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Original research article

Carbon emission reductions by substitution of improved cookstoves and cattle mosquito nets in a forest-dependent community

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ABSTRACT

Collection of fuelwood and its inefficient use for cooking and protecting animals from insects contribute to forest degradation and deforestation in developing countries. Assessment of fuelwood dependency can provide a basis for introducing effective measures for reducing emissions and fuelwood collection without compromising the basic needs of local people. Using a community located in Phnom Tbeng forest area in Cambodia, this case study assessed fuelwood dependency quantitatively via random surveys of 105 households and to project potential carbon emission reductions realized by the substitution of three-stone stoves with improved cooking stoves and the use of mosquito nets instead of wood burning to protect animals. Heads of households were targeted because of their main roles in daily family management. Three discounted rates were used to assess carbon prices as financial incentive for the substitution three-stone stove with improved cookstoves. We found that only 4% of the households had access to power from an independent power producer for lighting alone. Approximately 98% of the surveyed households collected firewood from nearby forests and used it as fuelwood for cooking, with the remaining 2% using both charcoal and fuelwood for this purpose. All respondents used the three-stone cooking stove for cooking. On average, fuelwood consumption was 2.0 ± 0.1 Mg household^{-1} yr^{-1} for daily cooking or 3.8 ± 0.2 $MgCO_2$ of carbon emissions. Burning wood for protecting cattle from insects consumed 4.3 ± 0.2 Mg household^{-1} yr^{-1} or 7.9 ± 0.3 $MgCO_2$ of carbon emissions. Using improved cookstoves and mosquito nets to protect cattle can reduce emission up to 1.1 $TgCO_2$ for the whole study site.

Substitution of conventional cookstoves with improved cookstoves and the use of mosquito nets instead of fuelwood burning could result in using less fuelwood for the same amount of energy needed and thereby result in reduction of carbon emissions and deforestation. To realize this substitution, approximately US$ 15–25 $MgCO_2^{-1}$ is needed depending on discount rates and amounts of emission reduction. Substitution of cookstoves will have direct impacts on the livelihoods of forest-dependent communities and on forest protection. Financial incentives under voluntary and mandatory schemes are needed to materialize this substitution.

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1. Introduction

Addressing climate change was a critical issue discussed at the 20th Conference of Parties to the United Nation Framework Convention on Climate Change in Lima 2014. Reducing emissions from deforestation and forest degradation was also discussed, given that these activities constitute the major source of greenhouse gas emissions in developing countries. Data for 2000–2009 suggest that land use change was responsible for the release of 1.1–2.7 PgC yr^{-1} (Friedlingstein et al., 2010; Pan et al., 2011). Fuelwood extraction from forests is an important driver of deforestation and forest degradation in developing countries. According to the International Energy Agency, 2.7 billion people or 40% of the global population rely on the use of biomass to meet their residential energy needs, predominantly cooking (IEA, 2006, 2010). Although the three-stone stove is the conventional technology for using wood biomass for cooking, this type of cookstove is not efficient and results in the unnecessary use of fuelwood by people in developing countries. In addition to deforestation, burning of biomass also releases atmospheric pollution, which threatens health and accelerates global warming (Zhang and Wang, 2005). Appropriate strategies for reducing fuelwood consumption by introducing more efficient cookstoves can reduce pressure on tropical forests and improve local people's standard of living.

Cambodia is the most vulnerable countries to climate change in the Mekong region (Yusuf and Francisco, 2009; Bradley, 2011; Tin, 2011). Climate change already became apparent in Cambodia as evident by the rise of mean temperature and erratic rainfall pattern since 1960s until recently (Tin, 2011). This change is likely to affect main sectors of Cambodian economy such as agriculture, forestry, fishery, and health. Climate impacts on forests coupled with rapid deforestation and forest degradation in Cambodia affect local livelihood because almost 100% of the rural population depend on forests and their ecosystems for daily subsistence and energy needs. Until recently, fuelwood and charcoal have been the most common sources of cooking energy for rural population in Cambodians (Geres, 2007). Depending on the location, 50% or more of fuelwood is collected from natural forests in Cambodia (CCCO, 2003). Firewood and charcoal are often considered as conventional fuels, yet they remain the dominant source of cooking energy in Cambodia, even in the cities. The World Bank (2009) reported in 2009 that over 90% of Cambodian population use firewood and charcoal, and that with increasing population, dependence on fuelwood has contributed to deforestation and forest degradation. In the late 1960s, forest cover in Cambodia was 13.2 million ha or 73% of total land area (Tran and Kol, 1987) but forest area has undergone a substantial decline to 10.4 million ha in 2010 (DFW, 1998; FA, 2011) due to logging and forest clearing during the civil wars, clearing for economy land concessions and dams, unsustainable exploitation of forests for fuelwood consumption, rapid expansion of urban area, and increasing population. Recent studies revealed that annual deforestation rate from 1973 to 2003 was 0.7% (Sasaki, 2006) and from 2002 to 2010 was 0.8% (FA, 2011; Sasaki et al., 2013), suggesting that forest cover in Cambodia is declining at an alarming rate. Firewood extraction is one of the main drivers of deforestation and forest degradation, because alternatives to fuelwood for cooking are generally expensive and rarely available in rural Cambodia (Ty et al., 2011). Although Cambodia has set a goal of providing an electricity grid to 70% of households by 2030 (Kunthy, 2012), there is still a long way to reaching this goal, and rural electricity prices are higher than urban prices due to lack of access to national grid. A fuelwood-saving solution is critically needed to reduce the massive collection of fuelwood for energy. With recently increasing interest in reducing deforestation under the REDD+ scheme, an improved cookstove (hereafter, ICS) project is seen as an ideal method for reducing fuelwood consumption with easy-to-use technologies for forest-dependent communities. In addition to emission reductions through the adoption of ICS, avoiding the burning of wood for protecting domestic cattle from insects can also result in huge emission reduction. Ty et al. (2011) reported that burning fuelwood to protect animals from insects at night was one of major drivers of forest degradation and deforestation in rural Cambodia. At night, local people traditionally burn fuelwood for several hours to protect their cattle and such burning results in huge carbon emissions. Ty et al. (2011) proposed to use mosquito nets instead of burning fuelwood. Not only this practice reduces wood collection from the forests, but it also improves human and animal health, the latter resulting in more livestock production from health animals (FAO, 2013). Until recently however, there is no study on potential carbon emissions and reductions from using mosquito nets to prevent domestic cattle in Cambodia.

Financial incentives for reducing carbon emissions in developing countries are available under Clean Development Mechanisms (CDM) of the Kyoto Protocol, the REDD+ scheme of the UNFCCC, and other voluntary carbon offsetting standards. Among the ongoing projects, ICS projects have attracted increasing attention from carbon developers. In recent years, ICS projects have been successfully implemented in Africa and Southeast Asia. CDM is one of the three flexibility mechanisms designed to reduce greenhouse gas emissions while contributing to sustainable development in developing or host countries through technology transfer and creation of environmental, social, and economic benefits. Under CDM projects, developers can acquire certified emission reductions (CERs) for activities that result in carbon emission reductions. These CERs can be sold in compliance and/or voluntary markets. To claim emission reductions (carbon credits) for sale under the CDM, carbon developers need to follow various processes and adopt the approved CDM methodologies of the UNFCCC. For example, five steps were used to obtain carbon credits in domestic cooking stoves program in Mozambique, namely development of an ICS project activity (step 1), approval by host country (step 2), validation and registration ICS project (step 3), monitoring of project activity (step 4) and verification and certification of carbon credits (step 5). According to the UNFCCC registry (PoA Registry, 2015), ICS projects generally claim emission reductions between 1 and 5 $MgCO_{2e}$ per ICS, as example ICS project in Cambodia, Nepal and Haiti has claimed emission reduction approximately 1, 1.9 and 2.5 $MgCO_{2e}$ per ICS, respectively. This change depends mainly on fuelwood consumption in a baseline scenario (a scenario occurs in the absence of project activities) and the efficiency of ICS projects. With these carbon-based incentives and given that most

Table 1
Household information in the study site.

Family size	Number of families (households)	Males (persons)	Females (persons)	Average (persons)	Average age (years)
Small (1–4 people)	44 (42%)	12	32	3.5	37.2
Medium (5–7 people)	55 (52%)	17	38	5.7	41.3
Large (>8 people)	6 (6%)	4	2	8.7	47.3
Total	105 (100%)	33	72	4.9	39.9

of the Cambodian population depends heavily on firewood and charcoal for daily energy needs but still uses inefficient cookstoves, in particular the high-fuelwood-consuming three-stone stove, large carbon emissions remain to be assessed.

The aims of this study were to assess fuelwood consumption by households in a forest-dependent community in Cambodia and to project future consumption of fuelwood, associated emissions, and emission reductions in the event that use of conventional cookstoves is substituted by the use of more efficient cookstoves and burning fuelwood is prevented by the introduction of the mosquito nets to protect cattle. A further aim was to estimate the range of carbon prices required for implementing the use of improved cookstoves and mosquito nets. The time frame for the assessment is the 10 years between 2015 and 2024, corresponding to approximately one crediting period for a verified CDM project (Geres, 2007). Qualitative and quantitative surveys were performed and data on wood consumption from 105 households in three villages in the northern part of Cambodia were collected and analyzed to provide a basis for future projection. This report also discusses a benefit-sharing mechanism and recommendations that could result in reducing deforestation and forest degradation driven by unsustainable extraction of fuelwood.

2. Socioeconomic condition of households

Ages of all 105 respondents ranged from 17 to 70 years with an average age of 40 years. Approximately 95% of respondents were father and mother, who were in charge of fuelwood collection for daily cooking and warmth. The household samples were categorized into three different family sizes; small (1–4 persons), medium (5–7 persons), and large (>8 persons). Numbers of families are 44 (42%), 55 (52%), and 6 (6%) with average age 37, 41, and 47 respectively for small, medium, and large families (Table 1). Respondents reported that cropping was the most important source of livelihood, followed by forest and non-timber forest products, livestock, labor, and fishing. Our surveys suggested that forest and non-timber forest products were firewood for daily energy needs, timber for construction, resin tapping from large trees (*Dipterocarp spp.*), rubber, wild meat, fruits and vegetables, rattan, and medicinal plants. Among 105 respondents, 30% of them owned 2–5 cattle per family. Cattle (cows and buffalo) are raised mainly for farm plowing to prepare soil for cropping, harvesting, and exporting crop products. Cattle provided important labor for daily household activities. Rainfall is the only source of water for farming, owing to the insufficiency of irrigation systems to cover agricultural land. Meat from livestock was used for household consumption as food and in some cases for sale. Most medium and large families owned cropping land, 2–5 ha per family, whereas small families owned <2 ha of land. Land tenure was recognized by the village chief and commune councils. Recognition of land tenure by the central government is not a concern of villagers because the land they own at present is socially accepted by villagers and neighboring villages (Chan and Sasaki, 2014).

3. Study method and materials

3.1. Site selection

The study sites were in the foot of Phom Tbeng forest in Preah Vihear province. Preah Vihear province is among the poorest provinces in Cambodia, experiencing a high rate of deforestation, and majority of the rural poor live on an income below US \$3 day^{-1} (World Bank PovCalNet Database, 2011). Up to 15% of the total provincial population has access to a power supply from an independent power producer (IPP), in comparison with only 4% in the study site. Although forests remain along the steep slopes of the mountain ranges, accessible forests are being threatened by clearing for agricultural cultivation, logging, and fuelwood collection. The total area of Phnom Tbeng forest is approximately 41,038 ha, including four types of forest: evergreen, semi-evergreen, deciduous, and other forest (Fig. 1). According to an unpublished analysis by the Japan Forest Technology Association (JAFTA), total forest area decreased from 41,530 ha in 2004 to 41,038 ha in 2009, with an annual decrease rate of 0.24%. More specifically, highly carbon stocked forests such as evergreen and semi-evergreen forests decreased sharply by 2.71 and 2.09%, respectively, whereas other forests decreased by 1.53% over the same period. In contrast, deciduous forest increased by 5.58% annually, from 10,954 ha to 14,013 ha, over the same period between 2004 and 2009.

Approximately 9700 households near Phnom Tbeng forests are farmers who depend entirely on agriculture and forest products for their livelihood. Firewood collection is the most common source of energy for cooking in this area. Chan and Sasaki (2014) have identified firewood extraction as one of the drivers of deforestation and forest degradation among illegal logging, clearing forest for slash-and-burn cultivation, clearing for large plantations, charcoal production, land encroachment, and forest fires.

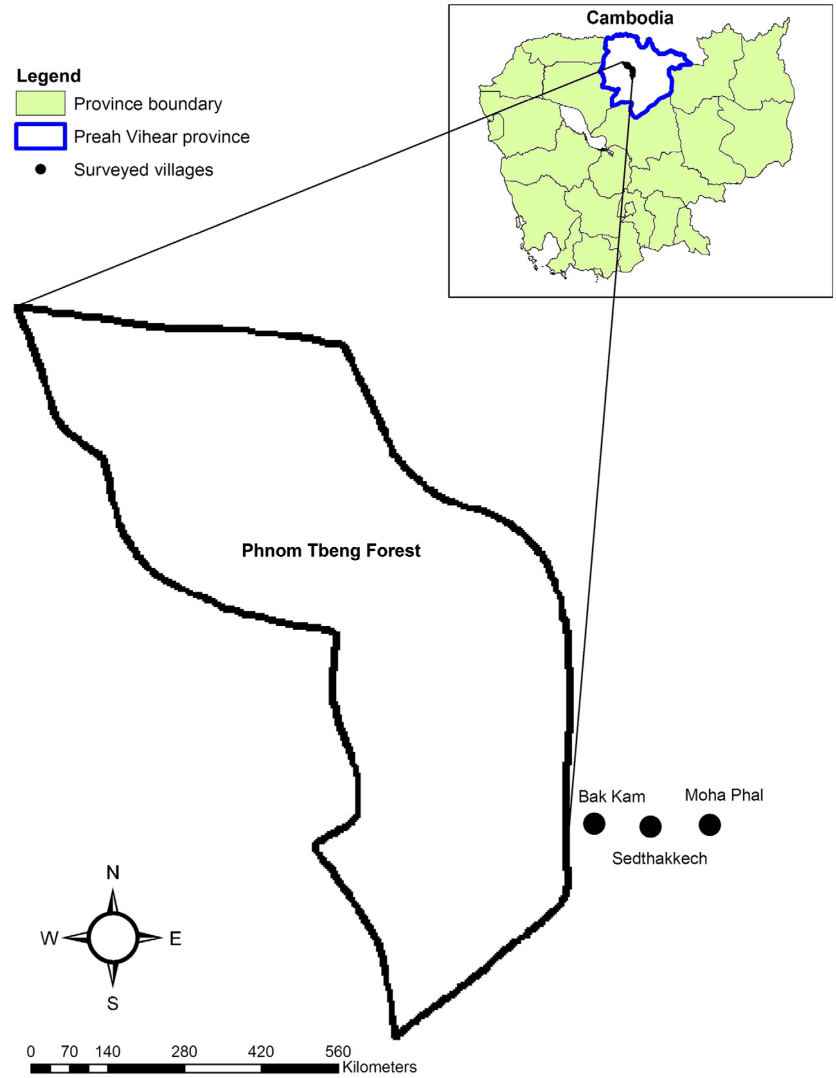

Fig. 1. Location of study site in Phnom Tbeng forest. Note: no fixed boundary for Phnom Tbeng forest was available at the time of writing this paper. It was considered as protected forest by forestry administration but there was no official decree from Cambodian government to recognize it as such.
Source: Open Development Cambodia (2008).

Field surveys were conducted in three villages (Fig. 1): Bak Kam (total population was 749 persons in 2010), Sethakech (775 persons), and Moha Phal (814 persons). These villages are located the Chhean Mukh commune, Tbeng Meanchey district, Preah Vihear Province (Fig. 1). These three villages are the closest villages to Phnom Tbeng forest and the villagers depend almost entirely on fuelwood collection for energy use. Therefore, they were selected as our study site. Owing to resource scarcity, poverty, and population growth, collection of forest and non-timber forest products is an almost daily activity for generating income. Fuelwood collection is particularly important for this community because fuelwood is the only source of cooking energy. As the forest area declines, the future availability of fuelwood is uncertain unless better methods of using fuelwood are made available.

3.2. Survey design and data collection

Prior to fieldwork, meetings with local forest rangers were organized to discuss the questionnaire surveys and the expected outcomes. Accompanied by forest rangers, the research team visited various locations in the Phnom Tbeng forest to observe the daily activities of local households. Revised questionnaires were then discussed with experts from Royal Phnom Penh University and foresters of the Forestry Administration (a governmental institution) to finalize the questionnaires and locations for data collection. The questionnaires were translated into Khmer, a Cambodian language used by households in the study site. The questionnaires had three broad headings: background information of respondents, socioeconomic data, and household energy consumption (fuelwood use, types of cookstove, and cooking patterns). The questionnaires contained a mixture of open-ended and confined questions that were administered in face-to-face interviews. In terms of fuelwood use, all respondents were asked about their purposes of using fuelwood, types and number of cooking per day, and the weight of fuelwood use for each cooking. Since respondents were not able to estimate the weight of fuelwood use, we brought and used our scales to weight fuelwood during interview so as to minimize bias. To obtain reliable answers from the households, local foresters were not allowed to accompany the research team during the interviews. The interviews were conducted intentionally just before midday because this is the time when villagers are cooking. With this timing, the research team could observe the actual practice of using fuelwood for cooking energy and the types of cookstoves being used. Villagers interviewed were heads of household responsible for cooking and even for fuelwood collection, with the aim of minimizing bias in the collected data. The household census was used as sampling frame and the respondents were chosen through a systematic random sampling method. A total of 105 randomly selected households (representing 517 family members) were interviewed in a week time from 4 to 10 April 2014. Because of the time and resource availability, members of the research group were divided into two teams; each team consists of one interviewer and one recorder. To reduce disturbing households during their busy cooking time, we tried to minimize the duration of the interviews. Average time for interview of one household was approximately 20 min. Carbon emission factors, efficiency of cookstoves, population, and other data were based on secondary sources including the Forestry Administration of Cambodia, Groupe Energies Renouvelables, Environnement et Solidarités (Geres), Royal Phnom Penh University, National Committee for Sub-National Democratic Development, Forest Trends' Ecosystem Marketplace and Bloomberg New Energy Finance.

3.3. Estimation of carbon credits and prices

On the basis of our surveys, the majority of the population in the study site used three-stone stoves (TSS) for cooking, boiling water, and burning wood to generate smoke to protect their cattle against insects. Previous studies have found that three-stone stoves consume more fuelwood than other cookstoves (Batchelor, 1997; Kituyi et al., 2001; Turker and Kaygusuz, 2001; World Bank, 2009). Two types of cookstoves are more efficient with respect to fuelwood consumption for producing needed energy. They are the Traditional Lao Stove (TLS) and the New Lao Stove (NLS) (Table 2). Geres (2007) and (World Bank, 2009) reported that both Lao cookstoves have net savings of 43.1% and 64.0% of wood consumption, respectively, compared with the three-stone stove (TSS). Assessments of carbon emissions from the use of fuelwood for cooking energy were performed for TSS, TLS, and NLS. Furthermore, the study found that another source of fuelwood consumption is burning wood to protect animals from insects at night, an activity for which emissions cannot be reduced by ICS. Regardless where cattle is kept at night (with or without barn), villagers commonly burn tree stumps and tree trunk close to their cattle in order to generate smoke to prevent insects, particularly mosquito from biting. Since using stove for this activity is not possible, preventing the burning of fuelwood for protecting could be possible through cattle mosquito netting method. There are various sizes of mosquito nets and the average price of one mosquito net is US$5 with 2 years effective lifetime (Erlanger et al., 2004). Given that TSS is the common daily practice in the study site, we considered TSS plus burning fuelwood for protecting cattle from insects (i.e. mosquitoes) as baseline practice (activities in the absence of financial incentives). Under project scenario 1, TSS will be substituted by TLS and cattle mosquito nets are used to replace burning fuelwood against insects. Under project scenario 2, TSS will be substituted by NLS and the use of cattle mosquito nets to replace burning fuelwood against insects. Ty et al. (2011) have introduced a method for protecting animals with mosquito net instead of burning fuelwood. Relative Impact Project (RPI) data of Ty et al. (2011) were used to estimate project emissions. These emissions will also be included in the whole assessment.

Carbon Credits (CC)

$$CC\,(t) = \left[CE_{\text{Baseline}}\,(t) - CE_{\text{Project}}\,(t)\right] \times \left[(1 - \text{Leakages})\right]. \tag{1}$$

$CC(t)$ represents carbon credits ($MgCO_2$) obtained through project implementation, $CE_{\text{baseline}}(t)$ represents carbon emissions under baseline ($MgCO_2$), $CE_{\text{project}}(t)$ represents carbon emissions under project ($MgCO_2$), and t indexes time steps. Leakages are carbon emissions outside project boundary being 15% (0.15) of emission reductions (Geres, 2007). $CE_{\text{baseline}}(t)$ is derived as

$$CE_{\text{Baseline}}(t) = \text{CE\_CB}(t) + \text{CE\_AI}(t). \tag{2}$$

$\text{CE\_CB}(t)$ represents carbon emissions from cooking and boiling for daily needs ($MgCO_2$),
$\text{CE\_AI}(t)$ represents carbon emissions from burning wood for protection against insects ($MgCO_2$).
$\text{CE\_CB}(t)$ and $\text{CE\_AI}(t)$ are derived as

$$\text{CE\_CB}(t) = \text{CB} \times \text{HH}(t) \times 0.5 \times 44/12. \tag{3}$$

$$CE_{\text{AI}(t)} = \text{AI} \times [\text{HH}(t) \times (1 - \text{HH}_{no\_cattle})] \times 0.5 \times 44/12. \tag{4}$$

CB is average fuelwood consumption for cooking and boiling per household per year (Mg yr^{-1}), AI is average fuelwood consumption for burning against insects per household per year (Mg yr^{-1}) taken as average of fuelwood consumption from 105 surveyed households. $\text{HH}(t)$ represents the number of households at time t, $\text{HH}_{\text{no\_cattle}}$ represents household without

Table 2
Characteristics, efficiency and cost of individual cookstoves.
Source: ICS design. http://www.cfsp.org.kh/ics_design.html.

Type of stove	 Three-stone stove (TSS)	 Traditional Lao stove (TLS)	 New Lao stove (NLS)
Materials	Stones	Metal covered, baked clay	Metal covered, baked clay
Weight (Kg)	Varies	3–8	12
Height (cm)	Varies	Multi	30
Width (cm)	Varies	Multi	25.4
Length (cm)	Varies	Multi	25.4
Efficiency (%)	10	24	29
Energy saving (%)	No	43.1 Used in Eq. (6)	64.0 Used in Eq. (6)
Cost	Free	US $1.5	US $3.5–5

cattle 10% (0.1) (NCDD, 2010), 0.5 represents carbon content (conversion rate from wood to carbon), and 44/12 is the ratio of the molecular weight of CO_2 to that of carbon. HH(t) is derived as

$$\mathrm{HH}\,(t) = \mathrm{HH}\,(0) \times e^{a \times t}. \tag{5}$$

HH(0) represents the number of households in the Phnom Tbeng forest area at time $t = 0$, a is population growth rate with 6.3% (NCDD, 2010), t is time step (year). $\mathrm{CE}_{\mathrm{project}}(t)$ is derived as

$$\mathrm{CE}_{\mathrm{Project}}\,(t) = [\mathrm{CE\_CB}\,(t) \times (1 - \mathrm{NS})] + [\mathrm{CE\_AI}(t) \times \mathrm{RPI}(t)]. \tag{6}$$

NS is net savings from ICS, 43.1% (0.431) (calculated from Geres data) by shifting from TSS to TLS (project 1), 64.0% (0.64) by shifting from TSS to NLS (project 2) (Geres 2007). 43.1% derived by 64.0%–20.9% (20.9% is net saving from TLS to NLS). RPI(t) is relative project impact taken from Ty et al. (2011). RPI(t) is derived from introducing mosquito nets rather than burning fuelwood to protect animals against insects.

Carbon price (CP)

$$\mathrm{CP} = \mathrm{PV\_TC} / \sum \mathrm{CC}(t). \tag{7}$$

CP is carbon price at break-even point (US \$ $MgCO_2^{-1}$) where there is neither profit nor loses, PV_TC is present value of total costs between 2015 and 2024 (US \$). PV_TC is derived as

$$\mathrm{PV\_TC} = \sum [\mathrm{TC}(t) \times (1 + r)^{-t}]. \tag{8}$$

TC(t) denotes total costs including ICS costs, rice costs, mosquito nets costs and transaction costs at time t. r denotes discount rate, with 5%, 10% and 15% assumed for financial comparison. The discount rates of 5%–15% were used in our study with reference to the rates of economic growth in Cambodia over the last 10 years. The rates were between 6% and 13% except in 2009 when Cambodia effected by global economic crisis (World Bank, 2015). $\mathrm{ICS}_{\mathrm{costs}}$ refers to costs of giving one ICS to a household every two years. One ICS unit costs US \$1.5 under project 1 and US \$4 under project 2, ICS(t) = US \$1.5 × HH(t) (project 1); ICS(t) = US \$4 × HH(t) (project 2). Assuming that 30 kg of rice is given every month as an incentive (1 kg of rice is valued at 1700 riels; World Food Program, 2014), this 30 kg of rice is valued at US \$12.75 month^{-1} or US \$153 yr^{-1}(US \$1 = 4000 riels), equivalent to 12% of Cambodian GDP per capita (US \$1108) (IMF, 2014). It will be sufficient to feed two members per family, given that the Ministry of Agriculture, Forestry and Fisheries of Cambodia reports that rice consumption per capita is 13 kg month^{-1}. $\mathrm{Rice}_{\mathrm{costs}}(t)$ = 30 kg × 1700 riels × 12 × HH(t). Average cost of a mosquito net is US \$5 with 2 years lifetime (Erlanger et al., 2004), thus Mosquito net Cost(t) = US \$5 × HH(t) × [$1 - \mathrm{HH}_{\mathrm{no\_cattle}}$]. On the basis of the Geres ICS project, the total transaction cost is US \$1.37 million with carbon emission reduction of approximately 2.4 million $MgCO_2$, equivalent to US \$1.75 $MgCO_2^{-1}$; thus, $\mathrm{Transaction}_{\mathrm{costs}}(t)$ = US \$1.75 × CC(t). Camille and Jayant (2007) reported similar figures for transaction cost, ranging from US \$0.22 to \$2.48 $MgCO_2^{-1}$ under an energy efficiency project. In other reviews, transaction costs for a small-scale CDM project comprise registration fee (maximum US \$350,000) (MOE, 2010), search and negotiation costs between US \$22,000 and US \$160,000, approval costs between US \$12,000 and US \$120,000, and monitoring costs between US \$5000 and US \$270,000 (Michelowa et al., 2003; de Gouvello and Coto, 2003; Krey, 2004; EcoSecurities, 2003).

4. Results and discussion

4.1. Household energy consumption

Among the 105 households interviewed, 98% used firewood to cook, boil water, prepare animal food, and protect their cattle from insects such as mosquitoes. The remaining 2% used both charcoal and fuelwood. Respondents reported that 5 plant species are the most preferred for fuelwood collection namely Pchoek (*Shorea obtusa*), Trosek (*Peltophorum ferrugineum*), Tbeng (*Dipterocarpus obtusifolius*), Khlong (*Dipterocarpus tuberculatus*) and Sokram (*Xylia xylocarpa*). Our previous study in the same area (Chan and Sasaki, 2014) found that firewood extraction for household energy consumption was one of the major causes of deforestation and forest degradation in Phnom Tbeng forest. The present study showed that the average household's fuelwood consumption for cooking was 3.23 ± 0.30 ($\pm$ refers to 90% of confidence level), 3.73 ± 0.23, and 4.83 ± 0.50 kg day^{-1} household^{-1} for small, medium, and large families, respectively. Boiling water consumption on average was 1.73 ± 0.60, 2.21 ± 0.15, and 2.66 ± 0.54 kg day^{-1} household^{-1} for small, medium, and large families, respectively. Overall average fuelwood consumption for cooking and boiling water was 5.62 ± 0.27 kg day^{-1} household^{-1} or $CB = 2.05 \pm 0.1$ Mg yr^{-1} household^{-1} (used in Eq. (3)). Geres (2007) reported that household monthly fuelwood consumption was 37.64 kg or 0.44 Mg yr^{-1} in Phnom Penh. The figures in our study are higher. There are many possible reasons. One reason could be that Geres surveyed an area where villagers had already changed to Traditional Cookstoves and the water was clean, whereas in Preah Vihear province there is not enough safe water to drink or proper water storage, and water must be taken from lakes or wells and boiled. Family size is also another factor increasing fuelwood consumption. As seen in figures above, fuelwood consumption increases with family size. This relationship is consistent with the results of Miah et al. (2009) who found that family size influences the amount of fuelwood consumption per family. Livestock and cattle play an important role in livelihoods. The study found that villagers usually protect their animals by burning fuelwood to produce smoke for protection against insects that are abundant at night, particularly during the rainy season. Households reported that they prefer to collect tree stumps rather than tree stems in the forest because stumps produce more smoke to protect their animals from insects. As the result of several hours of burning fuelwood, the average amount of fuelwood consumption is 11.77 ± 0.89 kg day^{-1} household^{-1} or $AI = 4.29 \pm 0.18$ Mg yr^{-1} household^{-1} (used in Eq. (4)) for those who raise cattle. This figure is double that for fuelwood consumption from cooking and boiling water. Thus, as fuelwood becomes increasingly scarce, an alternative method for reducing these emissions is needed. Although emissions from burning fuelwood for protection against insects cannot be reduced by ICS because cookstoves are not required for these activities, Ty et al. (2011) introduced a new method of protecting cattle against insects with mosquito netting instead of burning fuelwood. This method could be introduced to our study areas as well, but training for the appropriate use of the method is important because villagers tend not to adopt the new method readily. Some local people stated that they prefer a combination of fuelwood and rice straw or rice husks that produces more smoke without cost. Although smoke can prevent insects from their animals, it can also cause health problems for villagers (Jin et al., 2006).

4.2. Carbon emissions and carbon credits

Our projection suggests that during the 10-year modeling period between 2015 and 2024, households in the study site increased from 13,261 families in 2015 to 23,379 in 2024 based on the annual population growth rate of 6.3% in 2010 (NCDD, 2010). Chan et al. (2013) reported that without project activities to protect Phnom Tbeng forest, this forest is likely to decline 0.24% annually, suggesting that fuelwood increase due to forest growth is not sufficient to supply wood to local demand. Using the average fuelwood consumption in Section 4.1 ($CB = 2.05 \pm 0.10$ Mg household^{-1} yr^{-1} and $AI = 4.29 \pm 0.18$ Mg household^{-1} yr^{-1}), baseline emissions in the full project area were estimated. As seen in Table 3, carbon emissions from cooking and boiling water increase from 49,872 MgCO_2 in 2015 to 87,923 MgCO_2 in 2024, whereas emissions from burning fuelwood for protection against insects increase from 94,003 to 165,724 MgCO_2. In total, carbon emissions from cooking, boiling, and burning fuelwood for protection against insects were estimated at 673,082 MgCO_2 and 1,268,676 MgCO_2 respectively for the 10-year modeling period. Consequently, total carbon emissions under the baseline scenario or in the absence of project activities were estimated at 1,941,759 MgCO_2 over a 10-year period or 194,176 MgCO_2 yr^{-1}.

To reduce these emissions, two project scenarios have been introduced. Under project scenario 1, TSS has switched to TLS with 43.11% of fuelwood saved. Second, project scenario 2 affords 64% of fuelwood saving by switching from TSS to NLS. Under both scenarios, introduction of mosquito nets to replace burning fuelwood for protection against insects has been implemented. As seen in Table 4, carbon emissions under project scenario 1 were estimated at 847,475 MgCO_2 for the 10-year modeling period or 84,748 MgCO_2 yr^{-1} less than baseline emissions, whereas total leakages (15%) accounted for 164,142 MgCO_2 or 16,414 MgCO_2 yr^{-1}. Thus, the total CC under project scenario 1 was estimated at 930,141 MgCO_2 or 93,014 MgCO_2 yr^{-1}. These emission reductions are equivalent to 507,350 Mg of wood, corresponding to 6,187 ha of forest saved (this is based on average 1 hectare of forest in Asia contains 82 Mg of wood) (FAO, 2000). Under project scenario 2, carbon emissions were estimated at 706,801 MgCO_2 for the 10-year modeling period or 70,680 MgCO_2 yr^{-1} lower than baseline emissions and project scenario 1, whereas total leakages (15%) accounted for 185,244 MgCO_2 or 18,524 MgCO_2 yr^{-1}. Thus, total CC under project scenario 2 were estimated at 1,049,714 MgCO_2 or 104,971 MgCO_2 yr^{-1}. These emission reductions are equivalent to 572,571 Mg of wood, corresponding to 6,983 ha of forest saved.

Table 3
Household growth, carbon emissions from cooking and boiling, insect protection, and baseline emissions.

Year	Households	Cooking and boiling CE_CB ($MgCO_2$)	Insects protection CE_AI ($MgCO_2$)	Baseline emissions $CE_{baseline}$ ($MgCO_2$)
2015	13,261	49,872	94,003	143,875
2016	14,124	53,115	100,116	153,231
2017	15,042	56,569	106,626	163,195
2018	16,020	60,248	113,559	173,807
2019	17,062	64,165	120,944	185,109
2020	18,172	68,338	128,808	197,146
2021	19,353	72,782	137,184	209,966
2022	20,612	77,514	146,105	223,620
2023	21,952	82,555	155,606	238,161
2024	23,379	87,923	165,724	253,648
Total		673,082	1,268,676	1,941,759
Annual		67,308	126,868	194,176

Table 4
Emission reductions under project scenarios 1 and 2.

Year	Baseline emissions ($MgCO_2$)	Project emissions1 ($MgCO_2$)	Leakages1 ($MgCO_2$)	CC1 ($MgCO_2$)	Project emissions2 ($MgCO_2$)	Leakages2 ($MgCO_2$)	CC2 ($MgCO_2$)
2015	143,875	122,380	3,224	18,271	111,957	4,788	27,131
2016	153,231	123,130	4,515	25,586	112,029	6,180	35,022
2017	163,195	107,466	8,359	47,370	95,643	10,133	57,419
2018	173,807	79,023	14,218	80,566	66,432	16,106	91,269
2019	185,109	71,705	17,011	96,394	58,294	19,022	107,793
2020	197,146	62,843	20,146	114,158	48,560	22,288	126,298
2021	209,966	66,380	21,538	122,048	51,169	23,820	134,978
2022	223,620	69,674	23,092	130,854	53,474	25,522	144,624
2023	238,161	72,804	24,803	140,553	55,550	27,392	155,219
2024	253,648	72,070	27,237	154,341	53,694	29,993	169,961
Total	1,941,759	847,475	164,142	930,141	706,801	185,244	1,049,714
Annual	194,176	84,748	16,414	93,014	70,680	18,524	104,971

As seen in Fig. 2, project scenario 2 is the best option with carbon emissions clearly lower than those of project scenario 1 and the baseline scenario. This result suggested that one unit of ICS could reduce carbon emissions by approximately 1.4 ± 0.07 $MgCO_2$ yr^{-1} and 2 ± 0.09 $MgCO_2$ yr^{-1} respectively for project scenarios 1 and 2; whereas using mosquito net can reduce emissions 3.8 ± 0.18 $MgCO_2$ yr^{-1} for both project (90% confidence interval). The second project scenario appears to be the best option. Total costs and carbon prices of both project scenarios are discussed in the next section.

4.3. Carbon price for project implementation

Owing to the uncertainty of future carbon agreements, carbon prices have fallen from US \$6.2 to \$5.9 to \$4.9 $MgCO_2^{-1}$ in 2011, 2012, and 2013, respectively Forest Trends' Ecosystem Marketplace 2014. This issue has become a concern to carbon project developers. If carbon is traded at the current price of US \$5 $MgCO_2^{-1}$ (mean carbon price in the voluntary carbon market was US \$4.9 $MgCO_2^{-1}$ as reported by Forest Trends' Ecosystem Marketplace (2014)), total revenue from carbon sales will be only US \$4.7 million or US \$0.47million yr^{-1} and US \$5.2 million or US \$0.52million yr^{-1} respectively, for project scenarios 1 and 2. To compare the carbon price of this project with the current carbon price in the actual market, three types of discount rate (5%, 10%, and 15%) were used to calculate the present value of total costs from 2015 to 2024. As seen in Table 5, total costs are much higher than total revenues at the current carbon price. Total costs comprised ICS costs (US \$0.07–0.11 million under project 1), (US \$0.19–0.28 million under project 2); rice costs (US \$14.72–21.65 million under project 1), (US \$14.72–21.65 million under project 2), mosquito nets costs (US \$0.22–0.32 million under project 1), (US \$0.22–0.32 million under project 2) and transaction costs (US \$0.76–1.23 million under project 1), (US \$0.88–1.40 million under project 2). As the result, total costs range from US \$15.7 to 23.3 million under project 1 and US \$16 to 23.6 million under project 2 for the 10-year time frame. This result clearly shows that the current carbon price (US \$4.9 $MgCO_2^{-1}$) is insufficient to provide incentives for implementing these projects. On the basis of our study, the carbon prices should be at least US \$25.05, US \$20.35, and US \$16.96 $MgCO_2^{-1}$ under project 1 or US \$22.52, US \$18.30, and US \$15.25 under project 2 at discount rates of 5%, 10%, and 15% respectively (Table 5). However, there is still a high expectation that the carbon price will increase again after a new climate agreement is reached at the upcoming COP 21 in December 2015.

5. Framework for reducing carbon emissions from firewood extraction

Cambodia's energy sector plays a crucial role in the country's continued development. However, Cambodia has no proven fossil fuel reserves and is almost completely dependent on imported diesel fuel for electricity production and other power

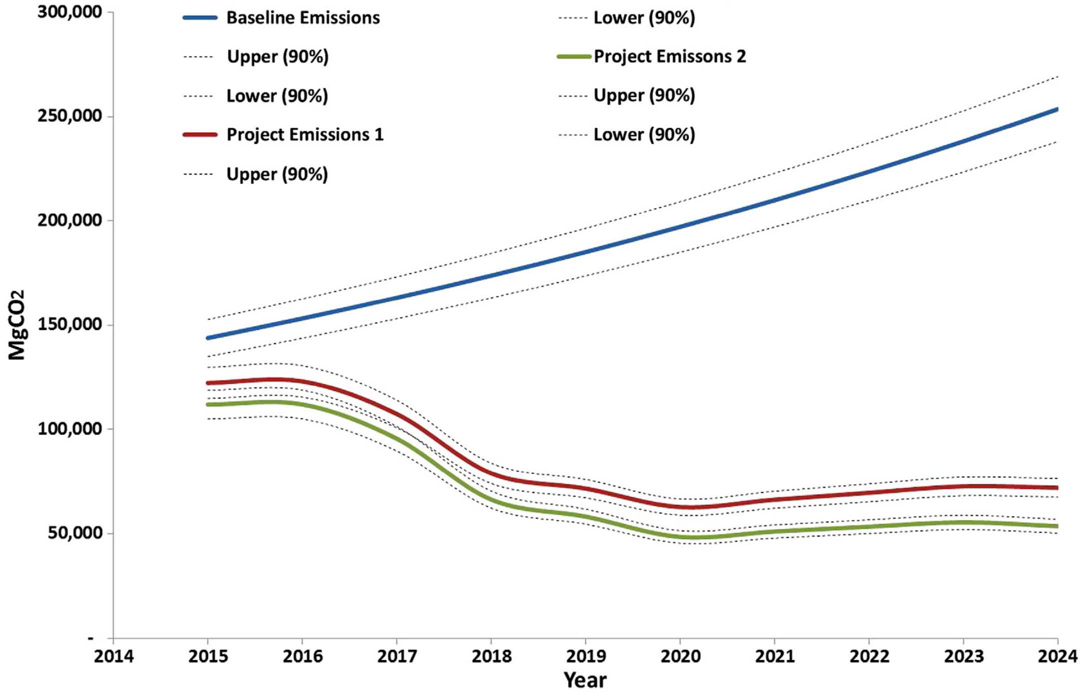

Fig. 2. Baseline emissions, project emissions 1, and project emissions 2.

Table 5
Total costs and carbon price of project 1 and project 2.

Description	Present value of total costs from 2015 to 2024 (US $)		
	5%	10%	15%
ICS_{costs}	105,362	87,767	74,901
$Rice_{costs}$	21,647,718	17,619,913	14,715,200
Mosquito $nets_{costs}$	316,087	263,302	224,702
$Transaction_{costs}$	1,229,622	953,747	757,680
Total cost under project 1	23,298,788	18,924,729	15,772,481
Carbon price under project 1 (US \$ $MgCO_2^{-1}$)	25.05	20.35	16.96
ICS_{costs}	280,966	234,046	199,735
$Rice_{costs}$	21,647,718	17,619,913	14,715,200
Mosquito $nets_{costs}$	316,087	263,302	224,702
$Transaction_{costs}$	1,395,044	1,088,390	870,126
Total costs under project 2	23,639,815	19,205,651	16,009,763
Carbon price under project 2 (US \$ $MgCO_2^{-1}$)	22.52	18.30	15.25

applications. The demand for fossil fuel imports in Cambodia grew by an average 33% yr^{-1} from 1997 to 2000 and there is no sign of slowing of this trend (Samy, 2004). Current energy prices in Cambodia may not be affordable for the poor. For this reason a majority of the population opts to use energy derived from biomass, particularly fuelwood, for daily consumption (MIME, 2004; Kunthy, 2012). Investment in hydroelectric dams and solar panels with cheap electricity prices is vital for reducing dependency on fuelwood. Introducing alternative renewable energy sources such as biogas to rural areas will also reduce dependence on wood. Small-scale biogas production has proved to be one of the most promising renewable-energy technologies, having very low generation cost and being widely used for cooking and lighting in rural areas of India, China, and Nepal (Nijaguna, 2002; Katuwal and Bohara, 2009). Biogas is usually generated from agricultural residues and livestock dung available around villages.

To date, only one foreign organization has worked on ICS programs in Cambodia: Groupe Energies Renouvelables, Environnement et Solidarités (Geres). Geres's ICS project ended in 2013 and a new ICS project is urgently required. However, a successful project requires appropriate intervention and the cooperation of the host country. It is not easy to change the behavior of local people from use of three-stone stoves unless the advantage of ICS use can be broadly disseminated and the impact of the project can be compensated with appropriate benefit-sharing mechanisms to ensure that livelihoods can be improved. In Vietnam, villagers are given 200,000 dong and 15 kg of rice every month as income in exchange for protecting the forest (Mucahid et al., 2014). As in the above study, local people have been given at least one ICS every two years and 30 kg of rice monthly per household as incentives to participate in project activities. However, it would not be enough to feed the whole family; thus, creating jobs at a local level through factory or enterprise development, especially in the ecotourism sector, can provide sustainable income to villagers. They can switch their jobs from producing charcoal, an occupation that threatens forest resources, to working as guides or as sellers of forest and non-forest products. In 2000, Qingkou forest-dependent communities in China have been developed as eco-cultural tourism villages where local people can earn money from sales of entry tickets, cultural performances, guiding services, renting camping sites, and selling forest products (Gu et al., 2012). Even after the above actions have been implemented, wood demand is still increasing owing to population growth. Plantations of fast-growing fuelwood species such as *Acacia* spp. and *Albizia* spp., in non-forest areas would also be an ideal method for supplying local and outside demand.

6. Conclusion

Rural households in the study area depend on fuelwood as a primary energy source for multiple purposes including cooking, boiling water, animal protection against insects, and preparation of animal feed. Not only is fuelwood extracted for household consumption, but in some cases, trees have been cut to produce charcoal for extra income. Approximately 98% of the 105 sampled households were using fuelwood for daily consumption and 2% were using charcoal and fuelwood. Current energy structure consumption in study site is dominated by biomass which TSS are commonly used. The results clearly showed that wood consumption in rural area is higher than urban area. Overall average fuelwood consumption for cooking and boiling water was 5.62 ± 0.27 kg day^{-1} household^{-1} or 2.05 ± 0.1 Mg yr^{-1} household^{-1}. Fuelwood is also burned to generate smoke for protecting animals against insects. This practice accounted for 11.77 ± 0.89 kg day^{-1} household^{-1} or 4.29 ± 0.18 Mg yr^{-1} household^{-1}. Carbon emissions and deforestation can be further reduced by using mosquito nets instead of burning wood to protect cattle from insects.

Altogether, using improved cookstoves and mosquito nets can reduce carbon emissions up to 1,049,714 $MgCO_2$ for 10-year project or about US $5.2 million depending on carbon price. This study suggested that total revenues at the current carbon price are insufficient to implement the low-carbon project unless the carbon prices are in the minimum range of US $15–25 $MgCO_2^{-1}$. The carbon price is a crucial factor in carbon project development; therefore, any carbon agreement should consider carbon price at a level that ensures that a carbon project is feasible. Moreover, developing countries do not have an obligation to reduce their emissions, but have a right to pursue development and poverty reduction as national priorities. Thus, a successful project should contribute to local livelihoods by both benefit sharing and technology transfer for long-term sustainable development. Further studies on collection and use of fuelwood by local people according to seasonal variations (i.e. two to four times of survey per year) would improve accuracy of our research findings such as carbon emission reductions and prices.

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