Thai J. For. 19-21 : 116-135 (2000-2002) วารสารวนศาสตร์ 19-21 : 116-135 (2543-2545)

AN ASSESSMENTS OF MITIGATION OPTIONS IN THAI FORESTRY SECTOR FOR REDUCING CARBON EMISSIONS

Chatchai Tantasirin[1] ชัชชัย ตันตสิรินทร์[1]

Nipon Tangtham[1] นิพนธ์ ตั้งธรรม[1]

ABSTRACT

Six mitigation options through six different management scenarios were assessed in terms of their effectiveness in reducing carbon emissions. They were analysed in terms of various alternative options; current trend scenario, based on current forest policies in operation, and two scenarios put forward in the Thai Forestry Sector Master Plan which are Master Plan Scenario and Self Sufficient Scenario. Three further scenario were considered combining the governments 5 Million Rai Plantation Project with the Current Trend Scenario, Master Plan Scenario and with the Self Sufficient Scenario.

The Modified Comprehensive Mitigation Assessment Process (M-COMAP) was employed in this study to analyse trends in land-use change, carbon pool and sequestration, total costs and benefits of forest protection and reforestation programmes and their cost effectiveness indicators.

The Current Trend Scenario was used as a baseline scenario, and analysis of the other five management scenario was compared to this baseline.

Results indicate that the Self Sufficient Scenario with 5 Million Rai reforestation project provides the most favourable scenario for mitigation of carbon emission and the medium rotation reforestation of Self Sufficient Scenario shows to be the most suitable mitigation option among all options.

INTRODUCTION

After three decades of deforestation, Thailand is now facing serious ecological, social and economic impacts. Biodiversity has been significantly reduced and soil fertility degraded tremendously. Sedimentation of rivers has increased and fluctuations of streamflow have been amplified. Emission of greenhouse gas (GHG), particularly carbon dioxide, from the clearing of forest vegetation has also risen. This environmental degradation has heightened rural needs and increased poverty even further. Demand for forest-based products has not been sustainable met. The reliance on imported timber has grown and the transferral of logging operations to neighbouring countries has tarnished Thailand's reputation. There is little doubt that the costs of deforestation have already far exceeded the initial benefits reaped from the cutting of the forest.

[1] Department of Conservation, Faculty of Forestry, Kasetsart University, Bangkok 10903

It was estimated by Thailand Development Research Institute (TDRI and TEI, 1993) that about 15.2 TgC were released through the conversion of Thailand's forest to other land uses, while the uptake of carbon by vegetation after deforestation was only 0.16 teragram carbon (TgC). Carbon released by deforestation of about 15.0 TgC corresponds to 0.3 tons per capita. In 1989 when about 14.34 million hectares of natural forest was monitored by LANDSAT, it was found that about 3,710 TgC were stored in various forest types. Of this figure, about 2,980 TgC were stored in the vegetation, while 730 TgC were stored in the soils.

To help mitigate global warming, TDRI suggested that, first Thailand must intensify its effort to control deforestation, and second, revert more of its deforested land to forest. These suggestions correspond to those forest management strategies put forward in the Thai Forestry Sector Master Plan (TFSMP) submitted to Royal Forest Department by the TFSMP core team in 1993. The master plan was based on building a state partnership with NGO's, the private industrial sector and with local people, whose interests have been ignored for more than 100 years.

In this plan, those forests designated as a Protected Area System (PAS) (which cover an area of about 14 M.ha) would be managed by the state in collaboration with local people. Those areas outside a PAS, which are already used by communities (an area of about 4.64 M.ha) would be managed by the communities themselves. Deforested state lands which are occupied by villages would be formally handed over to the villagers by agricultural land reform (accounting for about 2.24 M.ha) if the land can be sustainable farmed, or alternatively, forestry land reform if the land is best kept for forestry purpose. Land which is already used for forest plantation by the industrial sector will be able to demonstrated that the industrial forest can be a highly productive, and at the same time, sustainable land use that farm forestry can emulate with government support. The estimated area for farm forestry and industrial forestry is about 3.68 M.ha. The urban dweller will also be encouraged to plant trees and other vegetation to improve their living environment and to obtain other non-economic benefits (TFSMP, 1993 a ; b).

In term of CO_2 mitigation, it is generally considered that the proposed forestry sector policy in the TFSMP is most appropriate to implement for Thailand's future situation. This policy was selected for evaluating its effectiveness in mitigating carbon emission and generating economic return. This paper focus on the "forest protection and reforestation for conservation programme". The specific objectives of this study are

(1) to simulate land-use patterns that change with different mitigation options in various scenarios of forest management programmes

(2) to estimate the carbon sequestration potential of different mitigation options

(3) to estimate the total cost and benefit and the cost-effectiveness of the aforementioned forest management programmes.

MATERIALS AND METHODS

In order to provide policy makers with various options of management plan scenarios for reducing carbon emission, the Comprehensive Mitigation Assessment Process (COMAP), developed by Sathaye and Makudi of Lawrence Berkeley Laboratory (LBL) and Andrasko of US.EPA (LBL, 1995; Sathaye *et al.*, 1994) was applied to developed a M-COMAP for estimating the quantity of carbon sequestration and to evaluate cost-effectiveness indicators.

An evaluation of alternative options in different management scenarios proposed in

An evaluation of alternative options in different management scenarios proposed in the Thai Forestry Sector Master Plan was made based on change of land use simulated by the core team of the Thai Forestry Sector Master Plan (TFSMP, 1993b), together with information from the report entitled "Preparation of a National Strategy on Global Climate change : Thailand" edited by TDRI and TEI (1993) and the most update initial figures of remaining forest areas pulished by RFD. The following methodologies have been employed in this study.

Identification of mitigation options

In TFSMP, total forest management area of 22.43 million hectare (M.ha) was divided to 3 categories as follows:

- Protectec Area System (PAS), which 14.12 M.ha or 28% of total the whole country's area consists of national reserve forest, national park, wildlife sanctuary, etc., in which consisting of various condition of forest, i. e., good natural forest, secondary forest and those areas under disturbed and gradually become idle (non-forest area) under conservation zone promulgation.

- Community forest (CMF) of 4.95 M.ha or about 9 % of country area. The condition is almost the same as that in PAS but not yet declare as conservation zone by law.

- Non-protected area system (NPAS) are those disturbed and degraded to be non-forest area. This part consists of 3.72 M.ha or about 7 %. It is not yet declared as conservation zone.

According to the management area categories mentioned above, six mitigation options for reducing carbon emission were identified in this analysis. These are:

☞ Forest protection and reforestation for conservation in PAS (FP&RC-PAS)

☞ FP&RC in CMF (FP&RC-CMF)

☞ Short rotation reforestation in CMF(SRR-CMF)

☞ Long rotation reforestation in CMF(LRR-CMF)

☞ SRR in NPAS (SRR-NPAS)

☞ Medium rotation reforestation in NPAS (MRR-NPAS)

All these options were analyzed by three scenarios proposed in TFSMP with three additional 5 Million Rai plantation for conservation projects were assigned for M-COMAP analysis. They are :

1) **Current Trend Scenario (CTS)**, in which current policies of 6 mitigation options continue into the future. This was selected as a low goal attainment scenario in carbon sequestration.

2) **Master Plan Scenario (MPS)**, in which various programmes for the import of timber and wood products has been planned to meet the national demand due to insufficient supply from the remaining forest and plantation area. About 4 M.ha of plantation are proposed in this scenario.

3) **Self Sufficient Scenario (SSS)**, in which more forest land is needed to satisfy the future demand for forest products. In this scenario the country aims at self-sufficiency as soon as is technically possible, and about 5 M.ha is proposed for reforestation.

4) **Current Trend Scenario plus 5 Million Rai Plantation (CTS+5MR),** The 5 million rai plantation refer to the government policy to celebrate the 50^{th} anniversary of His Majesty the King's accession to the Throne by planting 5 million rai of trees in various regions over a 5 year from 1994 to 1998. This scenario take this plantation project into account when analysing CTS.

5) **Master Plan Scenarios plus 5 Million Rai Plantation (MPS+5MR),** in which the 5 million rai project is taken into account when analysing MPS.

6) **Selfsufficient Scenario plus 5 Million Rai Plantation (SSS+5MR),** in which the 5 million rai project is taken into account when analysing SSS.

Comparison to baseline scenario

All options of the five mentioned scenarios, namely MPS, SSS, CTS+5MR, MPS+5MR and SSS+5MR were analysed using M-COMAP. Results were used to compare benefits of carbon sequestration and cost-effectiveness indicators between the current trend scenario and each of the other four scenarios.

Projection of land-use pattern for each scenario

The proportion of land-use or land allocation was projected by the TFSMP core team (TFSMP, 1993c) and is considered as adequate to meet the demands of forest products and services. The projection of land-use patterns was therefore not re-analysed in the M-COMAP framework. Projected values obtained by TFSMP together with the updated figures of initial remaining forest area provided by RFD have been employed in this study. However, land-use projection given in TFSMP (from 1991 to 2017) does not correspond to that the base year, i.e., start with 1994 designed by IPCC for CO_2 emission, extrapolation for land use projection was thus made using trends given by TFSMP for a new time frame

Estimating carbon sequestration per unit area

Based on the fact that biomass density and carbon density in wood and in soil varies with forest type, weighted average values of carbon in biomass and in soil for natural forests and plantation were estimated from the following information.

Biomass density of natural forest

Weighted average values for biomass density, carbon content in wood and carbon stored in soil for various natural forests collected from various sources, are shown in **Table 1**. These values used to estimate changes in carbon storage in wood and in soil in natural forest area due to natural changes of the forest over an assigned period. A value of 334 t/ha (333.78 t/ha) was calculated to represent maximum biomass density for natural forest at the climax stage since all observation were taken from examples of pristine forest of each forest type.

Biomass density of regenerating forest

The logistic growth models representing relative biomass increment through the climax stage, developed using observed data of biomass change in secondary dry dipterocarp forest (studied by Yoda and Sahunalu, 1991) and in secondary dry evergreen forest (investigated by Drew *et al.*, 1978) were then used in simulating the increasing biomass density (BD) of regenerating forest. The equations are :

$$BD_{DDF(t)} = 168 / (1 + e^{1.9925 - 0.0353.t}) ; \quad R^2 = 0.9011 \quad (1)$$

for those areas once occupied by deciduous forest,

$$BD_{DEF(t)} = 449 / (1 + e^{3.5921 - 0.1054.t}) ; \quad R^2 = 0.8390 \quad (2)$$

for those areas once occupied by evergreen forest.

An equation for simulating the average values of increasing biomass density of regenerating forest was derived from the above equations. That is:

$$BD_{Average(t)} = 308 / (1 + e^{2.7928 - 0.0704.t}); \quad (3)$$

where

BD is biomass density in ton/ha

and t is number of year where base year is 0

Biomass density of reforested area for conservation

For areas of plantation, volume and biomass density of the actual species use for reforestation, i.e., teak (*Tectona grandis*), melia (*Melia azederach*), pine (*Pinus kesiya*) observed in different regions by Sahunalu *et al.* (1993) and eucalyptus (*Eucalyptus camaldulensis*) studied by Pohjonen and Pukkala (1994) were used to develop logistic growth models for predicting biomass density over time. Change in biomass density of plantation of each species and its calculated models are presented in Figure. 1.

To obtain the average biomass density for all species used in plantation that change over time, the proportion of 40:20:30:10 for *E. camaldulensis* : *P. kesiya* : *T. grandis* : *M. azederach* estimated by consulting plantation experts was applied.

Biomass density of reforestation for wood production

Biomass of various cutting rotation plantation was determined using the same logistic growth equation as that previously used for reforestated area for conservation. The short, medium and long rotations of 5, 15 and 30 years as assigned in the TFSMP for *M. azedarach*, *E. camaldulensis* and *T. grandis* were employed in this estimation. The logistic equation for each of them is as follows:

☞ *M. azederach* (short rotation)

$$BD_{Sht(t)} = 130 / (1 + e^{6..4559 - 1.574.t}) \; ; \qquad R^2 = 0.9622 \qquad (4)$$

☞ *E. camaldulensis* (medium rotation)

$$BD_{Med(t)} = 163 / (1 + e^{3.4706 - 0.3515.t}) \; ; \qquad R^2 = 0.9622 \qquad (5)$$

☞ *T. grandis* (long rotation)

$$BD_{Med(t)} = 212 / (1 + e^{2..5849 - 0.1642.t}) \; ; \qquad R^2 = 0.9622 \qquad (6)$$

Biomass carbon content

Based on available information in Table 1, the average carbon content of about 52 % of vegetation biomass was employed in estimating carbon content for the natural forests, regenerating forests and for plantations. This assigned value was derived from biomass carbon content in various natural forests ranging from 48 to 55 percent (Aksornkoae *et al.*, 1972; Xu Deying, 1992; TDRI and TEI, 1993; Tsutsumi *et al.*, 1983). The change in carbon stored for each forest category was dependent on the change in vegetation biomass over time of those forest catagories.

Soil carbon content

Available information on carbon content in the soil of different natural forests in Thailand (Yamakura and Sahunalu, 1990; Yoda and Sahunalu, 1991; Cerri and Volkoft, 1987; Maneeratana. 1996) indicated that carbon stored in soil (0-100 cm deep) ranges from 51 tC/ha for dry dipterocarp forest to 331 tC/ha in evergreen forest. The weighted average of soil carbon content of 205 tC/ha, based on the remaining forested area of each forest type in 1989 (Table 1), was used for representing soil carbon content in natural forests in Thailand.

In regenerating forest areas and in plantations, observed data on soil carbon content and its recovery rate are not yet available. Information collected by Openshaw (1995), implying that soil carbon contents in secondary forest, grassland and cropland are 75, 74 and 54 % of natural forest respectively, were therefore used in this study. The study of Lugo *et al.* (1986) also revealed that an increasing carbon content of about 0.3-0.5 tC/ha/yr was found in abandoned areas for 40 years after being used for agricultural practices. In this analysis, a soil carbon content of 153 tC/ha for regenerating forest and 111 tC/ha for plantations was applied as the initial value of soil carbon stored in soil (obtained from 75 and 54 % of weighted average soil carbon in natural forest, 204 tC/ha). An increasing rate of 0.4 tC/ha/yr was assigned for annual accumulating soil carbon content in such forest conditions.

Estimating Unit Costs and Benefits

To evaluate mitigation options, unit costs and benefits for each option in different scenarios must be estimated. In this study, only direct cost and benefit were estimated since indirect benefit is still controversial among disciplinary and different among countries. The estimation for costs and benefits in this study are as follows:

<u>Costs of forest protection</u>

Statistical data reported by RFD concerning budget contributed for forest protection activity including natural forest protection, forest improvement, forest fire control, national park, wildlife protection, watershed management and protection of reserved forest implied linear increasing with fiscal year as:

$$Y = 6.6425 \times 10^{2}(X) - 1.3189 \times 10^{6} \qquad (7)$$

where Y is budget of a given fiscal year for forest protection activity (baht) and X is fiscal year (e.g. 1998).

The future fiscal year budget for forest protection activity of the CTS was thus estimated using above equation. The annual budget for the future fiscal year of MPS and SSS was assigned at 100 % greater based on the expert's reasons that to assure the better efficiency forest protection activity than that of CTS, double budget is needed.

<u>Cost of reforestation for conservation</u>

The cost of reforestation detailed by RFD, estimates 500 $/ha (2,000 baht/rai) for initial cost and 92.5 $/ha/yr (370 baht/rai/yr) as maintenance cost for 5 consecutive years. The total unit cost of reforestation is thus the summation of initial cost in the first year and maintenance cost for 5 years.

<u>Cost of reforestation for wood production</u>

Determining cost of reforestation for short, medium and long rotation was done using initial and maintenance costs investigated by TFSMP (Volume 6, Table A3.2-3.5) (TFSMP, 1993c)

<u>Benefits from forest protection</u>

Returns in forms of financial benefit from protecting forest land are difficult to measure.However, investigation by TEI (1997) found that benefit from non-forest product, eatable forest products, fuel-wood

Table 1. Weighted average values for biomass density, carbon content and carbon stored in soils for various forest types in Thailand

Forest type[1/]	Forest area 1989[2/] (10^3 ha)	Weighted area proportion	Above - ground biomass (t/ha)	Under - ground biomass (t/ha)	Total biomass (t/ha)	Carbon content in vegetation (%)	Carbon stored in soil (0-55 cm.) (tC/ha)	Carbon stored in soil (55-100 cm) (tC/ha)	Carbon stored in soil (0-100 cm.) (tC/ha)	Aerial weighted value of: Weighted total biomass	Weighted carbon content (tC/ha)	Weighted soil carbon content (tC/ha)
EGF	6220	0.44	337[3/]	112[6/]	449	54[7/]	206[10/]	125[11/]	331	196	23.55	144
MDF	3116	0.22	226[3/]	89[6/]	354	52[7/]	111[10/]	67[11/]	178	77	11.36	39
DDF	4471	0.31	126[3/]	42[6/]	168	49[8/]	32[10/]	19[11/]	51	53	15.36	16
PF	198	0.01	160[4/]	53[6/]	213	48[9/]	-	-	169[12/]	3	0.67	2
MF	260	0.02	200[5/]	76[5/]	276	55[5/]	-	-	176[12/]	5	1.00	3
Total	14,265.00	1.00	-		-	-	-			334	52	205

Remark
1/ EGF = tropical evergreen forest: MDF = mixed deciduous forest; DDF = dry dipterocarp forest; PF pine forest; MF = mangrove forest
2/ Royal Forest Department (RFD) (1990)
3/ Average from various sources
4/ Sahunalu and Jaenpruksa (1980)
5/ Aksornkoae *et al.*, (1972)
6/ Above ground : below ground biomass ratio is 3 : 1 (Bhumibhamon *et al.*, 1980)
7/ Xu Deying (1992)
8/ TDRI and TEI (1993)
9/ Tsutsumi *et al.*, (1983)
10/ Yamakura and Sahanalu (1990)
11/ 55-100 cm. soil carbon = 61 % of 0-55 cm soil carbon
12/ Estimated from % carbon in soil

wood for construction was about 17.81, 12.25, 22.18 and 445.56 baht/hectare respectively. The total of 498 baht/ha is thus assumed as direct benefit from forest protection. This estimated value is considered as benefit which the local people can only take from the secondary forest. This figure is applied for CTS case of forest protection. The double income or benefits earned by the farmers would be, however, reduced if the forest protection could be implemented by MPS or SSS because of more serious forest protection activity must be excercised.

Benefits from reforestation

As this study considers only direct benefit from reforestation, monetary return from reforestation for conservation was therefore considered as none. The benefit from commercial reforestation for short, medium and long rotations derived from those values calculated by TFSMP (1993c)

Estimating total carbon, total cost and benefit and incremental carbon storage and net benefit

The methodology for estimating these parameters is rather comprehensive to describe herein. The principal steps however follow the COMAP model proposed by Sathaye *et al.* (1994). The following categories were estimated in this section.

- total carbon stored
- incremental carbon stored
- total benefit
- total cost
- total net benefit
- incremental net benefit

Evaluating cost-effectiveness

In evaluating the profit and loss of mitigation options, cost-effectiveness indicators suggested in the COMAP model and ALGAS analysis, i.e., net present value of incremental net benefit (NPVINB) per ha and per tC, net present value of cost (NPVC), mitigation potential were calculated in the analysis. In addition, the NPVINB/NPVC ratio which is the ratio between NPV of incremental of benefit and NPV of total cost was also applied for this analysis.

RESULTS

Land-use parameter projection

Projection of forest land-use from year 1994 to 2024 was simulated basing on the trend estimated by TFSMP (1993c). A comparison of forest land-use change during the mentioned period between CTS and the other 5 scenarios for all options was made using the modified COMAP spreadsheet model (M-COMAP). Simulated results of six options for mitigation programme can be described as follows:

Forest protection and reforestation for conservation in protection area system (FP&RC-PAS)

The projection indicates that if current trend management is left uninterrupted, the total area of natural forest in PAS would be decreased from 11.53 million hectare (M.ha) in 1994 to 9.84 M.ha in 2024. While there would be no increase in reforested in secondary forest, area without reforestation would be decreased from 1.22 M.ha in 1994 to 1.15 M.ha in 2024. In non-forested area but bounded under PAS, area with and without reforestation would be increased from 0.07 to 0.79 and from 1.29 to 2.34 in 1994 to 2024 for the respective protection areas (Table 2, item 1.1, column CTS)

If the MPS, or SSS or the other two scenaros (i. e., MPS+5MR and SSS+5MR) could be implemented, about 11.10 M.ha of natural forest would be kept in PAS by 2024. In secondary forest, reforested area under PAS would be increased to 1.15 M.ha for MPS and MPS+5MR and increased to 1.17 M.ha for SSS and SSS+5MR in year 2024 respectively. In the non forested area legally reserved as PAS, area with reforestation would be increased to 1.02 and 1.72 M.ha for MPS and SSS respectively in year 2024. In case of implementing MPS+5MR or SSS+5MR, about 1.67 or 1.72 M.ha of non-forested area in PAS would be reforested in year 2024. At the base year (1994), there is no increasing reforested area implemented by either scenario but about 0.07 and 0.12 M.ha were reported as reforested area in non-forest implemented by CTS and MPS+5MR (Table 2, item 1.1 column MPS to SSS+5MR)

Forest protection and reforestation for conservation in community forest (FP&RC-CMF)

Since there have been no policy to make reforestation for conservation by 5 MR project in CMF, only 3 scenarios, i. e., CTS, MPS and SSS are discussed herein. In base year 1994, about 1.78, 0.0, 2.64, 0.0 and 0.16 M.ha was reported as natural forest (NF-CMF), secondary forest with reforestation (SF wR-CMF), secondary forest without reforestation (SF woR-CMF), non-forest with reforestation (NF wR-CMF) and non-forest without reforestation (NF woR-CMF) respectively. The mentioned forest land-use categories would be changed to 1.55, 0.0, 2.47, 0.0 and 0.56 M.ha by the year 2024 if left the current trend management going on. The same categories of forest land area would be respectively estimated at 1.73, 2.33, 0.06, 0.0 and 0.20 at the year 2024 if the MPS could be implemented but they would be at 1.73, 2.19, 0.0, 0.0 and 0.20 M.ha respectively for SSS implementation. (Table 2, item 1.2, column CTS, MPS and SSS)

Short and long rotation reforestation in community forest system (SRR-CMF and LRR-CMF)

Of the total area 4.59 M.ha dedicated for commercial and utilized forest as community forest system, none of reforested area was reported as SRR-CMF and LRR-CMF in the base year 1994 (Table 2, item 1.3 and 1.4, col. CTS, MPS and SSS). It is, however, projected that by the end year 2024 about 0.20 and 0.39 M.ha of SRR-CMF would be expected if the MPS and SSS could be implemented and about 0.07 M.ha of LRR-CMF would be made if either MPS or SSS could be implemented

Short and medium rotation reforestation in non-protected area system (SRR-NPAS and MRR-NPAS)

There was no official report of area under SRR-NPAS and MRR-NPAS in base-year 1994. It is, however, projected that if the MPS could be implemented, about 0.20 and 0.07 M.ha of SRR-NPAS and MRR-NPAS would be possible in end year 2024 but the mentioned cutting rotational reforestation would be at 0.39 and 0.07 if the SSS could be implemented. (Table 2, item 1.4, all columns)

Concluding remark for reforestation programme

If the reforestation programme in the Thai Forestry Sector master plan could be implemented, additional conservation forest would be increased to about 1.15+1.02, 1.17+1.72, 1.15+1.67 and 1.17+1.72 M.ha in secondary forest + non-forested areas by implementation of MPS, SSS, MPS+5MR and SSS+5MR respectively by year 2024 (Table 2, item 1.1, SF wR-PAS + NF wR-PAS; all management secnarios). Without implementing any management scenario, an increase of only 0.79 M.ha of plantation in PAS would be expected by year 2024 (Table 2, item 1.1: NF wR-PAS, column CTS/2024).

It was reported that at base-year 1994, about 0.12 M.ha of reforestation for conservation had been established by CTS+5MR management project. About (0.0 + 0.79 + 0.0 + 0.0) = 0.79; (1.15 + 1.02 + 2.23 + 0.0) = 4.4; (1.17 + 1.72 + 2.19 + 0.0) = 5.08; would be preserved as man-made forest for conservation if any one of CTS, MPS or SSS could be implemented from 1994 to 2024 (Table 2, item 1.1 with SF wR-PAS + NF wR-PAS + SF wR-CMF + NF wR-CMF respectively, column CTS, MPS and SSS in 2024). If the 5 MR project could be continuously implemented, about (1.15 + 1.67) = 2.82 and (1.17 + 1.72) = 2.89 M.ha of reforested area would be made by CTS+5MR and MPS+5MR respectively by year 2024.

For the man-made forest for commercial and in country utilization, there has been no area dedicated for either SRR, MRR or LRR in CMF and NPAS in the base year (Table 2, item 1.3-1.6, col. CTS, MPS, SSS). It is however, projected that about (0.0 + 0.0 + 0.02 + 0.01; SRR-CMF + LRR-CMF + SRR-NPS + MRR-NPAS) 0.03; (0.20 + 0.07 + 0.25 + 2.64) 3.16 and (0.39 + 0.07 + 1.03 + 2.64) 4.13 M.ha would be expected by year 2024 if any one of the respective CTS, MPS or SSS could be implemented.

Carbon pool and sequestration

Six mitigation options consisting of two options of forest protection and reforestation for conservation in PAS and CMF (i. e., FP&RC-PAS and FP&RC-CMF) and other four options of reforestation programme, i. e., SRR-CMF, LRR-CMF, SRR-NPAS and MRR-NPAS were considered separately for carbon pool and sequestration analysis. Carbon pool and sequestration of each options in different management scenarios can be described as follows:

Total carbon stored

Based on the projection of forest-land use changes, the cumulative carbon pools in plant and soil in different management scenarios can be summarized as follows:

☞ ***FP&RC-PAS programme***

The cumulative carbon pools in the FP&RC-PAS managed by different scenarios in comparison to that of CTS in base year 1994 and end year 2024 are presented in Table 2 (item 2.1.1). With CTS, capability in storing C in the forest sector of Thailand is expected to decrease from 4,706 TgC in 1994 to 4,386 TgC in 2024, while it is expected to increase from 4,706 TgC to 4,877, 5044, 4,514, 5011 and 5,109 TgC if any one of the respective MPS, SSS, CTS+5MR, MPS+5MR and SSS+5MR could be implemented continuously to end-year 2024 (Table 2, item 2.1.1)

☞ ***FP&RC-CMF programme***

The cumulative carbon stored in the community forest under forest for protection and reforestation for conservation system at the base-year was estimated at 1,120 TgC in all master plan scenarios (i. e., CTS, MPS and SSS). Because there is no policy to reforest in community forest system for 5MR project, there is thus no estimated figures for MPS+5MR and SSS+5MR scenarios. At the end-year 2024, the carbon pool in community forest system would be reached to 1,182, 1,423 and 1,419 if the respective CTS, MPS and SSS could be implemented (Table 2, item 2.2.2)

☞ ***SRR-CMF and LRR-CMF programmes***

If these two options of reforestation programme could be managed, about 37 and 15 TgC and obout 73 and 15 TgC could be stored by the end-year of 2024 by the implementation of MPS and SSS respectively. It is assumed that there would be no short and long rotation reforestation programmes initiated by CTS (Table 2, item 2.1.3 and 2.1.4)

☞ ***SRR-NPAS and MRR-NPAS programmes***

These two options of reforestation programmes in non-protected area system area are assumed to initiatied by the CTS, MPS and SSS. At the base-year 1994, about 206 TgC was estimated to be stored in SRR and MRR which had been established in Thailand both by private and government investment. With the CTS, carbon pool in these reforestation systems would be reduced to 187 and 184 TgC in 2024 for SRR and MRR respectively (Table 2, item 2.1.5 and 2.1.6. column CTS 2024). If any of MPS or SSS could be implemented, carbon pool in these two reforestation programme would be cumulative at 229 and 465, and 349 and 533 for SRR and MRR management (Table 2, item 2.1.5 and 2.1.6, column MPS and SSS sub column 2024).

Incremental Carbon

As CTS is considered to be the baseline scenario, the total incremental carbon stored in the area dedicated under forest protection in PAS is projected to be 491, 658, 128, 635 and 723 TgC at end year 2024 by the MPS, SSS, CTS+5MR, MPS+5MR and SSS+5MR respectively. The incremental carbon was also estimated to be stored in FP&RC-CMF at about 241 and 237 TgC by the end of year 2024 if this option of forest management could be implemented by MPS and SSS respectively (Table 2, item 2.2.2 column MPS and SSS). If the master plan in terms of either MPS or SSS could be implemented, the incremental carbon in SRR-CMF, LRR-CMF, SRR-NPAS and MRR-NPAS would be about 37, 15, 43, and 280 TgC for the later scenario (SSS) (Table 2, item 2.2.3 –2.2.6, column MPS and SSS).

Overall, the combination of 6 options of forest management would yield incremental carbon through out the project period (from 1994 to 2024) at about 1,107, 1,494, 1,241 and 1,559 TgC for MPS, SSS, MPS+5MR and SSS+5MR respectively if either one could be continuously implemented. In case of only 5MR (CTS+5MR) could be implemented, 128 TgC would increase compare with the CTS.

Costs and benefits of each option

Estimated present value (PV) of costs, PV of benefits and PV of net benefit of carbon sequestration of all options in different scenario at end year-2024 are shown in Table 2 (cont.), item 3.1, 3.2 and 3.3 respectively. A summary of comparative incremental net benefit of various options at end-year 2024 is also presented in Table 2 (cont.), item 3.4.

Incremental net benefit (INB)

Due to the intangible benefit of forest protection and reforestation either for conservation or for commercial purposes are still controversial, the INB estimated herein ignored the indirect benefits for all options in each scenario. Without indirect benefits, all options except MRR-NPAS yield the negative value of INB for the whole project period. Among the designed management scenarios, CTS+5MR implies the best INB (-105,002 million baht; M.baht) while MPS, SSS, MPS+5MR and SSS+5MR yielded -139,098, -112,264, -147,525 and -119,056 M.baht of total INB. Among options, medium rotation of reforestation in NPAS managed by MPS or SSS yielded the positive INB of 5,678 and 49,444 M.baht respectively (Table 2 (cont.), item 3.4.6, column MPS, SSS, at 2024). This implies that the medium rotation reforestation in non-protected area system should be promoted and /or CTS+5MR in the Thai Forestry Sector Master plan should be implemented for CO_2 sequestration and other benefits purposes, if INB is a criteria to make decision.

Cost-effectiveness indicators (CEI)

CEI in terms of net present value of cost (NPVC), net present value of incremental net benefit (PVINB), mitigation potential (MP) and ratio for NPVINB to NPVC (NPVINB/NPVC) in unit of baht/ha and baht/tC in all mitigation options of different scenarios through out the project period were estimated and presented in Table 3. According to simulated results shown in Table 3, if we consider in overall of each management scenario, MPS indicates the

Table 2. The comparison of area to be dedicated under forest land-use, carbon pools, and costs and benefits of different mitigation options for 1994 and the end year,2024, between CTS and various forest management scenarios

Parameters estimated for various mitigation options	Management Scenario in TFSM											
	CTS		MPS		SSS		CTS + 5MR		MPS + 5MR		SSS + 5MR	
	1994	2024	1994	2024	1994	2024	1994	2024	1994	2024	1994	2024
1. Area : (mill. Ha)												
1.1 For. Prot.& Ref. For Cons. In PAS												
- Natural Forest	11.53	9.84	11.53	11.10	11.53	11.10	11.53	9.84	11.53	11.10	11.53	11.10
- Secondary Forest												
- area with reforestation	0.00	0.00	0.00	1.15	0.00	1.17	0.00	0.00	0.00	1.15	0.00	1.17
- area without reforestation	1.22	1.15	1.22	0.03	1.22	0.01	1.22	1.15	1.22	0.03	1.22	0.01
- Non Forest												
- area with reforestation	0.07	0.79	0.07	1.02	0.07	1.72	0.12	1.27	0.12	1.67	0.12	1.72
- area without reforestation	1.29	2.34	1.29	0.81	1.29	0.12	1.24	1.86	1.24	0.16	1.24	0.12
Total area in PAS	**14.12**	**14.12**	**14.12**	**14.12**	**14.12**	**14.12**	**14.12**	**14.12**	**14.12**	**14.12**	**14.12**	**14.12**
1.2 For. Prot.& Ref. For Cons. In CMF												
- Natural Forest	1.78	1.55	1.78	1.73	1.78	1.73						
- Secondary Forest												
- area with reforestation	0.00	0.00	0.00	2.33	0.00	2.19						
- area without reforestation	2.64	2.47	2.64	0.06	2.64	0.00						
- Non Forest												
- area with reforestation	0.00	0.00	0.00	0.00	0.00	0.00						
- area without reforestation	0.16	0.56	0.16	0.20	0.16	0.20						
1.3 Short Rotation in CMF	0.00	0.00	0.00	0.20	0.00	0.39						
1.4 Long Rotation in CMF	0.00	0.00	0.00	0.07	0.00	0.07						
Total area in CMF	**4.59**	**4.59**	**4.59**	**4.59**	**4.59**	**4.59**						
1.5 Short Rotation in NPAS	0.00	0.02	0.00	0.25	0.00	1.03						
1.6 Medium Rotation in NPAS	0.00	0.01	0.00	2.64	0.00	2.64						

Table 2. (Cont.)

Parameters estimated for various mitigation options	Management Scenario in TFSM											
	CTS		MPS		SSS		CTS + 5MR		MPS + 5MR		SSS + 5MR	
	1994	2024	1994	2024	1994	2024	1994	2024	1994	2024	1994	2024
2. Carbon Pools and Sequestration												
2.1 Total carbon store (TgC)												
2.1.1 For. Prot.& Ref. for Cons. In PAS	4,706	4,386	4,706	4,877	4,706	5,044	4,706	4,514	4,706	5,011	4,706	5,109
2.1.2 For. Prot.& Ref. for Cons. In CMF	1,120	1,182	1,121	1,423	1,121	1,419						
2.1.3 Short Rotation in CMF	0	0	0	37	0	73						
2.1.4 Long Rotation in CMF	0	0	0	15	0	15						
2.1.5 Short Rotation in NPAS	206	187	206	229	206	349						
2.1.6 Medium Rotation in NPAS	206	184	206	465	206	533						
2.2 Incremental carbon (TgC)												
2.2.1 For. Prot.& Ref. for Cons. In PAS				491		658		128		625		723
2.2.2 For. Prot.& Ref. for Cons. In CMF				241		237						
2.2.3 Short Rotation in CMF				37		73						
2.2.4 Long Rotation in CMF				15		15						
2.2.5 Short Rotation in NPAS				43		163						
2.2.6 Medium Rotation in NPAS				280		348						
Total				**1,107**		**1,494**		**128**		**1,241**		**1,559**
3. Costs and Benefits (NPV, M. baht)												
3.1 Cost												
3.1.1 For. Prot.& Ref. for Cons. In PAS		66,838		137,156		142,331		137,348		144,312		148,423
3.1.2 For. Prot.& Ref. for Cons. In CMF		21,160		52,169		57,018						
3.1.3 Short Rotation in CMF		0		2,901		6,924						
3.1.4 Long Rotation in CMF		0		1,388		1,388						
3.1.5 Short Rotation in NPAS		176		3,140		10,949						
3.1.6 Medium Rotation in NPAS		84		29,176		29,180						
3.2 Benefit from												
3.2.1 For. Prot.& Ref. for Cons. In PAS		48,740		15,359		15,341		15,390		15,359		15,342
3.2.2 For. Prot.& Ref. for Cons. In CMF		17,017		15,034		13,494						
3.2.3 Short Rotation in CMF		0		1,437		4,307						
3.2.4 Long Rotation in CMF		0		0		0						
3.2.5 Short Rotation in NPAS		116		2,250		7,459						
3.2.6 Medium Rotation in NPAS		98		34,868		78,639						

Table 2. (Cont.)

Parameters estimated for various mitigation options	Management Scenario in TFSM											
	CTS		MPS		SSS		CTS + 5MR		MPS + 5MR		SSS + 5MR	
	1994	2024	1994	2024	1994	2024	1994	2024	1994	2024	1994	2024
3.3 Net benefit from												
3.3.1 For. Prot.& Ref. for Cons. In PAS		-18,952		-124,363		-130,658		-123,954		-132,769		-137,450
3.3.2 For. Prot.& Ref. for Cons. In CMF		-4,144		-39,826		-46,709						
3.3.3 Short Rotation in CMF		0		-1,464		-2,617						
3.3.4 Long Rotation in CMF		0		-1,388		-1,388						
3.3.5 Short Rotation in NPAS		-60		-890		-3,490						
3.3.6 Medium Rotation in NPAS		15		5,692		49,459						
3.4 Incremental Net Benefit												
3.4.1 For. Prot.& Ref. for Cons. In PAS				-105,411		-111,707		-105,002		-113,818		-118,499
3.4.2 For. Prot.& Ref. for Cons. In CMF				-35,682		-42,566						
3.4.3 Short Rotation in CMF				-1,464		-2,617						
3.4.4 Long Rotation in CMF				-1,388		-1,388						
3.4.5 Short Rotation in NPAS				-830		-3,431						
3.4.6 Medium Rotation in NPAS				5,678		49,444						
Total				**-139,098**		**-112,264**		**-105,002**		**-147,505**		**-119,056**

Table 3. Cost effectiveness indicator (CEI) of various mitigation option in different management scenarios

Mitigation Options in different management scenarios	Net Present Value of Cost (NPVC)		Net Present Value of Incremental Net Benefit (PVINB)		Mitigation potential (MP)	NPVINB/ NPVC
	baht/ha	baht/tC	baht/ha	baht/tC	tC/ha	
MPS						
For. Prot.& Ref. for Cons. In PAS	9,802	282	-7,467	-215	35	-0.7618
For. Prot.& Ref. for Cons. In CMF	12,369	221	-8,273	-148	56	-0.6688
Short Rotation in CMF	14,589	79	-7,363	-40	186	-0.5047
Long Rotation in CMF	18,864	94	-18,864	-94	200	-1.0000
Short Rotation in NPAS	12,753	74	-3,371	-19	173	-0.2643
Medium Rotation in NPAS	11,042	104	2,149	20	106	0.1946
Average	**13,237**	**142**	**-7,198**	**-83**	**126**	**-0.5008**
SSS						
For. Prot.& Ref. for Cons. In PAS	10,213	219	-7,913	-170	47	-0.7748
For. Prot.& Ref. for Cons. In CMF	14,263	248	-10,329	-179	58	-0.7241
Short Rotation in CMF	17,713	95	-6,695	-36	187	-0.3780
Long Rotation in CMF	18,864	94	-18,864	-94	200	-1.0000
Short Rotation in NPAS	10,590	67	-3,318	-21	157	-0.3133
Medium Rotation in NPAS	11,045	84	18,715	142	132	1.6944
Average	**13,781**	**135**	**-4,734**	**-60**	**130**	**-0.2493**
CTS+5MR						
For. Prot.& Ref. for Cons. In PAS	9,818	1,082	-7,438	-820	9	-0.7576
MPS+5MR						
For. Prot.& Ref. for Cons. In PAS	10,370	234	-8,063	-182	44	-0.7775
For. Prot.& Ref. for Cons. In CMF	12,369	221	-8,273	-148	56	-0.6688
Short Rotation in CMF	14,589	79	-7,363	-40	186	-0.5047
Long Rotation in CMF	18,864	94	-18,864	-94	200	-1.0000
Short Rotation in NPAS	12,753	74	-3,371	-19	173	-0.2643
Medium Rotation in NPAS	11,042	104	2,149	20	106	0.1946
Average	**13,331**	**134**	**-7,297**	**-77**	**127**	**-0.5035**
SSS+5MR						
For. Prot.& Ref. for Cons. In PAS	10,696	209	-8,394	-164	51	-0.7848
For. Prot.& Ref. for Cons. In CMF	14,263	248	-10,329	-179	58	-0.7241
Short Rotation in CMF	17,713	95	-6,695	-36	187	-0.3780
Long Rotation in CMF	18,864	94	-18,864	-94	200	-1.0000
Short Rotation in NPAS	10,590	67	-3,318	-21	157	-0.3133
Medium Rotation in NPAS	11,045	84	18,715	142	132	1.6944
Average	**13,862**	**133**	**-4,814**	**-59**	**131**	**-0.2510**

Net Present Value (NPV) of Cost	
(baht/ha) per total area	= present value of cost / total area
(baht/tC) per incremental carbon	= present value of cost / Incremental carbon
NPV of Incremental Net Benefit (NPVINB)	
(baht/ha) per total area	= incremental net benefit / total area
(baht/tC) per incremental carbon	= incremental net benefit / incremental carbon
Mitigation potential	= incremental carbon / total area
NPVINB/NPVC	= incremental net benefit / NPV of Cost
Incremental Net Benefit	= NPVINB of Mitigation Scenario - NPVC of Baseline Scenario
Incremental Carbon	= Total Carbon stored Mitigation Scenario - Total Carbon stored in Baseline Scenario

lowest value of NPVC per ha (avg. 13,237 baht/ha) while the cost per ton of incremental carbon was least at SSS+5MR (avg. 133 baht/tC). However, if considering from the net present value of incremental net benefit (NPVINB) compared to CTS, SSS shows the largest value of NPVINB per unit area (avg. -4,734 baht/ha) but the SSS+5MR yielded the maximum NPVINB per tC, i.e., about - 59 baht/tC by average.

It is, however, considered that the cost and benefit parameters previously discussed could not be the good indicator to clearly decide which scenario is the most efficiency one in mitigating carbon emission. The new parameter, PVINB/NPVC (net present value of incremental net benefit per net present value of cost) is proposed herein as another alternative parameter for selecting mitigation option. By using this parameter, SSS reflected the best mitigation option (the minimal negative value).

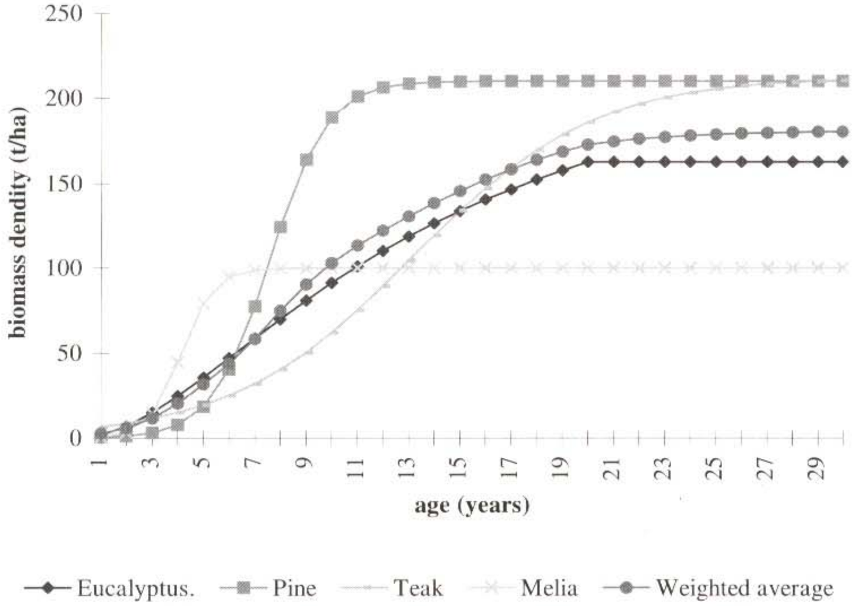
Besides the cost and benefit parameters, if the incremental carbon gained by different management scenarios per unit area is taken into consideration, the highest mitigation potential option is SSS+5MR i.e., about 131 tC/ha (Table 3, item SSS+5MR, row-average)

However, if CTS+5MR, which considered as the most promising option, could be implemented (in fact, it has been implemented during the past 3 years), the NPVC per unit area and per 1 unit incremental carbon are about 9,818 baht/ha and 1,082 baht/tC respectively. The NPVINB per unit area and per 1 unit incremental carbon was estimated at -7,438 baht/ha and -820 baht/tC respectively, and 9 tC/ha of mitigation potential were estimated at the end-year 2024.

DISCUSSION

Results from the simulation indicate that increasing the protected forest area or reforested area will increase carbon storage. For example, implementing the SSS would increase the area of forest plantations, supply the national demand for wood products and an additional 300 TgC (1,414 – 1,107 TgC, Table 2, item 2.2) would be increased when compared to the MPS. Additionally, implementing the 5MR project will add a further 1,559 TgC. However, the cost of achieving these goals must be taken into consideration and therefore the incremental carbon parameter alone is not sufficient for reaching a final decision.

In order to select the most feasible scenario, CEI should be considered. Based on the average values of CEI in Table 3, the SSS appears more feasible than the MPS, because the former CEI parameters reflect better cost effectiveness. Adding the 5MR to both scenarios causes only small changes in CEI values. In reality, the 5MR is under implementation and thus, SSS+5MR is suggested as the most suitable scenario for reducing carbon emissions.



$BD_{Euca.} = 163 / (1 + e^{3.5620 + 0.3557.Age})$ $r^2 = 0.9589$

$BD_{Pine} = 210 / (1 + e^{6.8567 + 0.9034.Age})$ $r^2 = 0.8387$

$BD_{Teak} = 212 / (1 + e^{3.7108 + 0.2828.Age})$ $r^2 = 0.9948$

$BD_{Melia} = 100 / (1 + e^{6.4679 + 1.5654.Age})$ $r^2 = 0.9628$

$BD_{Weighted\ average} = 180 / (1 + e^{3.5086 + 0.3373.Age})$ $r^2 = 0.9858$

Figure 1. Change of biomass density over time of different plantations and its mathematical models.

reforestation and forest protection. Reforestation is regarded as the most feasible mitigation option, because plantations of fast growing trees can sequester higher amounts of CO_2 than natural climax forests. Although naturally regenerating forests ultimately accumulate higher amounts of biomass than plantations, they take a much longer timescale to achieve this and hence absorb CO_2 at a slower rate than the fast growing plantations.

Taking the SSS+5MR as the most suitable scenario, it is not obvious which mitigation option is the best. This is because the CEI parameters do not show the same pattern of cost effectiveness. Under the NPVC, if the aim is to select the cheapest solution (both in baht/ha and baht/tC), the most suitable option is a short rotation in non-protected area system. Under the NPVINB, the most beneficial solution is a medium rotation in non-protected area system. Under MP, the highest incremental per unit area is derived from long rotation in CMF (Table 3, item SSS+5MR). Thus the best option derived from model varies according to the CEI selected.

Due to the lack of a clear mitigation option under the CEI considered, it is proposes in this study that the best CEI is NPVINB/NPVC. This indicator is equivalent to the B/C ratio – the ration between present value of incremental net benefit and present value of cost. Based on this indicator, the most suitable mitigation option is a medium rotation in a non-protected area system. This indicator is the most appropriated because it shows the highest incremental net benefit per 1 unit of cost.

CONCLUSION

Six categories of mitigation option were proposed for the Thailand Forestry Sector Master Plan namely: forest protection and reforestation for conservation in protected area system (FR&RC-PAS), FR&RC in community forestry system (FR&RC-CMF), short rotation reforestation in CMF (SRR-CMF), long rotation reforestation in CMF (LRR-CMF), SRR in NPAS (SRR-NPAS), and medium rotation reforestation in NPAS (MRR-NPAS). Six different management scenarios were then applied to these mitigation option, i. e., current trend scenario (CTS), master plan scenario (MPS), self sufficient scenario (SSS), CTS plus 5 million rai reforestation project (CTS+5MR), MPS+5M$ and SSS+5MR. They were employed to assess their capability in reducing carbon emission by using the modified COMAP model (M-COMAP). Carbon pool and sequestration, total costs and benefits, incremental net benefit (INB), incremental carbon and various parameters of cost-effectiveness index (CEI) of each option in the mentioned management scenarios were analysed to obtain the most suitable mitigation option. It was found that SSS+5MR was the most suitable management scenario when least cost and NPVINB/NPVC criteria was applied to determine mitigation efficiency. Among six mitigation option in this scenario, the MRR-NPAS shows the most effective in reducing carbon emission in term of economic investment.

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