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Energy and Carbon Input-Output Analysis of Tomato Production in Barangay La Paz, Zamboanga City, Philippines

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***Abstract*— *The study on tomato production was carried out in the barangay La Paz in Zamboanga City, Philippines, to estimate the carbon input and output and determine the tomato production system's carbon efficiency ratio. The input carbon has calculated from the total energy input (TEI), which is the sum of "direct energy input (DEI), indirect energy input (IEI), and embedded energy input (EEI). The tomato production produced a total input carbon of 2,444.51 CO_{2e} kg^{-1}. To obtain the CO_2 emission equivalent, the TEI in Mcal units has been converted into Liter Diesel Oil Equivalent (LDOE), where 1.0 LDOE equals 11.414 Mcal $unit^{-1}$ multiplied by 3.96. The results indicated that crop care and management activity received the most input carbon, with a potential CO_2 emission equivalent of 74.91%, followed by harvest and pre-harvest activity (9.41%) and pre-planting operation (8.10%). Crop establishment obtained the lowest input carbon at 7.58% CO_{2e} potential share. The tomato production produced 2,454.66 CO_{2e} kg ha^{-1} of output carbon, resulting in a total of 10.15 net CO_{2e} kg ha^{-1}. To the carbon efficiency (ratio), output carbon divided by input carbon has the result of 1.0. The carbon efficiency ratio has correlated with the typical yield of tomatoes. It demonstrates that the city's existing cultural practices for producing tomatoes led to positive carbon sequestration rates, whereas it does not emit carbon beyond the output carbon produced from the production of tomatoes. It indicates that tomato is one of the carbon-neutral crops because the amount of carbon released is less than the amount of carbon stored.*

***Keywords*— *Total Energy Inputs, Liter Diesel Oil Equivalent, Carbon Emission.*

I. INTRODUCTION

Climate change is one of the most critical global issues that have caught the attention of academic researchers, policymakers, and other professionals. Global warming, ecological imbalance, technological issues, economic issues, and societal issues are just a few of the consequences of climate change. These problems are due to the rising concentration of emissions of greenhouse gases [4].

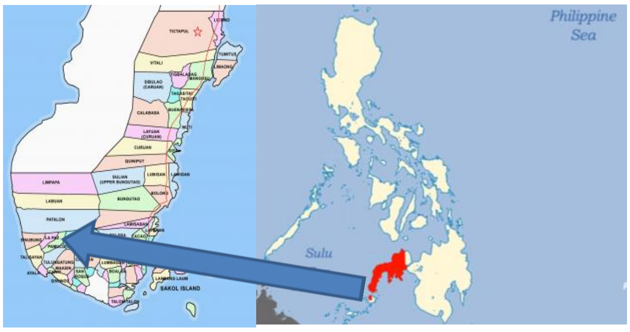
Earth's temperature rises caused by the greenhouse effect, which occurs when these gases in the atmosphere—carbon dioxide, water vapor, nitrous oxide, ozone, and methane—trap solar energy. Due to their similar behaviour to greenhouse glass panes, these gases are greenhouse gases. The greenhouse's glass panels let in light but keep heat from escaping. Similar to how these gases affect the Earth [6]. Through greenhouse gases, sunlight enters the Earth's atmosphere. The energy from the sun is absorbed by the land, water, and biosphere when it reaches the surface of the Earth. This energy is released back into the atmosphere after having absorbed it. Some of this energy returns to space, but the greenhouse gases keep most of it in the atmosphere. Without these gases, all the heat would return to the atmosphere, then the temperature drops by about 30 degrees Celsius (54 degrees Fahrenheit) on average. It is a natural process because the Earth would not be warm enough for humans to live on without the greenhouse effect. This process is crucial. However, the Earth might turn warmer than usual if the greenhouse effect increases. Indeed, even some additional warming might create issues for people, plants, and creatures [22].

It is extremely difficult to balance sustainability goals with the rising demand for resources in industrialized nations. As stated by the Food and Agriculture Organization of the United Nations [1], a limited causal understanding of the links between production and consumption exacerbates this issue. Producing tomatoes is based on a wide variety of production methods that are linked to various materials, energy, and technological requirements in relation to fresh produce. Regarding tomato production, the environmental effects of various production locations and homestead advancements have been thoroughly examined [3] [19] [20]. Thus, global researchers have focused a lot on finding ways to cut down on carbon emissions. As a result, carbon emission monitoring at various levels (product, organization, city, and national) has been recognized as a crucial reference in influencing environmental mitigation strategies and policies. Researchers have begun quantifying carbon emissions as a result of this growing focus on global emissions [21]. While some of these studies have only quantified emissions on a national scale, others have quantified carbon emissions globally. This study was therefore carried out by the researcher to estimate the carbon input and output, and determining the tomato production system's carbon efficiency ratio.

II. MATERIALS AND METHODS

A. Study Site and Cooperator

The study was conducted in barangay La Paz, Zamboanga City, Philippines. The study selected tomato growers for a period of 1.0 cropping season. Data were recorded, tabulated, and analyzed beginning from the purchase of inputs, and pre-plant preparation up to the delivery of harvested yield. The energy inputs for the manpower such as food, clothing, and miscellaneous living cost of the farming household were not included.



B. Collection of Data

The data on total energy inputs (TEI) is based on the work of Taib [15], where the total energy input (TEI) is the sum of 'direct energy input (DEI) including the use of diesel/gasoline to run the machines for farm operations and transport of farm products, while the 'indirect energy input (IEI)' were seeds used, NPK fertilizers, agrochemicals, and labor inputs. Lastly, the embedded energy input (EEI) accounted for the utilization of machines, farm equipment, implements, motorized vehicles, and draft animal indicated in Mcal. The equations below to compute the total energy inputs were adopted from the work of Tabal et al. [14].

1. *Direct Energy used (D_{EU}):*

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

$DEU_{FFOpe} = (A_{fu} \text{ X } E_{Fcoef})$ Eq. 1

Where:

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

A_{fu} = average fuel used per working hour (Lit hr^{-1})

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

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

$DEU_{Ftrans} = (A_{Ftrans} \text{ x } E_{Fcoef})$ Eq. 2

Where:

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

A_{Ftrans} = average fuel used per working hour (Lit hr^{-1})

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

2. *Indirect Energy Used (I_{EU})*

a. NPK fertilizers applied (NPK_{fert})

$IEU_{NPKfert} = (A_{NPKFERT} \text{ x } E_{NPKcoef})$ Eq. 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}

b. Human labor (HL)

$IEU_{HL} = (N_{lab} \text{ x } E_{HLcoef})$ Eq. 4

Where:

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

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

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

Animal labor (AL)

$IEU_{AL} = (N_{ani} \text{ x } E_{ALcoef})$ Eq. 5

Where:

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

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

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

c. Organic fertilizer (animal manure) (AM)

$IEU_{AM} = (A_{AM} \text{ x } E_{AMcoef})$ Eq. 6

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}

d. Seed used (S)

$IEU_S = (A_S \text{ x } E_{Scoef})$

Eq. 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 ha^{-1}

e. Pesticide (Insecticide, Fungicide, Herbicide) used (IFH)

$IEU_{IFH} = (A_{IFH} \text{ x } E_{IFHcoef})$ Eq. 8

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}

f. PHEI on PLP, CE and CCM

$PHEI_{PLP} = (PLP_{SA} \text{ x } E_{laborcoef})/Y_{sc}$ Eq. 9

Where:

$PHEI_{PLP}$ = pre-harvest energy input on pre-land preparation, Mcal

PLP_{SA} = specific activity on pre-land preparation, Mcal

$E_{laborcoef}$ = energy coefficient of labor, Mcal

Y_{sc} = number of unproductive years

g. $PHEI_{CE} = (CE_{SA} \text{ x } E_{laborcoef})/ Y_{sc}$ Eq. 10

Where:

$PHEI_{CE}$ = pre-harvest energy input on crop establishment, Mcal

CE_{SA} = specific activity on crop establishment, Mcal

$E_{laborcoef}$ = energy coefficient of labor, Mcal

Y_{sc} = number of unproductive years

h. $PHEI_{CCM} = (CCM_{SA} \text{ x } E_{laborcoef})/ Y_{sc}$ Eq. 11

Where:

$PHEI_{CCM}$ = pre-harvest energy input on crop care management, Mcal

CCM_{SA} = specific activity on crop care management, Mcal

$E_{laborcoef}$ = energy coefficient of labor, Mcal

Y_{sc} = number of unproductive years

3. *Embedded Energy Input (EEU)*
   a. Embedded Energy used in farm machineries (EFM)

$EFM = (W_M \times E_{Mcoef}) / (LS_M \times Hr)$ Eq. 12

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 a specific machinery, Mcal Kg^{-1}
LS_M = life span of machine, years $unit^{-1}$
Hr = the no. of hours the machine was used, hours ha^{-1}

   b. Embedded Energy used in farm equipment and tools (EET)

$EET = (W_{ET} \times E_{ETcoef}) / (LS_{ET} \times Hr)$ Eq. 13

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, years $unit^{-1}$
Hr = the no. of hours the equipment and tools was used, hours ha^{-1}

4. *Total Energy Inputs (TEI)*

$TEI = D_{EU} + I_{EU} + E_{EU}$ Eq. 14

Where:
TEI = total energy input, Mcal ha^{-1}
D_{EU} = direct energy input
I_{EU} = indirect energy input
E_{EU} = embedded energy input

TABLE 1. Energy coefficient of various farm inputs and outputs

Type of Inputs	Unit	Energy Equivalent Per Unit		References
		MJ	Mcal	
A. INPUT				
SEED				
Diamante max seed	kg	1.0	0.24	[35]
AGROCHEMICALS:				
a) Herbicide (gyphosate)	Lit	553.03	132.18[1]	[8, 24]
b) Herbicide (Gen.), average	Lit	274	65.5	[23, 25]
C) Insecticide (solid)	kg	315	75.29	[23, 34]
d) Insecticide (liquid), average	Lit	281.32	67.24	[8, 25]
e) Fungicide (solid)	kg	210	50.2	[23, 34]
F) Fungicide (liquid), average	Lit	104.1	24.88	[8, 25]
CHEMICAL FERTILIZERS				
a) Nitrogen	kg	102.23	24.43[2]	[5, 29, 33]
b) Phosphate (P_20_5), average	kg	20.6	4.92	[5, 10, 29, 33]
c) Potassium (K_20), average	kg	16.38	3.91	[5, 8, 10, 29]
FUEL				
a) Gasoline	Lit	42.32	10.11	[28]
b) Diesel fuel	Lit	56.31	13.46[3]	[22, 30]
LABOR				
a) Human labor	Hr	1.96	0.47	[18, 27]
b) Draft animal	Hr	12.01	2.87	[31, 26]
STEEL/METAL	Kg	75.31	18.0	[8]
B. OUTPUT Tomato (fresh)	Kg	0.8	0.19	[28, 32]

[1] *The energy for the production of Glyphosate is 440 MJ kg^{-1}, the formulation, and packaging, and transportation is 113.03 MJ kg^{-1}. In: Savuth [11].*

[2] *Estimates include the drilling processing, storage, and transport to sit of utilization (Rodolfo [33]; Mendoza [5].*

[3] *Estimates include the processing, storage, and transport to the site of utilization (Rodolfo [33]).*

C. CALCULATING INPUT CARBON

The total energy inputs (TEI) are the amount of direct energy input (DEI), indirect energy input (IEI), and the embedded energy input (EEI) shown in Mcal [8] [5] [12-15]. Then, were converted into Liter Diesel Oil Equivalent (LDOE), [9] [12], 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 [7] [8] [11] [12] [16] [17] as shown in Eq. 15.

   a. $IC = (TEI/11.414 \times 3.96)$ Eq. 15

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 [8]

D. CALCULATING OUTPUT CARBON

In determining the carbon output, it is necessary to obtain the total energy output (TEO). The TEO was based on the fresh yield of tomatoes indicated in Mcal. After obtaining the TEO, it will be converted into LDOE and then multiply by 3.96 kg CO2e emission equivalent [8].

   a. Total Energy Output (TEO)

$TEO = (Y \times E_{coef})$ Eq. 16

Where:
TEO = total energy output, Mcal ha^{-1}
Y = yield, Kg ha^{-1}
E_{coef} = energy coefficient of specific farm commodity, Mcal Kg^{-1}

   b. Output Carbon (OC)

$OC = (TEO / 11.414 \times 3.96)$ Eq. 17

Where:
OC = output carbon, CO_{2e} Kg^{-1}
TEO = total energy output, Mcal ha^{-1}
11.414 = LDOE default value
3.96 = carbon dioxide emission equivalent per LDOE [8]

E. CALCULATING CARBON EFFICIENCY RATIO

To determine whether tomato production results in greater carbon emissions, carbon sequestration, or carbon neutral by calculating the carbon efficiency ratio. The carbon efficiency ratio was calculated from output carbon divided by input carbon [2].

   a. Carbon Efficiency Ratio (CER)

$CER = OC / IC$ Eq. 18

Where:
CER = carbon efficiency ratio
OC = output carbon, CO_{2e} Kg^{-1}
IC = input carbon, CO_{2e} ha^{-1}

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F. Statistical Analysis

The researcher used the mean, percentage, and sum of all activities in tomato production to compare carbon emissions. All data were tabulated in Microsoft Excel and analysed using simple descriptive and inferential statistics.

III. Results

Based on Taib's [15] earlier work, Table 2 shows the input carbon derived from total energy inputs (TEI) for the entire tomato production activities. The overall energy inputs applied to tomato production was 7045.89 Mcal ha^{-1} (617.30 LDOE ha^{-1}). Crop care and management obtained the highest energy inputs at 5278.38 Mcal ha^{-1} (462.45 LDOE ha^{-1}) compared to other activities like harvest and pre-harvest activity with TEI value of 663.31 Mcal ha^{-1} (58.11 LDOE ha^{-1}) followed by pre-planting activity at 570.41 Mcal ha^{-1} (49.97 LDOE ha^{-1}). Meanwhile, crop establishment obtained a TEI value of 533.79 Mcal ha^{-1} (46.77 LDOE ha^{-1}), respectively.

The crop care and management activity obtained the highest input carbon of 1831.30 CO_{2e} kg^{-1}, or this is a 74.91% potential share of carbon emission, followed by harvest and pre-harvest at 230.12 CO_{2e} kg^{-1} (9.41%), the pre-planting operation obtained 197.88 CO_{2e} kg^{-1} (8.10%), among the entire activities, the crop establishment activity obtained the lowest carbon input of 185.21 CO_{2e} kg^{-1} (7.58%) potential share of carbon emission, respectively.

TABLE 2. Carbon emission CO_{2e} kg^{-1}of different types of labor applied on Tomato production, La Paz, Zamboanga City.

Type of Labor	TEI	LDOE	CO_2e	
	Mcal ha^{-1}	ha^{-1}	kg	%
I. Pre-Planting Operation	570.41	49.97	197.88	8.10
II. Crop Establishment	533.79	46.77	185.21	7.58
III. Crop Care and Management	5278.38	462.45	1831.30	74.91
IV. Harvest and Pre-Harvest	663.31	58.11	230.12	9.41
TEI	**7045.89**			
Input Carbon			**2,444.51**	

The fresh output yield of tomato was accounted for in the input-output carbon analysis using a 3.96 carbon equivalent shown in Table 3 [8]. The average production yield of tomatoes was 37,237.42 kg ha^{-1} giving the total carbon output of 2,454.66 CO_{2e} kg ha^{-1}. In the entire tomato production system obtaining net carbon of 10.15 CO_{2e} kg ha^{-1} was mainly derived from output carbon less input carbon to compute the carbon efficiency (ratio) was derived from output carbon divided by input carbon which gives the result of 1.0.

TABLE 3. Percentile distribution of Total Energy Inputs (TEI) applied on Tomato production.

Indicator	**Value**	**Unit**
Input carbon	2,444.51	CO_2e kg^{-1}
Output carbon	2,454.66	CO_2e kg^{-1}
Net carbon	10.15	CO_2e kg^{-1}
Carbon efficiency (ratio)	1.0	

IV. Discussion

The amount of input carbon attributed to total energy inputs obtained from direct energy inputs (DEI), indirect energy inputs (IEI), and embedded energy inputs (EEI), the results of these were accounted from the following activities: pre-planting operation obtained from land clearing with the use of machinery and vehicle, and purchased of inputs which use direct fuel, then, crop establishment activity attributed to plowing, harrowing, seedling, and weeding, while, crop management was mainly with the use of an insecticide and fertilizer application, finally, harvest and postharvest obtained from harvesting, bundling, hauling, and transport, furthermore, the input carbon of tomato production was 2,444.51 kg CO_2 equivalent/ha^{-1} (Table 2), it indicated that every hectare production of tomatoes would lead to a carbon emission of 2,444.51 kg CO_2 equivalent which the highest share of carbon emission was observed in crop care and management activity at 74.91%, followed by harvest and pre-harvest with a 9.41% potential share of carbon emission, pre-planting operation obtained 8.10%, and the crop establishment activity obtained the lowest with 7.58% share of carbon emission. It further indicates that the more usage of chemicals, diesel, and labor would incur more energy inputs that would lead to more CO_{2e} potential.

Tomato in Fresh form was the output yield considered in the input-output carbon analysis, according to Flores [2]. The average yield of tomato accounted for 37,237.42 kg ha^{-1} to give a total carbon output of 2,454.66 CO_{2e} kg ha^{-1} (Table 3), while the input carbon derived from TEI was 2,444.51 CO_{2e} kg ha^{-1}, or the carbon ratio in the entire production system of tomato was 1.0. It shows that the existing cultural practices of tomato production in the Barangay of La Paz, Zamboanga City, Philippines is not a C_{O2} emitter nor emit beyond the output carbon produced from the production of tomatoes. The current study showed that tomato production is not a carbon emitter.

Intensive agricultural production resulted in higher energy consumption per unit area. However, when intensive production could result in higher yields, it can be more efficient crop production. The impact of higher yields is twofold, as higher yields also lead to efficient use of the energy per unit weight of fruit produced. With the proper management, correct timing and amount of fertilizer application, the correct application of pesticide, good tillage, adequate irrigation, proper allocation of the laborer 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 production, reduce profits and energy loss, and lead to environmental and health problems for humans such as pollution, erosion, and greenhouse gas emission.

The excess of energy inputs will tend to increase the carbon emission escalating global warming. Thus, global warming will hamper agricultural production. Towards eco-friendly farming, there is a need to adopt the use of crop rotation with nitrogen-fixing plants such as leguminous plants, green manuring, composts, or organic fertilizers can be used instead of synthetic fertilizers should be considered to reduce the high utilization of energy, environment-friendly biological control agent for pests and diseases, biodiesel, utilization of new machinery for cultivation, more efficient pumps for extracting irrigation water, and application of mulches to conserve soil

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moisture and prevent the growth of weeds, thereby reducing irrigation frequency can lead to tomato cultivation with significant reduction of carbon emission.

V. CONCLUSION

Based on the data, the researcher concluded that 74.91% of carbon emissions came from crop care and management, which includes labor and fertilizer application could use as the target area to minimize carbon emission. Hence the researcher recommends checking diesel, gasoline, electricity use, and use of chemical inputs. Crop rotation with nitrogen stabilizer plants such as leguminous or green manure instead of chemical fertilizer and practices such as mulching using organic mulching materials can also reduce diesel fuel needed in irrigation and reduce the use of chemical herbicides/weedicides.

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