Energy and carbon input-output analysis of eggplant production in barangay Culianan, Zamboanga City, Philippines

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Abstract: The study on carbon efficiency ratio of eggplant production was conducted in barangay Culianan, Zamboanga City, Philippines, to estimate the input-output carbon needed to produce eggplant and to determine its carbon efficiency ratio. The total eggplant carbon production requirement was estimated to be 3,698.91 CO_{2e} kg^{-1} calculated from the total energy input (TEI), where the TEI is the sum total of 'direct energy input (DEI), indirect energy input (IEI)' and embedded energy input (EEI). The TEI in Mcal units was converted into Liter Diesel Oil Equivalent (LDOE), where 1.0 LDOE equals 11.414 Mcal $unit^{-1}$ and multiplied by 3.96 kg CO_{2e} emission to obtain the CO_2 emission equivalent. Results showed that crop establishment activity got the highest input carbon with 58.35% potential CO_2 emission equivalent, followed by pre-land preparation (38.46%), harvest, and postharvest (2.13%). Meanwhile, crop care and management obtained the lowest input carbon at 1.06% CO_{2e} potential share. While for the output carbon, the eggplant production obtained an output carbon of 4,437.50 CO_{2e} kg ha^{-1} giving a total of 738.57 net CO_{2e} kg ha^{-1}. The carbon efficiency (ratio) was derived from output carbon divided by input carbon which gives the result of 1.21, the ratio was related to the average yield of eggplant. It shows that the existing cultural practices of eggplant production in the city generated a positive rate of sequestered carbon, whereas it does not emit carbon beyond the output carbon produced from the production of eggplant. It implies that the amount of carbon emitted is less than that of carbon sequestered, indicating that eggplant is one of the crops that can mitigate carbon emissions.

Keywords: total energy inputs, input carbon, output carbon, carbon efficiency ratio

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1 Introduction

Climate change is one of the most prominent global issues that have attracted the attention of global academic researchers, policymakers, and other professionals. Climate change has caused several issues, such as global warming, ecological as well as technological imbalance, economic, and societal issues. Increasing concentration of greenhouse gas (GHG) emissions is considered a prime cause for these issues (Lui and Gallagher, 2010; Safa et al., 2011). Among the

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GHGs, carbon dioxide (CO_2) has been considered the most prominent influencer of global climate change (Yilmaz et al., 2005; Zhang et al., 2016). Human interventions are now increasing the amount of GHG in the atmosphere, which leads to changes in climate. These changes are affecting many human activities, including agriculture (Thu and Mendoza, 2011).

Agricultural crop production is a major consumer of energy and producer of GHG, it requires direct and indirect usage of fossil fuel which results in the emission of GHG such as CO_2, nitrous oxide (N_2O), and methane (CH_4). It was reported that the agricultural sectors contributed significantly to the atmospheric GHG emissions with a 14% contribution of the global emissions (IPCC-Intergovernmental Panel on Climate Change, 2007). The farm utilizes energy either direct or indirect. The direct energy utilized in the farm is primarily petroleum-based fuels to run trucks as well as machinery for preparing fields, planting and harvesting crops, applying agrochemicals, and transporting inputs and outputs to and from the market. Natural gas, liquid propane, and electricity are also used to run crop dryers and irrigation equipment while the indirect energy is consumed off the farm for manufacturing fertilizers and pesticides.

Utilization of energy in agriculture production has become more intensive due to the use of fossil fuel, the application of fertilizers, pesticides, machinery, and electricity to provide substantial increases in food production. However, the excessive use of energy has led to various environmental problems such as GHG emissions, loss of biodiversity, and pollution of the aquatic environment by agrochemicals such as fertilizers and pesticides (Nemecek et al., 2011). Higher temperatures increase heat-related illnesses, water is becoming scarcer in more regions, and can make it more difficult to work and move around, eventually, wildfires start more easily and spread more rapidly. There were more than 11,000 reported disasters attributed to these hazards globally, with over two million deaths and 3.64 trillion dollars in losses. More than 91 percent of deaths occurred in developing countries. It was also reported that the increasing energy input requirements may not always come up with maximum profits due to the losses in increased production cost (Erdal et al., 2007)

If this phenomenon is not properly addressed, humans will suffer from heat-related illnesses, disasters, and even death attributed to these hazards globally. Due to these issues, governments and policymakers around the world are making efforts through innovative solutions. One of these is the input-output analysis of energy balance analysis in crop production. Many researchers have studied energy and economic analysis to determine the energy efficiency of plant production, such as soybean, maize, and wheat (Sartori et al., 2005), eggplant (Flores et al., 2016; Taib et al., 2021), kiwifruit production (Gökdoğan, 2022), onion (Moore, 2010) and coriander, lettuce, radish, and spinach (Bojaca and Schrevens, 2010), sugar production (Mendoza, 2014), and agroforestry (Tabal and Mendoza, 2020), and enhancing the carbon sink. Enhancing carbon sink is a good strategy to neutralize carbon emissions by using some of the agricultural crops that are considered carbon neutral (Flores et al., 2016). One way to test whether the crops are carbon neutral is by using the carbon efficiency ratio as proposed by Flores (Flores et al., 2016). Flores used 0.45 as the default value to measure output carbon. But 0.45 default value is usually used for woody trees (Tabal et al., 2020a; Tabal et al., 2020b). Hence, this study aims to estimate the input-to-output carbon and efficiency ratio of eggplant production derived from energy input and output to produce eggplant.

2 Materials and methods

2.1 Study site and farmer cooperators

The study was conducted in Barangay Culianan, Zamboanga City, Philippines. The study selected eggplant growers for a period of 1.0 cropping season.

Data were recorded, tabulated, and analyzed beginning from the purchase of inputs, and preplant preparation up to delivery of harvested yield. The energy inputs for the manpower such as food, clothing, and miscellaneous living costs of the farming household were not included.

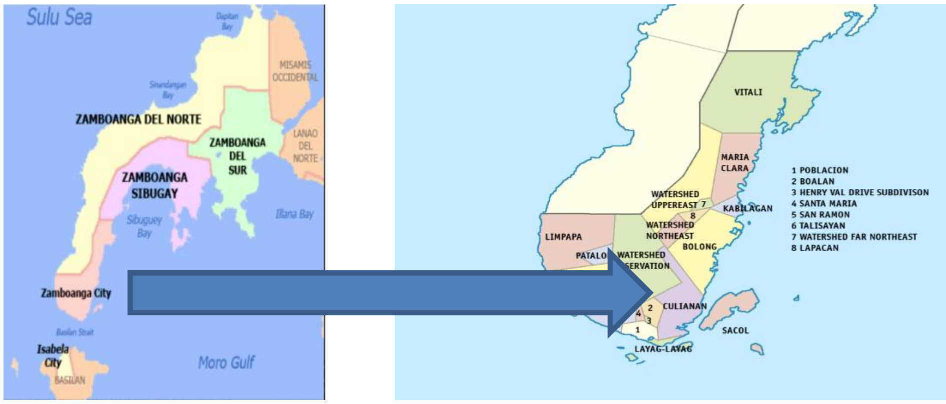

Figure 1 Location of the study

2.2 Collection of data

The collected data of total energy inputs (TEI) is based on the earlier work of Taib et al., (2021), where the TEI is the sum total of direct energy input (DEI) or this is the use of diesel/gasoline to run the machines for farm operations and transport of farm products, while the indirect energy input (IEI) includes the seeds used, NPK fertilizers, agrochemicals, and labor inputs. Lastly, the embedded energy input (EEI) was accounted for from the utilization of machines, farm equipment, implements, motorized vehicles, and draft animals indicated in Mcal. Equations 1-11 as expressed were used to compute the DEI, IEI, and EEI adopted from the work of Tabal et al. (2020b).

2.2.1 Direct energy used (*DEU*):

Direct energy (Diesel or gasoline) used ha^{-1} for field operations (FFOpe)

$$DEU_{FFOpe} = A_{fu} \times E_{Fcoef} \quad (1)$$

Where:

DEU_{FFOpe} = direct fuel used per field operation, Mcal ha^{-1}

A_{fu} = average fuel used per hectare (Lit ha^{-1})

E_{Fcoef} = energy coefficient of fuel, Mcal Lit^{-1}

Direct energy (diesel or gasoline) used ha^{-1} for hauling and transport (Ftrans)

$$DEU_{Ftrans} = A_{Ftrans} \times E_{Fcoef} \quad (2)$$

Where:

DEU_{Ftrans} = direct fuel used for hauling and transport, Mcal ha^{-1}

A_{Ftrans} = average fuel used per hectare (Lit ha^{-1})

E_{Fcoef} = energy coefficient of fuel, Mcal Lit^{-1}

2.2.2 Indirect energy used (*IEU*)

NPK fertilizers applied (NPK_{fert})

$$IEU_{NPKfert} = A_{NPKFERT} \times E_{NPKcoef} \quad (3)$$

Where:

$IEU_{NPKfert}$ = indirect energy used on fertilizer (NPK), Mcal ha^{-1}

$A_{NPKFERT}$ = amount of fertilizer (NPK) applied, Kg ha^{-1}

$E_{NPKcoef}$ = energy coefficient of NPK fertilizer, Mcal kg^{-1}

Human labor (*HL*)

$$IEU_{HL} = N_{lab} \times E_{HLcoef} \quad (4)$$

Where:

IEU_{HL} = indirect energy used on human labor, Mcal ha^{-1}

N_{lab}= number of laborers involved in farm operation, ha hr^{-1}

E_{HLcoef} = energy coefficient of human labor, Mcal hr^{-1}

Animal labor (*AL*)

$$IEU_{AL} = N_{ani} \times E_{ALcoef} \quad (5)$$

Where:

IEU_{Al} = indirect energy used on animal labor, Mcal ha^{-1}

N_{ani} = number of animals used in farm operation ha hr^{-1}

E_{ALcoef} = energy coefficient of animal labor, Mcal hr^{-1}

Organic fertilizer (animal manure) (*AM*)

$$IEU_{AM} = A_{AM} \times E_{AMcoef} \quad (6)$$

Where:

IEU_{AM} = indirect energy used on animal manure, Mcal ha^{-1}

A_{AM} = amount of animal manure applied, Kg ha^{-1}

E_{AMcoef} = energy coefficient of animal manure, Mcal Kg^{-1}

Seed used (*S*)

$$IEU_S = A_S \times E_{Scoef} \quad (7)$$

Where:

IEU_S = indirect energy used on seed (Long purple Eggplant), Mcal ha^{-1}

A_S = amount of seed used, Kg ha^{-1}

E_{Scoef} = energy coefficient of seed, Mcal Kg^{-1}

Pesticide (Insecticide, Fungicide, Herbicide) used (*IFH*)

$$IEU_{IFH} = A_{IFH} \times E_{IFHcoef} \quad (8)$$

Where:

IEU_{IFH} = indirect energy used on pesticides, Mcal ha^{-1}

A_{IFH} = amount of pesticides applied, Lit ha^{-1}

$E_{IFHcoef}$ = energy coefficient of specific pesticide, Mcal Lit^{-1}

2.2.3 Embedded Energy Input (EEU)

Embedded Energy used in farm machinery (EFM)

$$EFM = (W_M \times E_{Mcoef}) / (LS_M \times Hr) \quad (9)$$

Where:

EFM = specific embedded energy for machineries used for a field operation, Mcal ha^{-1}

W_M = weight of the machine, Kg unit^{-1}

E_{Mcoef} = energy coefficient of specific machinery, Mcal Kg^{-1}

LS_M = life span of machine, hours unit^{-1}

Hr = the no. of hours the machine was used, hours ha^{-1}

Embedded Energy used in farm equipment and tools (EET)

$$EET = (W_{ET} \times E_{ETcoef}) / (LS_{ET} \times Hr) \quad (10)$$

Where:

EET = specific embedded energy for farm equipment and tools used for a field operation, Mcal ha^{-1}

WET = weight of the farm equipment and tools, Kg unit^{-1}

E_{ETcoef} = energy coefficient of a specific farm equipment and tools, Mcal Kg^{-1}

LS_{ET} = life span of the farm equipment and tools, hours unit^{-1}

Hr = the no. of hours the equipment and tools were used, hours ha^{-1}

Total Energy Inputs (TEI)

$$TEI = DEU + IEU + EEU \quad (11)$$

Where:

TEI = total energy input, Mcal ha^{-1}

DEU = direct energy input

IEU = indirect energy input

EEU = embedded energy input

2.3 Input carbon determination

The TEI is the sum of DEI, IEI, and EEI indicated in Mcal (Mendoza, 2014; Pimentel, 1980a; Tabal et al., 2020; Tabal et al., 2020a; Tabal et al., 2020b). Then, were converted into Liter Diesel Oil Equivalent (LDOE), (Pimentel, 1980b; Tabal et al., 2020), where 1.0 LDOE equals 11.414 Mcal unit^{-1}. After getting the LDOE, it was multiplied by 3.96 kg CO_{2e} emission to obtain the carbon dioxide emission equivalent (Pimentel, 1980a; Savuth, 2018; Tabal et al., 2020; Taghavi et al., 2011; Thu et al., 2011) as shown in Equation 12.

$$IC = (TEI/11.414 \times 3.96) \quad (12)$$

Where:

IC = input carbon, CO_{2e} ha^{-1}

TEI = total energy input, Mcal ha^{-1}

11.414 = Mcal per LDOE [8]

3.96 kg = carbon dioxide emission equivalent per LDOE (Pimentel, 1980a).

Table 1 Energy coefficient of various farm inputs and output

Particulars	Unit	Energy equivalent Per unit MJ	Energy equivalent Per unit Mcal	References
A.) INPUTS				
SEED				
Long purple Eggplant seed	Kg	1.0	0.24	(Singh et al., 2002)
AGROCHEMICALS:				
a) Herbicide (gyphosate)	Lit	553.07	132.19	(Pimentel, 1980a; Barber, 2004)
b) Herbicide (Gen.), ave.	Lit	274	65.5	(Saunders 2006; Gundogmus, 2014)
C) Insecticide (solid)	Kg	315	75.29	(Saunders 2006; Wells, 2001)
d) Insecticide (liquid), ave.	Lit	281.32	67.24	(Pimentel, 1980a; Gundogmus, 2006)
e) Fungicide (solid)	Kg	210.0	50.2	(Saunders, 2006; Wells, 2001)
F) Fungicide (liquid), ave.	Lit	104.1	24.88	(Pimentel, 1980a, Gundogmus, 2006)
CHEMICAL FERTILIZERS				
a) Nitrogen	Kg	102.23	24.43**	(Mendoza, 2014; Lockeretz, 1980; Rodolfo, 2008)
b) Phosphate (P205), ave.	Kg	20.6	4.92	(Mendoza, 2014; Safa et al., 2011; Lockeretz, 1980; Rodolfo, 2008)
c) Potassium (K20), ave.	Kg	16.38	3.91	(Mendoza, 2014; Pimentel, 1980a; Safa et al., 2011; Lockeretz, 1980)
FUEL				
a) Gasoline	Lit	42.32	10.11	(Kitani, 1999)
b) Diesel fuel	Lit	56.31	13.46**	(Erdal et al., 2007; Mohammadi et al., 2008)
LABOR				
a) Human labor	Hr	1.96	0.47	(Yilmaz et al., 2005; Kazemi et al., 2015)
b) Draft animal	Hr	12.01	2.87	(Nassiri et al., 2009; Gliessman, 2014)
STEEL/METAL	Kg	75.31	18	(Pimentel, 1980a)
Output				
Eggplant (fresh)	Kg	5.9	1.41	(Kitani, 1999; Nabavi-Pelesaraei et al., 2013b)

Note: [Tabal et al., 2020a, Tabal et al., 2020b]

* The energy for the production of Glyphosphate is 440 MJ per Kg, and the formulation, packaging, and transportation is 113.03 MJ per Kg. In: (Savuth, 2018).

** Estimates include the drilling processing, storage, and transport to the site of utilization [Mendoza, 2014; Rodolfo, 2008].

*** Estimates include the processing, storage, and transport to the site of utilization (Rodolfo, 2008).

2.4 Output carbon determination

Obtaining the total energy output (TEO) is essential for calculating the output carbon. The TEO was based on the fresh harvest yield of eggplant indicated in Mcal. After obtaining the TEO, it will be converted into LDOE and then multiplied by 3.96 kg CO_{2e} (Pimentel, 1980a). The default coefficient to calculate for energy input and output equivalents.

Output Carbon (OC)

$$C = (OY \times E_{coef}) / 11.414) \times 3.96 \quad (13)$$

Where:

OC = output carbon, CO_{2e} Kg^{-1}

OY = Output yield

E_{coef} = energy coefficient of specific farm commodity, Mcal kg^{-1}

11.414 = LDOE default value

3.96 = carbon dioxide equivalent per LDOE (Pimentel, D., 1980a)

2.5 Net carbon determination

Net Carbon (NC)

$$NC = (OC - IC) \quad (14)$$

Where;

NC = net carbon

OC = output carbon

IC = input carbon

2.6 Carbon efficiency ratio determination

The carbon efficiency ratio was calculated from output carbon divided by input carbon (Flores, et al.

2016).

Carbon Efficiency Ratio (CER)

$$CER = OC / IC \quad (15)$$

Where:

CER = carbon efficiency ratio

OC = output carbon, CO_{2e} kg ha^{-1}

IC = input carbon, CO_{2e} ka ha^{-1}

2.7 Statistical analysis

All data were tabulated in Microsoft Excel and analyzed using simple descriptive and inferential statistics, mean, percentage, and sum were used to compare input-output carbon per activity in eggplant production.

3 Results

Table 2 shows the input carbon derived from TEI of the entire activities of eggplant production based on the earlier work of Taib et al. (2021). The overall energy inputs applied to eggplant production was 10,670.44 Mcal ha^{-1} (934.86 LDOE ha^{-1}). Crop management obtained the lowest energy inputs at 112.69 Mcal ha^{-1} (9.87 LDOE ha^{-1}), while crop establishment obtained the highest TEI at 6,220.54 Mcal ha^{-1} (544.99 LDOE ha^{-1}) compared to other activities such as pre-land preparation at 4,100.75 Mcal ha^{-1} (359.27 LDOE ha^{-1}) and harvest and Postharvest activity obtained 227.46 Mcal ha^{-1} (19.93 LDOE ha^{-1}), respectively.

The crop establishment activity obtained the highest input carbon of 2,158.17 CO_{2e} kg^{-1} or this is 58.35% potential share of carbon emission, followed by pre-land preparation at 1,422.72 CO_{2e} kg^{-1} (38.46%), then the harvest and postharvest obtained 78.92 CO_{2e} kg^{-1} (2.13%), among the entire activities, the crop management activity obtained the lowest carbon input of 39.10 CO_{2e} kg^{-1} (1.06%) potential share of carbon emission, respectively.

Table 2 Input carbon derived from total energy inputs (TEI) of eggplant production

Type of Labor	TEI Mcal ha^{-1}	LDOE ha^{-1}	CO_{2e} Kg ha^{-1}	%
I. Pre-Land Preparation	4,100.75	359.27	1,422.72	38.46
II. Crop Establishment	6,220.54	544.99	2,158.17	58.35
III. Crop Management	112.69	9.87	39.10	1.06
IV. Harvest and Pre-Harvest	227.46	19.93	78.92	2.13
TEI	10,661.44			
Inputs carbon			3,698.91	

Table 3 relates the input-output carbon and carbon efficiency ratio of eggplant production. The fresh output yield has a carbon content of usually 45% of the total yield according to Bolinder et al. (2007), as indicated in the work of Flores et al. (2016). But 45% default value of carbon equivalent used by Flores is for trees (Lasco et al., 2003; Pimentel, 1992; Pishgar-Komleh et al., 2011; Tabal et al., 2020a; Tabal et al., 2020b), not applicable for eggplant. The fresh output yield of eggplant was accounted for in the input-output carbon analysis using 3.96 carbon equivalent (Pimentel, 1980a). The average production yield of eggplant was 9,071.11 kg ha^{-1} to give a total carbon output of 4,437.48 CO_{2e} kg ha^{-1}. In the entire eggplant production system, the net carbon of 738.57 CO_{2e} kg ha^{-1} was mainly derived from output carbon less input carbon, to obtain the carbon efficiency (ratio) was derived from output carbon divided by input carbon that gives the result of 1.20.

Table 3 Input-output carbon and carbon efficiency ratio (sustainability index) of eggplant production

Indicator	Value	Unit
Input carbon	3,698.91	Kg CO_{2e} ha^{-1}
Output carbon	4,437.48	Kg CO_{2e} ha^{-1}
Net carbon	738.57	Kg CO_{2e} ha^{-1}
Carbon efficiency (ratio)	1.20	

4 Discussion

The amount of input carbon was attributed from TEI obtained from DEI, IEI, and EEI, the results of these were accounted for from the following activities: pre-land preparation obtained from land clearing with the use of machinery and vehicle, and purchased of inputs which use direct fuel. In Crop establishment activity was attributed to plowing, harrowing, fertilizer application, seedling, and weeding. For crop management was mainly with the use of insecticide. Harvest and postharvest were obtained from harvesting, bundling, hauling, and transport. The input carbon of eggplant production was 3,698.91 kg CO_2 equivalent ha^{-1} (Table 2). This indicated that every hectare production of eggplant would lead to carbon emission of 3,698.91 kg CO_2 equivalent. The highest share of carbon emission was observed in crop establishment at 58.35%, followed by pre-land preparation with 38.46% potential share of carbon emission, while harvest and postharvest obtained 2.13%, among the entire activities, the Crop Management activity obtained the lowest with 1.06% potential share of carbon emission. This further indicates that the more usage of chemicals, diesel, and labor would incur more energy inputs that would lead to more CO_{2e} potential.

Eggplant in fresh form was the output yield considered in the input-output carbon analysis according to Flores et al. (2016). The average harvested yield of eggplant accounted for 9,071.11 kg ha^{-1} to give a total carbon output of 4,437.50 CO_{2e} kg ha^{-1} (Table 3), while the input carbon derived from TEI was 3,698.91 CO_{2e} kg ha^{-1} (Table 2), or the carbon ratio in the entire production system of eggplant was 1.21. This shows that the existing cultural practices of eggplant production in Barangay of Culianan, Zamboanga City, Philippines not a CO_2 emitter nor emit beyond the output carbon produced from the production of eggplant, rather it sequesters more carbon. The result of the current study showed similar findings to Flores et al. (2016), which concluded that eggplant production is not a carbon emitter, the only thing that differs from the work of Flores et al. (2016) is the derivation in calculating output carbon since Flores et al. (2016) used the 0.45 default value whereas this default value is intended for trees according to Tabal and Mendoza, (2020) and Tabal et al. (2020a). Furthermore, using inappropriate default values will lead to over or underestimation of findings.

Intensive agricultural production results in large energy consumption per unit area of production. However, when intensive production results in elevated yields, it can result in more efficient crop production. The impact of high yields is twofold, as higher yields also lead to efficient usage of energy per unit weight of fruit produced. Proper management, correct timing and amount of fertilizer application, proper application of pesticide, proper tillage, adequate irrigation, proper allocation of manpower per unit area, and proper allocation of activity per working hour will lead to efficient usage of energy. The imbalance of these activities can affect the yield of the production, energy loss, reduce profits, and also can lead to environmental and health problems for humans such as pollution, erosion, and GHG emission.

5 Conclusion

The entire production of eggplant using the present cultural practices can store or sequester more carbon than what was generated from energy-based inputs used in production. With proper management, correct timing and amount of fertilizer application, proper application of pesticide, proper tillage, use of mulch, proper irrigation, proper allocation of manpower per unit area, and proper allocation of activity per working hour will lead to efficient usage of energy and adopting organic agriculture will lead to eco-farming system and less carbon emission.

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