Leaflet No. 8/2022

The Republic of the Union of Myanmar
Ministry of Natural Resources and Environmental Conservation
Forest Department

Estimation carbon emissions from fuelwood consumption in a forest-dependent community

Dr. Yu Ya Aye, Assistant Director
Khaing Wut Hmone, Staff Officer,
Zin Thet Hein, Project Secretary
Phyo Htet Zaw, Project Assistant
KFS REDD+ project
Forest Research Institute, Yezin

February, 2023

Contents

List of Tables

List of Figures

.

Estimation carbon emissions from fuelwood consumption in a forest-dependent community

Yu Ya Aye[1]*, KhaingWut Hmone[2], ZinThet Hein[3], PhyoHtet Zaw[4]

[1]Assistant Director, Forest Silviculture Section, Forest Research Institute; [2]Staff Officer, Forest Silviculture Section, Forest Research Institute; [3]Project Secretary, FD-KFS REDD+ project, Forest Research Institute; [4]Project Assistant, FD-KFS REDD+ project,

Forest Research Institute

Abstract

Fuelwood remains a dominant energy source in the developing world. Collection of fuelwood and its inefficient use for cooking 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 with compromising the basis needs of local people. Besides, there is concern over the carbon emission of the fuelwood use for cooking in rural areas; however, studied have mainly been limited to Myanmar. Using a community located the surrounding area of the North Zarmari Wildlife Sanctuary, this case study assessed fuelwood dependency quantitatively via surveys of 422 households and to project potential carbon emission reductions realized by the substitution of three-stone stoves with improved cooking stoves. All of the respondents used fuelwood (firewood and charcoal) for cooking. On average, fuelwood consumption was 4.02 ± 0.15 Mg household^{-1} yr^{-1} for daily cooking or 7.38 ± 0.27 MgCO_2 of carbon emissions. Substitution of conventional cookstoves with improved cookstoves could result in using less fuelwood for the same amount of energy needed and thereby result in reduction of carbon emissions and deforestation. Not only this study provide information on fuelwood consumption in rural community but the information is important for designing efficient use of fuelwood that could result in reduction of carbon emissions and deforestation.

Keyword: climate change, carbon emission, deforestation, forest degradation, fuelwood

*****Corresponding author: yuyaaye@gmail.com

သစ်တောအပေါ်မှီခိုသည့်ကျေးရွာများ၏ ထင်းလောင်စာသုံးစွဲမှုမှ ကာဗွန်ထုတ်လွှတ်မှု အခြေအနေအား လေ့လာခြင်း

စာတမ်းအကျဉ်း

ထင်းလောင်စာသည် ဖွံ့ဖြိုးဆဲနိုင်ငံများတွင် အဓိကအသုံးပြုလျက်ရှိသည့် စွမ်းအင် တစ်ခုဖြစ်ပါသည်။ ဖွံ့ဖြိုးဆဲနိုင်ငံများရှိ ကျေးလက်နေပြည်သူများ ထင်းလောင်စာ စုဆောင်း ခြင်းသည် သစ်တောပြုန်းတီးခြင်းနှင့် သစ်တောအတန်းအစားကျဆင်းခြင်းကို ဖြစ်စေသော အကြောင်းရင်း တစ်ရပ်ဖြစ်ပါသည်။ ထင်းလောင်စာသုံးစွဲမှုလျှော့ချခြင်း လုပ်ငန်းများ ဆောင်ရွက်နိုင်ရေးအတွက် ကျေးလက်နေပြည်သူတို့၏ ထင်းလောင်စာသုံးစွဲမှု စာရင်း ကောက်ယူရန် လိုအပ်လျက်ရှိပါသည်။ ထင်းလောင်စာသုံးစွဲမှုလျှော့ချခြင်းဖြင့် ကာဗွန် ထုတ်လွှတ်မှုကိုလည်း လျှော့ကျစေနိုင်မည် ဖြစ်ပါသည်။ သို့ရာတွင် မြန်မာနိုင်ငံ၌ ထင်းလောင်စာ သုံးစွဲခြင်းကြောင့် ကာဗွန်ထုတ်လွှတ်မှုကို လေ့လာသော သုတေသနများ လိုအပ်လျက်ရှိပါသည်။ ဤသုတေသနတွင် မြောက်ဇာမရီတောရိုင်းတိရစ္ဆာန် ဘေးမဲ့တော ပတ်ဝန်းကျင် ကျေးရွာများ၏ ထင်းလောင်စာသုံးစွဲမှုအား စာရင်းကောက်ယူ၍ ကာဗွန် ထုတ်လွှတ်မှုကို လေ့လာတွက်ချက်ထားပါသည်။ သုတေသနတွေ့ရှိချက်အရ မြောက်ဇာမရီ တောရိုင်းတိရစ္ဆာန်ဘေးမဲ့တော ပတ်ဝန်းကျင်ကျေးရွာများတွင် နေထိုင်လျက်ရှိသော အိမ်ထောင်စုများသည် နေ့စဉ်ချက်ပြုတ်စားသောက်ရေးအတွက် ထင်းလောင်စာကို အဓိက သုံးစွဲလျက်ရှိပြီး ပျမ်းမျှအားဖြင့် တစ်နှစ်လျှင် အိမ်ထောင်စုတစ်ခုတွင်ချက်ပြုတ်ရေးအတွက် ၄.၀၂± ၀.၁၅ တန် (ကာဗွန်ထုတ်လွှတ်မှုအနေဖြင့် ကာဗွန်ဒိုင် အောက်ဆိုဒ်ပမာဏ ၇.၃၈ ± ၀.၂၇ တန်) ရှိကြောင်း တွေ့ရှိရပါသည်။ ကျေးလက်နေပြည်သူတို့ ချက်ပြုတ်ရေးအတွက် အသုံးပြုနေသည့် မီးဖိုနေရာတွင် စွမ်းအားမြင့်မီးဖိုပြောင်းလဲသုံးစွဲစေခြင်းဖြင့် ထင်းလောင်စာ သုံးစွဲမှု လျော့နည်းကာ သစ်တောပြုန်းတီးမှုလျှော့ချနိုင်ပြီး ကာဗွန်ထုတ်လွှတ်မှု လျော့နည်း လာနိုင်မည်ဖြစ်ပါသည်။ ဤသုတေသနမှရရှိသည့် ထင်းလောင်စာသုံးစွဲမှုနှင့် ကာဗွန် ထုတ်လွှတ်မှု ဆိုင်ရာအချက်အလက်များသည် သစ်တောပြုန်းတီးမှုလျှော့ချရေးနှင့် ကာဗွန် ထုတ်လွှတ်မှုလျော့နည်းစေရေးလုပ်ငန်းများဆောင်ရွက်ရာတွင် အထောက်အကူပြုနိုင်မည် ဖြစ်ပါသည်။

Estimation carbon emissions from fuelwood consumption in a forest-dependent community

1. Introduction

The single most prominent challenge of the 21st century is global warming induced by surging levels of greenhouse gas (GHG) emissions. There are six major greenhouse gases that significantly influence the environment through global warming, and reducing the quantity of these greenhouse gases is the foremost concern of the global community (Zhang, et al., 2015). Among six greenhouse gases, carbon dioxide has a particularly great influence on climate change (Abeydeera, et al., 2019). Therefore, it is important to understand the factors responsible for increasing GHGs emissions and what policy options can be taken into consideration to counter this eminent threat. Human activities have played a significant role in the emissions of GHGs (Olivier, et al., 2017). Evidence suggests that aggregate pollution levels and shifts in world temperature have a strong relation to household activities, and the housing sector is one of the leading contributors to GHGs (Druckman, 2016). Abeydeera, et al., (2019) pointed out that household activities contribute 80 percent of global carbon emissions. The household sector is a major consumer of energy, and energy consumption has a significant share in total GHGs emissions. It is predicted that household energy demand will rise in the future, and this will increase the emissions of greenhouse gases (Nejat, et al 2015).

Household energy consumption is one of the major anthropogenic contributing factors (Song et al., 2012). About 2.9 billion people in developing countries are still dependent on fuelwood for cooking and heating (Johnson et al., 2010; Van et al., 2013; Goozee, 2017) and this has become one of the primary drivers of climate change. In 2011, fuelwood consumption was approximately 42 million m^3 (FAO, 2014) and is expected to increase to 55 million m^3 by 2030 (UN-REDD, 2017). Fuelwood contributes to GHGs emissions through unsustainable harvests and the combustion of biomass (CIFOR 2009). According to FAO (2020), the total global production of wood in 2020 reached approximately 3912 million m^3, of which 1928 million m^3 was used for fuelwood. This means that more than half of the total global wood removed from forests, and from areas outside forests, is used for energy production. Thus, the sustainable production and utilization of fuelwood for satisfying future demand has received considerable attention. Aggressive fuelwood and charcoal producers often extract fuelwood at much higher rates where demand is high. Consequently, the density of woodland biomass become reduced (Luoga et al., 2002) resulting in net CO_2 emission.

Forests provide the main sources of energy for the people living in rural parts of developing countries, and Myanmar is not an exception. Myanmar has high forest cover with high rate of deforestation. Myanmar had the seven-highest annual loss of forest area in 2015 to 2020 (FRA 2020). Somata (2014) stated that fuelwood extraction from forests is an important driver of deforestation and forest degradation in developing countries. Sovacool (2013) indicated that, in Myanmar, about 70% of all primary energy consumption was derived from fuelwood. Fuelwood extraction is one of the main driver of forest degradation and deforestation in Myanmar and fuelwood extractions from natural forests are very high (an estimated 31 – 39 million m^3 per year over the period of 2000 – 2012) (UNREDD National strategy 2017). According to the previous reports by James (2003); Leimgruber et al. (2005); Mon, Mizoue, Htun, Kajisa, & Yoshida (2012); Webb et al. (2013); Win et al. (2018) and Win et al. (2018), firewood collection and charcoal production largely contributed to deforestation there. Extraction of firewood and charcoal will still be an issue since the demand for wood energy for domestic use is increasing as long as there are either no reliable and affordable alternative energy sources available, especially in rural areas, or significant more wood energy from fuelwood. The sustainable development goals (SDGs) put the sustainable use of plant-based biomass as one of its central goals (Goozee, 2017). Thus, effective measures for sustainable use of biomass with compromising the needs of local people are essential.

Assessment of fuelwood consumption is necessary to provide baseline information for introducing effective measures for sustainable use of biomass and reducing emissions. Previous studies clarified the fundamental basis for understanding fuelwood supply and demand conditions in rural area (Win et al 2018), consumption rates and patterns of firewood (Win et al., 2018; Kyaw et al., 2020). However, none of the above studies estimate carbon emissions from fuelwood consumption and potential reductions in carbon emissions by substitution improved cook stoves. Thus, the aims of this study were to assess fuelwood consumption by households in a forest-dependent community and to project future consumption of fuelwood, associated emissions, and emission reductions by substitution more efficient cookstoves.

2. Objectives

- To assess fuelwood consumption in a forest-dependent community and to estimate the carbon emissions
- To project future consumption of fuelwood, carbon emissions and emissions reduction potential

3. Materials and Methods

3.1. Study Site

The study sites were in the foot of North Zarmari Wildlife Sanctuary-NZWS in Bago Region. Within Bago Region, NZWS have high ratio of closed forest and high biodiversity. But local communities surrounding the area are poor and depend on the forest 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.

Field surveys were conducted in 25 villages (Figure 1).These villages are located the Minhla Township and Kyauktaga Township. These villages are the closest villages to NZWS 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 the surrounding area of North Zarmari Reserve Forest to observe the daily activities of local households. The questionnaires had three broad headings: background information of respondents, socioeconomic data, and household energy consumption (cooking patterns, source of woodfuel and fuelwood use).

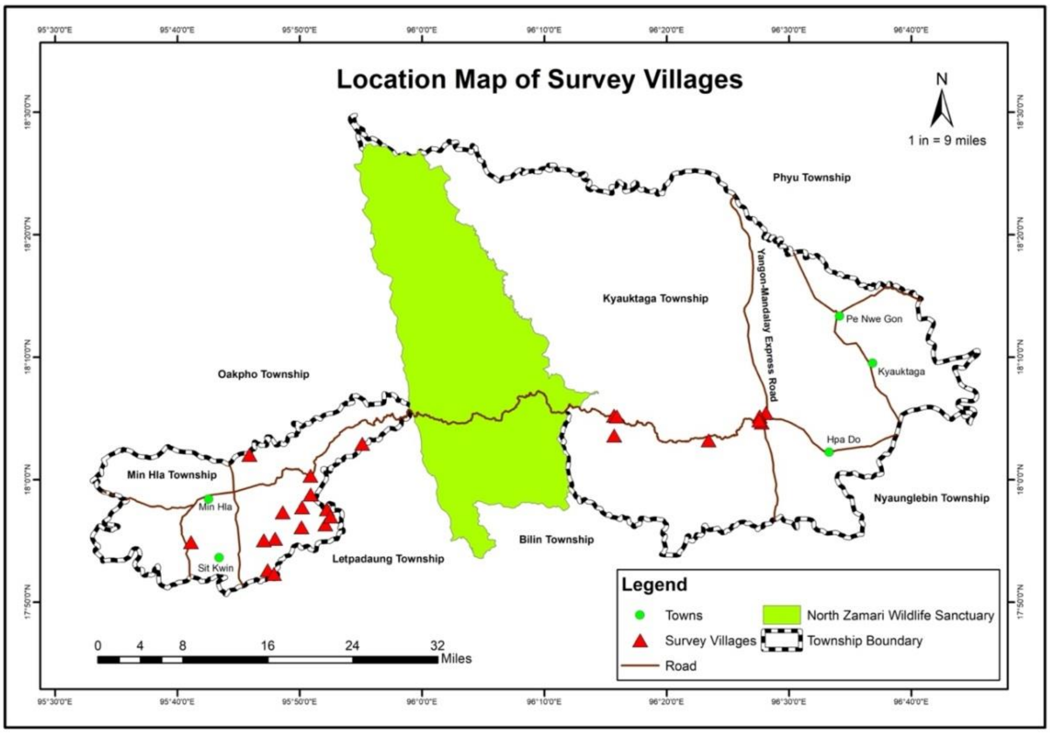


Figure 1. Location map of surveyed villages

This study mainly relied on primary data and data was collected by face-to-face interviews. For an interview, well-prepared structured questionnaires (both open-ended and close-ended) were used. In terms of wood fuel use, all respondents were asked about their purposes of using fuelwood, types and number of cooking per day, the amount of fuelwood use for cooking per year. Besides, all of the respondents were also asked preferable species and the sources of fuelwood collecting. 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. We selected 422 sample respondents as a sample size (at 95% confidence interval and 5% marginal error) for this study by using Taro Yamane Formula (Yamane, 1967).

$$n = \frac{N}{(1+Ne^2)} \tag{1}$$

where n = sample size; N = total population of household; e = allowable error (5% = 0.05).

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 Forest Department, Department of Population, Forest Trends' Ecosystem Marketplace.

3.3.Data analysis

In our study, consumption rate of firewood and charcoal was defined as per capita annual consumption. The per capita consumption was calculated by dividing the total consumption of each household by the number of family members in the household. Household size was defined as the number of family members in the household and classified into three groups depending on the number of individuals in a household. Households which include≤3 family members were categorized as “Small”, 4-6 family members as “Medium” and ≥7 as “Large”. Household status were also divided into three groups based on annual income per household; household with the lower income (G1), household with the medium income (G2) and household with the larger income (G3). The annual income for G1 was ≤1,500,000 MMK, G2 are between 1,500,000 and 3,000,000 MMK while G3 get the annual income of greater than 3,000,000 MMK.

During the interview, respondents provided estimates of annual firewood consumption based on the number of oxcart loads. Using the converter developed by the Myanmar Forest Department (firewood one cartload = 1.2743 m^3 stacked) and the number of oxcart loads, we determined the annual firewood use. To convert the estimated stacked volume into solid wood volume, a conversion factor developed by the Myanmar Forest Department (1.0 m^3 of stacked volume is 0.66 m^3 of solid volume) was applied. Then, a conversion factor developed by (Win,et al., 2018)was applied to convert the solid volume to air-dried firewood (1.0 m^3 of solid volume = 710 kg of air-dried firewood) which is relatively close to the average values for tropical species (700–720 kg/m^3 of solid volume) that the United Nations Food and Agriculture Organization reported. In case of charcoal, the solid wood volume required to produce charcoal was converted by using the conversion factor of 167 kg/m^3 reported by the United Nations Food and Agriculture Organization (FAO, 2014).

Microsoft excel was used to find out the Descriptive Statistics. Data were analyzed using statistical techniqueswith the support of IBM SPSS 20. Spearman’s correlation test was carried out to know how the consumption of wood fuel relates to households size and annual income. To know the consumption of fuelwood (firewood and charcoal) and difference among the townships, family size and household annual income, independent T-test and one-way ANOVA test was carried out for the homogenous variance variables and Kruskal–Wallis test for the heterogeneous variance variables.

3.4.Estimation of Carbon emissions and Carbon credits

Carbon emissions were estimated based on household level fuelwood consumption. CE_CB are derived as

$$CE\_CB = CB \times 0.5 \times 44/12. \quad (2)$$

CE_CB represents carbon emission of fuelwood consumption from cooking and boiling per household per year (Mg $CO_2 yr^{-1}$), CB is average fuelwood consumption for cooking and boiling per household per year (Mg yr^{-1}), taken as average of fuelwood consumption from surveyed households. 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.

On the basis of our surveys, the majority of the population in the study site used three-stone stoves (TSS) for cooking, boiling water. Previous studies have found that three-stone stoves consume more fuelwood than other cookstoves (Batchelor, 1997; Kituyi et al., 2001; Turker and Kaygusuz, 2001).

Improved cookstoves (ICS) (named as A1 efficient cookstoves in Myanmar) are more efficient with respect to fuelwood consumption for producing needed energy. ICS have net savings of 40% of wood consumption compared with the three-stone stove (TSS)(FD, 2001 and DZDG 2013).

Assessments of carbon emissions from the use of fuelwood for cooking energy were performed for TSS. Given that TSS is the common daily practice in the study site as baseline practice (activities in the absence of financial incentives). Under project scenario, TSS will be substituted by ICS.

Carbon Credits (CC)

$$CC(t) = [CE_{Baseline}(t) - CE_{Project}(t)] \times [(1 - Leakages)] \quad (3)$$

CC(t) represents carbon credits ($MgCO_2$) obtained through project implementation, CE baseline(t) represents carbon emissions under baseline ($MgCO_2$), CEproject(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, Chan et al 2014).

$CE_{baseline}(t)$ is derived as

$$CEBaseline(t) = CE\_CB(t_1) + CE\_CB(t_2) + \ldots\ldots + CE\_CB(t_{10}) \quad (4)$$

CE_CB(t) represents carbon emissions from cooking and boiling for daily needs ($MgCO_2$)

CE_CB(t) are derived as

$$CE\_CB(t) = CB \times HH(t) \times 0.5 \times 44/12. \quad (5)$$

CB is average fuelwood consumption for cooking and boiling per household per year ($Mg\ yr^{-1}$), taken as average of fuelwood consumption from surveyed households. HH(t) represents the number of households at time t, 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

$$HH(t) = HH(0) \times e^{a \times t}. \quad (6)$$

HH(0) represents the number of households at time t = 0, a is population growth rate, t is time step (year).

CE project (t) is derived as

$$CE_{Project}(t) = [CE\_CB(t) \times (1\text{-}NS)]. \quad (7)$$

$CE_{Project}(t)$ represents project emissions from cooking and boiling for daily needs ($MgCO_2$)

NS is net savings from Improved cookstove (ICS), 40 % by shifting from three-stone stoves (TSS) to improved cookstoves (ICS).

4. Results

4.1. Socioeconomic profile of respondent households

Ages of all 422 respondents ranged from 17 to 89 years with an average age of 47 years. Approximately 77.25% of respondents were the head of a household and 21.33 % were the wife who is in charge of fuelwood collection and of daily cooking. The Family size was categorized as per the number of individuals in the households as small (1–3 persons), medium (4–6 persons), and large (≥7 persons). Household size ranged from 1 to 9 persons, and average household size was found to be 4 members. According to family size classes, 38.15% belonged to the small household category, while 55.21% were in the medium and 6.64% in large category. Numbers of families are 161(38.15%), 233(55.21%) and 28 (6.64%)

respectively for small, medium, and large families. Among 422 respondents, half (54.03%) of the respondents were the primary education, followed by middle, illiteracy, high school, monastery and university education. Individual families relied on a great variety of different occupations for their livelihood and respondents reported that agriculture is the most important source of livelihood. Respondents' occupation were categorized into seven groups: (1) agriculture for farmers and home gardening, (2) forest dependent work for bamboo production, charcoal making and firewood collecting, (3) livestock, (4) own business, (5) government staff, (6) random, and (7) others. Random includes daily wagers and laboring while others include dependent and retired.

Table 1.General characteristics of respondent households (n = 422)

Variables		**Township**	
		Min Hla (n=304)	**Kyauktaga (n=118)**
Respondents Age	**Max.**	89	87
	Min.	18	17
	Avg.	48	44
Family member	**Max.**	8	9
	Min.	1	2
	Avg.	4	5
Income	**Max.**	68,000,000	10,800,000
	Min.	240,000	300,000
	Avg.	3,877,560	2,091,525

According to survey, it was found that majority of respondents 42% were working agriculture for their income, 39 % were random workers, 10% were working their own business. Others have some form of employment with 7% of forest dependent work, 7% of others and 3% of livestock. The average annual income per household varied among the individuals. The lowest average annual income (240,000 MMK) was found in Min Hla townships, whereas the highestannual income was estimated to be 68,000,000 MMK. The overall annual income was recorded as 3,378,126 MMK (Table 1).

4.2.Types of cooking energy use in study areas

Except for Myo Gyaung Ywarma in Kyauktaga city, almost all the villages surveyed do not have access to electricity. It was discovered that there are five main categories of energy sources, including electricity, solar energy, firewood, and charcoal. Since almost all of the study regions still lack access to electricity, they mostly relied on solar batteries for lighting and firewood and charcoal for cooking. In the research area, no home used kerosene, gas, or agricultural crop as a cooking fuel. Woodfuel (firewood and charcoal) accounts for the primary source of energy for cooking and is used by 366 households (86.72%) and 142 households (33.6%), respectively. Only 3 households (0.71%) used electricity for cooking. Of the 366 firewood users and 142 charcoal users, some households used both firewood and charcoal in combination (Table 2); about 21.09% of households reported the use of both firewood and charcoal for cooking, 65.64% used only firewood and 12.56% used only charcoal.

Among all combined-fuel and single-fuel users, the average (± standard error) per capita consumption of firewood and charcoal for cooking was 1072.73 ± 39.28 kgyear^{-1}and 203.19 ± 12.31 kgyear^{-1}, respectively; that is equivalent to 1.51 ± 0.05 m^{3} year^{-1}and 1.22 ± 0.07 m^{3} year^{-1}of solid wood, respectively (Table 3). Among single-fuel users, the consumption rate was about 1.1-fold the total average for both firewood and charcoal; that amounts to 1161.40 ± 47.66 kgcapita^{-1}year^{-1}for firewood and 232.43 ± 19.48 kgcapita^{-1}year^{-1} for charcoal (Table 2). Single-fuel users consistently had significantly higher consumption rates than multiple-fuel users for both firewood and charcoal.

Table 2. Average (± SE) annual per capita consumption of wood fuel in the study area

Types of Energy	Number of Households	Percent of Sample Households	Per-Capita Wood fuel Consumption (Weight) (kg year^{-1})	Per-Capita Wood fuel Consumption (Volume) (m^3 year^{-1})
Single-fuel users				
• Only Electricity	3	0.71%	-	-
• Only Firewood	277	65.64%	1161.40 ± 47.66	1.64 ± 0.07
• Only Charcoal	53	12.56%	232.43 ± 19.48	1.39 ± 0.12
Combined fuel users	89	21.09%		
• Firewood			796.74 ± 54.71	1.12 ± 0.08
• Charcoal			185.77 ± 15.65	1.11 ± 0.09
Total	**422**	**100.00%**		
Total firewood users	366		1072.73 ± 39.28	1.51 ± 0.05
Total charcoal users	142		203.19 ± 12.31	1.22± 0.07

4.3. Wood fuel source and type of species used in the study area

Households in Kyauktaga and Minhla townships primarily procured firewood on their own from various sources. As shown in the Figure 2, 61% of firewood was sourced from natural forests, 20% was purchased from nearby community areas, 12% was obtained from agricultural land, 3% from own gardens, and 3% from plantations. Information on the size of firewood used could not be determined during the interview.

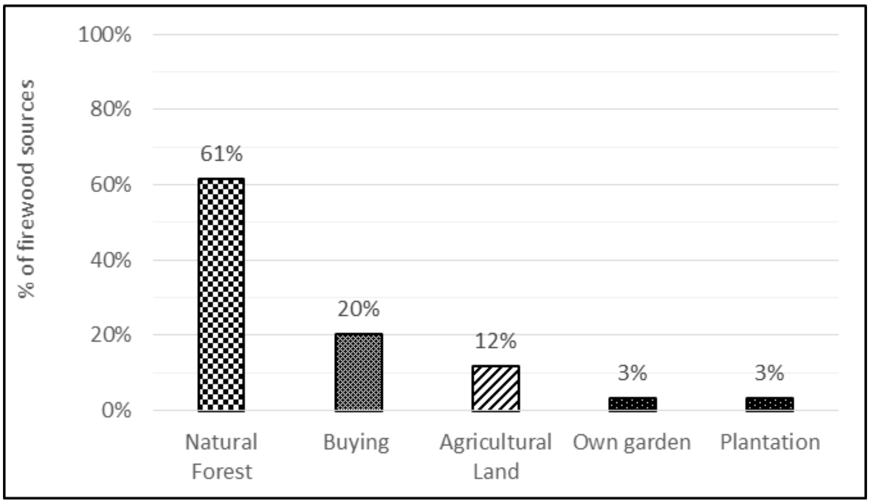


Figure 2. Proportion of firewood sources in the surveyed area

According to the respondents, it is getting harder to find preferred species, and almost every type of wood and dry bamboos are used as firewood. However, the respondents listed a few species that they preferred to use for their daily firewood consumption, depending on the wood's properties and availability. A total of 70 species from 59 genera and 32 families were used for firewood. Many species belong to the families Fabaceae (eleven species), Rubiaceae (six species), Anacardiaceae (five species), and Mimosaceae (five species). The most favored species for firewood were Yon (*Anogeissusacuminata*), Binga (*Mitragynarotundifolia*), Khabaung (*Strychnosnux-blanda*), Kokko (*Albizzialebbek*) and Lethtoke-gyi (*Holarrhenapubescens*).

Regarding charcoal use, 82% of respondents said they purchased charcoal for everyday use, while the remaining respondents said they made their own charcoal. For charcoal users, charcoal was readily available in the village and a 33-kg bag of charcoal costs between $3 and $5. According to respondents, it was found that twenty-seven species from 22 genera and 17 families were used to make charcoal. Most species belong to the families Fabaceae (six species), Mimosaceae (three species), Combretaceae, Lythraceae and Rubiaceae (two species for each). The most preferred and currently used species were Pyinkado (*Xyliaxylocarpa*), Yon (*Anogeissusacuminata*), Myaukchaw (*Homaliumtomentosum*), Thinwin (*Millettiapendula*), and Khabaung (*Strychnosnux-blanda*). It is said that the populations of species suitable for charcoal production is decreasing year by year. Therefore, almost all types are used today.

4.4. Fuelwood Consumption rates and its related factors

(a) Firewood

The average annual per capita consumption of firewood in a household is estimated to be (1072.72 ± 39.27) kg, ranging from a minimum of 149.28 kg to a maximum of slightly over 4478.53 kg. When comparing the consumption in each township, per capita consumption of firewood is (889.96 ± 80.79) kg in Kyauktaga township and (1122.22 ± 43.50) kg in Minhla township (Figure 3). It indicates that households in Kyauktaga township had significantly lower consumption of firewood than Minhla township. Firewood consumption is significantly difference at p=0.000 between Kyauktaga and Minhla townships.

The correlation analysis shown in Table 3 indicates that household size was a significant factor affecting firewood consumption. It is observed that there is a statistically significant at p=0.000 and very weak positive correlation between annual consumption of firewood and household size (HH Size). The consumption of firewood was significantly different from each other based on the household family members and retains the null hypothesis. The consumption rate of firewood is highest in the large household. And, the higher the family members, the more consumption of the firewood was found between or within groups. Small household is significantly different among all groups with the p value of less than 0.05. It revealed that large households (n=26) consumed the largest amount of firewood among the other groups with the mean value of about (1309.10 ± 176.11) kg. The second largest consumer of solid fuelwood was medium household (n=200) and consumed for (1100.22 ± 49.43) kgcapita^{-1}year^{-1}. Small household (n=140) used (989.54 ± 66.51) kg of solid fuelwood annually per capita.

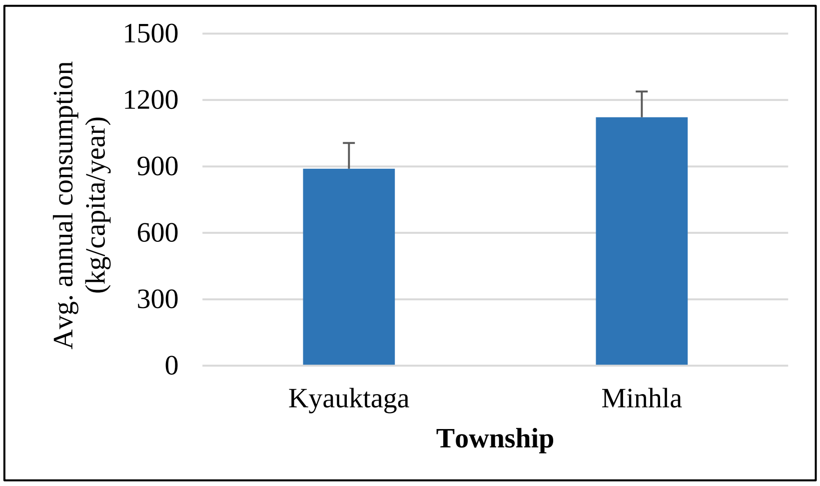


Figure 3 Average annual per capita consumption of firewood in the rural areas of Kyauktaga and Minhla Township

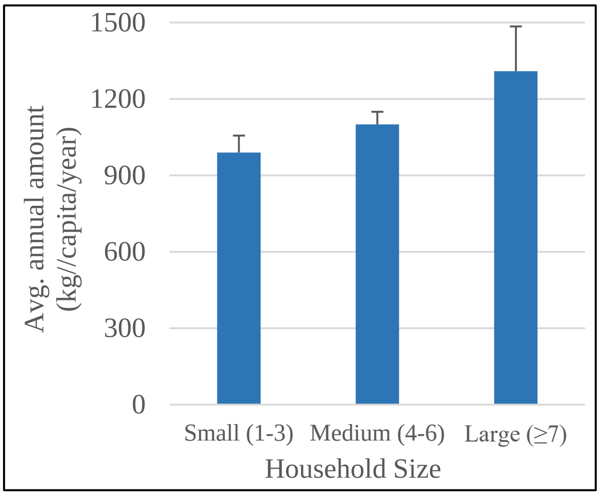
Household income also had a very weak positive correlation with per capita firewood consumption and significance difference was found at p=0.035. Household with the medium income group (G2) consumed the highest amount of firewood (1131.35 ± 77.66) kg than the others and significantly difference between or within groups. Households with the lower income group (G1) employed (1007.96 ± 67.22) kg of firewood and those with the higher income (G3) consumed an average of (1081.06 ± 57.68) kg of firewood per capita per year. Average annual per capita consumption of firewood between household size and income were described in Figure 4 (a) and (b), respectively.

Table 3. Correlation between wood fuel consumption and household characteristics

Variable		**Firewood ($kgcapita^{-1}year^{-1}$)**	**Charcoal ($kgcapita^{-1}year^{-1}$)**
HH_Size	Correlation Coefficient	0.197**	0.091
	Sig. (2-tailed)	0.000	0.280
Income Group	Correlation Coefficient	0.111*	-0.047
	Sig. (2-tailed)	0.035	0.577

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).



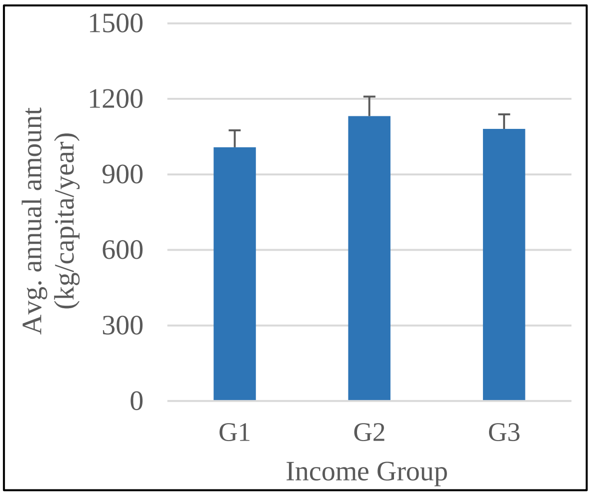


Figure 4. Average annual per capita consumption of firewood between (a) household size and (b) income

(b) Charcoal

Charcoal was used for an average amount of (203.18 ± 12.31) kgcapita^{-1}year^{-1}, ranging from a minimum of 10.21 kg to a maximum of 734.83 kg. Charcoal consumption was not significantly difference within townships nor household size and income. Consumption of charcoal is higher in Kyauktaga township than those in Minhla township (Figure 5). Per capita consumption of charcoal is (222.87 ± 17.69) kgyear^{-1}in Kyauktaga township (n=74) and (181.75 ± 16.90) kgyear^{-1}in Minhla township (n=68).

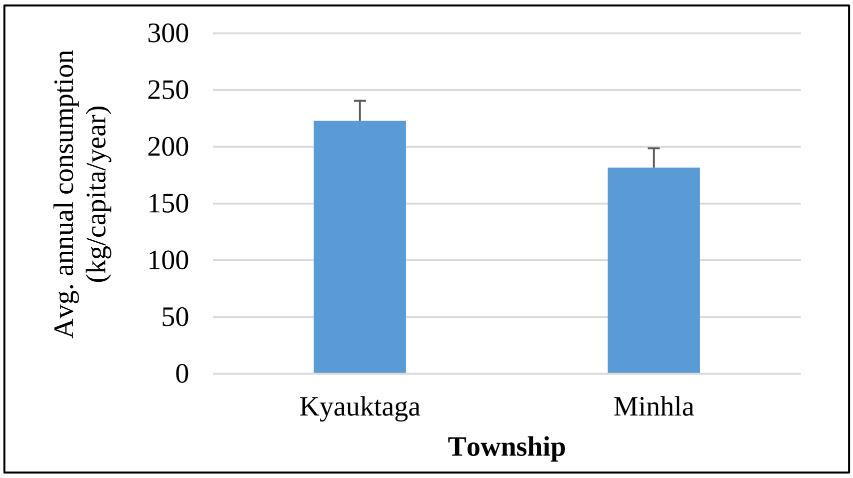


Figure 5. Average annual per capita consumption of charcoal in the rural areas of Kyauktaga and Minhla Township

There was no significant difference between the annual use of charcoal and HH size (p=0.091) and a very weak positive correlation was found (Table 3). The highest rate of charcoal consumption was found in large households with more families members. For small households (n=42), medium households (n=94), and large households (n=6), the average per capita annual consumption of charcoal is (204.84 21.58 kg), (200.53 15.58 kg), and (233.03 58.94 kg, respectively. Moreover, there is a very weak negative correlation between household income and per capita charcoal consumption and no significant difference was found between them (Table 3). The middle-income group (G2) (n=50) consumed the highest amount of charcoal (219.42 ± 19.00) kg compared to the other groups, yet there was no statistically significant difference between or within groups. The average amount of charcoal used by households with the low-income group (G1) (n= 49) was (206.20 ± 23.37) kg, while households in the high-income group (G3) (n=43) consumed an average of (180.85 ± 21.45 kg) per year. Figure 6 (a) and (b) shows how charcoal consumption relates to household size and income, respectively.

4.5. Carbon emissions and carbon credits

Among the interviewed households, 99.3% used fuelwood for cooking and boiling. Overall average fuelwood consumption per household was 4.02 ± 0.15 Mg yr^{-1} or 7.38 ± 0.27 MgCO_2 of carbon emissions. The majority of the population in the study site used three-stone stoves (TSS) for cooking, boiling water. In order to substitute the TSS, improved cookstoves (ICS) was initiated by Forest Research Institute, Forest Department starting from 1987. Improved cook stove (ICS) have net savings of 40% of wood consumption compared with the three-stone stove (TSS).

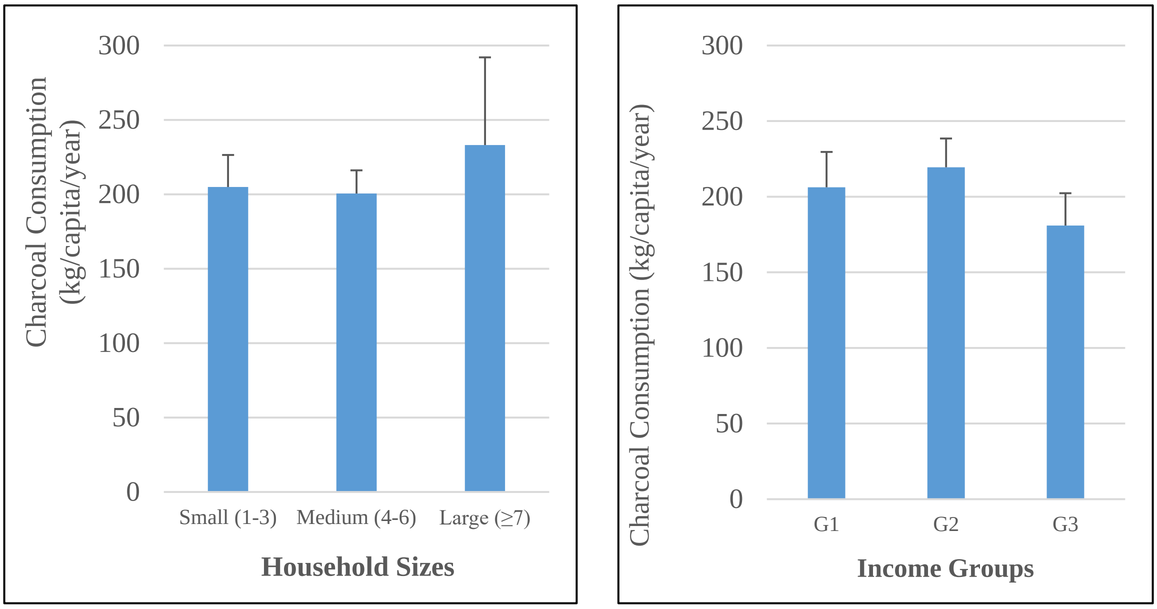


Figure 6. Average annual per capita consumption of charcoal between (a) household size and (b) income

Distribution is currently being conducted through the Forest Department, Dry Zone Greening Department and collaboration with international projects. This study estimated the carbon emissions of fuelwood consumption by substitution ICS in forest dependent community for 10 years modeling period.

Approximately 10,000 households live in project area. Thus, a baseline emission was estimated from the fuelwood consumption of 10,000 households. The time frame for the assessment is the 10 years, corresponding to approximately one crediting period for a verified CDM project (Geres, 2007). Our projection suggests that during the 10-year modeling period, households increased from 10,000 families in Year-1 to 10,824 in Year-10 based on the annual population growth rate of 0.88% in 2019 (Department of Population, 2019). Using the average fuelwood consumption (CB = 4.02 ± 0.15 Mg household^{-1} yr^{-1}), baseline emissions in the project area were estimated. Baseline carbon emissions from cooking and boiling water increase from 73,765 $MgCO_2$ in Year-1 to 79,845 $MgCO_2$ in Year-10 (Table 4 and Figure 7). The total carbon emissions from cooking and boiling were estimated at 767,697 $MgCO_2$ for the 10-year modeling period. The emissions are equivalent to 418,744 mg of wood, corresponding to 5,107 ha of forest area. Without any interventions, forest area 511 ha year^{-1} will lost to meet the fuelwood demand.

Table 4. Emission reductions under project scenarios

Year	Households	Baseline emissions (Mg CO_2)	Project emissions (Mg CO_2)	Leakages (Mg CO_2)	Carbon Credit (Mg CO_2)
Year 1	10,000	73,765	44,259	4,426	25,080
Year 2	10,088	74,417	44,650	4,465	25,302
Year 3	10,178	75,075	45,045	4,505	25,526
Year 4	10,268	75,739	45,443	4,544	25,751
Year 5	10,358	76,408	45,845	4,584	25,979
Year 6	10,450	77,084	46,250	4,625	26,208
Year 7	10,542	77,765	46,659	4,666	26,440
Year 8	10,635	78,452	47,071	4,707	26,674

Year	Households	Baseline emissions ($Mg\ CO_2$)	Project emissions ($Mg\ CO_2$)	Leakages ($Mg\ CO_2$)	Carbon Credit ($Mg\ CO_2$)
Year 9	10,729	79,146	47,487	4,749	26,910
Year 10	10,824	79,845	47,907	4,791	27,147
Total		**767,697**	**460,618**	**46,062**	**261,017**
Annual		**76,770**	**46,062**	**4,606**	**26,102**

To reduce these emissions, project scenarios have been introduced. Three stone stove -TSS has switched to improved cookstoves-ICS (A1 efficient cooking stove) with 40% of fuelwood saved. As seen in Table 4, carbon emissions under project scenario were estimated at 460,618 $MgCO_2$ for the 10-year modeling period or 46,062 $MgCO_2\ yr^{-1}$,whereas total leakages (15%) accounted for 46,062 $MgCO_2$ or 4,606 $MgCO_2\ yr^{-1}$.Thus, the total CC under project scenario was estimated at 261,017 $MgCO_2$ or 26,102 $MgCO_2\ yr^{-1}$. These emission reductions are equivalent to 142,373 Mg of wood, corresponding to 1,736 ha of forest saved (this is based on average 1 hectare of forest in Asia contains 82 Mg of wood) (FAO, 2000).

4.6. Carbon revenues from reducing emissions

Owing to the uncertainty of future carbon agreements, carbon prices have raised from US \$3.4 to \$4.3 to \$5.4 to 5.8 $MgCO_2^{-1}$ in 2018, 2019, 2020 and 2021 respectively Forest Trends' Ecosystem Marketplace 2020, 2022. The price has become a concern to carbon project developers. If carbon is traded at the price of US \$5 $MgCO_2^{-1}$, total revenue from carbon sales will be only US \$ 1.30 million or US \$0.13 millionyear^{-1}. This is just an estimation carbon revenues from reducing emissions by substitution ICS. But, a successful project requires appropriate intervention and the cooperation of the local community in targeted area. Moreover, the investment costs and carbon price are essential to take into account for benefit sharing.

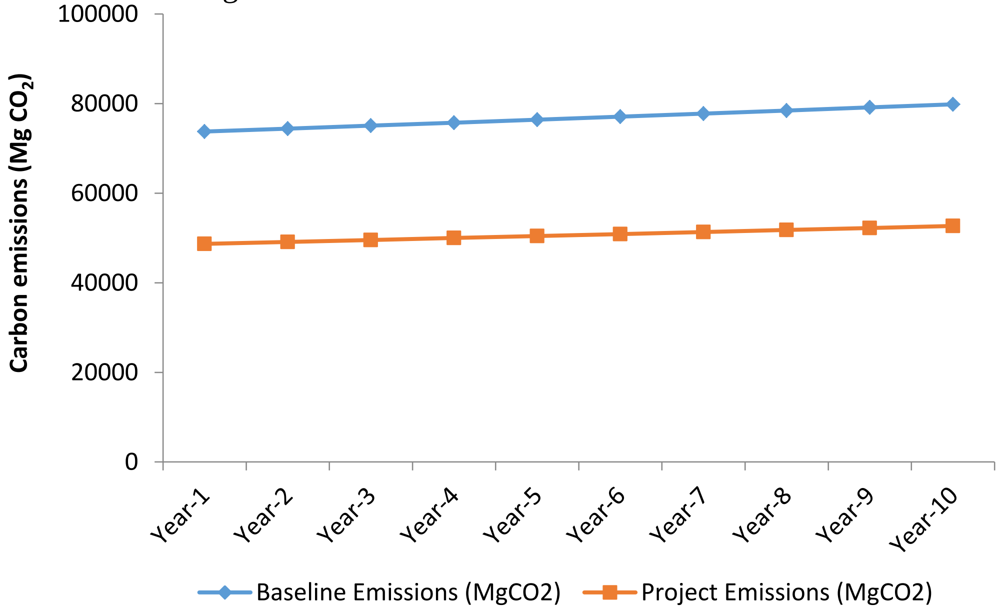


Figure 7. Baseline emissions and project emissions

5. Discussion

5.1. Wood fuel consumption rate in the study area

Our study found that per capital firewood consumption rate was 1072.73 ±39.28 $kgyear^{-1}$. This rate was generally higher than the values reported by the other researchers in Myanmar (780 ± 30 $kgyear^{-1}$ for the rural areas and 217.4 ± 38.9$kgyear^{-1}$ for the urban areas of Yedashe township) (Win, Mizoue, Ota, Kajisa, & Yoshida, 2018) and (503 $kgyear^{-1}$) (Kyaw et al., 2020). One of the possible explanations for the high percentage of firewood consumption in our study region is that almost all of the villages in our study cannot get access to electricity and only 0.71 percent of the sample household are using electricity, as opposed to the other study where larger households (over 70% of households) were using electricity as their primary source of energy for cooking (Win, Mizoue, Ota, Kajisa, & Yoshida, 2018). However, the quantity of charcoal employed annually per person in this study (203.19 ±12.31 kg) was lower than the numbers previously reported (69 ± 11 kg for urban regions and 280 ± 20 kg for rural areas, respectively). Even when comparing users in rural areas of Myanmar who only use firewood and charcoal, the consumption rates for the firewood (1161.40 ± 47.66 $kgcapita^{-1}year^{-1}$) are still 1.5 times higher than those in the rural areas of Yedashe township (780 kg), and the consumption rates (232.43 ± 19.48 $kgcapita^{-1}$ $year^{-1}$) for charcoal is less than half those in the rural area (280 kg) (Win, Mizoue, Ota, Kajisa, Yoshida, et al., 2018).

There have been many different studies on how much people in different parts of the world relied on firewood and charcoal for their daily activities, particularly in South Asian nations like India, Nepal, and Bangladesh as well as some African nations like Kenya and Tanzania.Our study's per capita consumption rates for firewood were comparable to those found in the Garhwal Himalaya (from 392.38 to 1019.2 $kgyear^{-1}$), (from 594.95 to 919.80 $kgyear^{-1}$) (Kumar & Sharma, 2009) and in India (880 $kgyear^{-1}$) (Malik et al., 2014). However, people in the eastern Himalayas (Bhatt et al., 2016) use more firewood (1790.0 to 3070.0 kg $year^{-1}$) than people in our study area. The consumption rate is roughly twice that in our study. This may be because people in the eastern Himalayas live higher up in the mountains, and the need for additional consumption for space heating at higher altitudes may account for the higher consumption. Perhaps the higher consumption in the eastern Himalayas is due to the higher consumption required for space heating at higher altitudes. The lower values were discovered in India (880 $kgyear^{-1}$) (Malik et al., 2014), Kenya (780 $kgyear^{-1}$) (Kituyi et al., 2001), and Cambodia (760 $kgyear^{-1}$) (San et al., 2012) as well as (180 $kgyear^{-1}$) (Top Neth & Nobuya Mizoue, 2003). It is common knowledge that per capita consumption rates decrease exponentially as household size increases, suggesting that larger households use wood fuel more effectively than smaller ones (Top Neth & Nobuya Mizoue, 2003).When compared to the household size, our study area had smaller household (4 persons $household^{-1}$) than that of Cambodia (7.2 persons $household^{-1}$). Perhaps, smaller household size could be one of the causes of the higher rate of firewood consumed in our study.Therefore, household size should be taken into account when comparing the consumption of fuelwood. For charcoal, the per capita consumption in our study (203 $kgyear^{-1}$) is approximately 1.5 times higher than the rates found for urban Tanzania (140 $kgyear^{-1}$) (Mwampamba, 2007), rural and urban areas in Kenya (95 and 130 $kgyear^{-1}$) respectively (Kituyi et al., 2001) and Kampong Thom Province, Cambodia (120 $kgyear^{-1}$) (Top Neth&NobuyaMizoue, 2003).The higher rate of firewood and charcoal consumption in our case study may arise from the fact that our data were obtained from respondents who only relied on firewood and charcoal for the daily cooking, while the data of the other studies likely came from those who used other fuels in addition to firewood and charcoal. In addition, the accuracy of the data on fuelwood consumption rates depends on the respondent's memory (Kituyi et al., 2001). (Mwampamba, 2007) also stated that for studies of recall information from respondents, rather than direct and quantitative measurements of use, consumption levels may have been overestimated by up to 14%. In our study, we did not calculate or compare the differences between user-stated estimates and actual consumption for daily use. Also, there may be some deviation in the estimates on annual consumption since we did not account for seasonal changes in daily consumption.

Moreover, members of individuals in a family and the income of a household are various underlying factors in determining the use of fuelwood as the household energy source. Taking into account different family sizes, our study found that large household consumed higher amount of firewood (1309 kg) and charcoal (233.03 kg) per capita per year than the medium and small households. The consumption of fuelwood increases with an increase in family size and household size positively affects firewood and charcoal consumption which is consistent with the results of previous studies in China (Démurger & Fournier, 2011), Nepal (Baral et al., 2019) and in a mountain area of Bangladesh (Miah et al., 2009). Our study found that there is a positive and negative correlation between the annual consumption of firewood and charcoal with the household income, respectively. Baral 2019 reported that as income increases, the use of alternative energy sources, such as kerosene and LPG, were increasing and is reducing the need for fuelwood. And, the relationship between household income and fuelwood consumption indicates that the higher the income, the lesser the consumption, which in contrast with our study. Perhaps, households in our study area were solely depending on the wood fuel and there is no alternative source such as electricity.

5.2. Carbon emissions and carbon credits

Carbon emissions were estimated based on household fuelwood consumption. For all combined-fuel and single-fuel users, overall average consumption per household was 4.02 ± 0.15 Mg yr^{-1} daily cooking or 7.38 ± 0.27 $MgCO_2$ of carbon emissions. According to the 30-year Comprehensive Master plan of Forest Department, the average fuelwood consumption was 1.87 Mg (2.5 Hoppus ton) per household per year in rural area. The figures in our study are higher. It may be due to site specific assessment and National level assessment. Fuelwood consumption of this study was higher than Chan(2014)'s study in forest dependent community of Phnom Tbeng forest area, Cambodia (2.0 ± 0.1 Mg $household^{-1}$ yr^{-1} for daily cooking or 3.8 ± 0.2 $MgCO_2$ carbon emissions). There are many possible reasons such as traditional cookstoves types, the number of combined-fuel and single-fuel users, family's income, education, and access to electricity. Family size is also another factor increasing fuelwood consumption since fuelwood consumption increases with family size.

The local communities in the study area are depending on forest products for their livelihood. Firewood collection is the most common source of energy for cooking in this area. In Myanmar, fuelwood extraction is one of the drivers of deforestation and forest degradation among illegal logging, shifting cultivation, mining and land encroachment. Collection of fuelwood and its inefficient use for cooking contribute to forest degradation and deforestation in developing countries (Chan et al 2014). 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).

In the study area, baseline carbon emissions from cooking and boiling were 76,770 $MgCO_2$ yr^{-1}. The emissions are equivalent to 41874 mg of wood. Annually, 511 ha of forest area will lost to meet the fuelwood demand. This study corresponds to the statement of Skutsh (2011) that fuelwood collection for cooking is a main driver of forest degradation and deforestation. 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). Hence, it is necessary to initiate strategies to reduce fuelwood consumption. There might have many interventions in order to reduce fuelwood consumptions and associated emissions. 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. Substitution of conventional cookstoves with improved cookstoves could result in using less fuelwood for the same amount of energy needed and thereby result in reduction of carbon emissions and deforestation (Chan et al., 2014). Distributing improve cookstoves (ICS) is an effective approach as an improved cookstove can be up to 40% more efficient than traditional open-fire cooking (FD, 2001 and DZDG 2013) . The Forest Research Institute of Myanmar has been producing and distributing ICS named as A1 efficient cookstoves since the 1990s. Distribution is currently being conducted through the Ministry's own programmes, as well as through collaborating with international projects.

Project emissions were estimated by substitution improved cook stoves (called A1 efficient cooking stove in Myanmar). Carbon emissions under project scenario were 46,062 $MgCO_2\ yr^{-1}$. Carbon credits from the project were estimated by measuring carbon emissions from reduced fuelwood consumption. However, projects are suspected to be prone to leakage. Leakages are carbon emissions outside project boundary. Potential for leakage will vary from project to project (Lasco & Pulhin, 2003). By assuming 15% leakage, Carbon credit under the project was 26,102 $MgCO_2\ yr^{-1}$. These emission reductions are equivalent to 1,423 Mg of wood, corresponding to 174 ha of forest saved annually. This study estimate the emissions reduction from fuelwood consumption by substitution only improved cookstoves. According to the survey results, the local community depends on fuelwood for household energy because they could not access the alternative energy such as electricity, CNG, solar energy and wind energy. In order to reduce the forest dependency, collaboration among line Ministries is necessary.

5.3. Carbon revenue and carbon price

If carbon is traded at the price of US \$5 $MgCO_2^{-1}$, total revenue from carbon sales will be only US \$ 1.30 million or US \$0.13 million yr^{-1}. This is just an estimation carbon revenues from reducing emissions by substitution ICS. But, a successful project requires appropriate intervention and the cooperation of the local community in targeted area. It is not easy to change the behavior of local people from use of three-stone stoves unless the advantage of efficient cooked stove-ECS use can be broadly disseminated. 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). In Cambodia, local people have been given at least one improved cooked stove every two years and 30 kg of rice monthly per household as incentives to participate in project activities (Chan, S., et al 2015). However, it would not be enough to feed the whole family; thus, creating jobs at local level through factory or enterprise development can provide sustainable income to villagers. They can switch their jobs that threaten forest resources and forest dependency will reduce.

This is estimated carbon revenues from reducing emissions by substitution ICS. In order to develop the project, total investment costs also take into account. The investment costs are ICS cost, implementation cost, the transaction costs, registration fee, negotiation costs, approval costs and monitoring cost. According to the literature (Chan, 2014; Camille and Jayant, 2007; Michelowa et al., 2003; de Gouvello and Coto, 2003; Krey, 2004; Eco Securities, 2003), transaction costs(t) US \$1.75 × CC(t), registration fee (maximum US

$350,000), 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. Carbon price also an important factor in carbon project development. However, there is still a high expectation that the carbon price will increase again after a new climate agreement is reached.

6. Conclusion

Rural households in the study area depend on fuelwood as a primary energy source for cooking, boiling water.Approximately 100% of the 422 sampled households were using fuelwood for daily consumption (only three household were using electricity). Current energy structure consumption in study site is dominated by biomass which three stone stove are commonly used. Among all combined-fuel and single-fuel users, the average per capita consumption of firewood and charcoal for cooking was 1072.73 ± 39kg year^{-1}and 203.19 ± 12.31 kgyear^{-1}, respectively. Overall average fuelwood consumption for cooking and boiling water was 4.02 ± 0.15 Mg household^{-1} yr^{-1} for daily cooking or 7.38 ± 0.27 MgCO_2 of carbon emissions. The results clearly showed that wood consumption in this study is higher than national level.

Based on 10,000 households, total carbon emissions from cooking and boiling were estimated at 767,697 MgCO_2 for the 10-year modeling period. Using improved cookstoves can reduce carbon emissions up to 261,017 MgCO_2 for 10-year project or 26,102 MgCO_2 yr^{-1}.Consequently, 1,736 ha of forest saved. If carbon is traded at the price of US $5 Mg$CO_2$$^{-1}$, total revenue from carbon sales will be only US $ 1.30 million or US $0.13 million yr^{-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. Besides, a successful project requires appropriate intervention and the cooperation of the local communities. 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. Further study on assessment of people perception for substitution ICS are recommended. Likewise, further studies on collection and use of fuelwood by local people according to seasonal variations (i.e. two to three times of survey per year) would improve accuracy of our findings such as carbon emission reductions and revenue.

7. Acknowledgements

This study was funded by Korea-Myanmar REDD+ Joint Project.

8. References

Angelsen, et al 2009. CIFOR. Realising REDD+, National strategy and policy options

Baral, S., Basnyat, B., Gauli, K., Paudel, A., Upadhyaya, R., Timilsina, Y. P., &Vacik, H. (2019). Factors affecting fuelwood consumption and CO2 emissions: An example from a community-managed forest of Nepal. *Energies*, *12*(23). https://doi.org/10.3390/en12234492

Batchelor, S.J., 1997. Testing wood fuel stoves available in the market in Cambodia. RERIC Int. Energy J. 19, 45–54

Bhatt, B. P., Rathore, S. S., Lemtur, M., &Sarkar, B. (2016).Fuelwood energy pattern and biomass resources in Eastern Himalaya.*Renewable Energy*, *94*, 410–417. https://doi.org/10.1016/j.renene.2016.03.042

Camille, A., Jayant, S., 2007.Assessing Transaction Costs of Project-based Greenhouse Gas Emissions Trading.Environmental Energy Technologies Division, US.

deGouvello, C., Coto, O., 2003. Transaction costs and carbon finance impact on small-scale CDM projects. PCF Plus, Washington DC.

Démurger, S., & Fournier, M. (2011). Poverty and firewood consumption: A case study of rural households in northern China. *China Economic Review*, *22*(4), 512–523. https://doi.org/10.1016/j.chieco.2010.09.009

Druckman, A.; Jackson, T. Understanding households as drivers of carbon emissions. In Taking Stock of Industrial Ecology; Springer International Publishing: Cham, Switzerland, 2016; pp. 181–203.

DZGD, 2013. Dry Zone Greening Department, Promoting the Utilization of fuelwood substitutes | Dryzone (dryzonegreening.gov.mm)

EcoSecurities, 2003. Transaction costs, efficiency and supportive governance, the clean development mechanism: A user's guide, UNDP, New York, pp. 55–68.

FAO 2020.Forest Product statistics.Global production and trade in forest products in 2020. https://www.fao.org/forestry/statistics/80938/en/

FAO, 2014. State of the World's Forests: Enhancing the Socioeconomic Benefits from Forests. Food and Agriculture Organization of the United Nations, Italy, Rome.

FD, 2001.The 30-years Master Plan.Ministry of Forestry. Myanmar.

Food and Agriculture Organization (FAO) 2000. Global Forest Resources Assessment 2000, Chapter 2: Wood volume and woody biomass. Available online http://www.fao.org/docrep/004/y1997e/y1997e07.htm#bm07.

Geres, 2007.Groupe Energies Renouvelables, EnvironnementetSolidarités (Gere). Efficient cookstoves to mitigate global warming and contribute to poverty alleviation in Cambodia. Phnom Penh, Cambodia.

Goozee, H. Energy Poverty: The Hidden Key to the Sustainable Development Goals; IPC-IG Working Paper 156; International Policy Centre for Inclusive Growth: Brasilia, Brazil, 2017.

James, H. (2003). Cooperation and community empowerment in Myanmar in the context of Myanmar agenda 21 doi:10.1111/1467-8411.t01-2-00020

Johnson, F.X.; Tella, P.V.; Israilava, A.; Takama, T.; Diaz-Chavez, R.; Rosillo-Calle, F. What woodfuels can do to mitigate climate change.FAO Pap. 2010, 1, 1–98.

Kituyi, E., Marufu, L., Huber, B., Wandiga, S. O., Jumba, I. O., Andreae, M. O., &UnterHelas, G. (2001). Biofuel consumption rates and patterns in Kenya.In *Biomass and Bioenergy* (Vol. 20).

Krey, M., 2004. Transaction costs of CDM project in India–an empirical survey, HWWA Report 238. Hamburg Institute of International Economics.

Kumar, M., & Sharma, C. M. (2009).Fuelwood consumption pattern at different altitudes in rural areas of Garhwal Himalaya.*Biomass and Bioenergy*, *33*(10), 1413–1418. https://doi.org/10.1016/j.biombioe.2009.06.003

Kyaw, K. T. W., Ota, T., &Mizoue, N. (2020). Forest degradation impacts firewood consumption patterns: A case study in the buffer zone of Inlay Lake Biosphere Reserve, Myanmar. *Global Ecology and Conservation*, *24*. https://doi.org/10.1016/j.gecco.2020.e01340

Lasco, R.D. and Pulhin, F.B. (2009) Carbon Budgets of Forest Ecosystems in the Philippines. Journal of Environmental Science and Management, 12, 1-13

Leimgruber, P.; Kelly, D.S.; Steininger, M.K.; Brunner, J.; Müller, T.; Songer, M. Forest cover change patterns in Myanmar (Burma) 1990–2000. Environ. Conserv. 2005, 32, 156–364. [CrossRef]

Luoga, E. J., Witkowski, E. T. F. and Balkwill, K. 2002 Harvested and standing wood stocks in protected and communal miombo woodlands of eastern Tanzania. Forest Ecology and Management 164(1-3): 15-30.

Malik, Z. A., Bhat, J. A., & Bhatt, A. B. (2014). Forest resource use pattern in Kedarnath wildlife sanctuary and its fringe areas (a case study from Western Himalaya, India). *Energy Policy*, *67*, 138–145. https://doi.org/10.1016/j.enpol.2013.12.016

Miah, M. D., al Rashid, H., & Shin, M. Y. (2009). Wood fuel use in the traditional cooking stoves in the rural floodplain areas of Bangladesh: A socio-environmental perspective. *Biomass and Bioenergy*, *33*(1), 70–78. https://doi.org/10.1016/j.biombioe.2008.04.015

Michelowa, A., Stronzik, M., Eckermann, F., Haunt, A., 2003. Transaction costs of the Kyoto mechanisms. Clim. Policy 3, 261–278.

Mon, M.S.; Mizoue, N.; Htun, N.Z.; Kajisa, T.; Yoshida, S. Factors affecting deforestation and forest degradation in selectively logged production forest: A case study in Myanmar. For. Ecol. Manag. 2012, 267, 190–198. [CrossRef]

Mucahid, M.B., Tran, N.T., Lawal, M.M., 2014. Creating social safeguards for REDD+: Lesson learned from benefit sharing mechanisms in vietnam. Land 3, 1037–1058. http://dx.doi.org/10.3390/land3031037.

Mwampamba, T. H. (2007). Has the woodfuel crisis returned? Urban charcoal consumption in Tanzania and its implications to present and future forest availability.*Energy Policy*, *35*(8), 4221–4234. https://doi.org/10.1016/j.enpol.2007.02.010

Nejat, P.; Jomehzadeh, F.; Taheri, M.M.; Gohari, M.; Muhd, M.Z.A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries). Renew. Sustain. Energy Rev. 2015, 43, 843–862. [CrossRef]

Olivier, J.G.J.; Schure, K.M.; Peters, J.A.H.W. Trends in Global CO2 and total Greenhouse Gas Emissions: 2017 Report. 2017. Available online: https://www.pbl.nl/sites/default/files/downloads/pbl-2017-trends-in-global-co2-and-total-greenhousegas-emissons-2017-report_2674.pdf (accessed on 12 December 2021).

San, V., Spoann, V., Ly, D., &Chheng, N. V. (2012).Fuelwood consumption patterns in Chumriey Mountain, Kampong Chhnang Province, Cambodia. *Energy*, *44*(1), 335–346. https://doi.org/10.1016/j.energy.2012.06.025

Skutsch, M.M.; Torres, A.B.; Mwampamba, T.H.; Ghilardi, A.; Herold, M. Dealing with locally-driven degradation: A quick start option under REDD+. Carbon Balanc.Manag. 2011, 6, doi: 10.1186/1750-0680-6-16.

Somata, C., Sasaki, N., Ninomiya, H., 2014. Carbon emission reductions by substitution of improved cookstoves and cattle mosquito nets in a forest-dependent community

Song, D.; Su, M.; Yang, J.; Chen, B. Greenhouse gas emission accounting and management of low-carbon community. Sci. World J. 2012, 2012, 6. [CrossRef] [PubMed]

Sovacool, B. K. (2013). Confronting energy poverty behind the bamboo curtain: A review of challenges and solutions for Myanmar (burma) doi://doi.org/10.1016/j.esd.2013.03.010

Top Neth,&NobuyaMizoue. (2003). *Woodfuel Consumption Rates and Flow in Kampong Thom Province, Cambodia*.

Turker, M.F., Kaygusuz, K., 2001. Investigation of the variables effects on firewood consumption as an energy source in forest villages of Turkey. Energy Convers. Manage. 42, 1215–1227.

UdaraWillhelmAbeydeera, L.H.; WaduMesthrige, J.; Samarasinghalage, T.I. 2019. Global research on carbon emissions: A scientometric review. Sustainability 2019, 11, 3972.

UN-REDD, 2017.Drivers of deforestation and forest degradation in Myanmar.Ministry of Natural Resources and Environmental Conservation (MONREC), REDDþ Myanmar, and UN-REDD Programme.

Van der Kroon, B.; Brouwer, R.; Van Beukering, P.J. The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis. Renew. Sustain. Energy Rev. 2013, 20, 504–513. [CrossRef]

Webb, E., Jachowski, N., Phelps, J., Friess, D., Maung Than, M., & Ziegler, A. (2013). Deforestation in the ayeyarwady delta and the conservaiton implications of an internationallyengaged Myanmar. doi:10.1016/j.gloenvcha.2013.10.007

Win, Z. C., Mizoue, N., Ota, T., Kajisa, T., & Yoshida, S. (2018). Consumption rates and use patterns of firewood and charcoal in urban and rural communities in Yedashe Township, Myanmar. *Forests*, *9*(7). https://doi.org/10.3390/f9070429

Win, Z. C., Mizoue, N., Ota, T., Kajisa, T., Yoshida, S., Oo, T. N., & Ma, H. ok. (2018). Differences in consumption rates and patterns between firewood and charcoal:

A case study in a rural area of Yedashe Township, Myanmar. *Biomass and Bioenergy*, *109*, 39–46. https://doi.org/10.1016/j.biombioe.2017.12.011

Yamane, T. Statistics: An Introductory Analysis, 2nd ed.; Harper and Row: New York, NY, USA, 1967.

Zhang, Y.J.; Da, Y.B.The decomposition of energy-related carbon emission and its decoupling with economic growth in China. Renew. Sustain. Energy Rev. 2015, 41, 1255–1266. [CrossRef]