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Net Energy Use and Carbon Emission Equivalent of Tomato and Eggplant Production in Zamboanga City, Philippines

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Abstract**—** *A study was conducted to calculate the energy inputs to produce eggplant and tomato and its carbon emission equivalent in Zamboanga City, Philippines. Energy accounting procedures and coefficients used were adopted from various literatures. All Mcal units derived in direct energy input (DEI), indirect energy input (IEI), and embedded energy input (EEI) were converted to liter diesel oil equivalent (LDOE) to account for the net carbon emission, where 11.414 Mcal = 1 LDOE = 3.96 kg CO_2 emission equivalent. The acreage of DEI, IEI, and EEI is called the total energy input (TEI). The net C emission equivalent is expressed in tCO2e ha-1. The TEI applied to eggplant production amounted to 10,661.44 Mcal ha-1 (934.07 LDOE ha-1), while for tomato production amounted to 7,045.89 Mcal ha-1 (617.30 LDOE ha-1), respectively or this is equal to 3.7 tCO2e ha-1 emission (eggplant) and 2.44 tCO2e ha-1 (tomato). Across the two (2) commodities, the IEI contributed 63.7-90.35 percent of the total TEI attributed largely to chemical fertilizers, agrochemicals, and labor, or these are called the 'energy hotspots', implicating the entire production systems a highly energy-intensive. Proper management, correct timing and amount of fertilizer application, proper application of pesticides, proper tillage, use of mulch, proper irrigation, proper allocation of manpower unit-1 area, and proper allocation of activity working-1 hour will lead to efficient usage of energy and adopting organic agriculture will lead to an eco-farming system with reduced energy usage and carbon emission production systems for Zamboanga City, Philippines.*

Keywords**—** *Direct energy input, indirect energy input, embedded energy input, liter diesel oil equivalent, eggplant, tomato.*

I. INTRODUCTION

Energy does everything for us, the cars running along the road and boats on the water. It bakes a cake inside the oven, maintains ice frozen inside the freezer, plays our favorite songs, and lights our homes at night. Energy enables human bodies to grow and minds to think. Energy is a changing, doing, moving, working/operating thing [1]. Direct energy refers only to the primary equivalent of energy purchased and used directly (e.g., fuels, electricity). Indirect energy refers to the energy applied in the production, storage, and transportation of goods and services. Embedded energy is referred to the energy that has been used in the work of making products. It measures the total of all the energy necessary for the entire product lifecycle [2].

Agriculture demands energy as an essential input to production and makes use of energy as fuel or electricity to run machinery and equipment, to warm or cool buildings, and for lighting the farming area, and indirectly in the agrochemicals produced off the farm. The government's effort of providing the needs of the growing population particularly the food is focused on increasing agricultural production. However, with the improvement of agricultural production and movement towards mechanization, there has been an increased requirement for energy resources. The utilization of energy in agricultural production has become more intensive due to the use of fossil fuel, agrochemical, machinery, and electricity to obtain substantial increases in food production [3].

The excessive use of energy has led to various environmental problems such as greenhouse gas (GHG) emissions, loss of biodiversity, and pollution of the aquatic environment by agro-chemical such as fertilizers and pesticides [4]. 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 [5,6]. For this reason, the analysis of the energy consumption is undertaken to evaluate the energy usage and environmental influences of agricultural production systems [7]. The efficient usage of energy will lead to sustainable production due to financial savings, fossil fuel preservation, and reduction of air pollution [8].

Agricultural crop production is a major consumer of energy and producer of greenhouse gases (GHGs), it requires direct and indirect usage of fossil fuel which resulted in the emission of GHGs such as carbon dioxide (CO2), nitrous oxide (N2O), and methane (CH4). This explains why the agriculture sector is one of the major contributors to the increasing GHG emissions with a 10% contribution of the total global emissions [9]. The study was carried out to acquire baseline information on energy consumption, determine the energy hotspot and calculate the carbon emission equivalent of energy input to produce tomato and eggplant in Zamboanga City, Philippines.

II. MATERIALS AND METHODS

A. Site Selection and Time of Study

The snowball sampling technique was used by selecting farmers, friends, and acquaintances that have directly experienced and knowledge of tomato and eggplant production. The study was conducted in Zamboanga City

Philippines from September 2020 to January 2021, at estimated coordinates of latitude: 6°54.6168'N and longitude 122°4.4334'E. Household activities, personal transactions, and other irrelevant activities were omitted in the accounting.

III. RESULTS

B. Energy Consumption Determination

The Indirect Energy Inputs (IEI) were calculated from various activities on pre-planting activity, Crop establishment, crop, care and maintenance, and harvest and postharvest operations. The Pre-planting activity was based on purchasing and hauling of farm inputs while the Crop establishment activity was based on plowing, harrowing, furrowing, holing, planting, and replanting. The crop care and management activity were based on the application of fertilizers, pesticides, and weeding. For harvest and postharvest activity was based on harvesting, repacking, hauling, loading, transporting the harvest into the market/consumer. A structured questionnaire was used to generate the information needed was adopted from the work of Tabal and Mendoza [10].

C. Energy Consumption Computation

The procedure of computation of energy consumption and energy equivalent coefficient was based on the work of Tabal and Mendoza [11], Tabal *et al.* [12], Mendoza [13], Pimentel [14], Pimentel [15], Flores *et al.* [16], Nabavi-Pelesaraei *et al.* [17], Djauhari *et al.* [18], Tripathi and Sah [19], Jeer Organization [20], Wilcke and Chaplin [21], NASS [22], Pimentel and Pimentel [23]. The energy consumption indicated in Mcal ha^{-1} was converted into Liter Diesel Oil Equivalent (LDOE) [14] and adopted from the work of Tabal *et al.* [12], where 1.0 LDOE is equal to 11.414 Mcal [14] for a common derivation. The human labor, chemical fertilizer, machinery, diesel fuel used in several operations, chemical pesticides, and irrigation were specified as inputs to estimate the amount of energy usage while the tomato and eggplant in fresh form were considered as output. The amount of each input was multiplied by the energy coefficient equivalent in Mcal unit^{-1} as listed in Table 1 to calculate the total energy input (TEI) ha^{-1} per commodity.

TABLE 1. Energy coefficient of various farm inputs and outputs

Type of Inputs	Unit	Energy Equivalent Per Unit		References
		MJ	Mcal	
A. INPUT				
SEED				
Long purple Eggplant seed	kg	1.0	0.24	Singh, 2002 [27]
Agrochemicals:				
a) Herbicide (gyphosate)	Lit	553.03	132.18[1]	Pimentel, 1980 [14] ; Barber, 2004[28]
b) Herbicide (Gen.), average	Lit	274	65.5	Saunders *et al.*, 2006 [29]; Gundogmus, 2006 [30]
C) Insecticide (solid)	kg	315	75.29	Wells, 2001 [31]; Saunders *et al.*, 2006 [29]
d) Insecticide (liquid), average	Lit	281.32	67.24	Pimentel, 1980 [14]; Gundogmus, 2006 [30]
e) Fungicide (solid)	kg	210	50.2	Wells, 2001 [31]; Saunders *et al.*, 2006 [29]
F) Fungicide (liquid), average	Lit	104.1	24.88	Gundogmus, 2006 [30] , Pimentel, 1980 [14]
Chemical Fertilizers				
a) Nitrogen	kg	102.23	24.43[2]	Lockeretz,1980 [32], Rodolfo, 2008 [26], Mendoza, 2014 [13]
b) Phosphate (P_2O_5), average	kg	20.6	4.92	Lockeret, 1980 [32], Rodolfo, 2008[26] , Mendoza, 2014[13] , Safa *et al.*, 2011[33]
c) Potassium (K_2O), average	kg	16.38	3.91	Lockeret, 1980[32] , Pimentel 1980[14] , Mendoza, 2014[13] , Safa *et al.*, 2011[33]
Fuel				
a) Gasoline	Lit	42.32	10.11	Kitani, 1999 [34]
b) Diesel fuel	Lit	56.31	13.46[3]	Mohammadi *et al.*, 2008 [35], Erdal *et al.*, 2007[5]
LABOR				
a) Human labor	Hr	1.96	0.47	Yilmaz *et al.*, 2005 [36]: Kazemi *et al.*, 2015 [37]
b) Draft animal	Hr	12.01	2.87	Nassiri and Singh, 2009 [38], Gliessman, 2014 [39]
Steel/Metal	Kg	75.31	18.0	Pimentel, 1980[14]
B. OUTPUT				Navabi-Pelesaraei *et al.*, 2013 [17]; Kitani, 1999[34]
Eggplant (fresh)	Kg	5.9	1.41	
Tomato (fresh)	Kg	0.8	0.19	Ozkan *et al.*, (2004) [7]

[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 [25].*
[2] *Estimates include the drilling processing, storage, and transport to sit of utilization (Rodolfo [26]; Mendoza [13].*
[3] *Estimates include the processing, storage, and transport to the site of utilization (Rodolfo [26]).*

D. Calculating the carbon emission equivalent

The total energy input (TEI) is the sum of direct energy input (DEI), indirect energy input (IEI), and embedded energy input (EEI). The DEI includes the use of diesel/gasoline to run the machines for farm operations and transport of farm products, while the IEI are seeds used, NPK fertilizers, agrochemicals, and labor inputs. Lastly, the EEI was accounted from the utilization of machines, farm equipment, and implements, motorized vehicles, and draft animal indicated in Mcal unit^{-1} then converted into Liter Diesel Oil Equivalent (LDOE) [14] and procedures were adopted from the work of Tabal *et al.* [12], where 1.0 LDOE is equal to

11.414 Mcal to get the total energy input (TEI). The TEI is multiplied by 3.96 kg CO_{2e} emission to obtain the carbon dioxide equivalent emission expressed in tCO_{2e} ha^{-1} [14].

The sum of carbon emission derived from DEI, IEI, and EEI is the inputs carbon, the inputs-outputs carbon was adopted from the work of Flores *et al*. [16] but was modified specifically for the computation of inputs carbon. To obtain the amount of output carbon, the output yield was converted to carbon (C) content equivalent. The carbon content is usually 45% of the total yield (Bolinder *et al.*, 2007 [24]; Flores *et al.* [16]. Net carbon was computed from output carbon less input carbon (Flores *et al.* [16].

IV. Results

The TEI applied to eggplant production amounted to 10,661.44 Mcal ha^{-1} (934.07 LDOE ha^{-1}) derived from DEI at 3,822.12 (35.85%), IEI at 6,791.34 (63.70%), and EEI at 47.98 (0.45%), while for tomato production, the TEI amounted to 7,045.89 Mcal ha^{-1} (617.30 LDOE ha^{-1}), where the DEI, IEI, and EEI contributed 525.62 Mcal ha^{-1} (7.46%), 6,365.96 Mcal ha^{-1} (90.35%) and 154.30 Mcal ha^{-1} (2.19%), respectively (Table 2).

Both eggplant and tomato are popular fruit vegetables grown in Zamboanga City. Across these two (2) crops, the energy input spent was computed from the various cultural practices and management operations such as the pre-land preparation (PLP), crop establishment (CE) crop care and management (CCM), harvest, and postharvest (HPH) activities. The EEI was small and insignificant due to the minimal utilization of farm machinery across the entire eggplant and tomato production system in Zamboanga City, Philippines.

The results further showed that for both crops, PLP at 570.41-4,100.75 Mcal ha^{-1} (49.97-359.27 LDOE ha^{-1}), while the CE at 5,245.19-6,220.54 Mcal ha^{-1} (449.54-544.99 LDOE ha^{-1}), CCM at 112.69-566.98 Mcal ha^{-1} (9.87-49.67 LDOE ha^{-1}) and HPH at 227.46-663.31 Mcal ha^{-1} (19.93-58.10 LDOE ha^{-1}), respectively. The energy inputs derived from PLP, CE, CCM, and HPH explain why eggplant and tomato production is an energy-intensive production system.

TABLE 2. Total energy inputs (TEI). Mcal ha^{-1} of different types of major farm activities on eggplant and tomato production.

Crops	DEI	%	IEI	%	EEI	%	TEI Mcal ha^{-1}
Eggplant	3,822.12	35.85	6,791.34	63.70	47.98	0.45	**10,661.44**
Tomato	525.62	7.46	6,365.96	90.35	154.30	2.19	**7,045.89**

DEI = direct energy input is average fuel used per working hour (Lit hr^{-1}) multiplied by energy coefficient of fuel, Mcal Lit^{-1}.
IEI = indirect energy input is the amount of inorganic fertilizers and pesticides used or number of human labor or fertilizer or animal labor multiplied by their corresponding energy coefficient in Mcal.
EEI = embedded energy input is (weight of the machine, kg unit-^{1} multiplied by energy coefficient of specific machinery, Mcal kg-^{1})
divided by (life span of the machine, years $unit^{-1}$ multiplied by the no. of hours the machine was used, hours ha^{-1}).
TEI = total energy input = DEI + IEI + EEI.
LDOE = liter diesel oil equivalent, 1.0 LDOE = 11.414 Mcal $unit^{-1}$, Pimentel, [14]. *In: Tabal et al.* [12].

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 animals used [12-14]. The high energy input for both crops was attributed to high energy usage on inorganic fertilizers, chemical pesticides, and labor which fall largely under indirect energy inputs (IEI), which shared about 63.70-90.35% of the TEI compared to DEI and EEI (Table 2). A similar trend was obtained in the study of Tabal *et al.* [12], where more than 94.0% of the TEI was attributed to IEI covering various agroforestry systems (AFSs) across the 16 community-based forest management (CBFM) sites located mostly in the upland of Zamboanga City, Philippines. In the case of eggplant and tomato production, inorganic fertilizers particularly N fertilizer was needed to achieved higher yield, while the energy spent on the use of agrochemicals such as herbicide, fungicide, and insecticide were necessary to control weeds, insect pests, and diseases. Pests and diseases are variables but at the time when this study was conducted, the use of chemicals was needed to contain such infestations and infections in order to maintain the desired level of yield output. The energy utilization attributed to animal and human labor was high making the entire production systems for both crops labor-intensive. Accounting for the energy spent derived from these three (3) major factors explains why the IEI is high in eggplant and tomato production. This finding conformed to the earlier studies of Pimentel [14], Mendoza [13], and Tabal *et al*. [12].

The direct energy inputs (DEI) include the use of diesel or gasoline fuel to run various types of machinery such as the tractor, hauling truck, motorcycle, and tricycle used for transportation; and water pump to supply irrigation water during the dry weeks and months. Among the activities, the HPH was significant due to the utilization of hauling truck in the purchase of the needed inputs such as fertilizers and agrochemicals and transport of fresh produce to markets and consumers, while CE obtained the highest DEI as a result of the utilization of farm tractor during land preparation. The energy input on the manufacture of any machinery is determined by using the machine energy coefficient consisted of the energy quantity of the materials used, energy utilized in the fabrication, transportation of the machine to the end-users, and the energy used for repair and maintenance that is spread through its entire lifespan [14]. This is the reason why the energy usage on EEI is small and insignificant contrary to the energy input spent on DE and IEI, respectively (Table 2).

The acreage of energy input from fertilizer usage and labor is called the 'energy hotspots' [12-14]. Energy hotspot is the activities or practices that require high energy inputs needed in various growth stages of both crops under different cultural practices and management which falls largely during CE operation. The energy hotspots for both crops ranged from 3,503.69-4,712.12 Mcal ha^{-1} (306.96-412.84 LDOE ha^{-1}) or this is about 32.86-66.88 percent share on TEI. Of this total, fertilizer usage contributed 3.83-79.05 percent, while labor contributed 20.95-96.16 percent, respectively (Table 3). The results further showed that labor requirements to produce a kilogram of eggplant were higher compared to fertilizer usage making the entire system highly labor-intensive. Similar findings in the study on wheat and cassava production Pimentel [40], where wheat was produced employing diverse techniques with energy sources ranging from human labor, to animal power to mechanization, while Jadidi *et al.* [41] accounted energy utilization on fertilizer usage the highest at 50.98% of the TEI.

TABLE 3. Energy hotspot of eggplant and tomato production (Mcal ha^{-1})

Commodities	**Fertilizer Mcal ha^{-1}**	**%**	**Labor Mcal ha^{-1}**	**%**	**Total Mcal ha^{-1}**
Eggplant	134.38	3.83	3,369.31	96.16	3,503.69
Tomato	3,725.12	79.05	987	20.95	4,712.12
Total					**8,215.81**

In any food production system, the ultimate goal is to increase yield ha^{-1} basis. In doing so, energy inputs in the form of DEI, IEI, and EEI are increased to achieve this goal. The acreage of DEI, IEI, and EEI is called the TEI. While increasing the TEI to increase yield comes a potential increase in carbon emission equivalents expressed in tCO_{2e} ha^{-1}. Table 4 shows the total input carbon derived from the TEI of the entire activities of eggplant and tomato production. The highest input carbon obtained from eggplant production amounted to 3,698.91 CO_{2e} kg ha^{-1} (3.7 tCO_{2e} ha^{-1}), while in tomato production at 2.444.51 CO_{2e} kg ha^{-1} (2.4 tCO_{2e} ha^{-1}), respectively or a total emission across the two crops 2.4-3.7 tCO_{2e} ha^{-1}. Of this total, the individual emission equivalents of DEI, IEI and EEI accounted to 2.1-15.2 tCO_{2e} ha^{-1}, 25.2-26.9 tCO_{2e} ha^{-1} and 0.19-0.61 tCO_{2e} ha^{-1}, respectively, this explains why vegetable production in Zamboanga City is a net carbon emitter attributed largely to IEI. On the other hand, of the four (4) major farm operations, the PLP emitted about 0.19-1.42 tCO_{2e}, CE at 1.82-2.16 tCO_{2e}, CCM at 0.04-0.20 tCO_{2e} and HPH at 0.07-0.23 tCO_{2e}, respectively, implicating PLP and CE as energy-intensive systems and high carbon emitter.

Generally, the results indicated that more usage of fuel, chemicals, and labor would incur more energy inputs that would lead to more potential of carbon dioxide emission.

TABLE 4. Input carbon Emissions derived from total energy inputs (TEI) of eggplant and tomato production

Commodities	**TEI Mcal ha^{-1}**	**LDOE ha^{-1}**	**CO_{2e} kg**
Eggplant	10,661.44	934.07	3,698.91
Tomato	7,045.89	617.30	2,444.51
Total Input Carbon			**6,143.42**

The potential carbon emission derived from total energy inputs (TEI), total energy inputs are the sum of direct energy input (DEI), indirect energy input (IEI)' and embedded energy input (EEI)' were converted into Liter Diesel Oil Equivalent (LDOE), according to Pimentel [14] adopted from the work of Tabal et al. [11], where 1.0 LDOE is equal to 11.414 Mcal $unit^{-1}$ and according to the work of Pimentel [14] multiplied by 3.96 kg CO_{2e} emission to obtained the net carbon dioxide emission.
TEI = total energy input = DEI + IEI + EEI.
LDOE= liter diesel oil equivalent, 1.0 LDOE = 11.414 Mcal $unit^{-1}$ [14]), In: Tabal et al. [12].

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 two-fold, as higher yields also lead to efficient usages 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 such as pollution, erosion, and greenhouse gas emission affecting in return humans and food production systems.

Correct usage of energy inputs and exact amount and number of laborers, diesel, chemical fertilizers, and pesticides must be considered since the inputs spent will affect the carbon efficiency ratio in both the eggplant and tomato production. The excess of energy inputs will tend to increase the carbon emission whereas it will lead to global warming that drives climate change, hence a need for a green agriculture technology that will promote the reduction of energy usage and climate-smart which include the adoption of crop rotation with N-fixing plants such as leguminous crops, green manuring, composts or organic fertilizers can be used instead of synthetic fertilizer should be considered to reduce the high utilization of energy, environment-friendly biological control agent for pest and diseases, biodiesel, utilization of new types of machinery for cultivation, more efficient pumps for extracting irrigation water, application of mulches to conserve soil moisture and prevent the growth of weeds thereby reducing irrigation frequency can lead to cultivation/production of vegetable crops with less energy inputs and carbon emission.

On contrary, human activities lead to increased levels of greenhouse gases (GHGs) in the atmosphere involving deforestation, mining, farming that adopt conventional farming systems; heavy tillage, high application of chemical fertilizer, application herbicide, and other agrochemicals. These changes are affecting many human activities, including agriculture. Take into account that 74.44% of carbon emission comes from crop establishment that includes plowing and harrowing with the use of draft animals, fertilizer application, etc. This 74.44% of emission could be higher when the production system engaged in heavy tillage and heavy application of fertilizer. The 74.44% of carbon emission determined on crop establishment could be used as a basis to minimize the carbon emission. With proper management especially on tillage practices, correct pattern and amount of application of fertilizer, proper pesticide application, proper tillage from zero tillage to minimum 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.

V. CONCLUSION

The entire production system has high total energy inputs with high potential for carbon emission, the proper usage of energy inputs is an important factor to consider particularly the direct and indirect energy such as the application of fertilizer, the use of diesel and gasoline, the balance of laborer per operation will help reduce the energy losses and increase the profit of the farmers unit-1 area. Using the present cultural practices could be enhanced by 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 systems for Zamboanga City, Philippines.

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