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ENERGY ACCOUNTING OF TOMATO PRODUCTION IN LAPAZ, ZAMBOANGA, PHILIPPINES

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ABSTRACT: The study was laid out in La Paz, Zamboanga City, Philippines, to determine the energy hotspot and evaluate the energy use efficiency in the entire tomato production system. The activities that have nothing to do with farm operations, such as doing household chores, food, clothing, and personal work, were excluded from the research. The study found that the DEI, IEI, and EEI values for the entire activity in tomato production ranged from 39.63% to 46.08%, 42.93% to 99.70%, and 0.29 percent to 10.99%, respectively. According to the findings, indirect energy inputs accounted for 42.93% to 99.70% of the total energy inputs. It explains that IEI was a hotspot, particularly in crop care and management activity. However, the EP and NE have calculated to determine the efficiency in energy input, giving the results of 1.00 Mcal ha^{-1} and 29.22 Mcal ha^{-1}, respectively. From there, it is observed in the existing production system the energy efficient since it obtains low TEI with high economic output, and the energy inputs did not exceed on energy output. Furthermore, this system can be more efficient if crop care and management activity properly managed include agrochemicals, particularly fertilizer.

KEYWORDS: *Energy Inputs, Total Energy Inputs, Energy Hotspot, Energy Productivity, Net Energy*

I. INTRODUCTION

Farmers stand to benefit greatly from significant economic opportunities and a growing role as a source of renewable energy. In cropping systems, the order in which crops are grown, the type of soil, the nature of tillage, the type and amount of chemical fertilizer, plant protection measures, harvesting, and threshing, and, finally, yield levels all influence energy consumption, energy forms, and input/output relationships from farm to location, each stage affects energy inputs [1].

Nowadays, energy is recognized and is directly related to crop yields and food supplies [2].

The most suitable system, with the highest harvest and lowest energy consumption, was identified through these analyses. In turkey, energy use for vegetable cultivation sets in a greenhouse was investigated, but the authors were not concerned with the functional relationship between energy inputs and yield [6].

Tomatoes are a popular vegetable grown in many parts of the country due to their adaptability and high nutrient content. One of the advantages of sustainable agriculture production is the efficient use of resources. In addition, one of the primary requirements for sustainable agriculture is the effective utilization of energy.

Agriculture has been consuming more energy due to a rising population, a limited supply of arable land, and a desire for higher living standards. To meet the demand for food, agrochemicals, farm machinery, and fuel was extensively utilized. However, excessive energy consumption results in issues that threaten public health and the environment. [20].

The intensity of energy use in agriculture cultivation has increased due to the use of fossil fuels, chemical fertilizers, pesticides, machinery, and electricity to produce significantly more food. The effect of energy use on the crop production system has been investigated by comparing the energy input and output to determine production efficiency [3], wheat, soybean, and maize [4], apple, wheat, maize, and sorghum [27], kiwifruit production [30], cucumber production [38], onion, lettuce, radish [42], and sugar production [7], and agroforestry [9]. However, no comparable study in the Philippines' energy efficiency and energy input optimization for tomato production [9].

II. MATERIALS AND METHODS

Study Site and Farmer Cooperators

The study has conducted in the barangay La Paz, Zamboanga City, Philippines. Two tomato growers worked as cooperators for a single cropping season. Data were recorded, tabulated, and analyzed, starting with the purchasing inputs, pre-plant operation, and delivery of harvested yield. The farming household's miscellaneous living expenses, including food, clothing, and other energy inputs, were not included.

Energy Consumption Determination

The following activities—pre-planting, crop establishment, crop care and management, and harvest and post-harvest operation—were used to calculate the direct energy input (DEI), indirect energy input (IEI), and embedded energy input (EEI) to obtain the total energy inputs (TEI), where the TEI is the 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, the 'indirect energy input (IEI)' includes the seeds used, NPK fertilizers, agrochemicals, and labor inputs. Lastly, the 'embedded energy input (EEI)' was accounted for machines, farm equipment, implements, motorized vehicles, and draft animal indicated in Mcal. The pre-planting activity entails purchasing and transporting farm inputs and planting and replanting diseased plants. Meanwhile, plowing, harrowing, furrowing, holing, plot establishment, and nursery establishment for seedlings were the primary components of crop establishment, as well as crop care and management activities like applying fertilizers, using pesticides, weeding, and putting down mulch. Lastly, harvesting, repacking, hauling, loading, and transporting the harvest into the market or consumer were the components of the harvest and post-harvest operations [14].

Energy Consumption Computation

The procedure of accounting for energy inputs and outputs and energy equivalent coefficient has based on the work of Tabal et al.[11-17][8][31][32].The energy accounting showed in Mcal was changed over into Liter Diesel Oil Same (LDOE), as per Pimentel [17] and indicated from the work of Tabal et al. [9] 1.0 LDOE is equivalent to 11.414 Mcal unit^{-1} to have a common understanding. The equations below show to compute the DEI, IEI, and EEI was 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)

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

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} Eq. 1

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

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

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} Eq. 2

2. Indirect Energy Used (I_{EU})

a. NPK fertilizers applied (NPK_{fert})

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

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} Eq. 3

b. Human labor (HL)

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

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} Eq. 4

c. Animal labor (AL)
$IEU_{AL} = (N_{ani} \times E_{ALcoef})$
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} Eq. 5

d. Organic fertilizer (animal manure) (AM)
$IEU_{AM} = (A_{AM} \times E_{AMcoef})$
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} Eq. 6

e. Seed used (S)
$IEU_S = (A_S \times E_{Scoef})$
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} Eq. 7

f. Pesticide (Insecticide, Fungicide, Herbicide) used (IFH)
$IEU_{IFH} = (A_{IFH} \times E_{IFHcoef})$
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} Eq. 8

g. PHEI on PLP, CE and CCM
$PHEI_{PLP} = (PLP_{SA} \times E_{laborcoef})/Y_{sc}$
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 Eq. 9

h. $PHEI_{CE} = (CE_{SA} \, xE_{laborcoef})/Y_{sc}$
Where:
$PHEI_{CE}$ = pre-harvest energy input on crop establishment, Mcal
CE_{SA} = specific activity oncrop establishment, Mcal
$E_{laborcoef}$= energy coefficient of labor, Mcal
Y_{sc}= number of unproductive years Eq. 10

i. $PHEI_{CCM} = (CCM_{SA} \, xE_{laborcoef})/Y_{sc}$
Where:
$PHEI_{CCM}$ = pre-harvest energy input on crop care management, Mcal
CCM_{SA} = specific activity oncrop care management, Mcal
$E_{laborcoef}$= energy coefficient of labor, Mcal
Y_{sc}= number of unproductive years Eq. 11

3. Embedded Energy Input (EEU)
a. Embedded Energy used in farm machineries (EFM)
$EFM = (W_M \times E_{Mcoef}) / (LS_M \times Hr)$
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} Eq. 12

b. Embedded Energy used in farm equipment and tools (EET)
$EET = (W_{ET} \times E_{ETcoef}) / (LS_{ET} \times Hr)$
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} Eq. 13

4. Total Energy Inputs (TEI)
$TEI = D_{EU} + I_{EU} + E_{EU}$
Where:
TEI = total energy input, Mcal ha^{-1}
D_{EU} = direct energy input
I_{EU} = indirect energy input
E_{EU} = embedded energy input Eq. 14

5. Energy Use Indicator
a. Total Energy Output (TEO)
$TEO = (Y \times E_{coef})$
Where:
TEO = total energy output, Mcal ha^{-1}
Y = yield, Kg ha^{-1}
E_{coef} = energy coefficient of specific farm commodity, Mcal Kg^{-1} Eq. 15

b. Energy Productivity (EP)
EP = TEO / TEI
Where:
EP = energy productivity, Mcal ha^{-1}
TEO = total energy output, Mcal ha^{-1}
TEI = total energy input, Mcal ha^{-1} Eq. 16

c. Net Energy (NE)
NE = TEO – TEI
Where:
NE = net energy
TEO = total energy output, Mcal ha^{-1}
TEI = total energy input, Mcal ha^{-1} Eq. 17

Table 1. Energy coefficient of various farm inputs and outputs

PARTICULARS	UNIT	ENERGY EQUIVALENT PER UNIT		REFERENCES
		MJ	Mcal	
A.) INPUTS				
SEED				
Diamante max seed	kg	1.0	0.24	[35]
AGROCHEMICALS:				
a) Herbicide (gyphosate)	Lit	553.07	132.19	[8, 24]
b) Herbicide (Gen.), ave.	Lit	274	65.5	[23, 25]
C) Insecticide (solid)	kg	315	75.29	[23, 34]
d) Insecticide (liquid), ave.	Lit	281. .32	67.24	[8, 25]
e) Fungicide (solid)	kg	210	50.2	[23, 34]
F) Fungicide (liquid), ave.	Lit	104.1	24.88	[8, 25]
CHEMICAL FERTILIZERS				
a) Nitrogen	kg	102.23	24.43**	[5, 29, 33]
b) Phosphate (P205), ave.	kg	20.6	4.92	[5, 10, 29, 33]
c) Potassium (K20), ave.	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**	[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	[8]
Output				
Tomato (fresh)	Kg	0.8	0.19	[28, 32]

* The energy for production of Glyphosphate is 440 MJ per Kg, the formulation and packaging, and transportation is 113.03 MJ per Kg. In: Savuth et al. [11}.
** Estimates includes the drilling processing, storage and transport to sit of utilization [33] [5].
*** Estimates includes the processing, storage and transport to site of utilization [33]

Statistical Analysis

The mean and sum of all activities were to compare the energy inputs and outputs in tomato production using descriptive and inferential statistics.

Results

The summary of total energy inputs (TEI) applied on tomato production in Lapaz, Zamboanga City, is shown in Table 2.

Table 2. Summary of Total Energy Inputs (TEI). Mcal ha^{-1} of different types of labor applied on Tomato production.

Type of Labor	DEI Total Mcal ha^{-1}	%	IEI Total Mcal ha^{-1}	%	EEI Total Mcal ha^{-1}	%	TEI TOTAL
I. Pre-plantingOperation	262.86	46.08	244.88	42.93	62.67	10.99	570.41
II. Crop Establishment	___		505.23	94.64	28.56	5.36	533.79
III. Crop care and Management	___		5276.72	99.97	1.66	0.03	5278.38
IV. Harvest and Pre-Harvest	262.86	39.63	338.4	51.02	62.05	9.35	663.31
Total Energy Inputs	525.72		6,365.23		154.94		**7045.89**

Farmers stand to benefit greatly from significant economic opportunities and a growing role as a source of renewable energy. In cropping systems, the order in which crops are grown, the type of soil, the nature of tillage, the type and amount of chemical fertilizer, plant protection measures, harvesting, and threshing, and, finally, yield levels all influence energy consumption, energy forms, and input/output relationships from farm to location, each stage affects energy inputs [10].

The energy inputs implied on entire tomato production is 7,045.89 Mcal ha^{-1} (617.30 LDOE ha^{-1}). Crop care and management has obtained the highest total energy inputs at 5,278.38 Mcal ha^{-1} (462.44 LDOE ha^{-1}) compared to other activities such as Pre-planting operation at 570.41 Mcal ha^{-1} (49.97 LDOE ha^{-1}), and Harvest and Pre-Harvest activity obtained 663.31 Mcal ha^{-1} (58.10 LDOE ha^{-1}). Meanwhile, the Crop establishment has the lowest energy inputs at 533.79 Mcal ha^{-1} (46.76 LDOE ha^{-1}).

The direct energy inputs (DEI) shown in Table 2 include diesel oil to run the Bongo Truck for purchasing inputs like seeds and agrochemicals and deliver of output to the market. The pre-planting operation obtained 262.86 Mcal ha^{-1} (23.03 LDOE ha^{-1}) consumed from purchasing inputs while the same result in hauling and transport output to market for harvest and pre-harvest activity at 262.86 Mcal ha^{-1} (23.03 LDOE ha^{-1}). Meanwhile, the DEI for crop establishment and crop care and management activity shows no result because done manually. The farmer only used diesel/gasoline when purchasing inputs and marketing outputs.

The highest indirect energy inputs were from crop care and management activity at 5276.72 Mcal ha^{-1} (462.30 LDOE ha^{-1}) was mainly from fertilizer and labor, followed by the Crop Establishment activity such as plowing, harrowing, seedling, transplanting, and weeding at 505.23 Mcal ha^{-1} (44.26 LDOE ha^{-1}). Then, the harvest and pre-harvest activity were at 338.4 Mcal ha^{-1} (29.65 LDOE ha^{-1}). Meanwhile, the lowest indirect energy input was from pre-planting activity at 244.88 Mcal ha^{-1} (21.45 LDOE ha^{-1}).

The embedded energy inputs accounted for the entire activities in tomato production. Pre-planting activity obtained the highest embedded energy inputs at 62.67 Mcal ha^{-1} (5.49 LDOE ha^{-1}), followed by harvest and pre-harvest at 62.05Mcal ha^{-1} (5.45 LDOE ha^{-1}). Then, crop establishment at 28.56 Mcal ha^{-1} (2.50 LDOE ha^{-1}). Finally, the lowest embedded energy inputs were from crop care and management activity at 1.66 Mcal ha^{-1} (0.145 LDOE ha^{-1}), as shown in Table 2.

Of this total, the DEI, IEI, and EEI of pre-planting operations contributed 46.08%, 62.67%, and 10.99%, respectively. The crop establishment contributed 94.64% and 5.36%. Then, crop care and management contributed 99.97% and 0.03%. Meanwhile, the harvest and pre-harvest activity contributed 39.63%, 51.02%, and 9.35%.

All the energy inputs were accounted for mainly to determine the energy hotspot. The energy hotspot means the activities or practices that require high energy inputs needed in the growth stage of a particular crop to gain a high yield. As discussed previously and shown in Table 2, the indirect energy input obtained the higher total energy inputs since the value for DEI, IEI, and EEI ranged from 39.63% - 46.08%, 42.93% - 99.97%, and 0.03% - 10.99%, respectively, which mean the IEI has contributed the highest energy input at 42.93% - 99.97% and by examining the activities of IEI shown in Table 2 the crop care and management activity are can be concluded as the energy hotspot among the activities across the entire tomato production since it contributed 99.97% of indirect energy input. Table 3 shows the two components of crop care and management. Fertilizer application was the highest with a value of 3,725.12 Mcal ha^{-1} (326.36 LDOE ha^{-1}) at 91.40% compared to insecticide application with a value of 350.4 Mcal ha-1 (30.70 LDOE ha^{-1}) at 8.60%. Furthermore, the energy input of human labor during fertilizer application was relatively higher at 82.17% compared to applying insecticide at 7.83%, similar to the work of Jadidi et al. (2012) which tomato production consumed a total of 65,238.9 MJ/ha of which fertilizers were 50.98%.

Table 3. ENERGY HOTSPOT (Mcal ha^{-1})

INDIRECT ENERGY INPUT (Mcal ha^{-1})						
Type of Activity	**Component**	Fertilizer Mcal ha^{-1}	%	Insecticide Mcal ha^{-1}	%	**Total**
Crop Care and Management	Chemical Application	3,725.12	91.40	350.4	8.60	4,075.52
	Labor	987	82.17	214.2	17.83	1,201.2
Total		**4712.12**		**564.6**		**5,276.72**

The energy use indicator determines whether the production system has consumed the energy input efficiently. In this regard, this system obtained low TEI with high economic output making this system efficient in the use of energy. On the other hand, computed energy productivity (EP) is mainly to determine the energy equivalent yield. Crop care and management activity obtained energy productivity of 1.00 Mcal ha^{-1}, which explains that every energy input (Mcal) invested gave an equivalent energy yield of 1.00 Mcal ha^{-1}. Lastly, the net energy in the tomato production system, the crop care and management activity obtained the NE of 29.22 Mcal ha^{-1}. The high NE attributed to energy output higher than TEI, meaning that in this particular production system, the energy inputs did not exceed from energy output.

Table 4. Energy Use Indicator (Mcal ha^{-1})

Energy Use Indicator (Mcal ha^{-1})					
Type of Activity	TEI Mcal ha^{-1}	OUTPUT Kg ha^{-1}	TEO Mcal ha^{-1}	EP Mcal ha^{-1}	NE Mcal ha^{-1}
Crop care and management	7,045.89	37,237.42	7075.11	1.00	29.22

TEI, Total Energy Inputs
Output, Fresh harvested yield in kilogram per hectare
TEO, Total energy output
EnROEI, Energy return on energy inputs
EP, Energy productivity
NE, Net energy

III. DISCUSSION

By examining the results in the entire activity in tomato production, the value for DEI, IEI, and EEI ranged from 39.63% - 46.08%, 42.93% - 99.97%, and 0.03% - 10.99%, respectively, where the range of 42.93% - 99.97% was from indirect energy inputs. Where the DEI has less activity which requires diesel and gasoline, the soil tillage by man and animal power. Therefore, diesel-oil consumption was purely for purchasing inputs such as seeds and agrochemicals for fertilizer, pesticides, and delivery output.

Synthetic fertilizers have consumed the most energy, which is significant in this regard, according to the findings. Nitrogen fertilizer has the potential for total energy savings. So, by monitoring the utilization of chemical inputs and nonrenewable energy sustainability of tomato production is maintained. To reduce the use of inorganic nitrogen fertilizer, crop rotation with nitrogen stabilizer plants like leguminous plants must be considered.

Similar to Kaplan et al.'s [36] findings about the proportion of nitrogen, phosphorus, and potassium fertilizer were 32.8%, 37.2%, and 30%, respectively. Accordingly, nitrogen was the second most important input. Again, the final yield per hectare reflects the optimal requirements of the plants in comparison to the excessive or inefficient use of nitrogen. According to Kaplan et al. [36], this excessive use suggests that the nitrogen the plants do not consume pollutes the environment and underground water.

Energy productivity of 0.74 kg/MJ has been used to produce tomatoes, according to Jadidi et al. [31]. While in another study, the rate of energy used in stake-tomato cultivation in Turkey's Tokat province [21] and tomato cultivation in an Antalya, Turkey, greenhouse have reported being 1.26 kg/MJ [6]. According to Cetin et al. [19], tomato production in Turkey's south Marmara region used an energy productivity of 0.99 kg/MJ. In Addition, in another Iranian study [39], greenhouse tomato cultivation requires energy productivity of 1.2 kg/MJ. This inefficiency may be attributable to the improper management of inputs, particularly chemical fertilizers, in conventional tomato farming [31]. However, according to Kelly et al. [37], [40], [41], the labor input for tomatoes in the United States is high at about 184 hrs/ha. Most of the energy input is for machinery, fuel, and fertilizers are the third largest input, obtaining a yield of 80,000 kg/ha, providing 16.0 million kcal of food energy, and with a fossil energy input of 20.6 million kcal and the resulting input-output ratio is 1:0.78. However, this study found that every energy input (Mcal) invested gave an equivalent energy yield of 1.00 Mcal ha-1, where this system obtained high economic output than the TEI in which the energy inputs did not exceed energy output showing this system was efficient in the use of energy. The efficient use of inputs will reduce environmental problems and promote sustainable agriculture as an economical production system.

Farmers or other organizations gain a better understanding of how energy has used and be motivated to take actions that can save money on utility bills with energy accounting. Be that as it may, numerous associations don't understand the full advantage of following energy utilization and cost. Energy accounting won't save any energy on its own. However, when used as a tool for energy management, it can assist in making adjustments to equipment or operations that reduce energy consumption. Budgeting, allocating resources for capital investment, and verifying the outcomes of all energy management activities can all benefit from energy accounting.

IV. CONCLUSION

The production of tomatoes makes inefficient use of chemical fertilizer inputs, which results in issues that go beyond the scope of the agricultural production system. It raises production costs and affects the environment, human health, and sustainability. Policymakers in the region are responsible for providing farmers with education opportunities on how to use inputs effectively.

As a result, the researcher concluded that if the entire production system uses higher energy inputs, the output will also rise. However, it is crucial to be sure that energy inputs are consumed wisely, especially in direct and indirect energy like fertilizer application, diesel and gasoline use, and the balance of laborers per operation, which helps farmers cut losses and make more money.

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