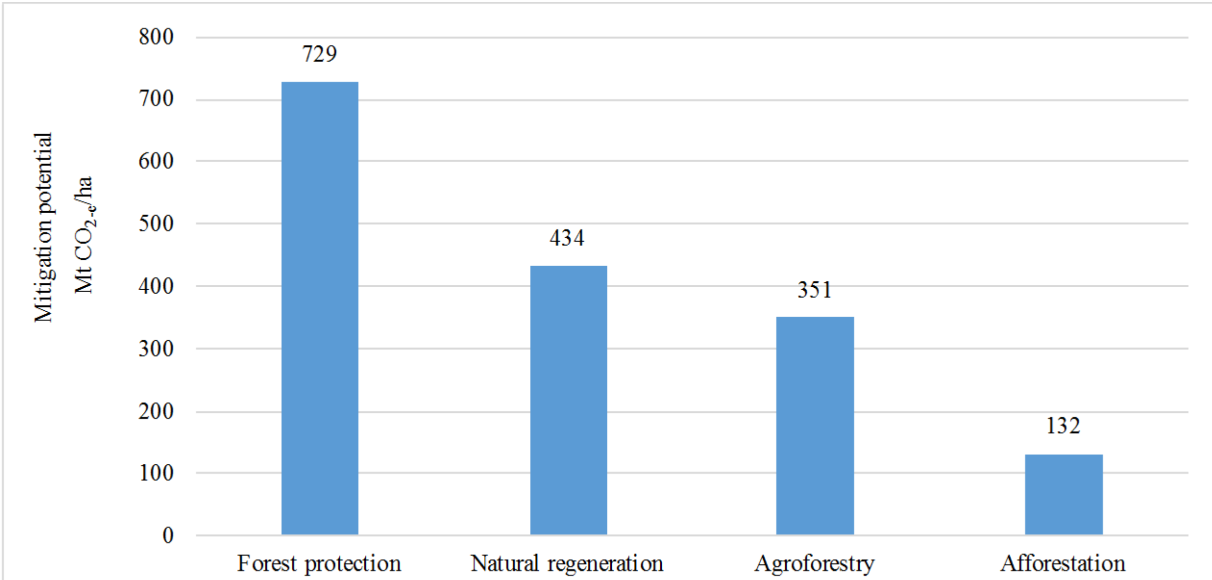

Figure 12: Mitigation potential per hectare of different forestry mitigation options for the period 2015-2030

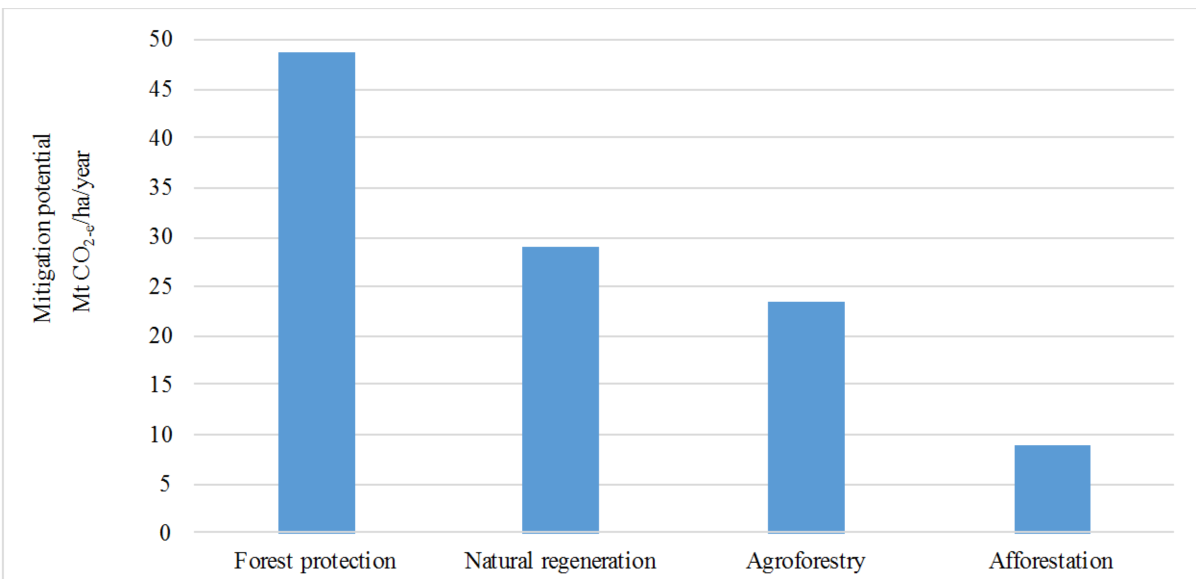

Figure 13: Annual mitigation potential per hectare across mitigation options for the period 2015-2030