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Energy use in The Management of Selected Coffee-Based Agroforestry Farms in Timor Leste

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Abstract:
Agroforestry is an important carbon sequestration strategy because of carbon storage potential in its multiple plant species and soil as well as its applicability in agricultural lands and in reforestation. The study was conducted in selected coffee-based agroforestry farms in Gleno, Ermera District, Timor Leste to determine the energy used in the management of coffee-based agroforestry farms.
The TEI (total energy input) of each agroforestry coffee farm was derived from direct, indirect, and embedded energy inputs. For coffee-based agroforestry, a total of 26.44 Mcal ha^{-1} was recorded from the use of farm trucks (19.22 Mcal ha^{-1}) and motorcycle (7.22 Mcal ha^{-1}). For the indirect energy, the largest consumption of energy was in the use of pesticides with 442.43 Mcal ha-^{1} (5049.90 LDOE ha-^{1}). The use of pesticides in large quantities made the indirect energy to increase compared to the indirect energy needs from other processes. The lowest energy input was field visit monitoring with 4.61 Mcal ha-^{1} (52.62 LDOE). The monoculture coffee had a total direct energy input of 46.28Mcal ha^{-1} derived from the use of farm trucks (33.65Mcal ha^{-1}) and motorcycle (12.63Mcal ha^{-1}).
The largest indirect energy input was observed in the use of fertilizers, particularly N with 2043.1 Mcal ha-^{1} (23318.80 LDOE Mcal ha^{-1}) and followed with the use of pesticide (Glyphosate) with 442.43 Mcal ha^{-1} (507.12 LDOE Mcal ha^{-1}). For human labor, weeding, field visit monitoring and picking activities required high energy input while insecticide spraying required the lowest amount of energy input. The pruned coffee cropping pattern had a total direct energy input of 46.29 Mcal ha^{-1} derived from the use of farm trucks (33.65Mcal ha^{-1}) and motorcycle (12.64Mcal ha^{-1}). The largest indirect energy input was observed in the use of organic fertilizers (705.08 Mcal ha^{-1}) followed by inorganic fertilizer (N) with 664.50 Mcal ha-^{1} (7584.60 LDOE Mcal ha^{-1}) and followed with the use of pesticide (Glyphosate) with 481.17 Mcal ha^{-1} (5492.07 LDOE Mcal ha^{-1}).
Abovementioned results reveal that in the management of coffee-based agroforestry system both direct and indirect energy are used. Energy from animal labor is higher than energy required from human labor. Cost and use of pesticides recorded the highest while field visit monitoring the lowest. The use of inorganic fertilizers was more expensive than organic fertilizers. The total energy ratio in the management of coffee-based agroforestry farm of 1.67 Mcal ha^{-1} indicates that the agroforestry practices are suitable for development because of a >1 energy ratio. With these findings, further study is required to account for different qualities and management of inputs to enable effective calculation of the carbon footprints (CF) from different cropping patterns and management strategies, and eventually come up with a more effective climate change mitigation strategies from site-specific studies.
Key Word*: Energy use, The Management of Coffee, Agroforestry*

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I. Introduction

Coffee is one of the most valued commodities of Timor Leste. Coffee producers in the country use a variety of agricultural techniques, including shaded and unshaded monoculture, agroforestry, and traditional polyculture with organic and conventional practices to meet the increasing demand of coffee in the world market. The management of coffee farms requires the use of energy or energy input. The energy use in the forms of direct energy, indirect energy, renewable energy, and non-renewable energy are potential contributor to global warming (Jamali et al., 2021). However, the very same agroforestry systems that has high potential for carbon arrest also requires enormous energy in the form of machineries, farm implements, equipment, farm tails, various inputs, like seeds, fertilizers and chemical pesticides, trucks and other forms of logistics used for hauling and transport, human and animal labor (Tabal, 2019). This brings to inquiry to the efficiency of performing carbon sequestration and the capacity more than the emitted GHG emissions from the coffee plantations. It is imperative to understand the relationship of energy use, carbon emissions and carbon sequestration capability. Hence, the conduct of the study in Timor Leste where coffee production has vital role in economic development.

II. Methodology

The research was conducted in the municipality of Gleno Ermera, specifically in Gleno Fatukeru and Ermera districts. The research site was selected based on the following criteria: (1) with farmers who were directly involved as coffee farming and (2) with a rural population consisting mostly of coffee farmers. These areas are located in the western region of Timor Leste.

However, the very same agroforestry systems that has high potential for carbon arrest also requires enormous energy in the form of machineries, farm implements, equipment, farm tails, various inputs, like seeds, fertilizers and chemical pesticides, trucks and other forms of logistics used for hauling and transport, human and animal labor (Tabal, 2019). This brings to inquiry to the efficiency of performing carbon sequestration and the capacity more than the emitted GHG emissions from the coffee plantations. It is imperative to understand the relationship of energy use, carbon emissions and carbon sequestration capability. Hence, the conduct of the study in Timor Leste where coffee production has vital role in economic development.

The 'energy inputs' derived from the questionnaire were processed using the MS Excel Software package. Quantitative outputs from this operation were converted into average ha^{-1}. The total energy bill was estimated from all major energy-consuming farm operations beginning at pre-planting and ending at postharvest. The total energy bill (or the total energy input) was derived from the direct, indirect and embedded energy of various tree and annual crop components. On one hand, the 'direct energy input (DEI)' includes the direct usage of diesel and/or gasoline to run the machines for farm operations and transport of farm products. On the other hand, the 'indirect energy input (IEI) and labor (such as pre-planting operations, crop establishment, crop care and management, harvest and post harvest operations). The 'embedded energy (EE)' was accounted for from the utilization of machines, farm equipment and implements, motorized vehicles and draft animal used. Energy accounting procedures and various energy coefficients were-based on the work of Pimentel (1980ab), Mohammadshirazi et al. (2012), Goe (1980), Ozkan et al. (2004), Shresta (2002), Esengan et al. (2007), Yaldiz et al. (1993), Singh et al. (2002), Yilmaz et al. (2005), Thu and Mendoza (2011), Egle and Mendoza (2013), Mendoza (2016), Taghavi and Mendoza (2011), Mendoza and Samson (2002), Pimentel, 2009; Karimi et al. (2008), Mendoza (2016), Gliessman (2014), and from other relevant literatures as cited by Wells (2001) and Bockari-Gevao et al. (2005).

All energy units in Mcal were converted into Liter Diesel Oil Equivalent (LDOE), where 1.0 LDOE = 11.414 Mcal $unit^{-1}$ (Pimentel et al., 1980a) to have a common understanding of the energy usage in this study.

The following equations were used to calculate the direct (Deb), indirect (Ieb) and embedded (Eeb) energy bills of the major agroforestry systems within coffee farm sites in Timor Leste:

1. Direct Energy Used (DEU):

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

DEUFFOPE = (Afu x EFcoef) Eq. 1

Where:

DEUFFOPE = direct fuel used for field operation, Mcal ha^{-1}

Afu = average fuel used per working hour (lit hr^{-1})

EFcoef = energy coefficient of fuel. Mcal lit^{-1}

b.) Direct energy (diesel of gasoline) used ha-1for hauling and transport (Ftrans)

DEUFtrans = (AFtrans x EFcoef) Eq. 2

Where:

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

AFtrans = average fuel use per working hour (lit hr^{-1})

EFcoef = energy coefficient of fuel. Mcal lit^{-1}

2. Indirect Energy Used (IEU)

a.) NPK fertilizers applied (NPKfert)

IEUNPKfert = (ANPKfert x ENPKcoef) Eq. 3

Where:

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

ANPKfert = amount of fertilizer (NPK) applied, kg ha^{-1}

ENPKcoef = energy coefficient of NPK fertilizer. Mcal ha^{-1}

b.) Human labor (HL)

IEUHL = (Nlab x Nhrs x EHLcoef) Eq. 4

Where:

IEUHL = indirect energy used on Human labor, Mcal ha^{-1}

Nlab = number of laborers involve in farm operation ha^{-1}

Nhrs = number of hours per field operation ha^{-1}
EHLcoef = energy coefficient on human labor, Mcal ha^{-1}
c.) Animal labor (AL)
IEUAL = (Nani x Nhrs x EAlcoef) Eq. 5
Where:
IEUAL = indirect energy used on animal labor, Mcal ha^{-1}
Nani = number of animals used in farm operation ha^{-1}
Nhrs = number of hours per field operation ha^{-1}
EALcoef = energy coefficient of animal labor, Mcal hr^{-1}
d.) Organic fertilizer (animal manure) (AM)
IEUAM = (AAM x EAMcoef) Eq. 6
Where:
IEUAM = indirect energy used on animal manure, Mcal ha^{-1}
AAM = amount of animal manure applied, kg ha^{-1}
EAMcoef = energy coefficient of animal manure, Mcal kg^{-1}
e.) Seeds used (S)
IEUS = (AS x EScoef) Eq. 7
Where:
IEUS = indirect energy used on seed, Mcal ha^{-1}
AS= amount of seed used, kg ha^{-1}
EScoef = energy coefficient of animal seed, Mcal kg^{-1}
f.) Pesticides (insecticide, fungicide, herbicide) used (IFH)
IEUIFH = (AIFH x EIFHcoef) Eq. 8
Where:
IEUIFH = indirect energy used on pesticides, Mcal ha^{-1}
AIFH = amount of pesticides applied, lit ha^{-1}
EIFHcoef = energy coefficient of specific pesticide, Mcal kg^{-1}
g.) PHEI on PLP, CE and CCM
PHEIPLP = (PLPSA x ELABORcoef)/YSC Eq. 9
Where:
PHEIPLP = pre-harvest energy input on pre- land preparation, Mcal ha^{-1}
PLPSA = specific activity on pre-land preparation, Mcal ha^{-1}
ELABORcoef = energy coefficient of labor, Mcal kg^{-1}
YSC = number of unproductive years of specific perennial component
PHEICE = (CESA x ELABORcoef)/YSC Eq. 10
Where:
PHEICE = pre-harvest energy input on crop establishment, Mcal ha^{-1}
CESA = specific activity on crop establishment, Mcal ha^{-1}
ELABORcoef = energy coefficient of labor, Mcal kg^{-1}
YSC = number of unproductive years of specific perennial component
PHEICCM = (CCMSA x ELABORcoef)/YSC Eq. 11
Where:
PHEICCM = pre-harvest energy input on crop care and management, Mcal ha^{-1}
CCMSA = specific activity on crop care and management, Mcal ha^{-1}
ELABORcoef = energy coefficient of labor, Mcal kg^{-1}
YSC = number of unproductive years of specific perennial component
3. Embedded Energy Used (EEU)
a.) Embedded energy used in farm machineries (EFM)
EFM = (WM x EMcoef) / (LSM x Hr) Eq. 12
Where:
EFM = specific embedded energy for machinery used for field operation, Mcal $^{ha-1}$
WM = weight of the machine, kg $unit^{-1}$
EMcoef = energy coefficient of a specific machinery, Mcal kg^{-1}
LSM = life span of the machine, years $unit^{-1}$
hr = number of hours the machine was used, hours $^{-1}$
b.) Embedded energy used in farm equipment and tools (EET)
EET = (WET x EETcoef) / (LSET x 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 $unit^{-1}$

EETcoef = energy coefficient of the farm equipment and tools, Mcal kg^{-1}
LSET = life span of the farm equipment and tools, years $unit^{-1}$
hr = number of hours the equipment and tools were used, hours $^{-1}$

Total Energy Input (TEI):

TEI = DE + IE + EE Eq.14

Where:
TEI = total energy input, LDOE ha^{-1}
DEU = direct energy
IEU = indirect energy
EEU = embedded energy

The energy inputs for the manpower that includes food, clothing and miscellaneous living costs of the farming household were not accounted for.

Energy Use Indicators

a) Total Energy Output (TEO)

TEO = (Y x Ecoef) Eq. 15

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

b) *Energy Return on Energy Input (EnROEI)*

EnROEI = TEY / TEI Eq. 16

Where:
EnREOI = energy return on energy input, kg $Mcal^{-1}$
TEY = total economic yields, kg ha-^{1}
TEI = total energy input, Mcal ha^{-1}

Total Energy Input (TEI):

TEI = DE + IE + EE Eq. 17

Where:
TEI = total energy input, LDOE ha^{-1}
DE = direct energy
IE = indirect energy
EE = embedded energy

Manpower inputs such as food, clothing and other living costs were not accounted for.

III. Results and Discussion

Energy Required in the Management of Coffee-based Agroforestry Farms

The amount of energy required in the management of agroforestry coffee in selected sites in Gleno Ermera District, Timor Leste was conducted through a survey/interview among 85 respondents. Based on the interview, various forms of energy were used such as human energy, fuel energy, energy from agricultural tools and machineries and energy in the form of seeds, fertilizers, pesticides among others.

The use of energy in the process of plant management and post-harvest handling of coffee needs to be done to minimize energy consumption in every process that takes place. Energy input in the management of coffee farmers can be in the form of direct energy, and embedded energy (indirect energy). Coffee handling requires energy in the form of human labor, while the direct energy used can be in the form of fuel energy, electrical energy, and water energy in each process. Meanwhile, indirect energy used is in the form of fertilizers, seeds and the use of tools, production equipment, machineries and production buildings.

All activities carried out in crop management and post-harvest handling of coffee require different energy input values. Thus, the amount of energy output produced from each activity differed and can be influenced by the number of workers, length of working hours and the number of days to complete each type of activity. From this process, the total energy requirement differs between direct energy use, and indirect energy from each activity carried out. The greatest value of indirect energy input in the post-harvest management and handling process is in the harvesting process.

Direct Energy Inputs of Different Coffee-Based Agroforestry Cropping Systems

For coffee-based agroforestry, a total direct energy of 26.44 Mcal ha^{-1} was recorded which was obtained from the use of farm trucks (19.22 Mcal ha-^{1}) and motorcycle (7.22 Mcal ha^{-1}). For monoculture coffee, it has a total direct energy input of 46.28Mcal ha^{-1} derived from the use of farm trucks (33.65Mcal ha^{-1}) and motorcycle (12.63Mcal ha^{-1}). For the pruned coffee cropping pattern, it has a total direct energy input of 46.29 Mcal ha^{-1} derived from the use of farm trucks (33.65Mcal ha^{-1}) and motorcycle (12.64Mcal ha^{-1}). Overall, the direct energy inputs of the different three cropping patterns used in the study is illustrated in Figure 1.

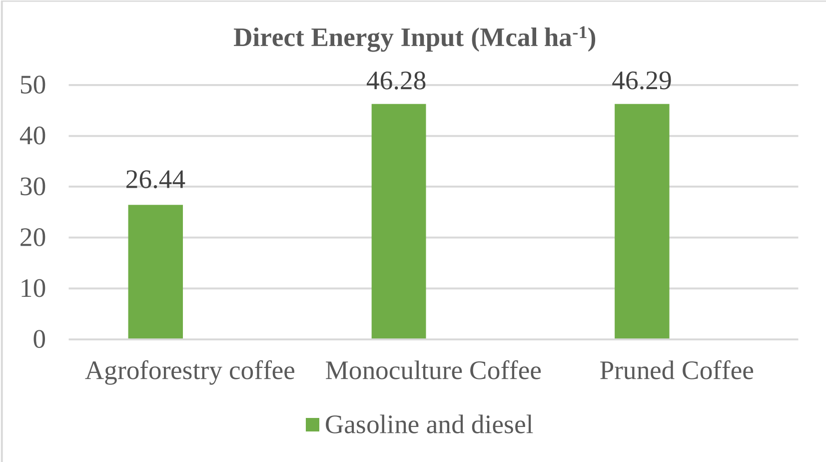

Figure 1. Total direct energy input (Mcal $_{ha}$$^{-1}$) in the management of coffee farm across three cropping patterns in Gleno Ermera District, Timor Leste

Indirect Energy Inputs of Different Coffee-based Agroforestry Cropping Systems

For the indirect energy recorded for the agroforestry coffee cropping system, the largest consumption of energy is in the use of pesticide which is 442.43 Mcal ha^{-1} (5049.90 LDOE ha-^{1}). The use of pesticides in large quantities makes the indirect energy to increase compared to the indirect energy needs from other processes. The lowest energy input is field visit monitoring with 4.61 Mcal ha-^{1} (52.62 LDOE). Among the various activities involved which requires human labor, picking, planting and weeding recorded high energy requirement while field visit monitoring the lowest. For animal labor, plowing required the highest energy input. Agroforestry coffee earned an energy ratio of <1.64 and an EnNROEI of 0.166 Mcal ha^{-1}.

For monoculture coffee, the largest indirect energy input was observed in the use of fertilizers, particularly N with 2043.1 Mcal ha^{-1} or 23318.80 LDOE Mcal ha^{-1}) and followed with the use of pesticide (Glyphosate) with 442.43 Mcal ha^{-1} or 507.12 LDOE Mcal ha^{-1}). For human labor, weeding, field visit monitoring and picking activities required high energy input while insecticide spraying required the lowest amount of energy input. For animal labor, planting required the highest energy input followed by field visit monitoring. The monoculture coffee cropping pattern earned an energy ratio of <1.24.

For pruned coffee cropping pattern, the largest indirect energy input was observed in the use of organic fertilizers (705.08 Mcal ha^{-1}) followed by inorganic fertilizer (N) with 664.50 Mcal $^{ha-1}$ or 7584.60 LDOE Mcal ha^{-1}) and followed with the use of pesticide (Glycophosate) with 481.17 Mcal ha^{-1} or 5492.07 LDOE Mcal ha^{-1}). For human labor, picking, weeding, and field visit monitoring activities required high energy input while herbicide spraying required the lowest amount of energy input. For animal labor, replanting required the highest energy input followed by planting. The pruned coffee cropping pattern earned an EnROEI of 0.55 Mcal ha^{-1} and an energy ratio of <1.09.

Data shows that in the management of agroforestry, indirect energy is the most expensive in terms of human and animal labor, fertilizers and pesticides. In terms of human labor, picking, weeding and planting are the first three most costly in descending order while field visit monitoring is the cheapest. For animal labor, the top three energy-intensive activities are plowing, planting and replanting. Animal labor is more expensive than human labor while pesticides, inorganic fertilizers and organic fertilizers followed. This shows that both direct and indirect energy is required in the management of agroforestry farms.

According to Chamsing et al. (2006), fertilizers consume the highest amount of energy. In Brazil, the energy use in fertilizer was about 66.96 MJ t^{c-1} (1.4 LDOE tc-1) or 35.27% of the total energy input in the agriculture industry (Copersucar, 1985 as cited by Egle and Mendoza, 2013). Egle and Mendoza (2013) and Savuth (2018) concluded that production systems on rice and cane sugar are highly fertilizer-intensive, particularly

N. According to Thu and Mendoza (2011), the indirect fossil energy use on fertilizer inputs accounted for the highest energy bill which account to about 86.22% and 58.48% in rice, 81.46% and 53% in cotton; and 68.23% and 41.86% in sugarcane production, respectively.

There are two types of pesticides used in the management of coffee farmers, insecticides and herbicides. Herbicides, particularly the use of Roundup, play an important role in weed management programs in the upland environment of Ermera district of Timor Leste. The popular use of Roundup is due to its accessibility as it is available at major farm stores locally, easy to use and inexpensive. Farmers often use Roundup to avoid high labor costs especially for soil brushing operations. Therefore, the energy bill of herbicides is very high compared to insecticides. Coffee plantation management is a herbicide-intensive system; this is due to the high use of Roundup which is applied to weeds under the coffee component. Among the three (3) coffee-based cropping systems with a high energy bill on herbicides is 442.43 Mcal ha^{-1} (5049.90 LDOE ha^{-1}). This is about 30% of an individual's energy bill for pesticides.

An illustration showing the total indirect energy inputs across the three cropping patterns used in the study is presented below (Figure 2):

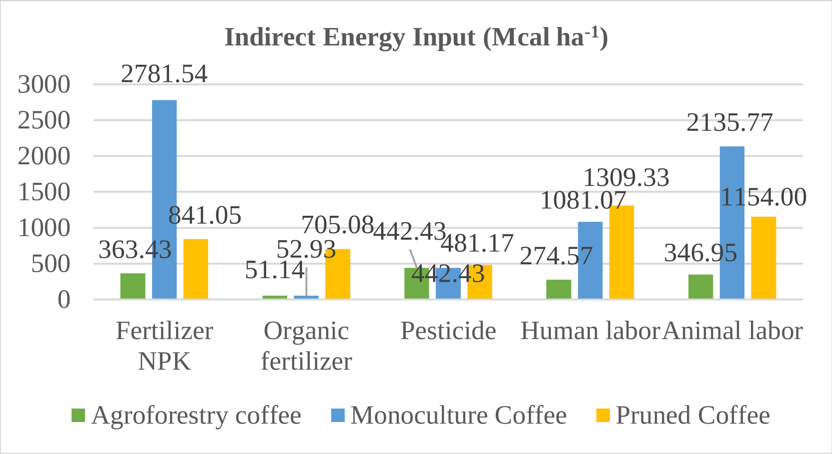

Figure 2. Total indirect energy inputs (Mcal $^{ha-1}$) in the management of across three cropping patterns in Gleno Ermera District, Timor Leste

Total Energy Inputs Across Three Agroforestry Cropping Patterns

Data reveal that agroforestry coffee had a total energy input of 1504.97 Mcal $^{ha-1}$ was recorded where only two (2) percent (26.44 Mcal $^{ha-1}$) for direct energy input and the remaining 98 percent went for indirect energy (1478.53 Mcal $^{ha-1}$). The pruned coffee followed with a total energy input of 4536.92 Mcal $^{ha-1}$and the monoculture coffee recorded the highest total energy input of 7004.38 Mcal $^{ha-1}$ (Table 1, Fig. 3).

Table 1. Summary of total energy inputs (Mcal $^{ha-1}$) in the management of coffee farm across three agroforestry systems in Gleno Ermera District, Timor Leste

	Energy Inputs						
Type of AFS	**DEI**		**IEI**		**EEI**		**TEI**
	Total Mcal $^{ha-1}$	%	Total Mcal $^{ha-1}$	**%**	Total Mcal $^{ha-1}$	**%**	Total Mcal $^{ha-1}$
Agroforestry coffee	26.44	2	1478.53	98	-	-	1504.97
Monoculture coffee	46.28	1	6958.10	99	-	-	7004.38
Pruned coffee	46.29	1	4490.63	99	-	-	4536.92

Legend: AFSs - agroforestry systems; DEI - direct energy input; IEI - indirect energy input; EEI - embedded energy input; and TEI - total energy input

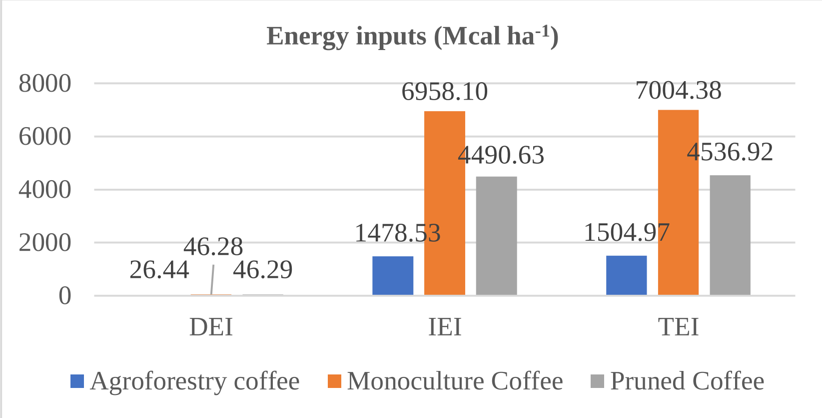

Figure 3. Summary of total energy inputs (Mcal $^{ha-1}$) in the management of coffee farms across three cropping patterns in Gleno Ermera District, Timor Leste

Total Energy Output

Total energy output (TEO) is calculated from the results of dry coffee production per hectare with a coefficient value. This strongly indicates that in one of the coffee cropping patterns, the main driver of increasing TEO is the economic yield per hectare. This strongly suggests that in any of the AFSs, the main drivers of increase in the TEO was the individual economic yield derived from each tree-crop component.

Energy Use Indicators

One way to evaluate the sustainable production system of upland agriculture is the use of energy flow analysis using the various approaches on energy use indicators (EUI). The EUI comprised of energy return on energy input (EnROEI), energy productivity (EP) and net energy balance (NEB).

EnROEI is a measure of the amount of energy required to produce a commodity in a given system – it is the ratio of output in terms of economic yield of tree crop components per AFS (kg ha^{-1} per system) over total energy input (TEI) in Mcal ha^{-1}.

The agroforestry coffee cropping pattern has an EnROEI of 0.166 kg Mcal^{-1}. This explains that a net of 0.166 and 250 kg per ha, respectively were produced for every unit of energy used (Mcal ha^{-1}). Coffee agroforestry had the lowest EnROEI across cropping patterns. EnROEI variability is directly related to higher TEI (Mcal ha^{-1}) per AFS relative to individual energy output at economic yield (kg ha^{-1}). This means that high TEI with lower economic output leads to lower EnROEI, thus making the system non-energy efficient.

On the other hand, energy productivity (EP) describes the ratio of total energy output (TEO), Mcal ha^{-1} to total energy input (TEI), Mcal ha^{-1}. As shown in Table 8, the coffee cropping system with a significant level of EP is the coffee-based agroforestry system. High EP is directly related to high energy output (Mcal ha^{-1}) and lower energy input (Mcal ha^{-1}). Technically, this simply means that for every energy input (Mcal) invested gives an equivalent energy return.

Table 2. Total energy output (Mcal ha^{-1}), energy return on energy input (kg Mcal^{-1}), energy productivity (Mcal ha^{-1}) and net energy (Mcal ha^{-1}) of the different types of coffee-based agroforestry in 3 sites in Gleno Ermera, Timor Leste

No.	Cropping Pattern	TEI	TEO	EnROEI	EP	NE
1.	Agroforestry coffee	1504.97	2475.00	0.17	1.67	997.45
2.	Monoculture coffee	7004.38	8685.50	0.35	1.24	1681.12
3.	Pruned coffee	4536.92	4950.00	0.55	1.09	413.08

TEO - total energy output.
EnROE - energy return on energy input.
EP and Ne - energy productivity and net energy, respectively.

Based on the different types of coffee-based cropping patterns, agroforestry coffee had the lowest EnROEI of 0.17 kg Mcal^{-1} followed by monoculture coffee with 0.35 kg Mcal^{-1} and pruned coffee with 0.55 kg Mcal^{-1} (Table 8). EnROEI variability is directly related to higher TEI (Mcal ha^{-1}) per type of agroforestry-based coffee relative to its individual energy output in economic yield (kg ha^{-1}). This means that high TEI with lower economic output will lead to lower EnROEI, thus making the system non-energy efficient.

On the other hand, the energy productivity (EP) explains the ratio of the total energy output (TEO), Mcal ha^{-1} over the total energy input (TEI), Mcal ha^{-1}. Table 8 also shows that the cropping system with significant levels of EP were agroforestry coffee 1.67 Mcal, monoculture coffee, 1.24 Mcal, and pruned coffee, 1.09 Mcal. The high EP was directly associated with high energy outputs (Mcal ha^{-1}) and lower energy inputs (Mcal ha^{-1}). Technically, this would simply mean that for every energy input (Mcal) invested it gave an equivalent energy yield of 1.67, 1.24 and 1.09 Mcal, respectively.

Finally, net energy (NE) is the product of total energy output (TEO) minus total energy input (TEI) in Mcal ha^{-1} per coffee cropping system. The coffee-based cropping pattern system had an NE of 3,021.69 Mcal ha^{-1} compared to AFS coffee-based -5506.88 Mcal ha^{-1}. This system yielded a negative net result. High NE is directly associated with lower TEI especially in direct and indirect energy use and negative NE means energy input exceeds energy output per agroforestry type coffee-based.

Production Levels

The computed production levels of each of the coffee-based agroforestry cropping pattern has been the basis for the estimates of annual income. Production levels were considered as one factor to describe the economic viability of the AFSs studied. Economic viability refers to the positive impacts of coffee-based agroforestry on upland communities and to the environment where people live. However, due to unequal tree components present within each system, there have been economic disparities, but this was disregarded for the purpose of quantitative comparisons. For this study, the various annual income levels of AFSs were used for further analysis.

Energy Return on Energy Input

Total energy inputs (TEI) or the energy bills of the different types of coffee-based agroforestry in the upland environments have been linked to potential carbon emissions. Procedures have been developed in order to quantify potential carbon emissions relative to total energy inputs (TEI) of each type of coffee-based agroforestry. This further revealed that systems found in the upland environment were energy-intensive.

Previous to this, all types of coffee-based agroforestry were considered beneficial-based on their individual total energy outputs (TEO). The relationships of total energy inputs (TEI) and TEO have been utilized to measures various energy use indicators such as the energy return on energy input (EnROEI), energy productivity (EP), and the net energy (NE). The different types of coffee-based agroforestry yielded different energy indicators due to the systems' disparity.

This study used the EnROEI as a factor for the integrative analyses. The EnROEI in particular has been defined as the ratio of total outputs on economic yields (kg ha^{-1}) over the total energy inputs (Mcal ha^{-1}) per AFS. This explains the return of outputs in the form of economic yields in kilograms per unit of Mcal energy that have been invested. The economic yields are farm produce such as agroforestry coffee, monoculture coffee, and pruning coffee.

IV. Conclusions and Recommendations

Results reveal that energy both direct and indirect forms are necessary in the management of agroforestry farms. Energy from animal labor is higher than energy required from human labor. Cost and use of pesticides recorded the highest while field visit monitoring the lowest. The use of inorganic fertilizers is more expensive than organic fertilizers. The coffee-based agroforestry farm had a total energy ratio of 1.67 Mcal ha^{-1} which indicates that the agroforestry practices are suitable for development because of a >1 energy ratio.

Based on these findings, the following are suggested: (1) Promote agroforestry coffee cropping pattern to serve as an alternative system of reducing and mitigating carbon dioxide from the atmosphere through carbon sequestration. (2) Encourage traditional smallholder coffee farmers to practice agroforestry in order to improve their income through the integration of other crops in their coffee farms and help in addressing the problem of soil degradation. (3) Incorporate other cash crops as well as perennial woody species in coffee plantation because it can contribute to C storage in vegetation and increase soil C through litter fall and root exudates. (4) Conduct training with emphasis on the benefits of agroforestry for coffee farmers in coordination with the village chief. Through this training, improved technologies will be shared to coffee farmers for better farming management practices. (5) Further studies on the dynamics of carbon stock and greenhouse gas emission in other crop-based systems should be pursued to validate results of this research.

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