International Journal of Agricultural Technology 2021Vol. 17(6):2403-2416
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Carbon emission equivalent of selected agroforestry systems in Zamboanga City, Philippines

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Tabal, E. P., Mendoza, T. C., Paelmo, R. F., Garcia, J. N. M. and Visco, R. G. (2021). Carbon emission equivalent of selected agroforestry systems in Zamboanga City, Philippines. International Journal of Agricultural Technology 17(6):2403-2416.

Abstract The study was estimated the carbon emission equivalent expressed in tCO_{2e} ha^{-1} derived from the individual energy inputs of the nine (9) major agroforestry systems (AFSs) identified across the 16 community-based forest management (CBFM) sites located mostly in the hilly and mountainous portion of Zamboanga City, Philippines. The energy input was calculated as direct energy input (DEI), indirect energy input (IEI) and embedded energy input (EEI) from the various cultural and management practices that falls on pre-land preparation, crop establishment, crop care and maintenance, harvest and postharvest operations. The total energy input (TEI) is the sum total of DEI, IEI and EEI computed in Mcal ha^{-1}. All Mcal units were then converted into Liter Diesel Oil Equivalent (LDOE), where 1.0 LDOE = 11.414 Mcal = 3.96 kg CO_2 equivalent emission $LDOE^{-1}$. The total CO_2 emission equivalent ranged from 2.01-4.09 tCO_{2e} ha^{-1} across the 9 AFSs. Of this amount, the DEI, IEI and EEI contributed 1.6-5.4%, 94.1-98.0% and 0.35-0.53%, respectively. The high CO_2 emission equivalent of IEI was attributed to high usage of external inputs such as inorganic fertilizers particularly N fertilizer, pesticides and labor. Other factors associated to high energy usage and its net carbon emission equivalent includes plant density and number of agricultural crop species present within an AFS. Understanding the significant contributions of various energy-intensive systems delineated into DEI, IEI and EEI will help policy makers and local planners to initiate a 'green agriculture economy' – a food production system with reduced energy and carbon footprints responsive to changing climate with higher economic potential for the upland growers in the City of Zamboanga, Philippines.

Keywords: Agroforestry systems (AFSs), Total energy inputs (TEI), Indirect energy input (IEI), Liter diesel oil equivalent (LDOE), Carbon emission equivalent

Introduction

Modern farms and agricultural operations work far differently than those a few decades ago, primarily because of advancements in technology

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including the use of fossil fuel-based farm inputs (Lal, 2004) such as the use of farm machineries that runs on diesel or gasoline, irrigation, cultivation, harvesting, food processing, storage and logistics (Pimentel, 1980; Tabal and Mendoza, 2020; Tabal *et al.*, 2021).

Energy has always been essential for the production of food but to produce it also require high amount of energy inputs in the form of seeds, inorganic fertilizers, chemical pesticides and labor (Pimentel, 1984; Mendoza, 2016; Savuth, 2018; Tabal *et al.*, 2021), more so if high production level is being achieved to meet food demand. The goal of increasing crop yield for food is associated with the impact of rapid population growth, then food production would become increasingly dependent on energy derived from fossil fuels (Thu and Mendoza, 2011; Taghavi and Mendoza, 2011; Egle and Mendoza, 2013; Tabal and Mendoza, 2020; Tabal *et al.*, 2021) which are carbon-based inputs (Marland *et al.*, 2003; Lal, 2004) derived as direct, indirect and embedded energy inputs attributed largely from the various cultural and management practices that falls on pre-land preparation (PLP), crop establishment (CE), crop care and maintenance (CCM), harvest and postharvest (HPH) operations (Tabal and Mendoza, 2020; Tabal *et al.*, 2021) which implicate our food system to be highly processed and energy intensive (Pimentel *et al.*, 1983; Pfeiffer, 2009; Pimentel *et al.*, 2008; Mendoza, 2016; Savuth, 2018).

Increase usage of energy inputs can lead to increase in carbon emission which have high powerful global warming potential (Mendoza and Samson, 2002). In short, from production to consumption, the entire process is energy intensive with high potential of greenhouse gas (GHGs) emission (Lal, 2004) implicating agriculture sector as one of the major contributors to increasing level of GHGs emissions (Nelson *et al.*, 2009; Hillier *et al.*, 2009) with a substantial share to global emission from fossil fuel combustion (Pacala and Socolow, 2014). In fact, the global average indicated that levels of CO_2, CH_4 and N_2O continue to increase (Sharma *et al.*, 2016) attributed largely to energy usage and this constitutes a record high of 53.5 $GtCO_{2e}$ in 2017, an increase of 0.7 $GtCO_{2e}$ compared to 2016 data. This implication strongly points out that climate changes forced by GHGs depend primarily on cumulative emissions (IPCC, 2017). Thus, an understanding of the emissions expressed in ton carbon dioxide equivalent per hectare (tCO_{2e} ha^{-1}) for various farm inputs derived from the different farm operations is essential to identify a viable policy framework that sets out exactly what needs to be done to stop climate disruption and reverse its impact (UNCAS, 2019).

Community-Based Forest Management (CBFM) is currently the Philippines' major strategy for the sustainable development of the country's forest resources. Its evolution as a policy and practice in forest management attributed from major government policies and programs. CBFM emerged as a major approach to the allocation of forestlands to communities and indigenous peoples by virtue of Executive Order (EO) 263 in 1995. The CBFM as a program is being managed by the Department of Environment and Natural Resources (DENR) through Administrative Order No. 96-29 that integrate and unify all the people-oriented programs where the development, promotion and establishment of agroforestry systems (AFSs) are exemplified in order to address poverty and environmental protection (Nair, 2007; Garrity, 2006; Jose 2009; Garrity, 2012).

However, food sources derived from AFSs such as fruits and annual crops also requires enormous energy to produce them in the form of machineries, farm implements, equipment, farm tools, various inputs like seeds, inorganic fertilizers and chemical pesticides, trucks and other form of logistics used for hauling and transport including human and animal labor. Before reaching our plates, our food is produced, stored, processed, packaged, transported, prepared, and served. The entire process is fossil fuel-based intensive (Tabal and Mendoza, 2020; Tabal *et al.,* 2021). Hence, at every stage, there is high carbon emission equivalent potential derived from energy usage.

The objective of this study was to estimate the carbon emission equivalent calculated from the energy inputs of the different agroforestry systems (AFSs) in Zamboanga City, Philippines.

Materials and methods

Site location

Zamboanga City is located at a latitude of 6°55’17.19”N and a longitude of 122°4’44.5”E, respectively with a total land area of 148,388.49 hectares (1,483.88 km^2). Record evaluation was done first at the regional office of the Community Environment and Natural Resources, Department of Environment and Natural Resources (CENRO-DENR) for the general overview of the community-based forest management (CBFM) sites and subsequently conducted field assessment and validation to determine the different dominant crops (forest and fruit trees), systems and practices, approximate geographic, environmental and climatic information.

The CBFM sites

There were sixteen (16) identified CBFM sites with a total land area of 12,406.6 hectares located mostly in the hilly and mountainous portion of

Zamboanga City, Western Mindanao, Philippines (Figure 1) and within these sites are the nine (9) identified dominant agroforestry systems (AFSs) with their individual tree and crop components (Table 1). These major AFSs were subjected for comparisons in terms of energy usage. All field information were derived from formal survey interviews. Data generated were all based on the personal understanding, records, awareness and available information provided by the respondents.

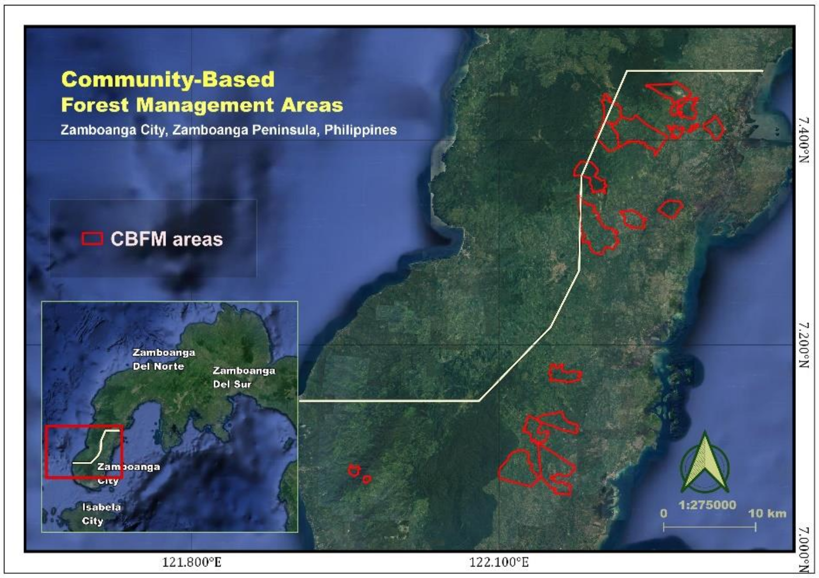

Figure 1. Community-Based Forest Management (CBFM) sites in Zamboanga City, Western Mindanao, Philippines

Table 1. List of Dominant Agroforestry Systems (AFSs) and their Tree and Crop Components across the 16 CBFM Sites in Zamboanga City, Philippines

Types of AFSs	Tree and Crop Components
Coconut+1based	Coconut+banana
Coconut+2based	Coconut+rubber+banana
Coconut+3based	Coconut+rubber+banana+mahogany
Rubber+1based	Rubber+uplandrice
Rubber+2based	Rubber+coconut+banana
Rubber+3based	Rubber+coconut+banana+marang
Lanzones-based	Lanzones+coconut+banana+spanishcedar
Mango-based	Mango+coconut+banana+mahogany
Marang-based	Marang+coconut+banana

Coconut (*Cocos nucifera)*, Rubber (*Hevea brasiliensis)*, lanzones *(Lanzium domesticum)*, mango *(Mangifera indica)*, and marang *(Artocarpus odoratissimus)*

Table 2. Energy coefficients of various farm inputs

PARTICULARS	UNIT	ENERGY EQUIVALENT PER UNIT		REFERENCES
		MJ	Mcal	
A) INPUTS				
1. SEEDS:				
(a) Rice	kg	16.75	4.00	Mendoza, 2005; Gliessman, 2014
(b) Corn	kg	14.69	3.51	Ozkan *et al.*, 2004
2. AGROCHEMICALS:				
(a) Herbicide (glyphosate)	Lit	553.07	**132.19**[1]	Pimentel, 1980; Barber, 2004
(b) Herbicide (Gen.), ave.	Lit	274.00	65.50	Wells, 2001; Saunders *et al.*, 2006; Gundogmus, 2006; Ziaei, 2015
(c) Insecticide (solid)	kg	315.00	75.29	Wells, 2001; Saunders *et al.*, 2006
(d) Insecticide (liquid), ave.	Lit	281.32	67.24	Pimentel, 1980; Gundogmus, 2006; Ziaei, 2015
(e) Fungicide (solid)	kg	210.00	50.20	Wells, 2001; Saunders *et al.*, 2006
(f) Fungicide (liquid), average	Lit	104.10	24.88	Gundogmus, 2006; Ziaei, 2015; Pimentel, 1980
3. CHEMICAL FERTILIZERS:				
(a) Nitrogen	kg	102.23	**24.43**[2]	Rodolfo, 2008; Mendoza, 2014
(b) Phosphate (P2O5), ave.	kg	20.60	4.92	Rodolfo, 2008; Mendoza, 2014; Fluck, 1992; Safa *et al.*, 2011; Shresta, 1998
(c) Potassium (K2O), ave.	kg	16.38	3.91	Rodolfo, 2008; Mendoza, 2014; Kitani, 1990; Fluck, 1992; Safa *et al.*, 2011; Pimentel, 1980
4. FUEL:				
(a) Gasoline	Lit	42.32	10.11	Kitani, 1999
(b) Diesel fuel	Lit	56.31	**13.46**[3]	Kitani, 1999; Mohammadi *et al.*, 2008; Erdal *et al.*, 2007
5. Electricity	kwh	3.60	0.86	Ozkan *et al.*, 2004; Khizilaslan, 2009
6. Irrigation	cu m	1.02	0.24	Mohammadi *et al.*, 2008

[1]The energy for production of Glyphosate is 440 MJ kg^{-1}, the formulation and packaging, and transportation is 113.03 MJ kg^{-1}. In: Savuth, 2018.

[2]Estimates includes the drilling, processing, storage and transport to site of utilization (Rodolfo, 2008; Mendoza, 2014).

[3]Estimates includes the processing, storage and transport to site of utilization (Rodolfo, 2008).

Calculating the energy inputs

The total energy input (TEI) is the sum total of direct energy input (DEI), indirect energy input (DEI) and embedded energy input (EEI) of various tree and annual crop components. The DEI includes the direct usage of diesel and/or gasoline to run the machines for farm operations and transport of farm products. While, the IEI are various inputs such as seeds, fertilizers (NPK) used, agrochemicals (pesticides) applied and labor; and the EEI was accounted from the utilization of machines, farm equipment and implements, motorized vehicles and draft animal used (Pimentel, 1980; Mendoza, 2016).

Energy accounting and coefficients

Energy accounting procedures were based from the work of Pimentel (1980); Ozkan *et al.*, 2004; Shresta, 1980; Thu and Mendoza, 2011; Egle and Mendoza, 2013; Mendoza, 2016; Taghavi and Mendoza, 2011; Mendoza and Samson, 2002; Karimi *et al.*, 2008; Gliessman, 2014; Savuth, 2018; Tabal and Mendoza, 2020; Tabal *et al.*, 2021. The various energy coefficients are shown in Table 2.

All energy units in Mcal were converted into Liter Diesel Oil Equivalent (LDOE), where 1.0 LDOE = 11.414 Mcal (Pimentel, 1980). The energy input for the manpower that includes food, clothing and miscellaneous living costs of the farming household were not accounted.

The following equations were used to compute for the DEI, IEI and EEI:

Direct Energy Input (DEI)

a) Direct energy (diesel or gasoline) used ha^{-1} for field operation (DFF_{Ope}): DFF_{Ope} = (Afu x EFcoef) (Eq. 1), where: DFF_{Ope} = direct fuel used per field operation, Mcal ha^{-1}; Afu = average fuel used per working hour (Lit hr^{-1}); and EFcoef = energy coefficient of fuel, Mcal Lit^{-1}.

b) Direct energy (diesel or gasoline) used ha^{-1} for hauling and transport (DFF_{trans}): $DEUF_{trans}$ = (AFtrans x EFcoef) (Eq. 2), where: DFF_{trans} = direct fuel used for hauling and transport, Mcal ha^{-1}; AFtrans = average fuel used per working hour (Lit hr^{-1}); and EFcoef = energy coefficient of fuel, Mcal Lit^{-1}.

Indirect Energy Input (IEI)

a) NPK fertilizers applied (NPKfert): $IEI_{NPKfert}$ = ($A_{NPKfert}$ x $Ecoef_{NPK}$) (Eq. 3), where: $IEI_{NPKfert}$ = indirect energy used on fertilizer (NPK), Mcal ha^{-1};

$A_{NPKfert}$ = amount of fertilizer (NPK) applied, kg ha^{-1}; and $Ecoef_{NPK}$ = energy coefficient of NPK fertilizer, Mcal kg^{-1}.

b) Human labor (HL): $IEI_{HL} = (N_{lab} \times N_{hrs} \times Ecoef_{HL})$ (Eq. 4), where: IEI_{HL} = indirect energy used on human labor, Mcal ha^{-1}; N_{lab} = number of laborers involved per farm operation ha^{-1}; N_{hrs} = number of hours per field operation ha^{-1}; and $Ecoef_{HL}$ = energy coefficient of human labor, Mcal hr^{-1}.

c) Animal labor (AL): $IEU_{AL} = (N_{ani} \times Nhrs \times Ecoef_{AL})$ (Eq. 5), where: IEU_{AL} = indirect energy used on animal labor, Mcal ha^{-1}; N_{ani} = number of animals used per farm operation ha^{-1}; Nhrs = number of hours per field operation ha^{-1}; and $Ecoef_{AL}$ = energy coefficient of animal labor, Mcal hr^{-1}.

d) Organic fertilizer (animal manure, AM): $IEU_{AM} = (A_{AM} \times Ecoef_{AM})$ (Eq. 6), where: IEU_{AM} = indirect energy used on animal manure, Mcal ha^{-1}; A_{AM} = amount of animal manure applied, kg ha^{-1}; and $Ecoef_{AM}$ = energy coefficient of animal manure, Mcal kg^{-1}.

e) Seeds used (upland rice and corn, S): $IEU_S = (A_S \times Ecoef_S)$ (Eq. 7), where: IEU_S = indirect energy used on seed (upland rice and corn), Mcal ha^{-1}; A_S = amount of seed (upland rice and corn) used, kg ha^{-1}; and $Ecoef_S$ = energy coefficient of seed (upland rice and corn), Mcal ha^{-1}.

f) Pesticides (insecticide, fungicide, herbicide – IFH) applied: $IEU_{IFH} = (A_{IFH} \times Ecoef_{IFH})$ (Eq. 8), where: IEU_{IFH} = indirect energy used on pesticides, Mcal ha^{-1}; A_{IFH} = amount of pesticides applied, Lit ha^{-1}; and $Ecoef_{IFH}$ = energy coefficient of specific pesticide, Mcal Lit^{-1}.

For the pre-harvest energy input (PHEI) on PLP, CE and CCM:

a) $PHEI_{PLP} = (SA_{PLP} \times Ecoef_L)/UY_{SPC}$ (Eq. 9), where: $PHEI_{PLP}$ = pre-harvest energy input on pre-land preparation, Mcal; SA_{PLP} = specific activity on pre-land preparation in Mcal; $Ecoef_L$ = energy coefficient of labor in Mcal; and UY_{SPC} = number of unproductive years of specific perennial component per AFS.

b) $PHEI_{CE} = (SA_{CE} \times Ecoef_L)/UY_{SPC}$ (Eq. 10), where: $PHEI_{CE}$ = pre-harvest energy input on crop establishment in Mcal; SA_{CE} = specific activity on crop establishment in Mcal; $Ecoef_L$ = energy coefficient of labor in Mcal; UY_{SPC} = number of unproductive years of specific perennial component per AFS.

c) $PHEI_{CCM} = (SA_{CCM} \times Ecoef_L/UY_{SPC}$ (Eq. 11), where: $PHEI_{CCM}$ = pre-harvest energy input on crop care and management in Mcal; SA_{CCM} = specific activity on crop care and management in Mcal; $Ecoef_L$ = energy coefficient of labor in Mcal; and UY_{SPC} = number of unproductive years of specific perennial component per AFS.

Embedded Energy Input (EEI)

a) Embedded energy input in farm machineries (EEI_{FM}): $EEI_{FM} = (W_M \times Ecoef_M) / (LS_M \times Hr)$ (Eq. 12), where: EEI_{FM} = specific embedded energy input for machinery used per field operation in Mcal ha^{-1}; W_M = weight of the machine, kg $unit^{-1}$; $Ecoef_M$ = energy coefficient of a specific machinery in Mcal kg^{-1}; LS_M = life span of the machine in years $unit^{-1}$; and Hr = the no. of hours the machine was used in hours ha^{-1}.

b) Embedded energy input in farm equipment and tools (EE_{FET}): $EE_{FET} = (W_{FET} \times Ecoef_{FET})/(LS_{FET} \times Hr)$ (Eq. 13), where: EE_{FET} = specific embedded energy for farm equipment and tools used per field operation in Mcal ha^{-1}; W_{FET} = weight of the farm equipment and tools in kg $unit^{-1}$; $Ecoef_{FET}$ = energy coefficient of a specific farm equipment and tools in Mcal kg^{-1}; LS_{FET} = life span of the farm equipment and tools in years $unit^{-1}$; and Hr = the no. of hours the equipment and tools were used in hours ha^{-1}.

Total Energy Input (TEI): TEI = DEI + IEI + EEI (Eq. 14).

Calculating the CO_2 emission equivalent

CO_2 emissions equivalent (tCO_{2e} ha^{-1}) was derived from the Total Energy Inputs (TEI) in Mcal ha^{-1}, where 11.414 Mcal = 1.0 LDOE = 3.96 kg CO_2 emission equivalent (Pimentel, 1980).

Sampling and statistics

Purposive sampling was used in selecting the fitted characteristics and identifying the actual respondents across the 16 CBFM sites. Subsequently, the identified 100 CBFM beneficiaries were interviewed as respondents using a structured questionnaire. Only the dominant identified AFSs were subjected for data collections. The major AFSs were determined and ranked based on the total land area cropped with more or less the same characteristics and crop/species involved within a system. The relationships of predictors such as the DEI, IEI and EEI per AFS were tabulated and analyzed using descriptive statistics. Means, percentages and sums were compared.

Results

Results on net carbon emissions equivalent expressed in tCO_{2e} ha^{-1} of various agroforestry systems (AFSs) is shown in Table 3. Across the nine (9) AFSs, the net C emissions ranged from 2.01 (rubber+1based) to 4.09 tCO_{2e} ha^{-1} (rubber+3based), while the rubber+2based, coconut+2based, coconut+3based, lanzones-based, marang-based, mango-based and coconut+1based obtained 3.9, 3.9, 3.88, 3.51, 2.68. 2.62 and 2.17 tCO_{2e} ha^{-1}, respectively. Of this ranged (2.01-4.09 tCO_{2e} ha^{-1}), 94.1-98.0 percent of the equivalent C emissions attributed to indirect energy input (IEI), while the remaining 2.0-5.9 percent obtained from the direct energy input (DEI) and embedded energy input (EEI), respectively. The sum total of EEI, IEI and EEI is called the total energy input (TEI) that were computed from the various cultural practices and management such as the pre-land preparation (PLP), crop establishment (CE), crop care and maintenance (CCM), harvest and postharvest (HPH) operations. The results further showed that the tree-based systems with three or more agricultural tree crop species within a system contributed to high energy usage which explain why carbon emission equivalent is high derived from IEI. Of the total IEI, the rubber+3based AFS obtained a total of 11,356.24 Mcal followed by coconut+2based at 10,963.03, rubber+2based at 10,954.65, coconut+3based at 10,899.10, lanzones-based at 9,637.70, mango-based at 7,383.73, marang-based at 7,262.59, coconut+1based at 6,018.22, and rubber+1based at 5,648.0 Mcal, or this is equal to 3.94, 3.80, 3.80, 3.78, 3.34, 2.56, 2.52, 2.09, and 1.96 tCO_{2e} ha^{-1} equivalent emission, respectively.

Table 3. Energy inputs (LDOE ha^{-1}) and carbon emission equivalent (tCO_{2e} ha^{-1}) of the different agroforestry systems (AFSs) across the 16 CBFM sites in Zamboanga City, Philippines

Types of AFS[1]	DEI[2] Mcal Ha^{-1}	%	IEI[3] Mcal Ha^{-1}	%	EEI[4] Mcal Ha^{-1}	%	TEI[5] Mcal Ha^{-1}	TEI LDOE[6] Ha^{-1}	Total tCO_{2e} Ha^{-1}
Rubber+1based	115.36	2.0	5,648.00	97.5	27.49	0.5	5,790.85	507.3	**2.01**
Rubber+2based	248.59	2.0	10,954.65	97.6	38.87	0.3	11,242.11	984.9	**3.90**
Rubber+3based	391.98	3.2	11,356.24	96.3	53.12	0.5	11,801.34	1,033.9	**4.09**
Coconut+1based	219.77	3.2	6,018.22	96.3	29.17	0.5	6,267.16	549.1	**2.17**
Coconut+2based	246.16	2.0	10,963.03	97.6	41.15	0.4	11,250.34	985.7	**3.90**
Coconut+3based	231.85	2.0	10,899.10	97.7	41.15	0.3	11,172.10	978.8	**3.88**
Lanzones-based	443.74	4.2	9,637.70	95.3	41.15	0.4	10,122.59	886.9	**3.51**
Marang-based	435.00	5.4	7,262.59	94.1	41.15	0.5	7,738.74	678.0	**2.68**
Mango-based	146.87	1.6	7,383.73	98.0	29.17	0.4	7,559.77	662.3	**2.62**

[1]agroforestry systems, [2]direct energy input, [3]indirect energy input, [4]embedded energy input, [5]total energy input and [6]liter diesel oil equivalent, respectively.
CO_2 emission equivalent (tCO_{2e} ha^{-1}) was derived from the TEI in Mcal, where 11.414 Mcal = 1.0 LDOE = 3.96 kg CO_{2e} emission (Pimentel, 1980).

Discussion

The energy footprint (EF) refers to the various energy inputs such as in the production of upland rice, corn seeds, inorganic fertilizers and pesticides (particularly nitrogen and round-up herbicide), diesel and/or gasoline fuel used to run the rice thresher and rice mill machines, man and animal labor, processing and transportation which has high carbon emission potential (Mendoza and Samson, 2002) in the form of carbon dioxide equivalents expressed in tCO_{2e} ha^{-1}. The carbon emission equivalent described in this study is the amount of CO_2 emitted from the total energy input (TEI) or the energy footprint (EF) in the form of liter diesel oil equivalent (LDOE) either directly or indirectly utilized (Pimentel, 1980) during farm operations or consumed on a particular agroforestry system (AFS). In this case, each of the AFSs with their specific TEI was considered as potential CF expressed in LDOE ha^{-1} where 1.0 LDOE is equivalent to 3.96 kg CO_{2e} emission (Pimentel, 1980). The total CF derived from TEI were considered as the net CO_{2e} emission equivalent.

The high C emission equivalent of rubber+3-based, coconut+2-based, rubber+2-based, coconut+3-based and lanzones-based were directly attributed to high energy inputs mostly derived from the indirect use of energy in the form of farm inputs such as inorganic fertilizers particularly nitrogen (N) fertilizer, herbicide and labor or call these as the 'energy hotspots' (Tabal and Mendoza, 2020; Tabal *et al.,* 2021) which explain the increase in CF. The 'energy hotpots' refers to the high requiring energy activities or processes relative to the growth stages of a particular crop or tree species in a particular AFS accounted in IEI during the pre-land preparation (PLP), crop establishment (CE), crop care and maintenance (CCM), harvest and postharvest (HPH) operations (Tabal *et al.,* 2020). On the other hand, the AFSs with low net C emission equivalent like the coconut+1based, mango-based and marang-based were mainly due to minimal energy usage on coconut, mango and banana components. While the upland rice had short gestation period, hence required no further energy inputs on agrochemicals and labor usage after the cropping period.

The C emission equivalent from direct energy input (DEI) was small that ranged only from 1.6-5.4% across the nine (9) AFSs. The direct use of diesel oil or gasoline fuel was necessary to run the rice thresher and milling machines for upland rice and the 'habal-habal' (motorized bike) used to transport fresh palay (unhusk rice) to the nearest dryer, to rice mill facility then to retail outlets. The main driver on increased amount of fuel usage was the bulk of farm produce being processed and transported to long distances crossing bad terrains and muddy conditions especially during rainy months. This explain the high energy inputs of multi-tree-based systems due to the volume of copra, rubber latex (cup lumps) and banana products being transported utilizing 'habal-habal' in a regular basis including the bulk of farm produce that comes from marang and lanzones fruits in a seasonal basis.

The rubber+1based AFS obtained about 2.01 tCO_{2e} ha^{-1} emission equivalent but this was significantly lower compared to coconut+1based, mango-based, marang-based, lanzones-based, coconut+3based, rubber+2based, coconut+2 based, and rubber+3based AFSs, respectively. This is the reason why the tree-based AFSs were considered energy-intensive systems due to high usage of agrochemicals and high labor requirements that were accounted from PLP, CE, CCM, HPH. The PLP includes the purchasing and hauling of farm inputs and the collection of soil samples that were required for analysis, brushing and clearing activities. The CE includes plowing, harrowing, furrowing, digging/holing, planting and replanting, watering, hilling-up, field visit and monitoring. The CCE includes weeding and application of fertilizers and pesticides. The HPH for permanent perennials includes harvesting (cutting) and picking, tapping (rubber), sorting, packing, hauling, loading and transport, while the HPH for cash crops (upland rice) includes cutting, field drying, hauling, stocking/piling, threshing, cleaning, bagging, grain drying, sacking, storage and milling, loading and transport. This answers why over 94.0% of the emission equivalent across the nine (9) AFSs were attributed to IEI. Of this total, 16.4-50.0% contributed by inorganic fertilizers, 15.5-23.5% by pesticides and 24.4-66.0% by labor, respectively. Insecticide input was used primarily to control 'cocolisap' infestation (coconut scale insect), while the herbicide was applied to avoid high cost on labor particularly on weeding. This means that the tree-based systems were energy-intensive systems due to high usage of NPK fertilizers, pesticides and labor utilized from crop establishments to harvest and postharvest operations, hence contributed high in the total C emission equivalent.

The case of rubber+1based AFS (rubber+upland rice), the upland rice farming has become a fossil fuel intensive system for the past five (5) years. The reason for this was a constant increase in inorganic fertilizer usage particularly N. Increase application on inorganic NPK fertilizers was necessary in order to achieve higher yields. Although, the similarity and/or variability of fertilizers usage was also influenced by other external factors such as capital on inputs and prevailing practices on fertilizer application and management. The results significantly revealed that the intensive energy requirements per AFS were due to fertilizer, pesticides and labor implicating the entire production system to be high C-emitter.

On the other hand, the C emission equivalent derived from embedded energy input (EEI) is small and insignificant because its expended energy usage was distributed in the entire lifespan of the machines used such as the 'habal-habal', rice thresher, rice mill and power sprayer utilized during the various farm operations including draft animal used for logistics, farm equipment such as the knapsack sprayer and moldboard plow. Clearly, the C emission equivalent from EEI was largely attributed to 'habal-habal' that was used for transporting of farm produce from the highlands over long distances and bad terrains in bulk volumes. The case of 'habal-habal', its contribution to the EEI was due to its constant use as it was the only practical way to transport farm produce crossing rough terrains bringing marang and lanzones fruits, copra, rubber latex and banana fruits.

The high plant density and the number of tree species present in the system contributed significantly in the overall energy inputs. This is due to the accrued energy usage that each individual tree crops contributed. Generally, the high TEI of multi-tree-based systems is attributed to high energy input on farm inputs, labor and transportation bringing the entire system a net C emitter expressed in tCO_{2e} ha^{-1} emission equivalent. Understanding the significant contributions of various energy-intensive systems delineated into DEI, IEI and EEI will guide local planners and legislators to initiate a food production system with reduced energy and carbon footprints responsive to changing climate for the upland communities in the City of Zamboanga, Philippines.

Acknowledgements

The authors wish to acknowledge the Commission on Higher Education (CHED), Philippine Council for Agriculture, Aquatic, and Natural Resources Research and Development (PCAARRD) and Yamang Bukid Healthy Products Inc. (YBHPI) for the funding support.

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(Received: 20 August 2021, accepted: 30 October 2021)