2. Materials and Methods

Net Present Value (*NPV*) for each land use type is derived by

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

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%.

Table 1

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

$$TR_t = R_{GOV} + R_{COM} + R_{CO2} \quad , \tag{2}$$

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_{CO2} 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 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} yr^{-1} (Cabinet Minister, 2000). Forest concession fees were reported to be about \$0.30 and \$2.40–\$3.90 ha^{-1} yr^{-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} yr^{-1} (Gray and Hagerby, 1997). For our study, \$1.0 ha^{-1} yr^{-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_{CO2} in Eq (2) can be estimated by

$$R_{CO2} = C_{PRICE} \times CS_{ALL} \quad , \tag{5}$$

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} CO2 (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} CO2. 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

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

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

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

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 1,622 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} = 2,400 (120 days × $20/day = $2400). With these assumptions, a total yearly salary for a government forester is 3,145.1 (=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 $1,572.55. 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 bufferzones, water surface, villages, rocky and steep slopes, and others). H_{AREA} is therefore 105,482.9 ha yr^{-1} [(5,274,143.6 × 0.5)/25] over the 25-yr 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

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

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 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**).

2.4. 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

Tables

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	

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	1,049.63	157.46	191.27	1,697.40
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 ($1 ha^{-1} yr^{-1}						25.00
4. Taxes on processed wood						
WP = 0.70 × HW (m3)	0.17	3.04	18.37	3.44	6.69	
VW = 0.54 × WP		1.64	9.92			
SW = 0.49 × WP	0.08			1.69	3.28	
Taxes (0.1 + 0.01 + 0.00085)						
FOB price of veneer		221.00	221.00			
FOB price of sawn wood	221.00			350.00	350.00	
Total taxes ($)	1.99	40.28	242.99	65.48	127.26	478.01
Subtotal	42.10	312.57	1316.24	225.40	323.31	2,244.63
II. Company (Eq. 4)	17.92	363.37	2,192.11	590.73	1148.08	4,312.20
III. Carbon revenues (Eq. 5)						1,264.00
Total revenues						
BAU-timber (I+II)						6,556.83
REDD-plus management (I+II+III)						7,820.83

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

Land-use options	Revenues	Costs	Benefits
BAU-timber	6,556.83	5,125.63	1431.19
Company	4,312.20	5,054.87	-742.67
Government	2,244.63	70.76	2,173.87
REDD-plus*	7,820.57	5,419.92	2,400.65
Teak plantation	1,000.00	41.25	958.75
Eucalyptus or acacia plantations	61.60	688.88	-627.28
Rubber plantation			
Case 1 (MAFF, 2006)	1,200.00	211.93	988.07
Case 2 (Marubeni, 2004)	1,200.00	250.50	949.50
Oil palm plantation	747.60	852.49	-104.89

Note

* Carbon price for calculating revenues under the REDD-plus option is $2.00 t^{-1} CO2

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} yr^{-1})		
BAU-timber	536.20	208.72	131.93	32.26	17.88	13.09
REDD-plus*	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

Note

* Carbon price for REDD-plus option is $2.00 t^{-1} CO2

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

Carbon Price	NPV ($ ha^{-1})			AEV ($ ha^{-1} yr^{-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	1,612.51	627.69	396.75	97.01	53.76	39.37
$38.15	9,471.51	3,686.88	2,330.43	569.81	315.80	231.26