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Input-output ratio of energy used on rice under convensional and organic farming

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All inputs into agro-ecosystems can be expressed in terms of energy which is a key input in production processes. Many environmental issues are associated to the production, transformation and use of energy. Improvements in energy efficiency will lead to more environment-friendly production systems. The objectives of the study are to develop an effective framework to carry out energy accounting operation in rice farming and to assess energy use of the existing rice production systems. This paper compares the energy use of 24 group paddy producers in two districts in East Java Province. The energy-ratio (output energy to input energy ratio), denoted by GJ, of farmers in crop production systems is indices that can define the efficiency and sustainability of farms.

Keywords: rice farming, energy efficiency, energy

INTRODUCTION

Impact of agrochemical inputs on environment and green house gas emissions of rice farming is a major environmental challenge of agriculture in Indonesia. Every year the country produces rice on more than 13 million hectares of harvested agricultural land mostly in Java Island (Indonesian Statistic, 2012). These vast farming areas, that are largely conventional systems, have been long history in contributing to the environmental deterioration (Suzuki et al., 1980; Bachelet and Neue, 1993; World Bank, 1994; Lumbanraja et al., 1998; Yuwono, 1998; Las et al., 2006).

All inputs to perform various operations for crop production can be expressed in terms of energy (Ozkan, 2004; Alam *et al.,* 2005; Nassiri and Singh, 2009). However, many environmental issues are associated to the production, transformation and use of energy (Dincer, 2002). Effects of increasing the consumption of fossil based energy on agriculture are of growing concern. In 1990's agriculture is responsible for about 5% of the total global energy consumption (Stout, 1990; Pinstrup-Andersen, 1999). Two decades later, energy for the world food sector shares for around 30 percent (FAO, 2012).

Many studies have shown that fossil energy input causes the release of carbon dioxide and nitrogen oxide from agricultural fields (Dyer and Desjardin, 2003; Robertson and Grace,

2004; Tzilivakis et al., 2005; Syvasalo *et al.*, 2006). For this reason, reducing the energy derived from fossil fuels has important implications for decreasing environmental pollution. This may lead to the application of best management practices through energy efficiency (Kaltsas et al., 2007; Franzese et al., 2009; Kavargiris et al., 2009).

Odum (2007) defined efficiency of energy transformation as the energy output (energy stored) divided by the energy input. In earlier reference, Spedding (1981) defined efficiency in biological term, so- called 'biological efficiency', as output over input where the outputs and inputs are measured in physical or biological units. Furthermore, in a wider view, biological efficiency is defined as the efficiency of a biological process or processes. Hence, we can assess the efficiencies of combined processes including a complicated combination such as agricultural ecosys-tem.

Input and output of energy are two important factors for determining the energetic and ecological efficiency of crop production (Rathke and Diepenbrock, 2006). Energy intensity and energy output/input ratio are integrative indicators of the environmental effects of crop production (Hulsbergen et al., 2001). For this reason improvements in energy efficiency will lead to more environment-friendly production systems (Gundogmus and Bayramoglu, 2006).Accordingly, efficient energy use is one of the most important conditions for a sustainable agriculture.

Within an agricultural region, many physical, chemical and biological properties directly related to the production system exhibit spatial variability, even at small distances. Such variation implies that different levels of input factors will result in varying output (Rilwani and Ikhuoria, 2006; Bojaca et al., 2012). The variability of a farming system can be exploited to characterize farmers in terms of their energy efficiency (Tabar et al., 2010). Such characterization can indicate pathways to optimize the energy efficiency of the system as a whole.

Considerable studies have been conducted in different countries on energy use in agriculture. Through comparative studies, energy analysis has also been used to assess the efficiency of different production systems such as conventional, organic, and integrated farming (Daalgard et al., 2001; Deike et al., 2008; Michos, 2011; Bojaca et al., 2012).

On a global scale, the input of energy for the crops production differs to a large extent. In some traditional low-input farming systems, e.g. in large areas of Africa, the energy input on arable land is lower than 1 GJ ha^{-1} (Norman, 1978), whereas in some modern high- input farming systems in Western Europe and USA can exceed 20 GJ ha^{-1} (Pimentel et al., 1983; Schroll, 1994; Hulsbergen et al., 2001). Therefore, there is a range of energy input and output relationships for the same crop based on the region and technological level.

Various methods may be applied to calculate the energy use for crop production depending on the goal of the study. The methods presented in the literature vary in the spatial and temporal system boundaries chosen, in the fluxes of materials and energy considered, and in the energy equivalents assigned to these fluxes (Jones, 1989). A widely applied method is the energy input/output analysis. In this method, all agricultural inputs in production process are multiplied by conversion factors to approximate input and output energy (Hulsbergen et al., 2001; Dallgaard et al., 2001; Muhammadi et al., 2008; Tabar et al., 2010). Once the inputs and outputs are transformed into energy units, indicators such as energy use efficiency, energy productivity, specific energy and net energy can be derived.

Green (1978) argued that high agricultural productivity is energy demanding and energy efficient is associated with low productivity. This thesis is particularly true in the energy intensive modern agriculture system. However, it is not necessarily always the case in other systems. Craumer (1979) found that less energy intensive of Old Order Amish farmer's methods in North America, including use of draft animals, lower energy inputs per unit of production more than the modern farms can accomplish without a lower overall productivityIn Java Island there are several alternative ways of rice farming with reduced inorganic agrochemicals that gave even higher yields compared to national's average yield of conventional farming (Setyono, 2010; Anonymous, 2011).

However, In Indonesia, the use of inorganic fertilizer is estimated continues to increase. By comparison, the total fertilizers for rice cropping in 2003 were 4.42 million tonnes and in 2006 reached 4.50 million tonnes (Las et al., 2006), whereas total requirement of N, P2O5, and K2O in 2015 is projected 6.9 million tonnes (Irawan et al, 2013).

In summary, improving the envi-ronmental performance of agricultural production can be traced through energy analysis. This paper attempts to analyse the energy use efficiency of rice farming being practiced by farmers at the field level which is ultimately aimed to promote sustainable agriculture.

Conceptual framework

All living systems (organisms, populations, communities, and ecosys-tems) can be considered as open thermodynamic systems that are not in thermodynamic equilibrium and that continuously utilize and convert energy.

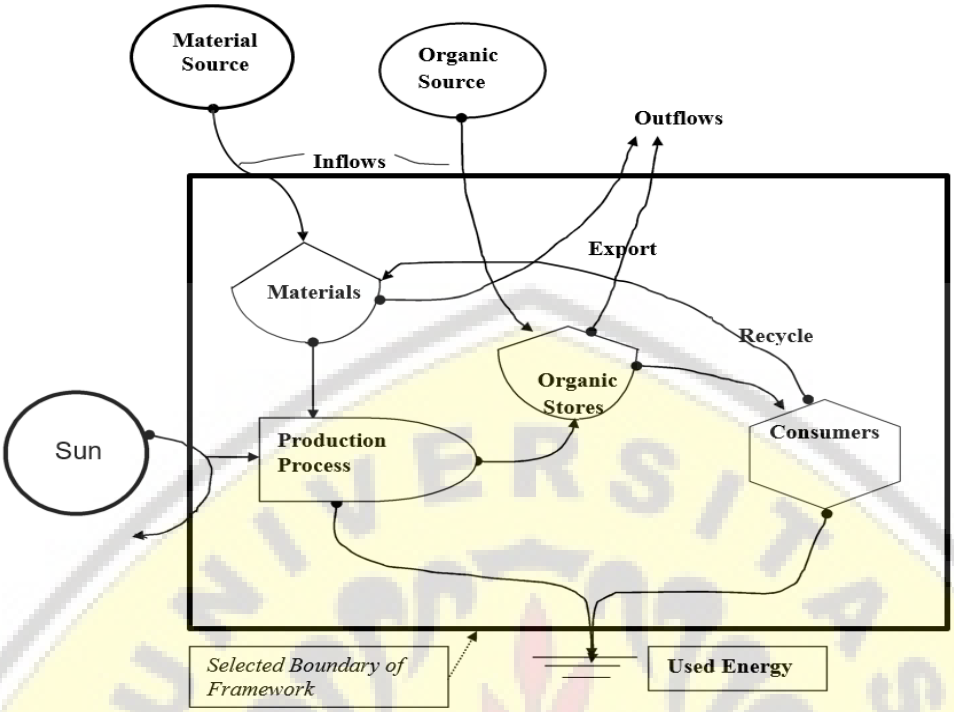


Figure 1. A system of production, consumption, and recycle that has inflows and outflows (Adapted from: Odum, 2007).

Energy transfers and conversions in these systems strictly obey the first and second laws of thermody-namics (Odum, 1971; Zhou et al., 1996).

Energy that enters a system either is stored there or flows out (Figure 1). Energy is constantly converted from one form to another by natural or human-controlled processes ruled by the laws of thermo-dynamics. The first law of thermodynamics (conservation of energy) states that energy can be neither created nor destroyed, although it can change form. The second law (law of entropy) states that it is impossible to convert a given quantity of heat completely into work. Energy is always degraded in the conversion process and lessening its ability to do work (Odum, 2007). The two laws may be resumed: although energy can be neither created nor destroyed, in any real process the availability of potential energy is lost. In recent years, available potential energy (the amount of energy which can be extracted as useful work) has been called *exergy*. Hence, the laws of thermodynamic are the basis of all energy analysis of any production systems, including agricultural systems.

The first law, also called energy balance principle, suggested that the energy of input (including any unpriced material from the environment) must exactly equal the energy of output (including the energy in the waste) for any transformation process. The flow of natural resources (materials/ mass/energy) taken from the environment goes to transfor-mational processes (such as production, consumption, and recycling) is eventually returned to theenvironment as wastes and pollution (Ayres, 1998; Akao and Managi, 2007; Ebert and Welsch, 2007). The first law is more concerned with the magnitude (quantity) of energy (Dincer et al., 2005). In this view, production is basically the transformation of materials into desired outputs. Due to the thermodynamic laws, this transformation can never be completed. Some residual unavoidably arises as a by-product or undesirable output. This residual is linked by the materials balance.

In regard to the second law, Odum (2007) explained that the potential energy, or available energy to carry out a process, is used up. It is degraded from a form of energy capable of driving phenomena into a form that is not capable to do so. Dincer (2005) added that the second law is concerned with the quality of energy, i.e. the quality of energy to cause change, degradation of energy during a process, entropy generation and the lost opportunities to do work.

In order to integrate environmental concern in any production systems, several attempts have been made to adjust the standard technical and economic efficiency measures. Many authors describe the environmental effects are caused by either a *bad output* or an environmentally *detrimental input* in production functions. For instances, nitrogen use in Dutch dairy farms (Reinhard and Thijssen, 2000), best management practices of agriculture in Canada (Ghazalian *et al.*, 2010), efficiency of American petroleum refineries (Mekaroonreung and Johnson, 2010). Based on the analysis, they found that input efficiency is a viable choice to reduce environmental impacts without affecting the productivity.

Based on Figure 1, a conceptual framework on energy input and output in paddy rice farming system was developed (Figure 2).The operational assessment of energy inputs and output follow the model of energy flows in rice production systems (Figure 3). Energy is utilized in food production process both off and on the farm. Off the farm energy is used in the manufacture of agricultural equipments, construction of agricultural structures, fertilizers and pesticides. On the farm, energy is consumed during the process of crop production. It divides energy usage of rice production into eight broadly distinct processes, including seedbed preparation, tillage (land preparation), transplanting, fertilization, irrigation, weed and pests control, harvesting and post harvest handling. This enables both the total energy inputs and the energy usage in each production process to be assessed.

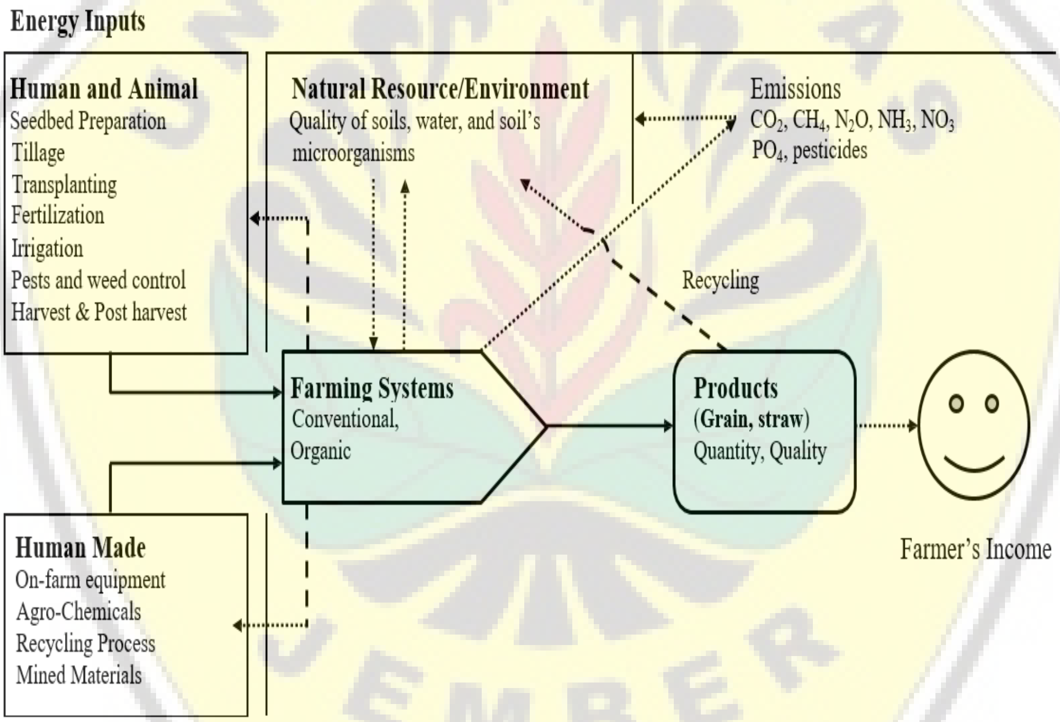


Figure 2. Conceptual framework of research on energy assessment in a paddy rice farming system

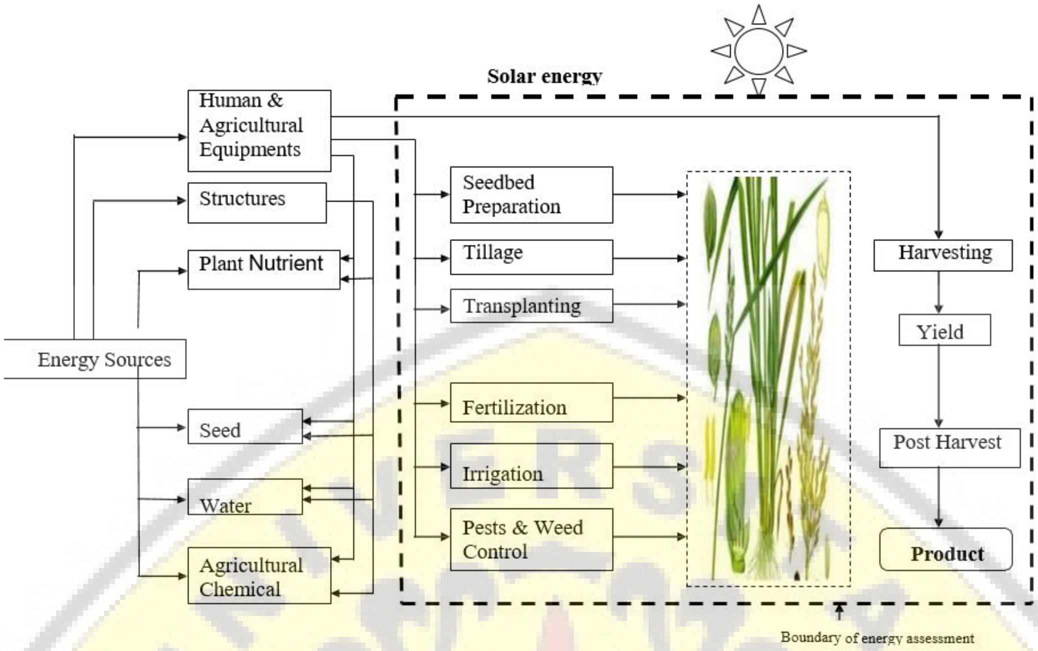


Figure 3. Model of energy flows in the production of paddy rice crop

MATERIALS AND METHODS

Method of Data Collection

The study area is in two regencies of East Java Provinces, i.e. Banyuwangi and Jember. The selected locations are consisted of three different zones, lowland, moderate and upland. The two regencies are the main rice-bowl in East Java. There is rice farming systems that are managed conventionally and (semi) organically.

Sampling procedure

Method of sampling was stratified random sampling. The first stage is intentionally selecting the regencies based on the capacity to produce rice and the differences in agro-ecosystem, such as soil type, average of rainfall, and micro climate. The second stage is selecting farmers' groups (a loose organization of farmers who have land in a neighbourhood area) based on the list available at the local agricultural offices. A planned question-naire for groups was applied as instrument to investigate the total energy used in their cropping activities.

Energy use efficiency

The data used in the study were collected from 24 groups of conventional and organic rice farmers at the same number in the district of Jember and Banyuwangi, East Java, Indonesia. The study areas were representing three different regimes, lowland, moderate, and upland zones. The energy input/output analysis was carried out following the standard approach where the production inputs and yield were averaged in hectare for over the entire dataset. Afterwards, average inputs and output were transformed into energy units according to the energy equivalents presented in Table 1. The energy content of the crop residues retained on the field was not considered.

Energy output and input is calculated and stated in giga-joule (GJ) per hectare (Hulsbergen et al., 2001; Dalgaard et al., 2001; Ozkan et al., 2004; Deike et al., 2008), for the entire sampled areas in one rice cropping season. Energy use assessment for the farming system was estimated through the energy use efficiency (EUE) according to the following formulas:

$$EUE = \frac{\text{Energy output (GJ/ ha)}}{\text{Energy input (GJ/ha)}}$$

The inputs used in the calculation of agricultural energy use include human and machinery, diesel fuel, fertilizers, pesticides, straw, manure, and seeds. In order to make an energy analysis, it is necessary to consider the use of human and machinery in agricultural processes. The age of Indonesian farmers is mostly about 40 years old (Ilham *et al.,* 2007). The working hour of agricultural workers are taken an average of 6 hours of work a day for men and 5 hours a day for women.

Table 1. Energy equivalent of inputs and outputs

Input Description	Energy equivalent	Reference
urea	59.83 MJ/kg	Lockeretz, 1980
nitrogen	61.50 MJ/kg	Lockeretz, 1980; Heichel, 1980; Rutger and Grant, 1980
phosphorus (P2O5)	12.55 MJ/kg	Pimentel and Burgess, 1980; Rutger and Grant, 1980
potassium (K2O)	6.69 MJ/kg	Pimentel and Burgess, 1980; Rutger and Grant, 1980; Lockeretz, 1980; Heichel, 1980
seed	14.64 MJ/kg	Stout, 1979; M.S. Alam *et al*, 2005; N.S. *et al*., 2006
diesel fuel	39.58 MJ/L	Huslbergen *et al*. 2001; Deike *et al*. 2008
pesticide	120 MJ/L	Nassiri and Singh, 2009; Chauhan *et al*. 2006
bio-pesticide	0.84 MJ/L	Based on calculation
tractor	24.90 MJ/ha	Calculation based on Doering, 1980
sprayer	0.04 MJ/ha	Calculation based on Doering, 1980
C-organic	41.84 MJ/kg	Salonen *et al*.1976
male labour	1.03 MJ/hr	Calculation based on FAO, 2001
female labour	0.84 MJ/hr	Calculation based on FAO, 2001

The calculation of human or manpower energy was based on a Joint FAO/WHO/UNU Expert Consultation (2001) formula. No animal's energy was used within the groups.

There is no precise way to account for the indirectly energy used in agricultural production. This would be the energy that goes into the production of machinery, equipment, building and other non-land resources that contribute to food and fiber production over the long term and are normally treated as capital assets. One of the most important of these is farm machinery. The calculation of energy used for tractor and plow based on formula given by Doering (1980 in Pimentel, 1980).

There are no energy data available for the application of bio-pesticides. Farmers used locally-made bio-pesticide. The calculation of bio-pesticide is based on the formula:

$$\mathrm{E\,bio-pesticide} = \mathrm{T \times CI}$$

Where, E is energy (Kcal); T is time required to make 1 litre bio-pesticide (hour); CI is average calorie intake of person (Kcal/hour). Here, CI is taken 2000 Kcal per-day (Indonesian Body of Statistic, 2012).

In order to be able to make the analysis, it is essential to consider energy sources, i.e. the amount of energy stored in the seed. Energy equivalent for seeds were taken to be equal to the energy equivalent of the product itself. Energy output was calculated by multiplying the production amount by its corresponding equivalent.

RESULTS

Energy analyses are made in agriculture in order to understand the role of direct and indirect energy inputs as production factors, to find measures for energy savings, and to improve energy efficiency. The performance evaluating indicators/parameters are presented in Table 2. In general view, it is evidenced that conventional farming system shows a higher output/input ratio. This means the conventional farmers can produce higher output per unit input.

In most publications, both smaller energy inputs and a higher energy use efficiency (=higher output per unit input or less input per unit output) were reported for organic farming. The majority of these comparisons between organic and conventional farming were carried out at the farm level (Dalgaard et al., 2001; Gundogmus and Bayramoglu, 2006).

In this research, it was found that most farmers groups in upland area and organic farmers used straw and manure for their energy sources. A high quantity of straw and manure use , i.e. 5 and 2 tonnes ha-1 respectively, contributed to high quantity of energy input. The use of straw and manure is of utmost importance in organic farming systems and in upland area where the inorganic fertilizers supply is generally limited. The higher application rates of straw and manure led to higher energy input, thus, lower in the output/input ratio (Graph 1 and 2).

It is assumed that the risk of harmful environmental effects is lower with organic than with conventional farming methods, though not necessarily so (Hansen *et al*., 2001). When comparing and assessing different farming systems in regard to terms of their performance not only energy use efficiency. The intensity of agrochemical use should be considered since possible contaminations of soil, water, and air, as well as the endangerment residues remaining on food (Deike *et al.,* 2008). Thus, long-term comparison of cropping systems comprising different management of energy sources as inputs such as presented in this study is indispensable.

Table 2. Input Output and Ratio Energy per Hectare

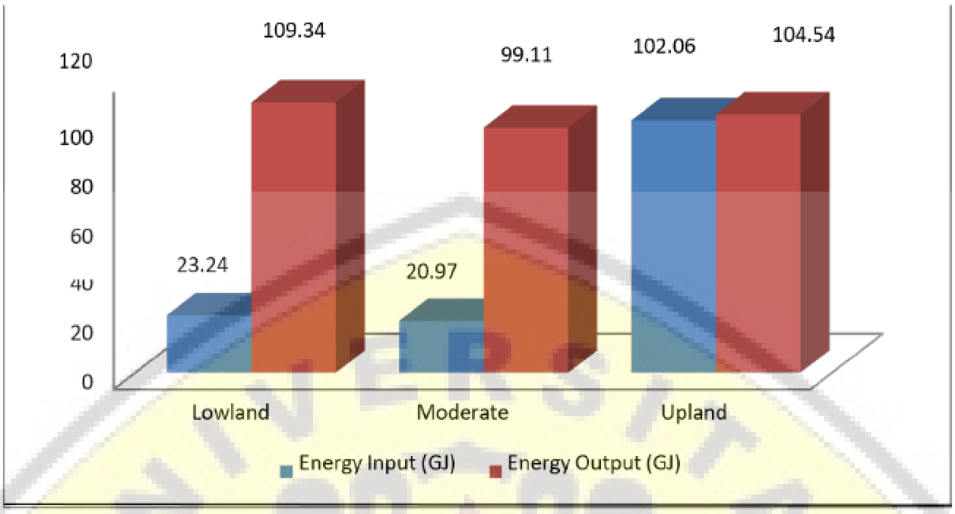
Farmer Group	Input (GJ)	Output (GJ)	Ratio O/I
jlcg-1	25.83	114.64	4.44
jlcg-2	26.45	116.05	4.39
jmcg-1	24.19	103.83	4.29
jmcg-2	24.72	104.17	4.21
jucg-1	142.75	151.21	1.06
jucg-2	91.13	95.40	1.05
jlog-1	60.44	131.35	2.17
jlog-2	54.15	107.31	1.98
jmog-1	53.45	98.11	1.83
jmog-2	52.37	98.32	1.88
juog-1	160.03	86.29	0.54
juog-2	155.62	86.32	0.55
blcg-1	19.11	98.44	5.15
blcg-2	21.44	108.23	5.05
bmcg-1	15.88	94.38	5.94
bmcg-2	19.09	94.04	4.93
bucg-1	85.92	85.42	0.99
bucg-2	88.44	86.12	0.97
blog-1	52.52	100.96	1.92
blog-2	48.83	102.52	2.10
bmog-1	55.05	88.38	1.60
bmog-2	42.18	88.03	2.09
buog-1	148.17	83.36	0.57
buog-2	148.55	85.49	0.57

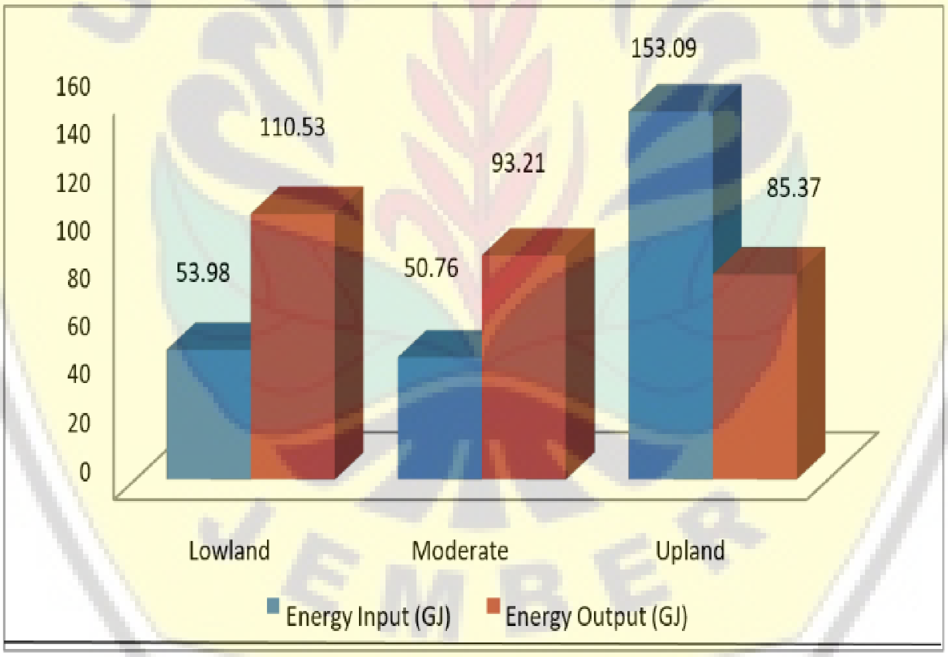
Note:

j : Jember l : lowland zone c : conventional

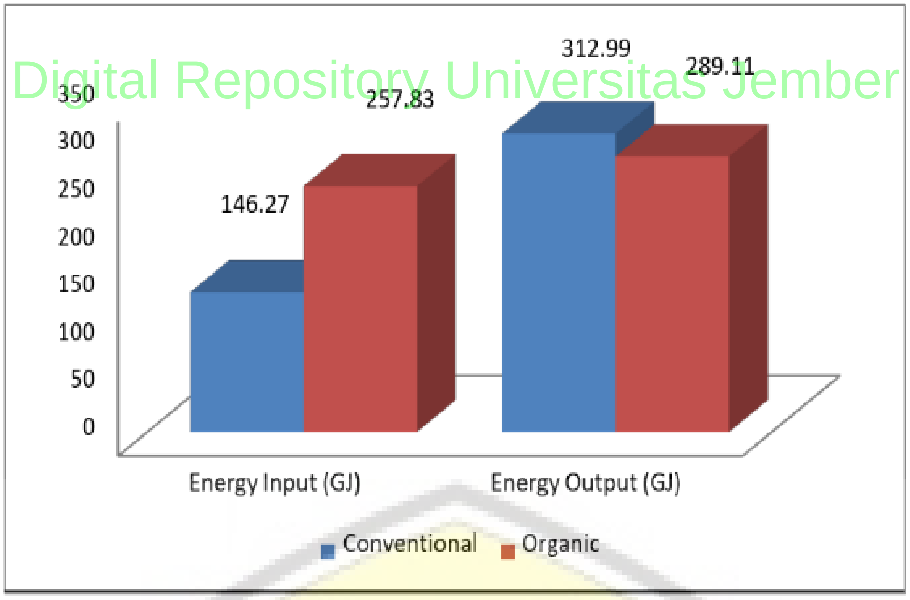
b : Banyuwangi r : moderate zone o : organic

Graph 1. Input-output energy use in conventional rice cropping based on zone(per-ha)





Graph 2. Input-output energy use in organic rice cropping based on zone (per-ha)



Graph 3. Input-output and ratio of energy use in conventional and organic rice cropping (per-ha)

CONCLUSION

Energy consumption per unit land area and the amount of energy needed for the production of one unit of product or one unit of energy output are fundamental indicators to assess the environmental effects of crop production.

The finding showed that the energy use in conventional farming systems more efficient with regard to energy require-ments, whereas the output input ratio is higher compare to organic one. Based on zone, farmers in lowland and moderate areas are more efficient compare to farmers in upland areas. However, there is no significantly different in output between the whole systems.

CONFLICT OF INTEREST

This study was conducted without any conflict of interest.

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AUTHOR CONTRIBUTIONS

Bambang Kusmanadhi Environmental Scince Program as whole. Moh. Setyo Poerwoko designed his plant breeding program as a whole.

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