ECONOMIC AND CLIMATE BENEFITS FROM UTILIZATION OF UNUSED FARMLANDS FOR EUCALYPTUS PLANTATIONS AND CHARCOAL PRODUCTION IN THAILAND

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ABSTRACT

Thai farmers plant eucalyptus trees on their unused farmlands with poor fertility soils to raise their incomes and in response to inducements from the Government. The conversion of unused farmlands to eucalyptus can contribute to climate change mitigation as the growing trees sequester carbon. To estimate the contribution of eucalyptus plantations to climate change mitigation requires not only accounting for the sequestered carbon, but also for the production of charcoal using eucalyptus wood residues from harvesting and from paper refineries. These by-products are the main raw materials used by rural communities in Thailand for charcoal making. This paper estimates the contribution of eucalyptus plantations on unused farmlands in Khon Kaen province in northeast Thailand, accounting for carbon sequestrated by the plantations, greenhouse gas emissions from eucalyptus charcoal production, and net avoided emissions from substituting fossil fuels with charcoal for heating. Carbon sequestration by the plantations was assessed for trees aged 1, 2 and 3 years by summing the aboveground biomass (stems, branches and leaves) and belowground biomass (roots). Three-year old eucalyptus trees are the main supply for the paper refineries. The amount of biomass and carbon stored in the eucalyptus plantations depend on age and productivity. The average carbon stored in 3-year old eucalyptus plantations at the study sites was 0.777 ton/ha. Eucalyptus growers received about 1,689 USD per ha from the harvesting of 3-4 year old eucalyptus plantations. Emissions from eucalyptus charcoal production were estimated by accounting for transportation of wood residues from the farms and refineries to kilns and charcoal processing. Emissions from charcoal production were estimated at 0.37 g CO_2eq/MJ, meaning that substituting fossil fuels with eucalyptus charcoal reduces emissions for heat production by 99.5%. The eucalyptus plantation on unused land provided climate benefits and alternative income for local farmers. Based on these findings, the government should consider promoting eucalyptus plantation and eucalyptus charcoal production on unused suitable farmland under its policies on climate change mitigation, energy security and rural development.

Key words: Biomass and carbon stocks, profitability, greenhouse gas emissions

1. INTRODUCTION

Government of Thailand has promoted reforestation with eucalyptus since 1975 (FAO 2004). Thai farmers became strongly interested in the eucalyptus, as they could receive seeding distribution from the government support in particular the decreasing trend in the cassava price during 1980-1990 (Ubukata and Jamroenpruksa 1997). The largest area of eucalyptus plantation was the northeast of Thailand (National Statistical Office 2010), the eucalyptus farm forests had rapidly expanded in the northeast from 0.35 million ha in 1997 to 0.68 million ha in 2007 (Thaiutsa 2008).

Eucalyptus can be fast grown in poor fertile soils and drought tolerant. The eucalyptus wood is used for furniture, paper and fuel (charcoal). In Thailand, the commercial charcoals are widespread produced from the eucalyptus, they provide more heat value (about 7,400 calories per kg) than raw wood and reducing smoke while cooking (Department of Alternative Energy Development and Efficiency 2010, Laemsak 2014). Under the 20 Year Energy Efficiency Development Plan (2011-2030), the Government of Thailand aims to replace use of fire wood by charcoal as higher energy efficiency improvement. Demand of charcoal is expected to increase to 8,173 10^6kg in 2030 (Ministry of Energy 2011). The eucalyptus wood has an increase demand in future due to their good growth, climatic adaptability and utilization.

The eucalyptus forest plantation is currently interested for absorption sources of greenhouse gases as fast growing plants, and can be reflected in the REDD plus activities. The eucalyptus plantation in the Northeast of Thailand at the age of 3 years could store more carbon dioxide than teak plantation at the age of 6 years and para-rubber plantation at the age of 5 years (Cheamwongsa 2010).

Some recent studies argue the eucalyptus planting have negatively affected water and soil quality, in addition to reducing the area of farmland (Petchmark 1987, Nampakdee, Tulaphitak et al. 2009). The promotion of eucalyptus plantation on the paddy dikes effected the growth of some neighbouring plants from their needing more water and Terpenes in eucalyptus leaves (Sirtwattanagarn 1989, Hirun 2000). The expansion of eucalyptus monoculture in the long period can decrease groundwater and disturb flora and fauna in farms (Homjan, Mongkolsawat et al. 1989). This point out a common understanding of impacts from eucalyptus plantation and sustainable management has to be considered among policy makers, scientists and rural farmers.

Optimal land use for eucalyptus plantation can contribute the formulation of sound national biofuel policies and avoiding conflicts. This study aims to examine economic and climate benefits of eucalyptus plantation on unused lands, how eucalyptus plantation can absorb the greenhouse gases and how eucalyptus charcoal used to substitute the fossil fuel for heat production can reduce greenhouse gas emission. How much local farmers could receive alternative income from eucalyptus plantation on their unused lands. Two villages in Kranuan District, Khon Kaen Province in the northeast of Thailand were selected as the general research area.

The Case Eucalyptus Farms and Rural Households' Charcoal Production

Eucalyptus plantation rapidly expanded in Kranuan District from 216 ha in 2000 to 988 ha in 2012 (Department of Land Development 2013). Primary data of the eucalyptus plantation and charcoal production at the study sites in Kranuan District was collected through interviews and observations from household survey responses and the village headmen. Generally, the most people in the study sites are mainly employed in agriculture as farmers or hired labourers. They still keep traditional farming activities such as rice, upland field crops and livestock. Some unused land was converted to eucalyptus because of poor fertile soil, water shortage, labor saving and the Government's seeding subsidy from the last decade.

Most of the household heads surveyed were male and their average age indicates they were economically active (age range: 25-64 years old). Their education background was mostly up to the elementary level. Family labor was principally used on their farms, though some farmers were engaged in factory work, general services and vending. Average operated land of the households ranged from 1.61to 4.8 ha. Some unused land was converted to eucalyptus because of poor fertile soil, water shortage, labor saving and the Government's seeding subsidy from the last decade. Majority of farmers were owner farmers. The major crops of households interviews included rice, para rubber, cassava, sugarcane, eucalyptus and vegetables. Their livestock included cattle, buffalo, pigs, ducks and chickens.

Fuel woods and charcoal are main traditional energy cooking sources in study sites. Women in particular collect wood daily from their farms and nearly public areas such as forest communities. The eucalyptus wood residues from farm are main raw materials of charcoal production by using the traditional earthen kilns which made from clay, as shown in figure 1. The earth kilns can be used to combust the wood residues at 120-150^{o}c. Some households used a 200 litres gasoline container connected with the chimney pipe to the outlet opening in the bottom of container, and made backfill it with clay. This not only reduces smoke and dust, but allows the farmers to produce wood vinegar, which can be used as herbicide and thus avoids emissions associated with commercial herbicides. Emissions from charcoal processing by using the earthen kilns were estimated in this study.

Figure 1 Charcoal production from eucalyptus wood residues using the earthen kilns

2. METHODS

In order to assess the climate and economic benefits of eucalyptus plantation on unused lands in Thailand, this study assess the carbon stocks of eucalyptus plantation, GHG emissions of eucalyptus charcoal processing and profitability of eucalyptus plantation. Generally, wood charcoals are produced from wood residues from farms after harvesting, and from paper refineries, and thus wood residues are considered as by-products of cultivation for the GHG emission calculation. Figure 2 shows the carbon stocks of eucalyptus plantation and emissions of charcoal production from the eucalyptus wood residues.

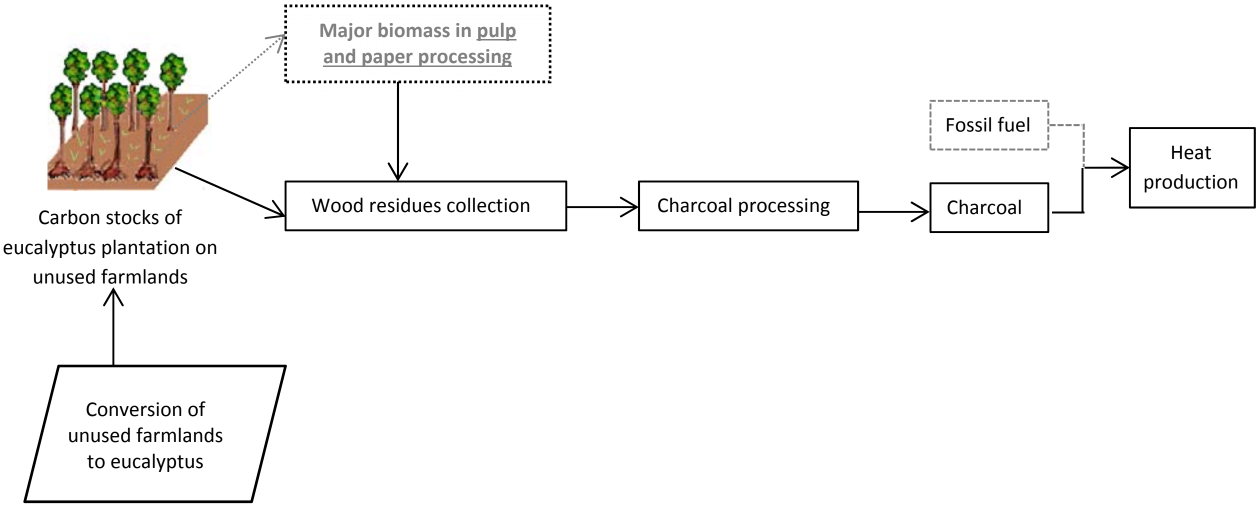

Figure 2 Flow diagram of the estimating of climate benefits from utilization of unused farmlands for eucalyptus plantations and emissions of charcoal production

2.1 Aboveground Biomass and Carbon Stocks Analysis

The species of eucalyptus mostly found in the study sites is *Eucalyptus camaldulenis Dehnh.* The eucalyptus at age 3 years is the proper size for supplying paper refineries. The cropland biomass is calculated by summing the aboveground biomass (stem, branch and leaf) and belowground biomass (root). Carbon stock was estimated by measuring diameter at breast height (DBH) and height (H) of *Eucalyptus camaldulenis Dehnh* at age 1, 2 and 3 years in 10 mx10 m sample plots (two sample plots of each age), and applying allometric equation. The equations used in the analyses are as follows (Chakrapholwararit 1985, Cheamworngsa 2010):

Biomass of stem (W_S) = 0.895 log D^2H - 1.372, R^2 = 0.993

Biomass of branch (W_B) = 0.794 log (D^2H) – 1.740, R^2 = 0.831

Biomass of leaf (W_L) = 0.898 log (D^2H) – 2.438, R^2= 0.862

Biomass of root (W_R) = 24% of total aboveground biomass of tree (Cairns et al., 1997; Jobbagy and Jackson, 2000)

Equation 1: Total biomass of tree (B_T) = $B_S + B_B + B_L + B_R$

Where,

B_T = Total biomass of tree (ton/ha)

B_S = Total biomass of stem (ton/ha)

B_B = Total biomass of branch (ton/ha)

B_L = Total biomass of leave (ton/ha)

B_R = Total biomass of root (ton/ha)

Equation 2: Total carbon stocks of tree (T_C) = B_T x 0.5

Where,

T_C = Total carbon stocks of tree (ton/ha)

B_T = Total biomass of tree (ton/ha)

2.2 GHG Emission Calculation from Charcoal Production

The eucalyptus wood residues after harvesting and from paper refineries as by-product are the main raw materials used for producing charcoal in the study sites. The emissions from charcoal production can be considered to be the results of charcoal processing (E_p), transportation of eucalyptus wood-wood residues (E_{td}) and emissions saving from wood vinegar utilization to replace paraquat for the agricultural farming (E_{ee}).

Combustion of woods in the earthen kilns emitted greenhouse gas. The N_2O and CH_4 emissions from this combustion were estimated based on the IPCC default emissions factors (IPCC 2006). The eucalyptus wood was delivered to charcoal kiln by pick-up car, an average total weight of 7 tonnes per trip was assumed. Average distance (one-way trip) from farms/local paper refineries was around 10-52 km. To produce 1 kilogram of charcoal, about 3.2 kilogram of eucalyptus woods/eucalyptus wood residues were required and around 0.2 litre of wood vinegar was obtained from the charcoal processing as a by-product.

The equations used in the emission calculation are:

Equation 3: Emissions from charcoal processing (E_p) = M_{woods} x $EF_{non\text{-}CO2}$ x GWP

Where,

M_{woods} = Amount of wood used for combusting (MJ)

$EF_{non\text{-}CO2}$ = Emissions factors for CH_4 and N_2O emissions from the wood combustion (kg CH_4/MJ and kg N_2O/MJ)

GWP= Global warming potential factors for the non-CO_2 GHG such as (1) GWP of CH_4 equals 25 kg CO_2-eq/kg CH_4 and (2) GWP of N_2O equals 298 kg CO_2-eq/kg N_2O

Equation 4: Emissions from transportation (E_{td}) = (M_{input} x D_{loaded} x EF_{loaded})+(M_{input} x $D_{empty\ load}$ x $EF_{empty\ loaded}$)

Where,

M_{input} = Average amount of feedstock required for producing biofuel (ton feed stock/ MJ)

EF_{loaded} = Emission factor for transportation with full load (kg CO_2-eq/ton -km)

EF_{empty} = Emission factor for transportation with empty load (kg CO_2-eq/ton -km)

D_{loaded} = Transport distance with load (km)

D_{empty} = Transport distance without load (return trip) (km)

Equation 5: Emissions saving from wood vinegar utilization (E_{ee}) = $M_{exc\text{-}wv\text{-}pq}$ x $EM_{sub\ pq}$

Where,

$M_{exc\text{-}wv\text{-}pq}$ = Average amount of wood vinegar from charcoal processing (L/ kg charcoal)

$EM_{sub\ pq}$ = Emission factor for wood vinegar utilization to replace paraquat (kg CO_2-eq/kg paraquat)

The GHG emissions saving potential from using eucalyptus charcoal was compared with emissions from using fossil fuel for heat production. The emissions from fossil fuel used for heat production was around 77 g CO_2-eq/MJ fossil fuel. The emissions saving potential of charcoal can be calculated based on the following equation.

Equation 6: Emissions saving potential (%)= $\frac{\text{Emissions from fossil fuel used} - \text{Emissions from charcoal used}}{\text{Emissions from fossil fuel used}}$ x 100

2.3 Profitability of Eucalyptus Plantation

Cost-benefit analysis was used to examine the profitability per ha of eucalyptus plantation on unused lands. Total costs (TC in USD per ha) consist of young plants, fertilizers, pesticides, depreciation, interest on capital and rental payment of land. Depreciation refers to value of the assets, which can be converted into cash cost per year. Depreciation was calculated per crop as the amount of equipment usage depends on the crop type. Total revenue (TR in USD per ha) was measured by price (P) and yield of eucalyptus (Y). Net profit (USD per ha) was obtained by deducting total cost from total revenue.

3. RESULTS AND DISCUSSION

3.1 Biomass and Carbon Stocks of Eucalyptus Plantation

Average spacing plantation of common eucalyptus farming in the study sites was 2m x 3m, it was about 13 trees per a sample plot (10 mx10 m). The diameter at breast height (DBH) and height (H) of *Eucalyptus camaldulenis Dehnh* at age 1 was 4.016 cm and 4.539 m based on data collected from two sample plots, presented in table 1. The amounts of DBH and H of eucalyptus at age 2 were 6.384 cm and 8.289 m, and 8.971 cm and 13.698 m for age 3 years old, as shown in table 2-3.

Total biomass calculation of eucalyptus at the age of 1 year can be illustrated as follows.

1) Stem

$\text{Log}(W_S) = 0.895 \log D^2H - 1.372$

$= 0.895 \log (4.016)^2 4.539 - 1.372 \quad = 0.284$

$W_S = 2.064$ kg/tree

Average number of tree in the area 1 rai with spacing plantation 2m x 3 m was about 267 trees. Conversion units were ton/rai and ton/ha (1 rai = 0.16 ha, and 1 ton= 1,000 kg):

$W_S = (2.064*267)/1000 = 0.551$ ton/rai

$= 0.551*0.16 = 0.088$ ton/ha

2) Branch

$\text{Log}(W_B) = 0.794 \log(D^2H) – 1.740$

$= 0.794 \log(4.016)^2 4.539-1.740 \quad = -0.271$

$W_B = 0.567$ kg/tree

Conversion units were ton/rai and ton/ha

$W_B = (0.567x267)/1000 = 0.151$ ton/rai

$= 0.151*0.16 = 0.024$ ton/ha

3) Leaf

$\text{Log}(W_L) = 0.898 \log(D^2H) – 2.438$

$= 0.898 \log(4.016)^2 4.539-2.438 \quad = -0.777$

$W_L = 0.180$ kg/tree

Conversion units were ton/rai and ton/ha

$W_L = (0.180x267)/1000$

$= 0.048$ ton/rai

$= 0.048*0.16 = 0.008$ ton/ha

4) Root

W_R = 24% of total aboveground biomass of tree

$= 24\% (W_S + W_B + W_L)$

$=24\% (2.064+0.567+0.180)$

$= 0.674$ kg/tree

Conversion units were ton/rai and ton/ha

$W_R = (0.674x267)/1000$

$= 0.180$ ton/rai

$= 0.180*0.16 = 0.029$ ton/ha

The average biomass of eucalyptus at the age of 1, 2 and 3 years old in the study sites were 0.149, 0.554 and 1.554 ton/ha, as shown in table 4. There is little difference between these results and other studies in table 5. It shows the eucalyptus plantation on unused land stored carbon stocks as climate benefits.

Table 1 The calculation on biomass of eucalyptus at the age of 1 year old
$\text{Log}(W_S) = 0.895 \log D^2H - 1.372$, $\text{Log}(W_B) = 0.794 \log(D^2H) – 1.740$,
$\text{Log}(W_L) = 0.898 \log(D^2H) – 2.438$, $W_R = 24\% (W_S + W_B + W_L)$
Sample plot no. 1

No.	DBH(cm)	H(m)	D^2	D^2H	logWs	Ws	logWb	Wb	log Wl	Wl	Wr
1	4.9	5.2	24.0	124.9	0.5043	3.194	-0.0755	0.841	-0.5554	0.278	1.035
2	4.8	5	23.0	115.2	0.4730	2.972	-0.1032	0.788	-0.5868	0.259	0.965
3	5	6	25.0	150.0	0.5756	3.764	-0.0122	0.972	-0.4839	0.328	1.215
4	4	4.5	16.0	72.0	0.2903	1.951	-0.2653	0.543	-0.7701	0.170	0.639

5	4	4.6	16.0	73.6	0.2989	1.990	-0.2577	0.552	-0.7615	0.173	0.652
6	4.44	4.8	19.7	94.6	0.3965	2.492	-0.1711	0.674	-0.6635	0.217	0.812
7	5.14	5.5	26.4	145.3	0.5632	3.658	-0.0231	0.948	-0.4963	0.319	1.182
8	4.4	4.8	19.4	92.9	0.3895	2.452	-0.1773	0.665	-0.6706	0.213	0.799
9	4.16	5.1	17.3	88.3	0.3695	2.341	-0.1951	0.638	-0.6907	0.204	0.764
10	3	3.8	9.0	34.2	0.0010	1.002	-0.5220	0.301	-1.0604	0.087	0.334
11	3.2	4.3	10.2	44.0	0.0992	1.257	-0.4348	0.367	-0.9619	0.109	0.416
12	4.32	4.8	18.7	89.6	0.3752	2.373	-0.1899	0.646	-0.6849	0.207	0.774
13	4.98	5.48	24.8	135.9	0.5372	3.445	-0.0462	0.899	-0.5224	0.300	1.115
Average	4.164	4.768			0.332	2.296	-0.228	0.623	-0.728	0.200	0.749

Sample plot no. 2

No.	DBH(cm)	H(m)	D^2	D^2H	logWs	Ws	logWb	Wb	log Wl	Wl	Wr
1	3.18	3.8	10.1	38.4	0.0463	1.112	-0.4818	0.330	-1.0150	0.097	0.369
2	4.96	6	24.6	147.6	0.5694	3.710	-0.0177	0.960	-0.4901	0.323	1.198
3	3.55	4	12.6	50.4	0.1518	1.418	-0.3882	0.409	-0.9091	0.123	0.468
4	3.8	5.4	14.4	78.0	0.3213	2.096	-0.2378	0.578	-0.7390	0.182	0.686
5	2.75	3.2	7.6	24.2	-0.1335	0.735	-0.6413	0.228	-1.1953	0.064	0.247
6	3.72	4.2	13.8	58.1	0.2071	1.611	-0.3391	0.458	-0.8536	0.140	0.530
7	4.26	4.6	18.1	83.5	0.3478	2.227	-0.2143	0.611	-0.7124	0.194	0.728
8	4	4.2	16.0	67.2	0.2635	1.834	-0.2891	0.514	-0.7970	0.160	0.602
9	3.96	4.2	15.7	65.9	0.2557	1.802	-0.2960	0.506	-0.8049	0.157	0.591
10	4.14	4.3	17.1	73.7	0.2994	1.992	-0.2572	0.553	-0.7610	0.173	0.653
11	3.1	3.6	9.6	34.6	0.0054	1.013	-0.5180	0.303	-1.0560	0.088	0.337
12	4.2	4.4	17.6	77.6	0.3195	2.087	-0.2394	0.576	-0.7408	0.182	0.683
13	4.75	5	22.6	112.8	0.4649	2.916	-0.1104	0.775	-0.5950	0.254	0.947
Average	3.868	4.31			0.235	1.831	-0.314	0.510	-0.826	0.159	0.600

Average DBH (cm) = 4.016, Average Height (m) = 4.539

Table 2 The calculation on biomass of eucalyptus at the age of 2 years old

Sample plot no. 1

No.	DBHZ(cm)	H(m)	D^2	D^2H	logWs	Ws	logWb	Wb	log Wl	Wl	Wr
1	7.3	9	53.3	479.6	1.027	10.651	0.389	2.447	-0.031	0.932	3.367
2	7.29	8.49	53.1	451.2	1.004	10.085	0.368	2.331	-0.054	0.882	3.192
3	7.49	9.85	56.1	552.6	1.082	12.091	0.438	2.738	0.025	1.058	3.813
4	6.3	8.1	39.7	321.5	0.872	7.446	0.251	1.781	-0.187	0.651	2.371
5	6.5	8.1	42.3	342.2	0.896	7.874	0.272	1.872	-0.162	0.688	2.504
6	6.84	8.66	46.8	405.2	0.962	9.159	0.331	2.140	-0.096	0.801	2.904
7	7.14	9.1	51.0	463.9	1.015	10.339	0.377	2.383	-0.044	0.905	3.270
8	6.89	8.65	47.5	410.6	0.967	9.269	0.335	2.163	-0.091	0.811	2.938
9	6.46	8.95	41.7	373.5	0.930	8.515	0.302	2.006	-0.128	0.745	2.704
10	5.6	7.65	31.4	239.9	0.758	5.730	0.150	1.412	-0.301	0.500	1.834
11	5.5	8.19	30.3	247.7	0.771	5.897	0.161	1.448	-0.288	0.515	1.886
12	6.81	8.6	46.4	398.8	0.956	9.030	0.325	2.114	-0.103	0.790	2.864
13	7.18	9.33	51.6	481.0	1.029	10.678	0.390	2.453	-0.030	0.934	3.376
Average	6.522	8.533			0.915	8.394	0.289	1.977	-0.143	0.734	2.665

Sample plot no. 2

No.	DBHZ(cm)	H(m)	D^2	D^2H	logWs	Ws	logWb	Wb	log Wl	Wl	Wr
1	5.58	7.65	31.1	238.2	0.755	5.693	0.147	1.404	-0.304	0.497	1.823
2	7.26	9.8	52.7	516.5	1.056	11.382	0.414	2.595	-0.002	0.996	3.594
3	5.55	7.7	30.8	237.2	0.754	5.671	0.146	1.399	-0.305	0.495	1.816
4	6.25	9.15	39.1	357.4	0.913	8.186	0.287	1.937	-0.145	0.716	2.602
5	4.95	6.8	24.5	166.6	0.616	4.135	0.024	1.057	-0.443	0.361	1.333
6	6.12	7.85	37.5	294.0	0.837	6.874	0.220	1.659	-0.221	0.601	2.192
7	6.66	8.2	44.4	363.7	0.920	8.315	0.293	1.964	-0.138	0.727	2.642
8	6.5	8.05	42.3	340.1	0.894	7.831	0.270	1.863	-0.165	0.685	2.491
9	6.19	8.05	38.3	308.4	0.856	7.175	0.236	1.723	-0.203	0.627	2.286
10	6.54	7.8	42.8	333.6	0.886	7.697	0.263	1.834	-0.172	0.673	2.449
11	5.5	7.45	30.3	225.4	0.734	5.418	0.128	1.343	-0.325	0.473	1.736
12	6.6	8.25	43.6	359.4	0.915	8.226	0.289	1.946	-0.143	0.719	2.614
13	7.15	8.85	51.1	452.4	1.005	10.109	0.369	2.336	-0.053	0.884	3.199

Average	6.246	8.045			0.858	7.397	0.238	1.766	-0.201	0.647	2.354
Average DBH (cm) = 6.384, Average Height (m) = 8.289											

Table 3 The calculation on biomass of eucalyptus at the age of 3 years old

No.	DBHZ(cm)	H(m)	D^2	D^2 H	logWs	Ws	logWb	Wb	log Wl	Wl	Wr
Sample plot no. 1											
1	9.95	14.46	99.0	1431.6	1.452	28.344	0.766	5.831	0.396	2.488	8.799
2	9.89	13.89	97.8	1358.6	1.432	27.047	0.748	5.593	0.376	2.374	8.404
3	9.99	15.31	99.8	1527.9	1.478	30.045	0.788	6.140	0.421	2.638	9.318
4	9	13.45	81.0	1089.5	1.346	22.197	0.672	4.694	0.289	1.947	6.921
5	9.15	13.5	83.7	1130.3	1.361	22.940	0.684	4.833	0.304	2.013	7.149
6	9.44	14.12	89.1	1258.3	1.402	25.252	0.721	5.263	0.346	2.216	7.856
7	9.79	14.5	95.8	1389.7	1.441	27.601	0.755	5.695	0.384	2.423	8.573
8	9.54	13.95	91.0	1269.6	1.406	25.456	0.724	5.300	0.349	2.234	7.918
9	8.96	14.41	80.3	1156.9	1.370	23.423	0.692	4.923	0.313	2.055	7.296
10	8.25	12.85	68.1	874.6	1.261	18.236	0.596	3.943	0.204	1.599	5.706
11	8	13.65	64.0	873.6	1.260	18.217	0.595	3.939	0.203	1.597	5.701
12	9.46	14.05	89.5	1257.4	1.402	25.236	0.721	5.260	0.345	2.215	7.850
13	9.83	14.79	96.6	1429.1	1.452	28.300	0.765	5.823	0.395	2.485	8.786
Average	9.142	13.927			1.370	23.686	0.693	4.967	0.313	2.078	7.376
Sample plot no. 2											
No.	DBHZ(cm)	H(m)	D^2	D^2 H	logWs	Ws	logWb	Wb	log Wl	Wl	Wr
1	8.23	13.11	67.7	888.0	1.267	18.485	0.601	3.991	0.210	1.621	5.783
2	9.76	15.2	95.3	1447.9	1.457	28.633	0.770	5.883	0.400	2.514	8.887
3	8.15	13.1	66.4	870.1	1.259	18.152	0.594	3.927	0.202	1.591	5.681
4	8.9	14.5	79.2	1148.5	1.367	23.272	0.690	4.895	0.310	2.042	7.250
5	7.45	12.25	55.5	679.9	1.163	14.556	0.509	3.228	0.106	1.275	4.574
6	8.57	13.31	73.4	977.6	1.304	20.145	0.634	4.307	0.247	1.767	6.293
7	9.31	13.6	86.7	1178.8	1.377	23.820	0.699	4.997	0.320	2.090	7.418
8	8.99	13.5	80.8	1091.1	1.347	22.227	0.672	4.700	0.290	1.950	6.930
9	8.84	13.51	78.1	1055.7	1.334	21.582	0.661	4.578	0.277	1.893	6.733
10	8.99	13.15	80.8	1062.8	1.337	21.710	0.663	4.603	0.280	1.904	6.772
11	8.15	12.91	66.4	857.5	1.253	17.916	0.589	3.881	0.196	1.571	5.608
12	9	13.65	81.0	1105.7	1.352	22.493	0.677	4.749	0.295	1.973	7.012
13	9.8	14.31	96.0	1374.3	1.437	27.327	0.752	5.645	0.380	2.399	8.489
Average	8.8	13.469			1.327	21.505	0.654	4.558	0.270	1.886	6.708
Average DBH (cm) = 8.971, Average Height (m) = 13.698											

Table 4 Biomass and carbon stock (ton/ha) of eucalyptus at the age of 1, 2 and 3 years

Eucalyptus at the age of	Biomass (ton/ha)					Carbon from plant biomass (ton/ha)
	Stem (W_S)	Branch (W_B)	Leaf (W_L)	Root (W_R)	Total	
year 1	0.088	0.024	0.008	0.029	0.149	0.074
year 2	0.337	0.080	0.029	0.107	0.554	0.277
year 3	0.965	0.203	0.085	0.301	1.554	0.777

Table 5 The previous studies on aboveground biomass and carbon stock (ton/ha) of *Eucalyptus camaldulensis Dehnh* at the age of 1, 2, 3 and 4 years old

Eucalyptus at the age of	Biomass content (ton/ha)	Carbon content
[1/]Year 1	0.235	0.117
[2/]Year 2	0.624	0.312
[3/]Year 3	1.313	0.657
[4/]Year 4	1.933	0.967

Sources: [1/]Cheamwongsa, 2010,[2/]Chakraponwararit, 1985,[3/]Vannaprasert, 1996, [4/]Petsri, 2004.

3.2 Emissions from Charcoal Production

The emissions from charcoal processing were the highest (0.2 g CO_2eq/MJ) for charcoal production, followed by transportation (0.19 g CO_2eq/MJ) in table 6. The wood vinegar as by-product of charcoal production was used to substitute paraquat for the agricultural farming. The emissions saving from wood vinegar utilization were 0.02 g CO_2eq/MJ. The emissions were reduced by 99.5% for the use of eucalyptus charcoal comparing with the fossil fuel used for the heat production. This study showed the eucalyptus plantation on unused lands could be promoted to rural communities for climate benefits and utilization of wood residues. To reduce the harmful smoke and pollution from using earthen kilns, the proper kilns are necessary for rural communities.

Table 6 Net GHG emissions per year of eucalyptus charcoal production

Type of emissions	Value (g CO_2eq/MJ)
Emissions from charcoal processing (E_p)	0.2
Emissions from transportation (E_{td})	0.19
Emissions saving from wood vinegar utilization (E_{ee})	-0.02
Net GHG emissions (E_p+ E_{td}+E_{ee})	0.37
Emissions saving potential from use of eucalyptus charcoal compared with emissions from use of fossil fuel for heat production equals	99.5%

Note: Minus (-) means positive impacts of by-product utilization

3.3 Profitability of Eucalyptus Plantation

The data collected from the questionnaire survey were used to estimate profitability per ha of eucalyptus planting on unused lands. The majority of eucalyptus were harvested within 3-4 years old. The average planted area of eucalyptus per household was 0.28 ha. Main causes of conversion of unused lands to eucalyptus were low soil fertility, hard soil and water scarcity that were not suitable for other crops growing. The costs of eucalyputs plantation depended on seeding, fertilizers, pesticides and labor. Most eucalyptus growers did not use much fertilizer after planting eucalyptus in the rainy season. Average total costs of eucalyptus plantations after 3 years were 338 USD per ha. Seeding had the highest cost (57% of total costs), followed by fertilizers and pesticides (35% of total costs) in table 7. Average renevues were 1,689 USD per ha, the profitability of eucalyptus farming was about 1,351 USD per ha. According to a provincial report, in 2012, the average annual income per farm household owning land was 5,178 USD. Therefore, the planting of eucalyptus on unused lands can be alternative farm incomes.

Table 7 Economic value of eucalyptus farming in study sites in Khon Kaen Province

Items	Values	
1. Total costs (USD per ha)	338	%
Seeding	192	57
Fertilizer and pesticides	119	35
Labors	21	6
Others (land tax and rent charge)	6	2
2. Total revenues (USD per ha)	1,689	
Net Profits (1) – (2)	1,351	

4. CONCLUSIONS

The study analysed the amount of carbon stored by the eucalyptus plantation on unused lands and GHG emissions from charcoal production by eucalyptus wood residues from farms. The emissions from eucalyptus charcoal used were lower than the fossil fuel used for heat production. The wood vinegar as by-product of charcoal production can be used to substitute chemical pesticide and insecticide and provide emissions saving. Economic analysis revealed that the eucalyptus farming was the profitable farming for local farmers.

The environmental impacts from using the earthen kilns found in study sites were smoke and pollution. The proper kilns should be promoted to reduce the negative impacts and made good quality of charcoal. The eucalyptus expansion is now entering to the arable areas. The Thai Government should encourage agricultural zoning to avoid anti-eucalyptus movement, make productive use of unused land to improve rural incomes.

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