Potential Carbon Sinks in Tropical Forests under the REDD+ Mechanism

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Abstract: Accounting for up to 25% of global carbon emissions, tropical deforestation and forest degradation have increasingly brought international attention. The recognition of reducing emissions from deforestation and forest degradation, forest conservation, sustainable forest management, and enhancing carbon sinks in tropical forests (REDD+) in the Copenhagen Accord and the pledge of \$3.5 billion fast-start climate finance for REDD+ preparatory activities suggests that appropriate approaches to managing tropical forests become necessary. As REDD+ involves the carbon-based financial compensation, avoided carbon emissions from the forests needs to be assessed. Here, we develop a carbon stock model for projecting carbon stock changes under two management scenarios, namely the baseline (business-as-usual) and REDD+ management. Baseline scenario is the management of forest using conventional logging practice, while REDD+ scenario involves the use of reduced impact logging (RIL) and RIL plus liberation treatment (RIL+). Our results suggest that REDD+ scenario could avoid carbon emissions of 2.06 MgC ha^{-1} at the beginning of the management to 36.76-54.26 MgC ha^{-1} at year 60 of the management. The REDD+ revenues from carbon sales are estimated at just about \$2 in the first year to \$107 and \$159 ha^{-1} under RIL and RIL+, respectively. REDD+ agreements will ensure the adoption of REDD+ scenario for managing tropical forests.

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1. Introduction

New climate agreements are expected to reach at the 16th Conference of the Parties (COP16) of the United Nations Framework Convention on Climate Change (UNFCCC) to be held in Mexico in December 2010. Among the anticipated agreements are the inclusion of reducing emissions from deforestation and forest degradation, forest conservation, sustainable forest management, and enhancement of carbon sinks, altogether commonly known as REDD+ as greenhouse gas mitigation option which may be adopted by countries committing to emission reductions.

REDD+ reduction option is attractive because it is less expensive (Kindermann *et al.*, 2008, Sasaki and Yoshimoto, 2010, van Kooten *et al.*, 2004) than other options being taken under the Kyoto Protocol; it has direct contribution to improving the livelihood of forest-dependent communities and therefore achieving sustainable development of the poor nations, and the potential emission reductions are huge (Kindermann *et al.*, 2008, Houghton, 2003). The anticipated REDD+ agreements have also attracted increasing research on estimating carbon emission reductions and associated costs for implementing ground-based activities, and how such emission reductions can be monitored and verified. For instance, Sasaki and Yoshimoto (2010) focused their research on opportunity costs from managing tropical forests against clearing tropical forests for industrial plantations and provided suggestions that tropical forests should be managed for timber production under REDD+ mechanism because monetary revenues as well as co-benefits from ecosystem services are huge.

Process-based modeling approach has recently been used to estimate carbon emissions from tropical forests (Gumpenberger *et al.*, 2010). Gumpenberger *et al.* (2010) suggest that REDD alone could not reduce carbon emissions from tropical forests unless it is implemented along with forest protection.

Although previous studies provide fundamental basis for understanding the REDD+ potentials, many of these studies fail to address the potential carbon emission reductions and timber supply from sustainable forest management. Sustainable forest management is very important option under REDD+ because it maintains wood supply from the forests to meet increasing demand for wood while generating employment and revenues to forest resource owners or governments in developing countries. Wood supply and carbon stocks in tropical forests are strongly influenced by logging practices (Kim Phat *et al.*, 2004, Sasaki, 2006, Sist *et al.*, 2003).

Here, we analyze potential carbon emission reductions and carbon-based revenues in a one-ha hypothesized forest area under two management systems, namely the use of conventional logging and reduced impact logging practices and liberation treatment for managing tropical forests. The latter is likely to adopt for the REDD+ mechanism.

2. Study Methods and Materials

2.1. Baseline and REDD+ scenarios

In this study, baseline scenario is the management scenario that employs the conventional logging practice (CVL). CVL refers to logging practices that has neither formal planning nor trained staff. CVL causes huge logging damages to residual stands and create greater wood wastes in the forest and at the timber factory (see Holmes *et al.*, 2002).

REDD+ scenario involves the use of reduced impact logging (RIL) and RIL+ liberation treatment (RIL+). RIL is a logging practice that involves the proper training of the logging operations, well-thought logging plans, planning roads and trails prior to harvesting, employing directional tree felling, cutting stumps low to the ground, minimizing wood waste caused by tree felling, skidding or transporting, constructing roads and trails to minimum widths, constructing landings to minimum size and spacing, minimizing ground disturbance, paying attention to aesthetics, and minimizing residual stand damages (see Sasaki and Putz, 2009 and Holmes *et al.*, 2002 for more about RIL practices). RIL is a promising logging practice for managing tropical forests (Putz *et al.*, 2008). It has well-defined logging plan and well-trained logging crews to carry out logging operations that results in less damages to residual stands and reduce wood wastes in the forest. RIL+ is the same as RIL, except that it additionally employs the liberation silvicultural treatment technique, a technique to girdle and kill unwanted but competing tree species with future-crop trees. By reducing competition from unwanted trees, growth rates are found to have increased to about 20-60% compared to growth rate in forests where only RIL is implemented (Pena-Claros *et al.*, 2008, Villegas *et al.*, 2009).

2.2. Carbon stock changes

Above-ground carbon stock changes in one hectare of hypothesized tropical forest under conventional (CVL) and reduced impact logging (RIL) practices can be estimated by

[1] $$\frac{dCSi\,(t)}{dt} = MAI - LMi\,(t) - H_i\,(t) \times BEF$$

(modified from Kim Phat *et al.*, 2004)

[2] $$H_i(t) = \frac{f_M \times f_H}{1-r} \times \frac{CS_i(t)}{T_c \times BEF}$$

(modified from Kim Phat *et al.*, 2004)

[3] $$BRA_i(t) = H_i(t) \times (BEF - 1)$$

where:
$CS_i(t)$: Above-ground carbon stock under i
(i is CVL, RIL+ techniques) in (MgC ha^{-1})
MAI: Mean Annual Increment (MgC ha^{-1} year^{-1})
BEF: Biomass expansion factor (proportion of total above-ground biomasses to stem biomass)
$H_i(t)$: Harvested carbon (MgC ha^{-1} year^{-1})
$LM_i(t)$: Carbon in dead trees due to logging mortality (MgC ha^{-1} year^{-1})
f_M: Proportion of mature trees
f_H: Legal rate of harvesting
r: Rate of illegal logging
T_c: Cutting cycle (yrs)
$BRA_i(t)$: Carbon in branches (including leaves) of harvested timber (MgC ha^{-1} year^{-1})
Values for variables, parameters, justifications and sources are given in Table 1.

2.3. Wood product model

Under both logging practices, various wood components such as wood product (WP), wood waste (WAS), end-use wood products (EWP),wood waste at processing factory or end-use wood waste (EWAS) can be obtained by

[4] $$WP_i(t) = (1 - s_i) \times H_i(t)$$

(adopted from Kim Phat *et al.*, 2004)

[5] $$WAS_i(t) = H_i(t) - WP_i(t)$$

(adopted from Kim Phat *et al.*, 2004)

Table 1. Initial values and parameters used in this study

Description	CVL	RIL	Sources
CS(0)	134.01	134.01	Sasaki (2006)
f_M	0.50	0.50	Kim Phat *et al*. 2004
f_H	0.30	0.30	Kim Phat *et al*. 2004
r	0.50	-	Assumed based on Kim Phat *et al*. (2004)
Tc	60.00	60.00	Assumed based on FAO (1997)
MAI (Mean Annual Increment)	0.66	0.66	Elsewhere in tropics 0.64 reported in Lewis *et al*. (2009) and 0.72 reported in Phillipns *et al*. (1998)
BEF	1.74	1.74	Brown (1997)
LM(0)	0.39	0.07	Dead tree, value obtained from model
BRA(0)	0.28	0.18	Branches, value obtained from model
WAS(0)	0.12	0.02	Wood waste, value obtained from model
EWP(0)	0.13	0.13	End-use wood product, value obtained from model
EWAS(0)	0.13	0.09	End-use wood waste, value obtained from model
s (WAS)	0.30	0.10	30% waste for CVL, and 10% for RIL. See Kim Phat *et al*. (2004) for details
Wood waste due to processing			
a (EWAS)	0.50	0.40	50% waste for CVL, 40% for RIL (see Kim *et al*. 2006)
α	1.00	0.30	proportion of H(t) (see Kim Phat *et al*. 2004)
Turnover time (years)			
τ_{EWP}	43.50*	60.00**	* is taken from IPCC (2003), ** is assumed

[6] $$LM_i(t) = \alpha \times H_i(t)$$

[7] $$EWP_i(t) = (1 - a_i) \times WP_i(t)$$

[8] $$EWAS_i(t) = WP_i(t) - EWP_i(t)$$

where:

s_i: proportion of usable wood after deducting wastes due to logging, skidding and transporting damages under i (CVL or RIL) logging practice

α: Proportion of logging mortality

a_i: wood processing efficiency under i logging practice

All units of WP, LM, WAS, EWP, and EWAS are in MgC ha^{-1} year^{-1}

2.4. Maintaining wood supply

Sustainable forest management could not be achieved if maintaining wood supply is not part of the management goals. It is assumed that end-use wood product (EWP) under conventional logging practice is a baseline against which EWP from RIL is compared. Therefore, the EWPs from both logging practices must be equal:

[9] $$EWP_{CVL}(t) = (1 - a_{CVL}) \times WP_{CVL}(t)$$

[10] $$EWP_{RIL+}(t) = (1 - a_{RIL+}) \times WP_{RIL+}(t)$$

In order to maintain wood supply under the REDD+ scenario (using RIL or RIL+) comparable to that under baseline scenario (using CVL), wood supply under CVL must be maintained:

[11] $$EWP_{RIL}(t) = EWP_{CVL}(t)$$

or

[12] $$H_{RIL}(t) = \frac{(1-a_{CVL})(1-s_{CVL})}{(1-a_{RIL})(1-s_{RIL})} \times H_{CVL}(t)$$

2.5. Carbon fluxes in various wood components

For simplicity, carbon remaining in short-lived wood component BRA, LM, WAS, and EWAS are estimated using IPCC (2006)'s Tier 1 method (i.e. fluxes for harvested wood in year t=n is equal to the amount of harvested wood in that year because it is assumed to emit at the time of harvesting). Therefore, carbon remaining at time t in each wood component ($WC_{F,j}(t)$) is estimated by

[13] $$WC_{F,j}(t) = \frac{WC_j(t)}{0.5} \times 0.09 \times 21$$

where:
$WC_j(t)$: wood component j (MgC ha^{-1})
0.5: carbon content in dry wood biomass (MgC Mg^{-1})
0.09: emission factor from wood wastes ($MgCH_4$ Mg^{-1})
21: conversion factor (greenhouse gas effect potential in MgC per $MgCH_4$)

Carbon remaining in long-lived wood component i.e. EWP can be estimated by

[14] $$\frac{dEWP(t)}{dt} = EWP(t) - \frac{EWP(t)}{\tau_{EWP}}$$

τ_{EWP}: turnover years (years) (see Table 1)
Total carbon fluxes in each wood component accumulated at year t =n:

[15] $$WC_{F,j}(t_n) = WC_{0,j}(t_n) + WC_{1,i}(t_{n-1}) + ... + WC_{n,i}(t_0)$$

Total fluxes in all wood components:

[16] $$TWC_F(t_n) = \sum_{j=1}^{5} WC_{F,j}(t_n)$$

2.6. Additionality and potential revenues

Additionality is the difference between overall carbon stocks and carbon fluxes occurred during the CVL and RIL practices assuming that RIL+ will be adopted under the REDD+ mechanism. For this study, leakages and project emissions such as emissions due to logging operations, wood transporting, and wood processing at the sawmill are not included. Potential revenues are obtained by multiplying the additionality with carbon price of \$3 MgC^{-1} (about \$0.82 $MgCO_2^{-1}$). Carbon traded in European compliance market is priced at about \$20 $MgCO_2^{-1}$ or \$73.4 MgC^{-1}. However until international agreements are reached, carbon credits gained under the REDD+ projects are likely to go to voluntary carbon market where average carbon price was \$7.34 $MgCO_2^{-1}$ in 2009 (Hamilton *et al.*, 2010).

3. Results and Discussions

3.1. Carbon stock changes

Under conventional logging practice of baseline scenario, carbon stocks decrease from 134.0 MgC ha^{-1} at the start of the modeling period to 103.3 MgC at the year 60, representing a decrease of 0.5 MgC ha^{-1} $year^{-1}$ or 0.4% annually. While maintaining the flow of wood supply from the forests, carbon stocks under REDD+ scenario increase to 140.0 MgC ha^{-1} for forest with the same mean annual increment (RIL practice), representing an increase of 0.2 MgC ha^{-1} $year^{-1}$ over the same period; and to 156.6 MgC for forest with 50%

increase in MAI (RIL+ practice), representing an increase of 0.4 MgC ha^{-1} year^{-1} or 0.3% annually over the same modeling timeframe (Fig.1).

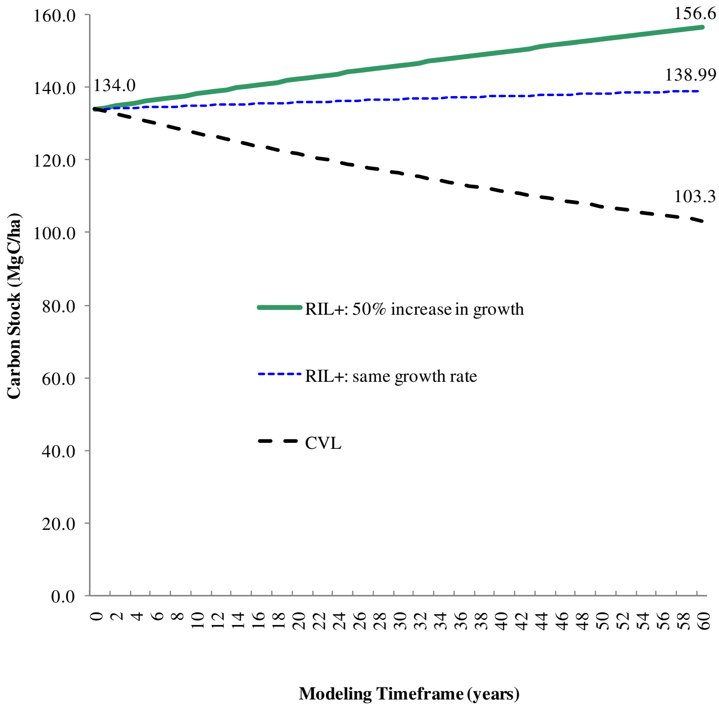

Figure 1. Carbon stock changes under conventional logging and reduced impact logging.

3.2. Carbon fluxes in harvested wood components

Depending on the tracking methods (i.e. Tier 1 or Tier 2) and length of turnover years for each wood component, carbon fluxes in branches, wood wastes in the forests, wood waste at the sawmill, and damaged wood decrease about 0.013 MgC ha^{-1} during the 60-year modeling timeframe while carbon fluxes in end-use wood product increase about

0.055 MgC ha^{-1} $year^{-1}$ over the same period. Carbon fluxes under RIL decrease about 0.005 MgC ha^{-1} $year^{-1}$ in branches, wood wastes in the forests, wood waste at the sawmill, and damaged wood. Under RIL, carbon fluxes in end-use wood product increase 0.064 MgC ha^{-1} $year^{-1}$ (Fig.2).

Please note that the amount of total harvested wood components under RIL and RIL+ scenarios are the same, and therefore the above mentioned figures for RIL is applied to both scenarios. Altogether, carbon fluxes (sinks) in all harvested wood component under RIL scenario is 0.017 MgC ha^{-1} $year^{-1}$ higher than that under CVL.

3.3. End-use wood product

Production of end-use wood depends very much on harvested wood, logging damages, and wood processing efficiency. In order to produce the same amount of end-use wood product at the start of the modeling, 0.39 MgC ha^{-1} $year^{-1}$ (about 0.79 m^3 ha^{-1}) has to be harvested from forests if conventional logging is employed, while only 0.25 MgC ha^{-1} $year^{-1}$ (0.50 m^3 ha^{-1}) are harvested from forests with RIL practice (Fig.2). Illegal logging results in the decline of carbon stocks, and thus harvested wood continues to decline. At year 60, the ending of the modeling timeframe, the available timber declines to 0.30 and 0.19 MgC ha^{-1} under conventional and reduced impact logging practices, respectively for producing 0.10 MgC ha of end-use wood products (Fig.3).

3.4. Additionality and carbon-based revenues

By maintaining the end-use wood products produced under CVL, about 2.06 MgC (7.56 $MgCO_2$) ha^{-1} can be avoided at the first year of the modeling period if reduced impact logging is implemented. Respectively under RIL and RIL+ scenarios, this amount increases to 36.76 and 54.26 MgC ha^{-1} at the year 60 of the modeling timeframe. Using a

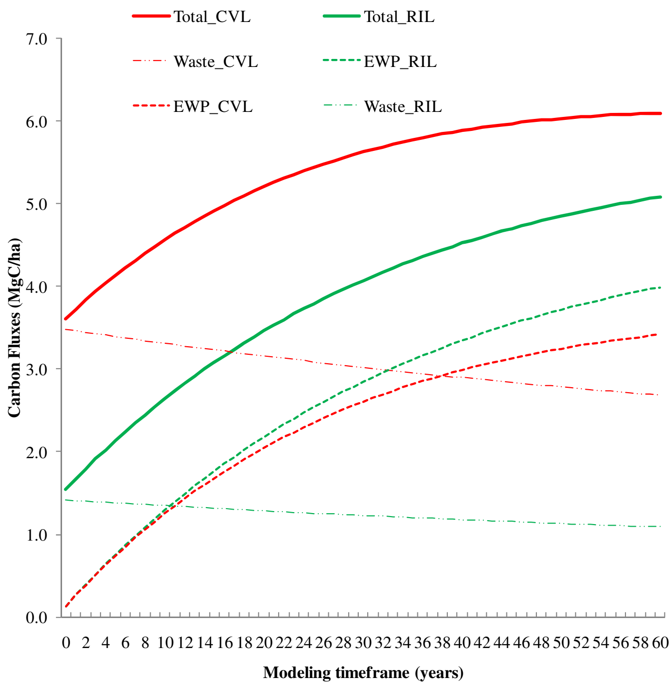

Figure 2. Carbon fluxes in harvested wood components under conventional and reduced impact logging

Note: 1. "CVL" is conventional logging; "RIL" is reduced impact logging; "Waste" includes BRA, LM, WAS, EWAS; and "Total" is the sum of EWP and Waste

2. EWP and Waste are the same for RIL and RIL+. For simplicity, only RIL is used.

harvesting costs of US$4.5 and $4.8 m^{-3} of harvested wood (see Sasaki and Yoshimoto, 2010) and a carbon price of $3 MgC, potential revenues from managing one hectare of tropical forests for timber production increase from $1.99 ha^{-1} at the first year to $107.04 and $159.53 ha^{-1} at the 60 year of the modeling timeframe, respectively under RIL and RIL+ practices (Fig.4). Because RIL or RIL+ harvest less wood than

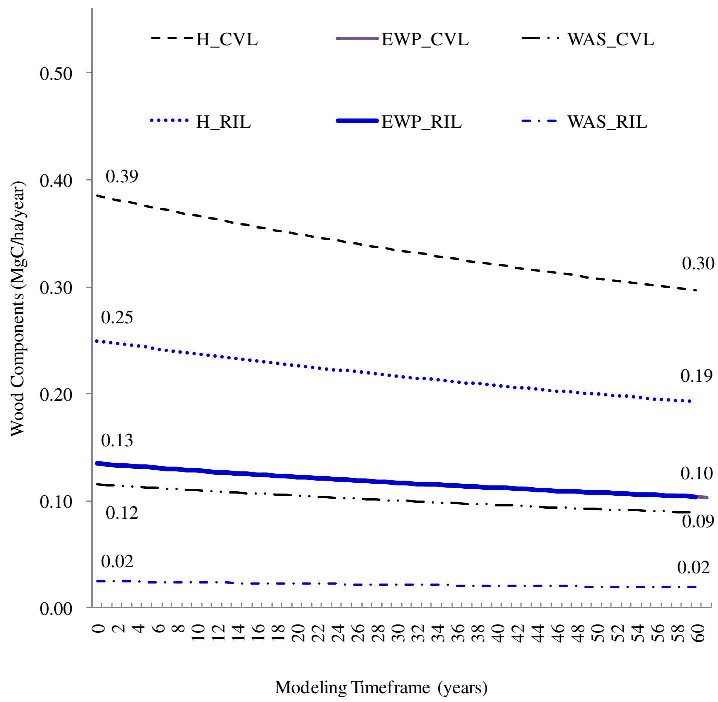

Figure 3. Harvested wood (H) required for producing the same amount of end-use wood products (EWP), and logging-driven wood waste (WAS) under CVL and RIL practices

CVL, harvesting costs per hectare of forest land are reduced. In addition to carbon-based revenues, revenues from timber royalties and payment for other ecosystem services can also be generated but they are beyond the scope of this paper.

3.5. Sensitivity of the analysis

Our results are strongly influenced by the favorable assumptions on the use of RIL or RIL+ practices in managing tropical forests under the anticipated REDD+ mechanism. RIL or RIL+ concept has been

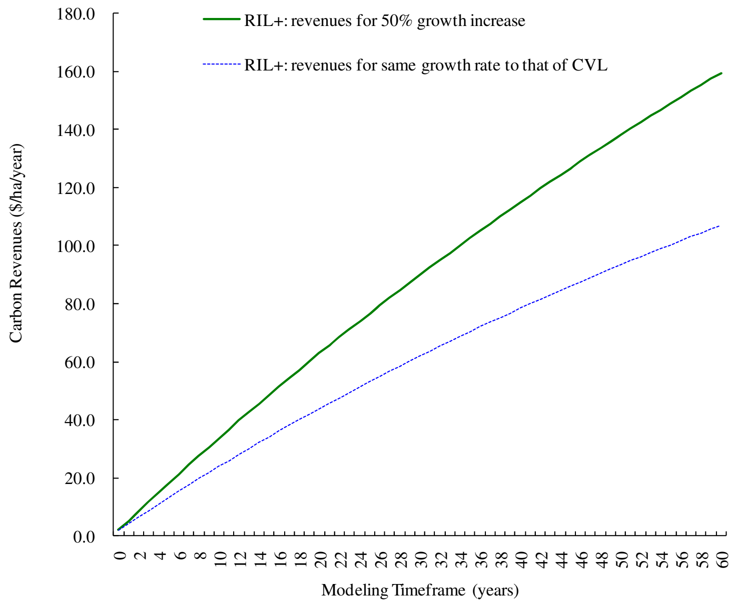

Figure 4. Potential revenues under RIL+ with 50% growth increase and same growth rate to that of CVL

perceived to have high start-up costs although its long-term revenues would be much better than that under the conventional logging practice (Holmes *et al.*, 2002). Furthermore, harvesting intensity also affects damages to residual stands and the flow of future timber production and growth regardless logging practices (Sist *et al.*, 2007), and therefore RIL or RIL+ should be well designed not to harvest the timber more than the forests can produce. As part of the new climate agreement, individual countries should be obligated to offer RIL or RIL+ training to their logging companies before new logging license is issued.

4. Conclusion

Achieving sustainable forest management under the REDD+ mechanism requires the adoption of a sound logging practice that will reduce damages to forest stands, soils, and disturbances to upstream resources while maintaining end-use wood product. Our study suggests that reduced-impact logging plus liberation treatment (RIL+) is likely to be an appropriate logging practice that should be adopted for use in managing tropical forests under the REDD+ agreement because not only wood supply is maintained but also carbon emissions are avoided, and thus increasing carbon-based revenues.

Depending on the assumed growth rates, RIL practices (of REDD+ scenario) lead to the avoided emission reductions of 36.76-54.26 MgC ha^{-1} at the 60-year increasing from only 2.06 MgC ha^{-1} at the first year. In terms of carbon revenues, the RIL practices generate \$107.04-159.53 ha^{-1} at the year 60 increasing from only \$1.99 ha^{-1} at the first year. It is expected that when REDD+ mechanism is officially agreed, carbon price would go up leading to the increase of carbon-revenues. Financing support from the fast-start climate finance would materialize the implementation of RIL+ practices. Furthermore, as REDD+ is going to be a binding agreement at national level for reducing leakages, illegal logging will be reduced gradually, which in turn will result in more carbon loss being prevented. Increasing efficiency of wood processing will increase end-use wood product, and thus long-lived wood products in which more carbon will be accumulated, and will reduce short-lived wood residues i.e. wood wastes at the factory.

On a negative perspective as REDD+ will use existing infrastructures and human resources which have been blamed for corruption and mismanagement of forest resources. Successful implementation of the REDD+ projects require transparency and strong and sustained political commitments from Annex 1 countries that provide financial and technological supports to developing countries and non-Annex 1 countries that will act as hosting and implementing countries. Capacity building to hosting countries i.e. non-Annex 1 countries will also contribute to the success of the REDD+ projects as the concept and implementation are new to them.

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