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Benefits of tropical forest management under the new climate change agreement—a case study in Cambodia

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ABSTRACT

Promoting sustainable forest management as part of the reduced emissions from deforestation and degradation in developing countries (REDD)-plus mechanism in the Copenhagen Accord of December 2009 implies that tropical forests will no longer be ignored in the new climate change agreement. As new financial incentives are pledged, costs and revenues on a 1-ha tract of tropical forestland being managed or cleared for other land use options need to be assessed so that appropriate compensation measures can be proposed. Cambodia's highly stocked evergreen forest, which has experienced rapid degradation and deforestation, will be the first priority forest to be managed if financial incentives through a carbon payment scheme are available. By analyzing forest inventory data, we assessed the revenues and costs for managing a hypothetical 1 ha of forestland against six land use options: business-as-usual timber harvesting (BAU-timber), forest management under the REDD-plus mechanism, forest-to-teak plantation, forest-to-*acacia* plantation, forest-to-rubber plantation, and forest-to-oil palm plantation. We determined annual equivalent values for each option, and the BAU-timber and REDD-plus management options were the highest, with both options influenced by logging costs and timber price. Financial incentives should be provided at a level that would allow continuation of sustainable logging and be attractive to REDD-plus project developers.

1. Introduction

Tropical deforestation was responsible for the annual release of about 5.5 (IPCC, 2007; Gullison et al., 2007) to 8.1 billion tonne CO_2 year^{-1} (Houghton, 2003) in the 1990s. Consequently, the Intergovernmental Panel on Climate Change (IPCC) has recognized the prevention of carbon emissions from tropical forests as the largest and most immediate carbon stock impact in the short term. In addition, forest degradation (the loss of commercial and large trees, trees damaged by unplanned logging and fires) may account for another 25–42% of carbon emissions from tropical forests in Asia (Flint and Richards, 1994; Iverson et al., 1994) and 132% from Africa (Gaston et al., 1998). World leaders recently met in Copenhagen to discuss new climate change agreement to replace the Kyoto Protocol when it expires in 2012. Although a binding commitment for greenhouse gas emission reduction was not reached, global climate change mitigation through reducing emissions from deforestation and forest degradation (REDD), promoting sustainable forest management, and enhancing carbon sinks (hereafter referred to as REDD-plus) in the Copenhagen Accord was reached at the Fifteenth Conference of the Parties (COP15) to the United Nations Convention on Climate Change (UNFCCC) in December 2009. REDD-plus recognition coupled with a new pledge of annual fast-start funds of about US$3.5 billion between 2010 and 2012

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suggests that sustainable forest management in the tropics will be promoted to include sustaining timber production and other ecosystem services.

Defined here as *managing forests for sustained flow of timber and other ecosystem services*, sustainable forest management could be achieved if logging regulations are strictly followed, and with the right incentives (Pearce et al., 2003). Financial incentives for managing tropical forests that would be made available under the REDD-plus mechanism must be comparable to incentives from other land use options; otherwise clearing of natural forests for land use with high financial returns could not be prevented. Although various studies on the costs for avoiding tropical deforestation have been carried out in recent years (van Kooten et al., 2004; Bellassen and Gitz, 2008; Kindermann et al., 2008), only a handful of studies have focused on the costs for managing tropical forests (Kim Phat et al., 2004; van Kooten et al., 2004; Karky and Skutsch, 2010). Yet, important parameters, such as the costs for logging planning, harvesting, transporting, reforesting, wood processing, selling, and fees, and revenues from the sale of timber were not explicitly taken into consideration in the above studies. The REDD-plus mechanism would likely require that such parameters be incorporated in the estimates of costs of and revenues from managing tropical forests.

Deforestation and logging were responsible for the release of about 50.3 million t CO_2 $year^{-1}$ from natural forests in Cambodia during the 1970s, 1980s, and 1990s (Sasaki, 2006). Although a logging ban was imposed in 2002, forested lands are continuously granted as land concessions for industrial plantations without proper assessment of the long-term financial returns from each land use option. In this study we estimated the financial returns from six land use options (see descriptions and justifications in Table 1: business-as-usual timber harvesting (BAU-timber), forest management under the REDD-plus mechanism (REDD-plus management), forest-to-teak (*Tectona grandis*) plantation (clearing of forested land for teak plantation), forest-to-*acacia* plantation, forest-to-rubber plantation, and forest-to-oil palm plantation). Our study is structured as follows: forest inventory data are revisited and analyzed, and the resulting stem density, basal area, and volume data are classified into five tree grades so that revenues from timber harvesting for each tree grade can be estimated. We then estimate net present values (NPVs) and annual equivalent values (AEVs) from timber harvesting and compare them with values from other land uses over one management cycle each for each land use option. Finally, we suggest policy direction for materializing REDD-plus project implementation.

2. Materials and methods

2.1. *Current uses of deforested lands*

Forest cover in Cambodia declined to 10.9 million ha in 2006 from 11.1 million in 2002, representing a loss of 50,000 ha annually. Deforested lands are being replaced by forest plantations of acacia and eucalyptus and other plantations such as rubber (*Hevea brasilliensis*), teak (*Tectona grandis*), oil palm, and other industrial crops (MAFF, 2010). For this study, revenues from six land uses on a hypothetical 1 ha of cleared or managed forestland were estimated over a management cycle (Table 1), a cycle when forest or plantations are harvested. Due to the differences in management cycles for all land uses, we analyzed the annual equivalent value (AEV) so that potential revenues could be compared on a yearly basis. AEV is important tool for measuring investment performances in land use projects of unequal management cycles or time horizon (see Section 2.3) Evergreen forest accounts for 33.8% of the 10.9 million ha of forests in

Table 1 – Land use options and their management cycles considered in this study.

Land use options	Management cycle, *T* (years)	Description
BAU-timber	25	This option adopts a logging system being practiced without properly trained staff and well-defined plan. Such logging practice which is commonly practiced in tropical countries creates huge damages to residual stands and soils, and also creates huge wood waste in the forests (see Sasaki and Putz, 2009 for more details).
REDD-plus management	25	This option adopts a well-planned logging system that involves the use of well-trained staff for well-planned logging operations. This logging system is known as reduced impact logging (RIL). This option additionally involves the adoption of liberation treatment, a practice that involves the girdling of unwanted species (including invasive species, defected trees and/or lianas) to reduce competition with commercial timber species. RIL+, which includes RIL and liberation treatment shows promising results (Peña-Claros et al., 2008; Villegas et al., 2009). It is expected that all signatory countries will be required to adopt a sound logging system under the REDD-plus mechanism. This option is for REDD-plus project developers
Teak Plantation	30	Forestlands are currently being granted as economic land concessions for teak, *acacia* (including *eucalyptus*), rubber, and oil palm plantations (MAFF, 2010). Other industrial plantations have been reported but no detailed information is available.
Eucalyptus or acacia plantations	10	
Rubber plantation	30	
Oil palm plantation	25	

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Cambodia, contains high stocks of high-value timber, and is harvested for timber legally and illegally. In addition, about 29% of Cambodia's primary forests (mainly evergreen forest) were lost to severe degradation or other types of land use between 2000 and 2005 (FAO, 2006). Consequently, evergreen forest should be given the highest priority for management when the REDD-plus agreement is reached. Further descriptions of the forest, data collection, analytical methods, and results are available as online Supplementary Materials (SM).

2.2. Net present values for land use options

A brief introduction to forest resources in Cambodia, forest inventory data, and analytical results of stem density, basal area, and stand volume by timber grades are given online as SM.

Net present value (NPV) for each land use type is derived by

$$NPV = \sum_{t=0}^{T} \frac{(TR_t - TC_t)}{(1+r)^T}, \quad (1)$$

where NPV is the net present value for each land use type (US$ ha^{-1}), TR_t is total revenue ($ ha^{-1}), TC_t is total cost ($ ha^{-1}), T is the management cycle (years), and r is the discount rate (Table 1). For comparisons, three discount rates were used: 10%, which represents unstable economic growth; 8.0%, which is representative of stable economic development in least-developed countries (Hunt, 2002); and 4.0%, which was used by van Beukering et al. (2003) to study ecosystem services in a national park in Sumatra, Indonesia. Annual economic growth in Cambodia is about 6–7%.

Total revenue (TR_t) in Eq. (1) for BAU-timber and REDD-plus management can be estimated by

$$TR_t = R_{GOV} + R_{COM} + R_{CO_2}, \quad (2)$$

where R_{GOV} is revenue to the government from timber harvesting (in $ ha^{-1}), R_{COM} is revenue to the logging company ($ ha^{-1}), and R_{CO_2} is carbon revenue to REDD project developers ($ ha^{-1}).

R_{GOV} in Eq. (2) is derived by

$$R_{GOV} = \left(\sum_{i=0}^{5} R_i \times HW_i + Tax \right), \quad (3)$$

where R_i is the timber royalty (in $ m^{-3}) of harvested wood (HW_i in m^3 ha^{-1}) of tree grade i (see Table SM5 for this calculation) and Tax is the revenue from various taxes, fees, and services related to timber harvesting and wood exporting (see Table 2 for details). Tax includes fees for reforestation, the export tax on final products (i.e., 10% of the reference price of freight on board [FOB] for veneer or sawn wood), the service charge for export (1% of the FOB reference price), custom charge (0.085% of the FOB reference price), concession fees, and fees for social and infrastructure obligations (Kim Phat et al., 2001). The reforestation tax in 1997 was reported to be about $8.7, $2.6, $0.9, $0.5, and $0.5 per m^3 of harvested wood for luxury grade trees (GLT), first grade trees (G1T), second grade trees (G2T), third grade trees (G3T), and out of grade trees (OGT), respectively (Kim Phat, 1999). In Cambodia, G1T and G2T are processed for veneer and the remaining grades are processed for sawn wood for export (see SM and Table SM5). Information on forest concession fees in Cambodia was not available but fees for economic land concessions are $0.00–$10.00 ha^{-1} year^{-1} (Cabinet Minister,

Table 2 – Revenues ($ ha^{-1}) under BAU-timber and REDD-plus management options for government and REDD-plus project developers.

Description	Harvested timber and revenues by tree grades					
	GLT	G1T	G2T	G3T	OGT	Total
I. Government (Eq. (3))						
Harvested wood (30% cut in m^3)	0.24	4.35	26.24	4.92	9.56	45.31
1. Royalty ($ ha^{-1})	38.06	260.98	1049.63	157.46	191.27	1697.40
2. Reforestation						
$ m^{-3} of HW	8.70	2.60	0.90	0.50	0.50	
Total	2.06	11.31	23.62	2.46	4.78	44.22
3. Concession fees ($1 ha^{-1} year^{-1})						25.00
4. Taxes on processed wood						
WP = 0.70 × HW (m^3)	0.17	3.04	18.37	3.44	6.69	
VW = 0.54 × WP		1.64	9.92			
SW = 0.49 × WP	0.08			1.69	3.28	
Taxes (0.1 + 0.01 + 0.00085)						
FOB price of veneer		221.00	221.00			
FOB price of sawn wood	221.00			350.00	350.00	
Total taxes ($)	1.99	40.28	242.99	65.48	127.26	478.01
Subtotal	42.10	312.57	1316.24	225.40	323.31	2244.63
II. Company (Eq. (4))	17.92	363.37	2192.11	590.73	1148.08	4312.20
III. Carbon revenues (Eq. (5))						1264.00
Total revenues						
BAU-timber (I + II)						6556.83
REDD-plus management (I + II + III)						7820.83

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2000). Forest concession fees were reported to be about $0.30 and $2.40–$3.90 ha^{-1} $year^{-1}$ in Gabon (GFW, 2000a) and Cameroon (GFW, 2000b), respectively. The lowest forest concession fee was reported for Nicaragua at $0.7 km^{-2}$ or about $0.007 ha^{-1} $year^{-1}$ (Gray and Hagerby, 1997). For our study, $1.0 ha^{-1} $year^{-1}$ was used as the concession fee in Cambodia.

R_{COM} in Eq. (2) is derived by

$$R_{COM} = VW \times FOB_{VW} + SW \times FOB_{SW}, \quad (4)$$

where VW is veneer wood (m^3), FOB_{VW} is the FOB price for VW, SW is sawn wood (m^3), FOB_{SW} is the FOB price for SW (see Table SM5 for calculations). Prices for VW and SW in Cambodia were $221 m^{-3} in 1998 (Kim Phat et al., 2001). To be consistent with the cost data, we assumed a price of $221 m^{-3} for both VW and SW for this study. This price should be adjusted when more current data on logging costs in Cambodia are available.

R_{CO_2} in Eq. (2) can be estimated by

$$R_{CO_2} = C_{PRICE} \times CS_{ALL}, \quad (5)$$

where C_{PRICE} is the carbon price per tonne CO_2. We have assumed the carbon price to be $2 t^{-1} CO_2, which is within the range of previous studies (Osborne and Kiker, 2005; Bellassen and Gitz, 2008; Kindermann et al., 2008). Carbon price varies whether it is a project-based or national-based price, and from one country to another. For example governments of Norway and Guyana recently undersigned a deal for protecting Guyana's forests at $5.00 t^{-1} CO_2 (national-based price) (Norway, 2009). Based on 11 cases of avoided deforestation projects, Hamilton et al. (2008) estimated average carbon price at $4.8 t^{-1} CO_2. CS_{ALL} is the total aboveground and belowground carbon stock (see Table SM4 for calculation). Fast growth and yield have been reported under reduced impact logging (RIL) and liberation treatment practices (RIL+ hereafter) (Peña-Claros et al., 2008; Villegas et al., 2009), and we have therefore assumed that, under REDD-plus management, stand volume (also carbon stocks) can be restored to preharvest levels.

Total cost (TC_t) in Eq. (1) can be derived by

$$TC_t = TC_{GOV} + TC_{COM} + TC_{REDD}, \quad (6)$$

where TC_{GOV} is total cost incurred by the government ($ ha^{-1}), TC_{COM} is total cost incurred by logging companies ($ ha^{-1}), and TC_{REDD} is total cost for REDD-plus project developers ($ ha^{-1}). Total reported costs for one logging company in producing and selling the final products (veneer wood and sawn wood in this study) were $298.75 m^{-3} for veneer wood and $316.96 m^{-3} for sawn wood in 1998 when prices for veneer and sawn wood were $221 m^{-3} (Kim Phat et al., 2001). This particular company was already running at a loss in 1998.

TC_{GOV} in Eq. (5) can be derived by

$$TC_{GOV} = \left[\frac{(W_{STAFF} + A_{STAFF} + O_{STAFF}) \times T_{STAFF}}{H_{AREA}}\right], \quad (7)$$

where W_{STAFF} is the mean annual basic wage ($ $staff^{-1}$), A_{STAFF} is the mean annual allowance ($ $staff^{-1}$), O_{STAFF} is the mean annual overhead ($ $staff^{-1}$), T_{STAFF} is the total forestry staff in Cambodia, and H_{AREA} is the annual harvesting area (ha).

Due to the lack of reliable information for wages of government officers (staff in this study), we assumed the gross domestic product GDP per capita of $745.1 to be the same as the mean annual wage for the 1622 forestry staff (T_{STAFF}) in 1998 (Kim Phat, 1999). Fieldwork (forest management activities) is carried out in the dry season between November and April, so for this study, we assumed that each forester spends 4 months (4 × 30 = 120 days) per year for fieldwork activities. Based on personal communications with Cambodian government foresters, daily allowances of $10 for food and another $10 for accommodation are currently being paid to government foresters by logging companies or development agencies that request technical government assistance (i.e., Forestry Administration), and therefore, A_{STAFF} = 2400 (120 days × $20/day = $2400). With these assumptions, a total yearly salary for a government forester is 3145.1 (=745.1 + 2400) or about $262.09 per month, which is reasonable for government officers without relying on other sources of incomes. We assumed that $O_{STAFF} = (W_{STAFF} + A_{STAFF}) \times 0.5$, or $1572.55. According to Kim et al. (2006), the total area of forest concessions in Cambodia was 5,274,143.6 ha in 1997, of which 50% were operable (forest area suitable solely for logging, excluding all buffer zones, water surface, villages, rocky and steep slopes, and others). H_{AREA} is therefore 105,482.9 ha $year^{-1}$ [(5,274,143.6 × 0.5)/25] over the 25-year cutting cycle currently permitted in Cambodia. Although Cambodian Code for Forest Harvesting requires that logging companies pay for social and infrastructure development to forest-dependent communities, the rate for such payments is not available and is therefore neglected in our study. Under REDD-plus management, this type of payment needs to be well-defined before REDD projects can be successfully implemented.

TC_{REDD} in Eq. (5) can be derived by

$$TC_{REDD} = TC_{IMPL} + TC_{MONI}, \quad (8)$$

where TC_{REDD} is zero for BAU-timber because such activity is not implemented, and TC_{IMPL} is implementation costs, including for BAU-timber and RIL+. Additional costs for RIL are $4.50 m^{-3} of harvested wood (Kim Phat et al., 2004); total harvested wood was estimated to be 45.31 m^3 ha^{-1} (see Table SM5), therefore RIL costs are $203.90 ha^{-1} (4.50 × 45.31) in addition to the costs incurred under the BAU-timber option. The costs for liberation treatments are $25.17 ha^{-1} (Ohlson-Kiehn et al., 2006; Wadsworth and

Table 3 – Net benefits under all land use options per management cycle ($ ha^{-1}).

Land use options	Revenues	Costs	Benefits
BAU-timber	6556.83	5125.63	1431.19
Company	4312.20	5054.87	−742.67
Government	2244.63	70.76	2173.87
REDD-plus[a]	7820.57	5419.92	2400.65
Teak plantation	1000.00	41.25	958.75
Eucalyptus or acacia plantations	61.60	688.88	−627.28
Rubber plantation			
Case 1 (MAFF, 2006)	1200.00	211.93	988.07
Case 2 (Marubeni, 2004)	1200.00	250.50	949.50
Oil palm plantation	747.60	852.49	−104.89

[a] Carbon price for calculating revenues under the REDD-plus option is $2.00 t^{-1} CO_2.

Zweede, 2006). TC_{MONI} is the total costs for monitoring, reporting, and verifying as required under the REDD agreement (REDD-plus management). Due to the lack of information on TC_{MONI}, we assumed a fee equivalent to that of forest certification of \$1.40 m^{-3} of harvested wood (Kim Phat et al., 2004); therefore, TC_{MONI} = 45.31 × 1.40 = \$63.43 ha^{-1}.

TR_t and TC_t in Eq. (1) for other land uses (i.e., forest-to-teak, forest-to-*acacia*, forest-to-rubber, and forest-to-oil palm plantations) were obtained from published reports (Table 3).

2.3. Annual equivalent value (AEV) for all land use types

Due to variations in management cycle for all land use options, AEV for each option is analyzed so that financial benefits can be compared on a yearly basis. *AEV* is derived by

$$AEV = \frac{NPV \times r \times (1+r)^T}{(1+r)^{T+1} - 1} \quad (9)$$

See Eq. (1) for NPV, *r*, and *T*.

3. Results and discussions

Total stand volume of all trees with a diameter at breast height (DBH) ≥5 cm was calculated as 244.5 m^3 ha^{-1} (equivalent to about 632.0 t CO_2) (see Table SM4), of which 61.8% or 151.0 m^3 is that of mature trees (mature trees are determined in accordance with the DBH minimum size for harvesting: all trees with DBH ≥ the DBH minimum size are considered to be mature trees, of which 30% are then available for harvest. See SM for more explanation). Because only 30% of mature trees in a stand can be harvested, the total volume of wood available for harvest is 45.31 m^3 ha^{-1} for all trees per 25-year cutting cycle. This comprises G1T 4.35, G2T 26.24, G3T 4.92, and OGT 9.56 m^3 ha^{-1}, and we assumed that 0.24 m^3 ha^{-1} of GLT would be harvested due to unavoidable road construction. Timber royalties (per ha) received are \$38.06 (GLT), \$260.98 (G1T), \$1049.63 (G2T), \$157.46 (G3T), and \$191.27 (OGT), for a total of \$1697.40 ha^{-1} per 25-year cycle. Revenues per management or cutting cycle from taxes on reforestation, concession fees, and export services of processed wood (sawn wood and veneer wood) were estimated to be \$44.22, \$25.00, and \$478.01 ha^{-1}, respectively (Table 2). Altogether, we estimated revenues for the government from harvesting 1 ha of tropical natural forest to be \$2244.63 ha^{-1} per 25-year cutting cycle (management cycle) and revenues for the company to be \$4312.20 ha^{-1}. Under BAU-timber, total revenues were estimated to be \$6556.83 ha^{-1} (Table 2); while under REDD-plus management, total revenues were estimated to be \$7820.57 ha^{-1} at a carbon price of \$2.00 t^{-1} CO_2 (Table 2). Revenues under REDD-plus are strongly influenced by the price of carbon. Price of carbon is likely to rise when REDD-plus agreement is finally reached. Currently, carbon under the European Union Allowances and Certified Emission Reductions (CERs) is traded at \$17.29 (Euro 12.69) and \$15.30 (Euro 11.23) (www.pointcarbon.com).

To generate the above revenue (\$2244.63 ha^{-1}), the government employs 0.015 staff ha^{-1}, equivalent to about \$70.76 ha^{-1} [=0.015 × (745.1 + 2400 + 1572.55)]. For the company, total costs were estimated to be \$5054.87 ha^{-1} (Table 3). Due to the low timber price, logging operates at a loss of \$742.67 ha^{-1} per management cycle. Costs for government and company are the same for both BAU-timber and REDD-plus options. Due to the low costs incurred by the government, the total benefit from logging under BAU-timber is \$2173.87; however, the government can only continue to generate revenue if legal logging occurs. Without sufficient financial incentives, logging companies might hide the revenues, for example, by paying corrupt officers or through an abandoned logging business. Costs for REDD-plus project developer are \$292.50 ha^{-1} in addition to costs incurred by government and company. Therefore, total benefits under REDD-plus option are \$2400.65 [=7820.57 − (292.50 + 5125.63)], of which \$1264.00 (=2 × 632, total carbon stock is 172.2 t C or 632.0 t CO_2 in Table SM4) is from the sale of carbon avoided from deforestation and forest degradation. Under BAU-timber, AEVs were estimated to be \$32.26, \$17.88, and \$13.09 ha^{-1} for discount rates of 4.0, 8.0, and 10%, respectively. The corresponding REDD-plus AEVs are \$54.18, \$30.03, and \$21.99 ha^{-1} (Table 4). Revenues under REDD-plus option would have been higher if co-benefits such as from watershed protection, soil erosion control, recreation, and other non-carbon ecosystem services were included in

Table 4 – Annual equivalent values for all land use types.

Land use type	NPV (net present values)			AEV (annual equivalent values)		
	Discount rate (%)					
	4	8	10	4	8	10
	(\$ ha^{-1})			(\$ ha^{-1} year^{-1})		
BAU-timber	536.20	208.72	131.93	32.26	17.88	13.09
REDD-plus[a]	900.52	350.54	221.57	54.18	30.03	21.99
Teak plantation	295.60	95.28	54.94	16.16	7.77	5.27
Eucalyptus or acacia plantations	−423.77	−290.55	−241.84	−46.51	−37.68	−33.85
Rubber plantation						
Case 1 (MAFF, 2006)	304.64	98.19	56.62	16.65	8.01	5.43
Case 2 (Marubeni, 2004)	292.75	94.36	54.41	16.00	7.70	5.22
Oil palm plantation	−39.35	−15.32	−9.68	−2.37	−1.31	−0.96

[a] Carbon price for REDD-plus option is \$2.00 t^{-1} CO_2.

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our estimates. Information on co-benefits is difficult to quantify and it is not available for present study.

3.1. *Benefits from forest-to-teak*

Converting natural forest to a teak plantation incurred a total cost of \$41.25 ha^{-1} over a 30-year period, with a total return of about \$1000 ha^{-1} (Table 3) (Agrifood Consulting International, 2005). The benefit from this option is \$958.75 ha^{-1} per management cycle, with AEVs of \$16.16, \$7.77, and \$5.27 for 4.0, 8.0, and 10% discount rates, respectively (Table 4).

3.2. *Benefits from forest-to-acacia*

If a plantation of *Acacia* or *Eucalyptus* species is established over a 10-year cutting rotation, the annual cost and revenue are \$688.88 and \$61.60 ha^{-1} year^{-1}, respectively (Agrifood Consulting International, 2005), representing an AEV loss of about \$46.51, \$37.68, and 33.85 ha^{-1} year^{-1} for discount rates of 4.0, 8.0, and 10%, respectively (Table 4). Converting natural forest to *Acacia* or *Eucalyptus* plantations (mainly *E. grandis* and *A. auriculiformis*) is not profitable because the mean annual growth increment for these species in Cambodia is low (about 2.8 m^3 ha^{-1} year^{-1}) (Agrifood Consulting International, 2005) compared to 34 and 45 m^3 ha^{-1} year^{-1} (average) for *A. mangium* and *Eucalyptus* hybrid clone 0321, respectively, in Brazil (Rossi et al., 2003), 68 m^3 ha^{-1} year^{-1} for *E. grandis* in Brazil (Dedecek et al., 2001), 21 m^3 ha^{-1} year^{-1} for *E. robusta* in Malaysia and India (NAS, 1983), 28 m^3 ha^{-1} year^{-1} for *Eucalyptus* species in Thailand (Mayers, 2000), and 7–15 m^3 ha^{-1} year^{-1} for *Eucalyptus* species in Vietnam (GTZ, 2007). The lack of access to a local market is another factor that increases production costs.

3.3. *Benefits from forest-to-rubber*

Rubber plantations are the second highest source of government revenues, earning \$83 million or about 4% of the total national exports in 2004. The area covered by rubber plantations is projected to increase rapidly from 66,000 ha in 2004 to 94,000 ha in 2010, 124,000 ha in 2020, and 150,000 ha in 2030 (Cambodian Embassy, 2007). Although information on total costs and revenues from rubber plantations in Cambodia is only partially available, for the initial years between year 0 and year 6, the average cost per ha ranges from \$1520.00 (MAFF, 2006) to \$2460.00 (Marubeni, 2004) or about \$253.30 to \$410.00 ha^{-1} year^{-1}. The annual maximum maintenance cost after year 6 is estimated to be \$200.00 ha^{-1} year^{-1} (Agrifood Consulting International, 2005), whereas the annual revenue from rubber production is, on average, \$1500.00 ha^{-1} from year 6 until year 30. Over a 30-year period, the average cost for a rubber plantation has been estimated to be \$211.93 (MAFF, 2006) or \$250.50 (Marubeni, 2004) and proceeds are \$1200.00 ha^{-1} year^{-1}, while the AEVs are \$16.00 to \$16.65, \$7.70 to \$8.01, and \$5.22 to \$5.43 ha^{-1} year^{-1} for the discount rates of 4.0, 8.0, and 10%, respectively (Table 4).

3.4. *Benefits from forest-to-oil palm*

Oil palm productivity is lower in Cambodia (10.6 t ha^{-1} year^{-1} over a 25-year cycle; Agrifood Consulting International, 2005) as compared to Sumatra, Indonesia (23.0–26.0 t ha^{-1} year^{-1}; Redshaw and Siggs, 1993; Butler et al., 2009). The total annual cost over a 25-year management cycle (from planting to harvesting) for oil palm plantations in Cambodia is \$852.49 ha^{-1}, while the total revenue is only \$747.60 ha^{-1}, resulting in a loss of AEVs of about \$2.37, \$1.31, and 0.96 ha^{-1} year^{-1} at the discount rates of 4.0, 8.0, and 10%, respectively (Table 4) (Agrifood Consulting International, 2005). Therefore, converting natural forests to oil palm plantation is currently not profitable in Cambodia

3.5. *Clean development mechanism or CDM credit through afforestation and reforestation*

The Marrakesh Accord of 2001 (updated at COP9 of the UNFCCC) allows afforestation or reforestation activities as carbon sinks on land that has not been forested for at least 50 years (afforestation) or on land that was once forested but had been converted to nonforested land prior to 1990 (reforestation) (UNFCCC, 2002). Therefore, any carbon sinks resulting from other land use options that replace natural forests are not eligible for carbon credits (i.e., through CDM's afforestation and reforestation activities), and therefore carbon sinks resulting from converting natural forests to plantations and associated carbon trading are not considered in this study

4. Sensitivity analysis of financial benefits for REDD-plus option

AEVs for managing tropical forests are strongly influenced by the carbon prices whose value varies from \$1.04 to as high as \$38.15 t^{-1} CO_2 (Kindermann et al., 2008). If REDD-plus projects in Cambodia are priced at \$1.04, AEVs are estimated at \$40.53, \$22.46, and \$16.45 ha^{-1} for discount rates of 4, 8, and 10%, respectively. If the price of carbon is \$5.00 as that in the undersigned deal between governments of Norway and Guyana, AEVs are \$97.01, \$53.76, and \$39.37 ha^{-1}. If carbon is priced at \$38.15, AEVs are \$569.81, \$315.80, and \$231.26 ha^{-1}, respectively for the same discount rates above (Table 5).

Table 5 – AEVs for REDD-plus projects under various carbon prices.

Carbon Price	NPV (\$ ha^{-1})			AEV (\$ ha^{-1} year^{-1})		
	4%	8%	10%	4%	8%	10%
\$2.00 (this study)	901.29	350.84	221.76	54.22	30.05	22.01
\$1.04	673.70	262.24	165.76	40.53	22.46	16.45
\$5.00	1612.51	627.69	396.75	97.01	53.76	39.37
\$38.15	9471.51	3686.88	2330.43	569.81	315.80	231.26

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5. Policy implications

Although interests in purchasing carbon credits from REDD activities have increased (Neeff et al., 2009), transaction costs (the costs for pre-project assessments, project site identification, and documentation for buyers and regulators) for REDD-plus option remain uncertain. Transaction costs for 11 forest projects are estimated at \$0.03–\$1.23 t^{-1} CO_2 (Antinori and Sathaye, 2007). Countries with less capable human resource are likely to incur higher transaction costs. In addition to providing capacity building on REDD-plus scheme, making utmost use of existing professionals from eco-friendly logging companies, experienced environmental NGOs and local communities would help reduce the transaction costs.

REDD-plus inclusion in the new climate change agreement and firmed financial commitment from countries with emission reduction and financial obligation (Annex II in the Kyoto agreement) to developing countries would result in increase of forestlands being allocated for the REDD-plus project development. Nevertheless, as technology developed and experience gained, productivity from industrial crops in Cambodia would also increase, which subsequently would encourage government to turn their forests for clearing for industrial crop plantations. Sustained financial commitment and competitive carbon price (comparable to that being traded under compulsory market) from REDD-plus projects would keep REDD-plus revenues competitive to that from other land use options.

Furthermore, if REDD-plus mechanism only considers onsite benefits such as timber and fuelwood collection but ignores other co-benefits such as meat and food (from sustainable exploitation of wild animals, mushroom, and so on), traditional medicines, recreation, watershed protection, soil erosion control, and other non-carbon ecosystem services, less-tree but high-biodiversity forests would not be attractive to REDD-plus developers, which would result in high-biodiversity forests being converted to other land uses putting sustainable development in developing countries at risk. Achieving emission reduction while helping developing countries achieve sustainable development is among the important goals for the Kyoto protocol (2008–2012), and it would probably be retained in the new climate change agreement as well. Sustainable forest management in the new climate change agreement should be broadly defined to include all co-benefits a forest could provide since such inclusion is likely to result in reducing opportunity costs for other land uses compared to that from REDD-plus option (Pagiola and Bosquet, 2009) while sustaining forest functions.

Three types of forestland use can be classified in natural tropical forests, namely protection, production, and conversion forests (Kim Phat et al., 2004). While commercial logging i.e., through RIL+ practices under the REDD-plus mechanism should only be allowed in production forest, enhancement of carbon sinks through restoration could take place in all three forestland use types, especially on conversion forest where large trees have been logged. Protection forest has multiple ecological functions and contains high-biodiversity, and therefore commercial logging should not be allowed.

Participation of all stakeholders is important for the success of the REDD-plus projects, especially where concession forests are proposed for financial support under the REDD-plus program. In addition to adopting the REDD-plus management, logging companies must fully abide by the Code for Forest Harvesting (or logging regulations) so that adverse impacts on forests and forest-dependent communities living inside forest concessions or nearby could be reduced. Forest-dependent communities should be allowed to play a role in selecting trees for harvesting because such trees as resin or culturally important trees are very important for their livelihood and cultural or spiritual practices. Carbon-based revenues from REDD-plus project should then be distributed to all stakeholders depending on individuals' involvement in the REDD-plus project activities.

In 2009, the Royal Government of Cambodia and US-based Terra Global Capital agreed to a REDD-plus project to conserve 67,000 ha of forests in northwestern Cambodia (Khun, 2008), which will offset about 8.5 million t CO_2 over a 30-year period. This agreement is being carried out under the voluntary carbon market, which increased in its global value from \$335 million in 2007 to \$705 million in 2008. In addition, the Cambodian prime minister has pledged to place all forests in Cambodia under the anticipated REDD-plus agreement if new climate change agreement includes REDD-plus activities, indicating that Cambodia has the political will and basic infrastructure for implementing sustainable forest management or REDD-plus projects. Taking account the opportunity costs, biodiversity conservation, and co-benefits as described earlier, it is essential, therefore, that the Cambodian government prepares detailed management plans for forest resources across the country. The detailed plans should include identifying the forests to be designated for REDD or REDD-plus projects, information on forest stand structures (for degradation monitoring), scheduling regular resource assessments, identifying the roles and responsibilities of all stakeholders at all levels, and defining the benefit-sharing scheme among stakeholders. Capacity building such as regular training and related materials should also be made available to all stakeholders to ensure smooth and effective implementation of REDD projects. Socioeconomic and environmental impact assessments of resource use and management should also be provided.

6. Conclusion

Our results indicate that the economic return for managing natural forests is influenced by costs and timber and carbon prices. Under BAU-timber, logging companies operate at a loss because of the market price of timber, but government revenues are positive because taxes are based on the amount of timber harvested and sold regardless of the market price as long as there is logging going on. Logging is an essential activity as long as it is managed sustainably and there is a timber supply, and such implementation would not be possible without financial support. Under REDD-plus management, incorporating RIL and liberation treatment, the economic return is higher than for other land use options in Cambodia, although this depends on carbon prices. The carbon price from REDD-plus projects should be comparable to that from other sectors in either voluntary or compulsory

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markets, but it should be at a level that maintains logging and that is attractive to REDD-plus developers. Including all co-benefits in the REDD-plus option would maintain the opportunities costs of REDD-plus option competitive to that of other land use options. Well-defined forest management ensures the sustainability of forest resources, ecosystem functioning, and, most importantly, sustainable development of poor communities that depend almost entirely on ecosystem services that cannot be obtained elsewhere. A forest management plan that identifies the roles and responsibilities of all stakeholders is required to ensure the success of the REDD-plus projects. Importantly, this plan should not compromise the traditional, cultural and social uses of natural forests by indigenous populations. High-biodiversity forest and environmentally and ecologically sensitive forests (such as protection forest, watershed forest, and other forests prohibited by logging regulations) should be avoided from commercial logging even under the RIL+ practices as such practices will adversely affect ecological functions of forest and downstream communities. As REDD-plus is a new management concept, capacity building in terms of forest resource management and education on the consequences of different management options should be provided to all stakeholders.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.envsci.2010.04.007.

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