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Comparative energy input–output and financial analyses of greenhouse and open field vegetables production in West Java, Indonesia

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ABSTRACT

This paper estimates energy consumption per unit floor area of greenhouse and open field for tomato, chili and lettuce production. Primary data were collected from 530 vegetable farmers during Jan–Dec, 2010 in West Java, Indonesia. Energy estimates were calculated from actual amount of inputs and outputs and corresponding conversion factors. Results reveal that the total input energy used in greenhouse (GH) production of tomato, chili (medium and high land) and lettuce were 47.62, 41.55, 58.84, and 24.54 GJ/ha respectively. Whereas, the requirement of total input energy for open field (OF) production of tomato, chili (medium and high land) and lettuce were 49.01, 41.04, 57.94 and 23.87 GJ/ha, respectively. The ratio of output to input energy was higher in greenhouse production (0.85, 0.45 and 0.49) than open field vegetable production (0.52, 0.175 and 0.186) for tomato, chili medium land and chili highland, respectively, but output–input ratio of lettuce open field production was twice as that of greenhouse vegetable production. Financial analysis revealed higher mean net returns from greenhouse vegetable production as 7043 $/ha (922–15,299 $/ha) when compared to 571 $/ha (44–1172 $/ha) from open field vegetable production. Among the greenhouse vegetables, tomato cultivation was the most profitable in terms of energy efficiency and financial productivity.

1. Introduction

Indonesia is regarded as an agricultural-based country with 48.1 million ha of agricultural land that constitutes 26.6% of the total geographic area (60% of the country's cultivated land is in Java). Land area under forest is about 95.8 million ha, followed by 37.1 million ha arable land and 15.1 million ha with permanent crops [1]. The agricultural sector has been one of the important economic pillars of the country which contributed 15.48% of national GDP in 2011. The National Labor Survey 2010 confirmed that 38.34% of total 15 years and older population worked in the agricultural sector [2].

Rapidly growing population (1.49% growth rate in 2010) demands proportionately increasing food production. Moreover, Indonesian consumption pattern is also shifting with increasing economic growth. The consumption of rice and other staple crops is declining and the consumption of fruit, vegetable and processed food is increasing. These factors are driving more farmers towards vegetables and horticultural products as attractive agricultural diversification options. Total harvested area under vegetables production in Indonesia reached to 1.09 million ha with total production of 9.56 million tonnes in 2010. Even though the total area and production of vegetables increased but yield decreased by 4.6% in 2010 [1]. Based on the climate and altitude suitability in Indonesia, lowlands (<200 m) are prevailed by cassava, rice, estate crops and fruit, and highlands (>800 m) are dominated by vegetables and other cool climate crops. About 30% of total vegetable production comes from the highlands. In medium land (201–800 m) mostly vegetables are cultivated. In total, 1.3 million ha area was used for vegetables and potato production [3].

West Java Province is the most densely populated province of Indonesia with the highest population in the country having more than 43 million (18.12% of total population of Indonesia) on 1.72% of national land (3.7 million ha). As one of Indonesia's most important agricultural provinces, which have favorable climate and fertile land, this province is Indonesia's largest producer of rice and horticultural products. With the mounting stress of increasing population and prevailing change in the land usage, intensive use of land with modern agricultural technology like protected cultivation, is needed. This controlled environment and resource-intensive agriculture offers high quantity of quality production especially for vegetables, and thereby may fetch attractive returns to growers.

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Resource use efficiency and economic benefits are synonymous to farmers. The Indonesian government, through its agricultural policy, is also making efforts to increase farmers' income through the optimal utilization of resources in the agriculture sector. However, FAO (2005) [4] reported that despite regulations of production, use, and distribution of fertilizer have been modified periodically, yet they fail to impart desired impact. Crop protection is a major factor affecting production and profitability in chili in West Java [5]. Therefore, government of Indonesia also strives to achieve food self-sufficiency through expansion of arable acreage, improved farming techniques (especially the use of fertilizers and improved seeds), extension of irrigation facilities, and training for farmers [6]. In line with the government's objectives reflected in its policy, it is therefore necessary to investigate the resource use efficiency of vegetable production in term of energy values.

Energy, economy and environment are the three interrelated factors which can't be ignored when evaluating any agricultural production system, especially in the current context. Furthermore, due to rapid increase in food demand, limited agricultural land availability, and expensive and erratic labor availability for agricultural tasks, the energy use in agricultural production has increased by several fold since green revolution. This is further intensified by heavy use of agricultural inputs such as pesticide, chemical fertilizer, and agricultural machinery. Stout (1990) [7] mentioned that crop yields and food supplies are highly correspondent to energy. Optimal utilization of resources in agricultural sector also leads to increasing the income of the farmer and contributes to the sustainability of agriculture, especially in rural areas [8].

There are several ways to compute the efficiency of agricultural practices. A number of researchers have calculated the efficiency of agricultural processes by converting the agricultural products into energy as output, and the commercial energy input in the form of energy efforts from human, animal, machinery fuel, fertilizer, pesticide, irrigation fuel in the form of petroleum and electricity, and energy from seed. Researchers have successfully applied this method for major crops like rice and wheat [9], boro rice [10], wheat [11], sugarcane [12] and potato [13]. A case study on energy use in vegetable production in Turkey was performed by Canakci et al. (2005) [14] which revealed that the range of total energy input in tomato, pepper, cucumber and eggplant production was between 45.8 and 49.9 GJ/1000 m^2 having an energy ratio (output to input) of 0.32, 0.19, 0.31, and 0.23 respectively.

Literature reflects that the most profitable crop in greenhouse production was tomato with high benefit-to-cost (B/C) ratios which varied from 1.57 [14] to 3.28 [15]. For tomato cultivation in greenhouses, the highest energy consumption corresponded to diesel oil [15,16]. Non-renewable forms of energy consumption were more than 80% of the total energy use in greenhouse tomato production [16,17]. Recently, Ozkan et al. (2011) [17,18] reported that chemical fertilizer was the highest energy consumer in greenhouse production of a single crop. The human (labor) energy has significant effect on crop yield [15,19]. Another case study for grape production in greenhouse and open field showed that the total input energy was 24.5 and 23.6 GJ/ha, respectively, but the output energy of greenhouse grapes was lower than open field grapes as well as the output–input ratio [20]. Due to the higher investment requirement, the production cost of greenhouse grape was higher than that of open field production. Even though the B/C ratio of greenhouse grape production was lower than open field, it was more profitable because it could produce 3–4 months early harvest and thereby offered higher selling price. Furthermore, only limited number of studies are reported focusing on energy and financial analyses of greenhouse and open field vegetable production in Indonesia.

This study compared three vegetable crops – tomato, red chili and lettuce – for their energy use (direct, indirect, renewable, and non-renewable energy), and their economic performance when produced in greenhouse and open field conditions.

2. Material and methods

Primary data required for this study were collected through a survey of farmers who grew tomato, chili and lettuce in greenhouse (GH) and open field (OF) in West Bandung and Sukabumi regencies, West Java Province, during year 2010. Both regencies are of significant agricultural importance, which produce sizable quantities of vegetables and horticultural products (chili, tomato and lettuce) and cater to local, national as well as export market. Majority of people in the two regencies are engaged in agricultural activities as the geographic and climatic conditions favor cultivation of vegetable and horticultural crops. A total of 530 farmers who grew tomato, chili and lettuce in open field and 27 greenhouse vegetable growers were interviewed using structured questionnaire and one-on-one informal discussion.

The inputs and outputs in agricultural production system were converted into energy units to perform the input–output analysis. Appropriate energy equivalents of inputs and outputs for both greenhouse and open field vegetable production were obtained from previous studies (Table 1).

As generally practiced in the study area, tomato, chili and lettuce were hand transplanted. Rotary tiller was used in land preparation for stirring and pulverizing soil. The energy consumption was calculated by combining inputs as human effort, machine usage, fertilizer, chemical, manure, diesel, and electricity consumption in the vegetable production. Necessary data pertaining to input/output of the respective production system were collected from primary sources and converted into corresponding energy values. Cultivation of chili and tomato started in March–April both in greenhouse and in open field, and lettuce was planted during January–February. Popularly grown varieties (Warani for tomato, TW for chili and Grand Rapids for lettuce) in the respective areas were considered.

Table 1
Energy equivalents of major inputs and outputs in vegetable production (values as taken from literature).

Energy source	Energy equivalent (MJ)	Reference
Human (head)		
Man	1.96	[11,21–23]
Woman	1.57	[11,21–23]
Chemical fertilizer (kg)		
Nitrogen	60.6	[11,21–23]
Phosphorus	11.1	[11,21–23]
Potassium	6.7	[11,21–23]
Chemical		
Pesticide (kg)	199	[25,26]
Pesticide (l)	196	[27]
Fungicide (l)	168	[20,28]
Fungicide (kg)	92	[26,28]
Herbicide (l)	238	[26,28]
Zinc sulfate (kg)	20.9	[29]
Manure (kg)	0.3	[24,30]
Diesel (l)	56.31	[11,15,23,24]
Machines (h)		
Power tiller	2.74	[9,22]
Rotavator	2.35	[9,22]
Knapsack sprayer	1.4	[31,32]
Electricity (kWh)	11.93	[11]
Water irrigation (m^3)	0.63	[15,20,25]
Output (kg)		
Chili	0.8	[23,24,29]
Tomato	0.8	[15,23,24]
Lettuce	0.46	[16,28]

The output–input ratio, energy productivity and specific energy were calculated by following equations, as suggested by Refs. [8,16,22,33–35]:

$$\text{Output} - \text{input ratio} = \frac{\text{Energy output}\left(\text{MJ ha}^{-1}\right)}{\text{Energy input}\left(\text{MJ ha}^{-1}\right)} \quad (1)$$

$$\text{Energy productivity}(\text{kg/MJ}) = \frac{\text{Vegetable output}\left(\text{kg ha}^{-1}\right)}{\text{Energy input}\left(\text{MJ ha}^{-1}\right)} \quad (2)$$

$$\text{Specific energy}(\text{MJ/kg}) = \frac{\text{Energy input}\left(\text{MJ ha}^{-1}\right)}{\text{vegetable output}\left(\text{kg ha}^{-1}\right)} \quad (3)$$

Direct and *Indirect* are the two energy classification on the basis of source – popularly considered in agricultural production [36]. The direct energy sources are those that bring out the intended energy directly, like efforts from human and animal, diesel, and electricity; whereas the indirect sources of energy consist of pesticide, fertilizer, manure and machinery which do not release directly but by conversion process [20,36]. Furthermore, energy also can be classified into *renewable* and *non-renewable* sources. Renewable energy sources consist of the human, animal and manure, whereas non-renewable energy sources include diesel, electricity, chemicals, fertilizer and machinery [16,20,36,37].

The production function summarizes the process of conversion of input factors into a specific desired commodity; and it determines the efficient allocation of resources. It is important to observe that the production function describes technology, not economic behavior. For this purpose Cobb-Douglass (CD) production function was chosen as it has been reported as an appropriate function in term of statistical significance and expected sign of parameters [15,17,18,38]. The CD production function is expressed as:

$$Y = f(x) = \exp(u) \quad (4)$$

This function has been used by several researchers to examine the relationship between energy inputs and yield [15,16,37–39].

The linear form of eq. (4) can be written as:

$$\ln Y_i = \alpha_0 + \sum_{j=1}^{n} \alpha_j \ln\left(X_{ij}\right) + e_i \quad i = 1,2 \quad (5)$$

where, Y_i represents the yield of *i*th grower, X_{ij} is vector of inputs used in the production process, α_0 is a constant term, α_j denotes coefficient of inputs that are estimated from the model and e_i is the error term. As a function of energy input, yield can be expressed as:

$$\begin{aligned} \ln \mathrm{Y_i} = {} & \alpha_0 + \alpha_1 \ln \mathrm{X_1} + \alpha_2 \ln \mathrm{X_2} + \alpha_3 \ln \mathrm{X_3} + \alpha_4 \ln \mathrm{X_4} \\ & + \alpha_5 \ln \mathrm{X_5} + \alpha_6 \ln \mathrm{X_6} + \alpha_7 \ln \mathrm{X_7} \end{aligned} \quad (6)$$

where, Y_i represents the *i*th grower's yield and X_j (j = 1, 2, ….7) designates input energies including human labor (X_1), machinery (X_2), manure (X_3), fertilizer (X_4), chemical (X_5), diesel fuel (X_6), electricity (X_6) and irrigation water (X_7). Seed energy was neglected considering that it has a negligible contribution to the total energy input [15]. The constant term α_0 in Eq. (5) is taken zero as there was no meaningful production without any energy input.

In term of effect of direct and indirect, and renewable and non-renewable energy sources, the vegetable production is expressed as:

$$\ln Y_i = \beta_1 \ln \mathrm{DE} + \beta_2 \ln \mathrm{IDE} \quad (7)$$

$$\ln Y_i = \gamma_1 \ln \mathrm{RE} + \gamma_2 \ln \mathrm{NRE} \quad (8)$$

where, Y_i represents the *i*th grower's yield in each classification category, β_i and γ_i are the coefficients of exogenous variables, DE and IDE are direct and indirect energy, RE and NRE are renewable and non-renewable energy.

Application of farm manure is mostly recommended to increase organic matter content of soil. Manpower was needed for activities including land preparation, transplanting, weeding, pruning, watering, fertilizing and spraying. Fertilizer was applied 6–8 times depending on the crop condition. Chemical application varied from farm to farm depending upon pests/disease infestation. One of the major benefits of greenhouse production is to minimize the potential losses from pests/disease. This is also reflected in the study area, where the application of chemicals in greenhouses was lower than that in open field vegetable production. In the study area, chemical was not applied for greenhouse lettuce production (no pesticide vegetables). Drip irrigation system was used in greenhouse lettuce production, whereas conventional/manual irrigation methods were used in the rest of the vegetables.

Frequent harvesting should be done at the right stage of maturity. Human energy was used to harvest the vegetables. Normally, women handled most of the harvesting, meanwhile men transported the produce from field to storage locations. Grading was also a necessary activity in tomato production to screen defective and discolored pieces.

Financial analyses of collected data (Eqs. (9)–(13)) provided gross return, net return, benefit to cost ratio (B/C ratio) and financial productivity.

$$\begin{aligned} \text{Total revenue}\left(\$\,\text{ha}^{-1}\right) = {} & \text{Yield}\left(\text{kg ha}^{-1}\right) \\ & \times \text{price of commodities}\left(\$\,\text{kg}^{-1}\right) \end{aligned} \quad (9)$$

$$\begin{aligned} \text{Gross return}\left(\$\,\text{ha}^{-1}\right) = {} & \text{Total revenue}\left(\$\,\text{ha}^{-1}\right) \\ & - \text{Variable cost of production}\left(\$\,\text{ha}^{-1}\right) \end{aligned} \quad (10)$$

$$\begin{aligned} \text{Net return}\left(\$\,\text{ha}^{-1}\right) = {} & \text{Total production value}\left(\$\,\text{ha}^{-1}\right) \\ & - \text{Total production cost}\left(\$\,\text{ha}^{-1}\right) \end{aligned} \quad (11)$$

$$\text{B/Cratio} = \frac{\text{Total revenue}\left(\$\,\text{ha}^{1}\right)}{\text{Total production cost}\left(\$\,\text{ha}^{-1}\right)} \quad (12)$$

$$\text{Financial productivity}\left(\text{kg}\,\$^{-1}\right) = \frac{\text{Yield}\left(\text{kg ha}^{-1}\right)}{\text{Total production cost}\left(\$\text{ha}^{-1}\right)} \quad (13)$$

3. Results and discussion

3.1. Study area

West Java Indonesia, geographically located at 5°50′–7°50′ latitude and 104°48′–108°48′ longitude, shares boundaries with Java Sea and Capital Regency of Jakarta in north; Central Java Province in east; Indian Ocean in south; and the province of Banten and Jakarta in west. Unlike most other provinces in Indonesia which have their capitals in coastal area, the provincial capital, Bandung, is located in the mountainous area in the center of the province. West Java has rich and fertile volcanic soil. The total area of West Java Province is 3.71 million ha with about 756 km long coastline. Land use in West Java is in the form of mixed farms (22.89%), rice (20.27%), and plantations (17.41%), while forest covers only 15.93% of the total area. The climate in this province is tropical, with average temperatures of 17.4–30.7 °C and humidity between 73 and 84%. The population of West Java is about 43.1 million having 91% of them engaged in agricultural sector. Based on the data from Indonesia State Secretary, the total harvested area of rice in West Java Province was 1.96 million ha which produced 11.5 million tons of paddy in 2011. Beside that, West Java also produces horticultural products including 22.05 million tons vegetables, 0.23 million tons fruits, and 0.64 million tons medicinal plants/herbs [2].

The West Bandung regency has 130,577 ha area spread over 60° 41′ to 70° 19′ latitude and 107° 22′ to 108° 05′ longitude, with an average altitude of 110 m and maximum 2242.9 m above mean sea level. The average annual rainfall is 1500–4000 mm and average temperature is 19–24 °C [40]. Out of the 1.53 million total population of this region, there are about 0.45 million economically active people, the maximum number of those (43.83%) subscribe to agriculture and farm work as their livelihood, followed by industrial sector 16.53%, trade sector 15.51%, service sector 9.51% and others 24.59%. Moreover, agriculture occupies the largest land use (66,500 ha) in West Bandung regency.

The Sukabumi regency is geographically located between 6° 57′ to 7° 25′ latitude and 160° 49′ to 107° 00′ longitude and has an area of 412,800 ha which is 14% of the West Java province or 3% of the of Java Island. The average annual rainfall is 235 mm–777 mm and average temperature is 20–30 °C with relative humidity between 88 and 91%. The total population of Sukabumi regency is 2.5 million, with 2.37% population growth rate and 606.65 people/km^2 population density [41]. Forty seven per cent of the total population is engaged in the agricultural sector. Out of the total 64,077 ha of paddy cultivation, 19,338 ha is under irrigation system built by local government, 19,490 ha is under rainfed irrigation, and the rest is under other methods of irrigation. Dry land in Sukabumi district is mostly used for yards/villages (18,987 ha); followed by dry field/garden (69,426 ha); 42,345 ha for plant estate and 30,245 ha of forest [41]. The study area is shown in Fig. 1.

3.2. Socio-economic characteristics of vegetable growers

In the study area, open field vegetable production is generally practiced by small farms, whereas greenhouse vegetable production is generally carried out by medium and big farms even though their number is limited.

Socio-economic characteristics of vegetable growers in open field are presented in Table 2, and in greenhouse in Table 3.

3.3. Energy use in greenhouse and open field production

Energy input use and their energy equivalents, percentage in total energy input, energy output–input ratio, energy productivity and specific energy in greenhouse and open field vegetable productions are presented in Tables 4 and 5. As can be seen from these tables, total manure that was used in this study for tomato, chili (medium land), chili (highland) and lettuce was 30, 10, 30 and 20 t/ha respectively – applied during land preparation for both greenhouse and open field vegetable production. The value of human energy involved in chili (highland) was higher than other crops. The values were 8380 h/ha and 7440 h/ha for greenhouse and open field respectively, which are due to the higher frequency of human involvements during plant husbandry and harvesting.

Total fertilizer (NPK 16:16:16) applied in tomato and chili were 1000 and 1500 kg per ha. About 400 kg/ha of fertilizer for lettuce (NPK 16.2: 16.2: 16.2) was used that was applied only once. Reducing the use of chemicals is one of the purposes in greenhouse vegetable production. This is also reflected in the study area, where the application of chemicals in greenhouses is lower than that in open field vegetable production and it was not applied for both greenhouse and open field for lettuce production. The average yield of tomato was 50.4; 32 ton/ha, chili medium land 23.4; 9 ton/ha, chili highland 36; 13.5 ton/ha and lettuce 8; 16.5 ton/ha in greenhouse and open field vegetable production, respectively.

Results also revealed that the highest total energy requirements from different sources was 58.8 GJ/ha for chili (highland) in greenhouse vegetable production and the lowest (23.9 GJ/ha) for producing lettuce in open field. Total energy input for greenhouse chili production in highland is higher than other crops because it needs more fertilizer to improve the soil quality, and more chemical needed due to pests and disease in this study area. Chemical-free vegetables is one of the market requirements which results in minimizing the energy input for greenhouse lettuce production.

As can be seen from Table 4, among energy sources, the highest energy consumer was fertilizer, followed by human and chemical for greenhouse chili production in Sukabumi medium land with 33.25%, 31.86% and 21.71% of total energy used, respectively. Latosol and Podzolic are the major types of soil in Sukabumi Regency with low fertility [42]. Due to poor soil condition, crop production requires more fertilizer than others. Meanwhile, in greenhouse tomato production, fertilizer (26.3%) was the highest energy consumer, followed by human (25.5%) and manure (18.90%). Energy consumption of chemical was relatively low because the hybrid tomato 'TW' has strong fusarium wilt tolerance and disease resistance [43]. Ozkan et al. (2011) [17] also revealed that fertilizer was the highest energy consumer in tomato production (38.22%) followed by electricity and manure.

The highest electricity consumption was computed as 10,737 MJ/ha (43%) for greenhouse lettuce production. This was mainly due to the drip irrigation system. Djevic and Djevic and Dimitrijevic (2009) [28] reported that fertilizer was the third largest input in total energy consumption, after energy for heating and the energy embodied in boxes, for lettuce packaging.

The energy equivalents of input/output items for open field vegetable production are shown in Table 5. Even though the chemical consumption was estimated having the highest 33.4% share in total input for lettuce, followed by 28.07% for chili medium land, 25.17% for chili highland and 22.68% for tomato production but as an edible leafy vegetable, relative consumption of pesticide was the lowest agriculture input than other crops with 7960 MJ/ha. Lettuce is generally used as green leafy vegetable for salad crops, which is consumed fresh. Greater amount of fertilizer was consumed in chili highland (26.68%), followed by tomato (26.45%), chili medium land (26.36%) and lettuce (21%). Human energy was computed as 23.74% energy consumer for chili medium land, followed by tomato, chili highland and lettuce with 21.32%, 19.9% and 14.4% share, respectively. For tomato production, consumptions of fertilizer and chemical were the highest energy intensive input with 26.5% and 22.68% share in total input energy, followed by human (21.3%). Higher energy consumption pertaining to manure was found (25.1%) in lettuce production.

In this research generally higher output–input ratios were obtained in greenhouse vegetable production; 0.85 for tomato, followed by chili in highland (0.49), and chili-medium land (0.43) (Table 4). Meanwhile, output–input ratio for lettuce was higher in the open field (0.32) (Table 5). Results revealed that although the use of greenhouse technology could not be translated into energy efficiency for lettuce production, yet the investment is justified to maintain product quality – which is deteriorated otherwise. Lettuce is vulnerable to attack by several insect pests. The purpose of growing lettuce in greenhouse is to minimize losses due to disease and insect pests. The product has to be fresh, crisp and green while

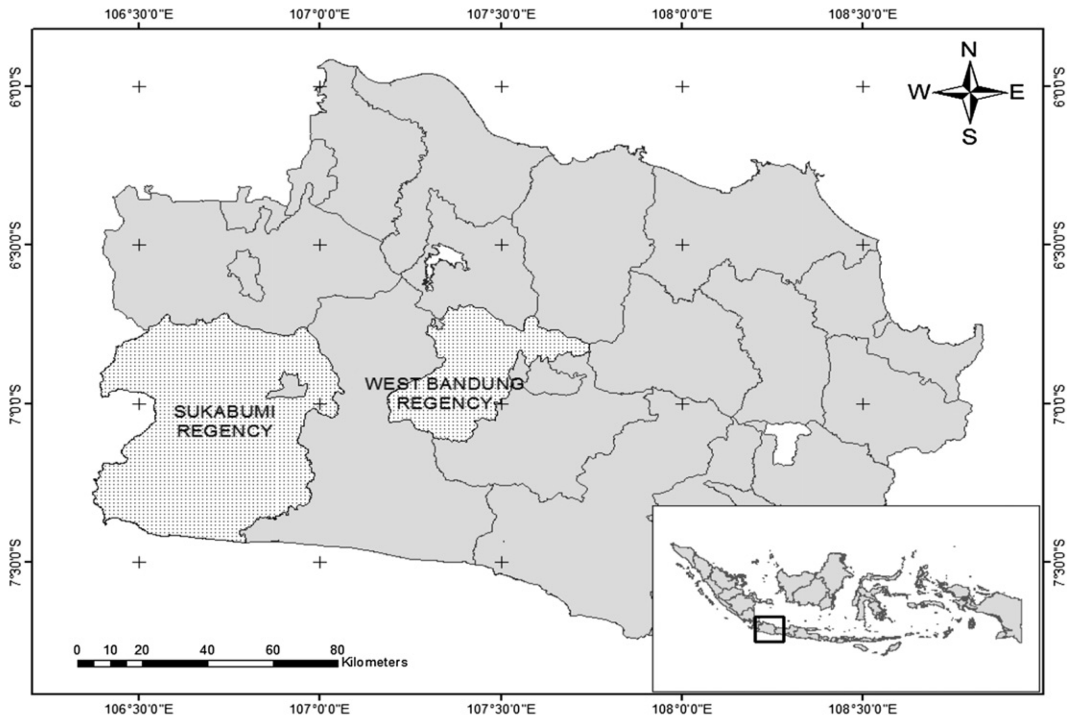

Fig. 1. Study area.

harvesting. For greenhouse tomato production, Esengun et al. (2007) [44] and Ozkan et al. (2011) [17] reported output–input ratio of 0.8, whereas, Hatirli et al. (2006) [16] noted 1.2 instead. Canakci et al. (2005) [14] reported that the output–input ratio for field crops and vegetables production in Turkey were 1.5 (sesame), 4.8 (cotton), 2.8 (wheat), 3.8 (maize), 0.7 (tomato), 1.9 (melon), 2.0 (water-melon), and 0.6 for vegetable. The comparison of energy consumption for grapes in greenhouse and open field production systems by Ozkan et al. (2007) [20] showed that energy output–input ratio of open field production was 1.07 folds than the greenhouse production.

The energy productivity for tomato, chili medium land, chili in highland, and lettuce greenhouse production were 1.06 kg/MJ, 0.56 kg/MJ, 0.61 kg/MJ, 0.33 kg/MJ respectively. From the result of open field vegetable production, it was shown that energy productivity for tomato is 0.65 kg/MJ, chili medium land is 0.22 kg/MJ, chili highland is 0.23 kg/MJ and lettuce is 0.69 kg/MJ. This research reveals that energy productivity to produce tomato in the greenhouse was higher compared to other vegetables. Meanwhile, lettuce in open field production showed the highest energy productivity compared to other vegetables in the study.

The specific energy for greenhouse vegetable production was 0.94 MJ/kg, 1.78 MJ/kg, 1.63 MJ/kg, 3.07 MJ/kg for tomato, chili medium land, chili highland and lettuce respectively. It can be seen that production of tomato had less energy consumption compared to others in greenhouse vegetable production. The specific energy in open field vegetable productions were 1.53 MJ/kg for tomato, 4.56 MJ/kg for chili medium land, 4.29 MJ/kg for chili highland and 1.45 MJ/kg for lettuce. It also implies that to produce 1 kg of lettuce, the lowest amount of energy input is needed than other vegetable in open field vegetable production.

3.4. *Energy on the basis of sources*

Energy plays important role in crop production. On the basis of source, the energy can be classified into direct energy and indirect energy [36]. This may also be classified as renewable and non-renewable energy.

3.4.1. *Direct and indirect form of energy inputs*

Direct energy is the energy that is directly exerted by human, animal, diesel and electricity, and indirect energy is the energy

Table 2
Socio-economic characteristics of open field vegetable growers.

Features	Tomato	Chili (medium land)	Chili (highland)	Lettuce
Average farm size (ha)	0.29	0.28	0.68	0.24
Average age (years)	43	45	42	45.6
Number of farm family	4	3	4	4
Farming experience (years)	15.4	17	13	14.1
Education (%)				
Non formal	5.9	7.1	3.13	6.1
6 grade or less	77.6	85.7	83	76.1
7 th to 12 th grade	12.9	7.1	10	11.1
Certificate	0	0	0	2.2
Diploma	1.8	0	1.9	3.3
Degree	1.8	0	1.9	1.1

Table 3
Socio-economic characteristics of greenhouse vegetable production.

Features	Tomato	Chili (medium land)	Chili (highland)	Lettuce
Average farm size (ha)	2	0.03	1.02	2
Average age (years)	46.4	42.3	44.2	45
Number of farm family	4	5	4	4
Farming experience (years)	11	8.3	11.5	9.2
Education (%)				
Non formal	0	0	0	0
6 grade or less	0	33.3	20	0
7th to 12th grade	20	0	0	0
Certificate	0	0	0	0
Diploma	0	0	0	0
Degree	80	66.7	80	100

Table 4
Energy input use and output for greenhouse vegetable production.

Energy source	Units	Quantity per unit area (unit ha^{-1})				Total energy equivalents (MJ ha^{-1})							
		Tomato	Chili (M)	Chili (H)	Lettuce	Tomato	(%)	Chili (M)	(%)	Chili (H)	(%)	Lettuce	(%)
A. Input													
Human		**6740**	**7360**	**8380**	**1325**	**12141.8**	**25.50**	**13240**	**31.86**	**15122.2**	**25.70**	**2269.4**	**9.2**
Man	h	4000	4320	5040	485	7840	16.46	8467.2	20.38	9878.4	16.79	950.6	3.9
Woman	h	2740	3040	3340	840	4301.8	9.03	4772.8	11.49	5243.8	8.91	1318.8	5.4
Chemical fertilizer	kg	**480**	**513**	**720**	**192**	**12544**	**26.34**	**13815.6**	**33.25**	**18816.00**	**31.98**	**5017.6**	**20.4**
Nitrogen	kg	160	175	240	64	9696	20.36	10605	25.52	14544	24.72	3878.4	15.8
P_2O_5	kg	160	215	240	64	1776	3.73	2386.5	5.74	2664	4.53	710.4	2.9
K_2O	kg	160	123	240	64	1072	2.25	824.1	1.98	1608	2.73	428.8	1.7
Chemical						**7423.6**	**15.59**	**9020**	**21.71**	**12690**	**21.57**	**0**	**0.0**
Pesticide	kg	20	20	30	0	3980	8.36	3980	9.58	5970	10.15	0	0.0
Pesticide	l	0	0	0	0	0	0.00	0	0.00	0	0.00	0	0.0
Fungiside	l	20	30	40	0	3360	7.06	5040	12.13	6720	11.42	0	0.0
Herbiside	l	0	0	0	0	0	0.00	0	0.00	0	0.00	0	0.0
Zinc sulfate	kg	4	0	0	0	83.6	0.18	0	0.00	0	0.00	0	0.0
Manure	kg	30000	10000	30000	20000	**9000**	**18.90**	**3000**	**7.22**	**9000**	**15.30**	**6000**	**24.5**
Diesel	l	80	0	0	7	**4504.8**	**9.46**	**0**	**0.00**	**0**	**0.00**	**394.17**	**1.6**
Mechine		510	617	767	30	**753.9**	**1.58**	**903.7**	**2.17**	**1113.7**	**1.89**	**70.5**	**0.3**
Power tiller	h	0	0	0	0	0	0.00	0	0.00	0	0.00	0	0.0
Rotovator	h	42	42	42	30	98.7	0.21	98.7	0.24	98.7	0.17	70.5	0.3
Knapsack sprayer	h	468	575	725	0	655.2	1.38	805	1.94	1015	1.72	0	0.0
Electricity	KWh	70	90	120	900	**835.1**	**1.75**	**1073.7**	**2.58**	**1431.6**	**2.43**	**10737**	**43.8**
Water irrigation	m^3	660	792	1062	76.5	**415.8**	**0.87**	**498.96**	**1.20**	**669.06**	**1.14**	**48.195**	**0.2**
Total input (MJ ha^{-1})						**47,619**		**41,552**		**58,843**		**24,537**	
A. Output													
Crop yield (kg ha^{-1})	kg	50400	23400	36000	8000	**40320**		**18720**		**28800**		**3680**	
Energy output–input ratio						**0.85**		**0.45**		**0.49**		**0.15**	
Energy productivity	kg MJ^{-1}					**1.06**		**0.56**		**0.61**		**0.33**	
Specific energy	MJ kg^{-1}					**0.94**		**1.78**		**1.63**		**3.07**	

Note: Bold-faced values are sub-total of corresponding category.

which comes from fertilizer, manure, chemical and machinery. Total energy inputs as direct, indirect, renewable and non-renewable forms for greenhouse and open field are shown in Fig. 2. From the analysis it is clear that more energy was needed in open field vegetable production than in greenhouse production except for lettuce. Total energy input used for greenhouse tomato, chili-medium land, chili-highland and lettuce were 47,619 MJ/ha, 41,552 MJ/ha, 58,843 MJ/ha and 24,536.9 MJ/ha, respectively (Table 4). In range of 62–71% of total energy, input use in greenhouse tomato and chili production was in the form of indirect

Table 5
Energy input use and output for open field vegetable production.

Energy source	Units	Quantity per unit area (unit ha^{-1})				Total energy equivalents (MJ ha^{-1})							
		Tomato	Chili (M)	Chili (H)	Lettuce	Tomato	(%)	Chili (M)	(%)	Chili (H)	(%)	Lettuce	(%)
A. Input													
Human		**5756**	**6420**	**7440**	**1916.12**	**10450.67**	**21.32**	**11631.6**	**23.74**	**13513.8**	**19.90**	**3427.995**	**14.4**
Man	h	3625	3980	4700	1076	7105	14.50	7800.8	15.92	9212	13.57	2109.20	8.8
Woman	h	2131	2440	2740	840	3345.67	6.83	3830.8	7.82	4301.8	6.34	1318.80	5.5
Chemical fertilizer	kg					**12961.1**	**26.45**	**12916.8**	**26.36**	**18117.1**	**26.68**	**5017.6**	**21.0**
Nitrogen	kg	170	165	231	64	10302	21.02	9999	20.41	13998.6	20.62	3878.4	16.3
P_2O_5	kg	146	185	231	64	1620.6	3.31	2053.5	4.19	2564.1	3.78	710.4	3.0
K_2O	kg	155	129	232	64	1038.5	2.12	864.3	1.76	1554.4	2.29	428.8	1.8
Chemical						**11114**	**22.68**	**11520**	**28.07**	**14584**	**25.17**	**7960**	**33.4**
Pesticide	kg	10	0		40	1990	4.06	0	0	0	0	7960	33.4
Pesticide	l	15	40	50	0	2940	6.00	7840	19.10	9800	16.91	0	0.0
Fungiside	kg	10	40	52	0	920	1.88	3680	8.97	4784	8.26	0	0.0
Fungiside	l	3	0		0	504	1.03	0	0.00	0	0.00	0	0.0
Herbiside	l	20	0		0	4760	9.71	0	0.00	0	0.00	0	0.0
Zinc sulfate	kg	0	0		0	0	0.00	0	0.00	0	0.00	0	0.0
Manure	kg	30000	10000	30000	20000	**9000**	**18.36**	**3000**	**6.12**	**9000**	**13.26**	**6000**	**25.1**
Diesel	l	80	0	0	7	**4504.8**	**9.19**	**0**	**0.00**	**0**	**0.00**	**375.4**	**1.6**
Machine						**728.7**	**1.49**	**868.7**	**1.77**	**1122.1**	**1.65**	**70.50**	**0.3**
Power tiller	h	0	0	0	0	0	0.00	0	0.00	0	0.00	0.00	0.0
Rotovator	h	42	42	42	30	98.7	0.20	98.7	0.20	98.7	0.15	70.5	0.3
Knapsack sprayer	h	450	550	731	0	630	1.29	770	1.57	1023.4	1.51	0	0.0
Electricity	KWh	0	75	105	112.5	**0**	**0.00**	**894.75**	**1.83**	**1252.65**	**1.85**	**1342.13**	**5.6**
Water irrigation	m^3	396	330	562	76.5	**249.48**	**0.51**	**207.90**	**0.42**	**354.06**	**0.52**	**48.20**	**0.2**
Total input (MJ ha^{-1})						**49,008.75**		**41,039.75**		**57,943.71**		**23,866.42**	
A. Output													
Crop yield (kg ha^{-1})	kg	32000	9000	13500	16500	**25600**		**7200**		**10800**		**7590**	
Energy output–input ratio						**0.522**		**0.175**		**0.186**		**0.318**	
Energy productivity	kg MJ^{-1}					**0.65**		**0.22**		**0.23**		**0.69**	
Specific energy	MJ kg^{-1}					**1.53**		**4.56**		**4.29**		**1.45**	

Note: Bold-faced values are sub-total of corresponding category.

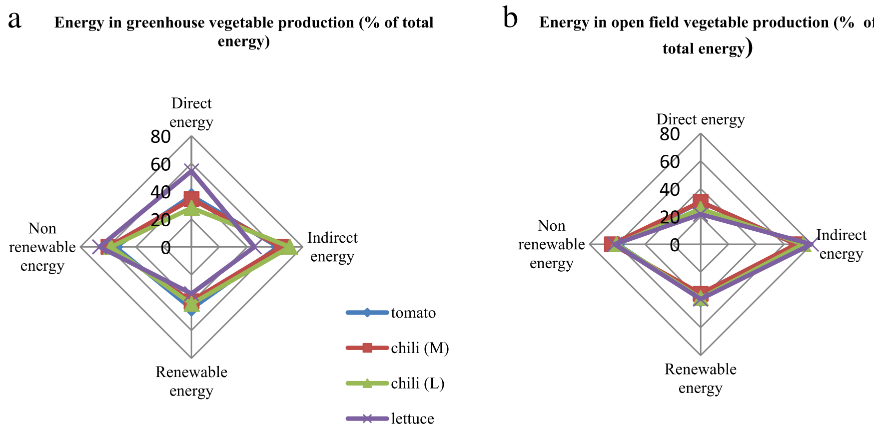

Fig. 2. Total energy input in form of direct, indirect, renewable and non-renewable energy: a) In greenhouse vegetable production; and b) in open field vegetable production.

energy. Other researchers reported that 42 and 45% of total energy input was in the form of indirect energy for tomato on glasshouse tomato production fall crop, summer crop respectively [18]. In this research, it was also noted that more than 50% energy used was in form of direct energy for lettuce in greenhouse production.

In the open field production, more than 68% of total input consumed was in the form of indirect energy. In the open field, a total of 49,009 MJ/ha, 41,039.75 MJ/ha, 57,943.71 MJ/ha and 23,866.42 MJ/ha energy was consumed for tomato, chili medium land, chili highland and lettuce, respectively (Table 5).

3.4.2. Renewable and non-renewable forms of energy inputs

Renewable energy is the energy in form of human, animal, seeds and manure. Whereas, the non-renewable energy is in form of diesel, electricity, chemical, fertilizer and machinery. Results revealed that the total energy inputs used in both greenhouse and open field vegetable production were mostly depended on the non-renewable form of energy (Fig. 2). It was in the range of 54–66% in greenhouse and 59–64% in open field vegetable production. Heidari and Omit (2011) [15] reported that non-renewable energy is the mostly constituted energy for tomato and cucumber, 94% and 90% respectively in greenhouse vegetable production.

3.5. Energy input and crop yield relationship

3.5.1. Greenhouse vegetable production

The plots of total energy input versus crop yield are presented in Figs. 3–6 for chili, tomato and lettuce greenhouse production.

It is shown that the crop yield in greenhouse increased as a function of the energy inputs (eq. (6)). The coefficients of determination (R^2) between yield and total energy input for chili-medium land, chili highland, tomato, and lettuce in greenhouse

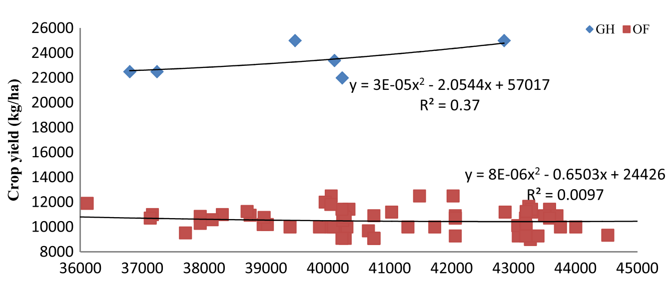

Fig. 3. Crop yield versus total energy input for chili-medium land crop.

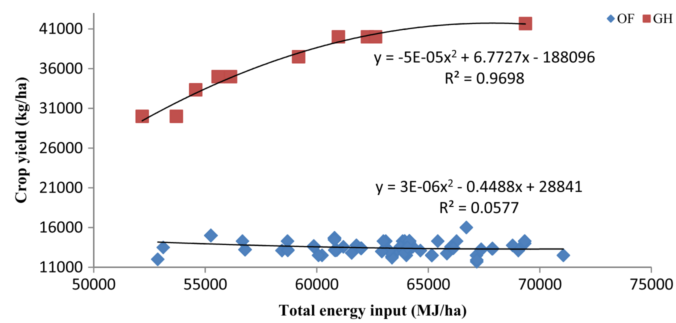

Fig. 4. Crop yield versus total energy input for chili-highland crop.

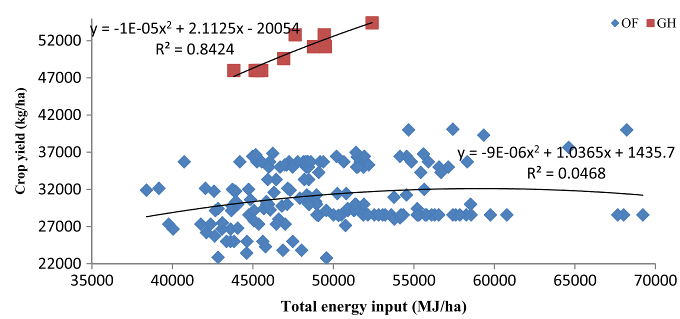

Fig. 5. Crop yield versus total energy input for tomato crop.

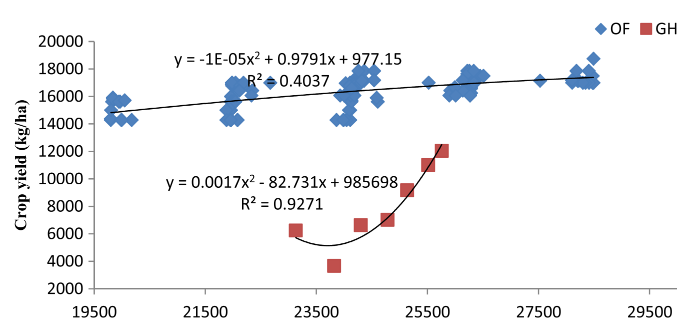

Fig. 6. Crop yield versus total energy input for lettuce crop.

Table 6
The relationships among inputs and greenhouse vegetable yield for tomato, chili and lettuce.

Variable	Tomato		Chili- medium land		Chili-highland		Lettuce	
	α_i	t-Ratio	α_i	t-Ratio	α_i	t-Ratio	α_i	t-Ratio
Human labor (x1)	0.20	0.54	−11.56	−1.27	23.74	2.25	0.31	1.79
Machinery (x2)	2.52	1.63	0.69	0.89	0.14	0.49	3.47	6.73
Manure (x3)	0.78	1.73	0.25	1.43	−0.12	−0.78	–	–
Fertilizer (x4)	0.41	3.09	−3.89	−0.49	0.05	0.33	–	–
Chemical (x5)	0.47	1.61	–	–	0.32	1.25	–	–
Diesel (x6)	−0.028	−0.27	–	–	–	–	2.87	20.91
Electricity (x7)	−4.71	−1.57	–	–	0.26	1.56	−20.62	−6.66
Water irrigation (x8)	−1.43	−1.40	–	–	−0.14	−0.43	0.69	4.51
Durbin–Watson	2.22		1.99		2.03		1.75	
R^2	0.97		0.76		0.986		1	
F	0.354		0.681		0.048		0.028	

Table 7
The relationships among direct (DE), indirect (IDE), renewable (RE), non-renewable (NRE) energy and greenhouse vegetable yield.

Variable	Tomato		Chili- medium land		Chili-highland		Lettuce	
	α_i	t-Ratio	α_i	t-Ratio	α_i	t-Ratio	α_i	t-Ratio
DE	0.22	1.26	1.14	0.22	−0.69	−0.21	3.13	3.32
IDE	0.49	5.73	0.33	0.64	0.99	5.57	5.39	0.82
Durbin–Watson	0.64		3.08		1.34		1.23	
R^2	0.85		0.42		0.82		0.98	
F	0.001		0.441		0.003		0.000	
RE	0.27	1.39	0.33	0.63	0.72	1.29	1.95	1.43
NRE	0.45	6.01	0.32	0.61	0.75	3.64	8.21	3.57
Durbin–Watson	0.67		3.24		1.46		1.28	
R^2	0.85		0.42		0.80		0.96	
F	0.001		0.442		0.003		0.001	

vegetable production were 0.37, 0.97, 0.84 and 0.93, respectively. It implies that the variation in total energy input for chili in highland had a major influence (97%) on the yield compared to other crops. Whereas, for the other crops there is no significant relationship of increasing yield with additional use of energy input. The yield variation in those crops is probably due to some other factors such as microclimate, GH management, structure of greenhouse, etc.

The product yield was assumed to be a function of inputs including human labor, machine, manure, fertilizer, chemical, diesel, electricity and irrigation water (eq. (6)). The auto correlation was determined using Durbin–Watson (DW) test [16,37]. The production variables are however found to be insignificant ($p > 0.05$) for all the crops in greenhouse vegetable production. The relationship among inputs and yield in greenhouse vegetable production is shown in Table 6.

The relationships among the direct (DE) and indirect (IDE) energies, as well as renewable (RE) and non-renewable (NRE) energies on yield of each greenhouse vegetable production are shown in Table 7. No significant influence of DE, IDE, RE and IDE on yield noticed for all the greenhouse vegetable production at the 5% level of significant.

3.5.2. Open field vegetable production

The correlation of total energy inputs and crop yield for open field vegetable production was very weak. The coefficients of determination (R^2) between yield and total energy inputs for chili-medium land, chili highland, tomato, and lettuce were 0.0097, 0.0577, 0.0468 and 0.4037 respectively (Figs. 3–6). It was noticed that in lettuce production, 40% of the variability observed in yield can be explained by total energy inputs (Fig. 6). Thus, the total energy input of the lettuce in open field vegetable production contributes relatively higher to the yield as compared to other crops.

The results of regression of energy input and open filed vegetable yield are shown in Table 8. Results indicated that regression coefficient (α) of human labor was the highest among other inputs and significantly contributed to the yield ($p < 0.05$) for tomato (13.35), chili-medium land (0.74), chili highland (0.85) and lettuce (2.11). This

Table 8
The relationships between input and open field vegetable yield for tomato, chili and lettuce.

Variable	Tomato		Chili- medium land		Chili-highland		Lettuce	
	α_i	t-Ratio	α_i	t-Ratio	α_i	t-Ratio	α_i	t-Ratio
Human labor (x1)	13.35	38.24**	0.74	3.27*	0.846	4.12**	2.105	6.57**
Machinery (x2)	0.66	0.98	−0.71	−0.57	−0.19	−5.11**	−0.021	−0.45
Manure (x3)	−0.33	−1.93	−0.28	−2.15	−0.013	−0.695	0.171	3.23*
Fertilizer (x4)	0.42	4.2**	0.55	8.02**	−0.036	−2.38	0.021	0.19
Chemical (x5)	−0.04	−4.33	−0.01	−0.46	0.024	1.01	−0.086	−1.221
Diesel (x6)	−0.06	−0.73	−0.084	1.71			−0.001	−0.086
Electricity (x7)					−0.03	−0.79	0.029	0.425
Water irrigation (x8)	0.27	0.92	0.095	2.34	0.402	14.25**	0.216	1.29
Durbin–Watson	1.89		1.47		2.35		1.658	
R^2	0.91		0.59		0.65		0.802	
F	0.000		0.000		0.000		0.000	

Note: * denotes significant at $p < 0.05$; ** denotes significant at $p < 0.01$.

Table 9
The relationships between direct (DE), indirect (IDE), renewable (RE), non-renewable (NRE) energy and open field vegetable yield.

Variable	Tomato		Chili-medium land		Chili-highland		Lettuce	
	α_i	t-Ratio	α_i	t-Ratio	α_i	t-Ratio	α_i	t-Ratio
DE	0.14	1.59	0.3	0.345	0.993	3.496*	−0.326	−1.796
IDE	0.15	2.66	0.03	0.71	−0.2	−3.89**	0.395	10.54**
Durbin−Watson	1,78		1.92		2.4		1.58	
R^2	0.57		0.013		0.13		0.416	
F	0.008		0.64		0.000		0	
RE	0.214	1.55	0.047	0.51	0-0.13	1.57	0.445	21.91**
NRE	0.139	2.98	−0.005	0.946	−0.11	−2.2	0.000	0.008
Durbin−Watson	1.759		1.89		2.48		1.67	
R^2	0.06		0.005		0.053		0.75	
F	0.006		0.857		0.014		0	

Note: * denotes significant at $p < 0.05$; ** denotes significant at $p < 0.01$.

Table 10
Economic analysis of greenhouse vegetable production (1$ = 8920 IDR).

Cost and return components	Units	Tomato	Chili-m	Chili-h	Lettuce
Yield	kg ha^{-1}	50,400.00	23,400.00	36,000.00	8000.00
Sales price	$ kg^{-1}	0.45	0.90	0.90	1.68
Total revenue	$ ha^{-1}	22,600.90	20,986.55	32,287.00	13,452.91
Variable cost	$ ha^{-1}	4508.43	4627.65	5737.03	1319.58
Fixed cost	$ ha^{-1}	11,250.34	11,250.34	11,250.34	11,210.76
Total cost of production	$ ha^{-1}	15,758.77	15,877.99	16,987.36	12,530.34
Total cost of production	$ kg^{-1}	0.31	0.44	0.59	1.57
Gross return	$ ha^{-1}	18,092.46	16,358.90	26,549.97	12,133.34
Net return	$ ha^{-1}	6842.13	5108.56	15,299.63	922.58
B/C ratio		1.43	1.32	1.90	1.07
Financial productivity	kg $$^{-1}$	3.20	1.47	2.12	0.64

shows that human labor has greater impact on open field vegetable yield. The other important input was fertilizer with elasticity of 0.42, 0.55 for tomato and chili-medium land. Machinery was also an important input with elasticity −0.19 for chili in highland. Meanwhile, manure significantly contributed in increasing the yield with 0.17 elasticity ($p < 0.05$) for lettuce. The Durbin−Watson values were in the range of 1.5−2.35, which indicate that the error deviation are uncorrelated.

The relationships between DE, IDE, RE and NRE with yield of each open field vegetable production are presented in Table 9. The regression coefficients (α) of IDE ($p < 0.01$) and DE ($p < 0.05$) for chili in highland were significant. The effect of DE was more than IDE on the yield of chili in highland. Meanwhile, the significant influence ($p < 0.05$) was observed in terms of IDE and RE on lettuce production. IDE and RE highly contributed to the yield of lettuce with α of 0.39 and 0.44 respectively.

Table 11
Economic analysis of open field vegetable production (1$ = 8920 IDR).

Cost and return components	Units	Tomato	Chili-m	Chili-h	Lettuce
Yield	kg ha^{-1}	32,000.00	9000.00	13,500.00	16,500.00
Sales price	$ kg^{-1}	0.17	0.56	0.56	0.11
Total revenue	$ ha^{-1}	5381.17	5044.84	7567.26	1849.78
Variable cost	$ ha^{-1}	4454.63	4823.47	6355.42	1773.37
Fixed cost	$ ha^{-1}	39.57	39.57	39.57	32.29
Total cost of production	$ ha^{-1}	4494.20	4863.05	6394.99	1805.66
Total cost of production	$ kg^{-1}	0.14	0.54	0.47	0.11
Gross return	$ ha^{-1}	926.54	221.37	1211.84	76.41
Net return	$ ha^{-1}	886.96	181.79	1172.27	44.12
B/C ratio		1.20	1.04	1.18	1.02
Financial productivity	kg $$^{-1}$	7.12	1.85	2.11	9.14

3.6. Financial analyses

Results of the financial analyses of greenhouse and open field vegetable production are summarized in Tables 10 and 11. The cost of production per hectare in greenhouse was about thrice of the cost of open field vegetable production due to high investment cost. The share of variable cost in total cost production was 29% for both tomato and chili medium land, 34% for chili highland and 11% for lettuce in greenhouse vegetable production, whereas almost 99% was shared by variable cost in total production cost for all vegetable open field production.

Mainly due to the high quality of the product such as low pesticide and good appearance, the price of greenhouse vegetables was higher than open field production. From this study it was reaffirmed that yield of greenhouse vegetable production was higher than open field, except for lettuce production, which influenced on the gross value of product. Benefit−cost ratio (B/C) was calculated by dividing total revenue by total cost to find out the economic efficiency. The results indicated that greenhouse production has higher B/C ratio than open field production for all selected vegetables in the study area. Other researchers reported similar results for some crops under greenhouse vegetable production, such as; 1.74 for strawberry [45], 1.68 for cucumber, 3.28 for tomato [15], 1.83 for grape [20], 1.57 for tomato, 1,15 for pepper, 1.29 for cucumber, 1,10 for eggplant [46,47].

Even though B/C ratio of tomato is less than chili production in greenhouse, but tomato has higher financial productivity with 3.2 kg/$. Moreover, lettuce has the highest financial productivity with 9.14 kg/$ than others in open field vegetable production.

4. Conclusions

Based on this study following conclusions are drawn:

1. Total energy input in greenhouse production of tomato and chili was higher than open field production, which is mainly due to fertilizer, followed by human interventions for management, chemicals, and manure.
2. Energy output−input ratio in greenhouse production was 0.85 for tomato, 0.45 for chili medium land, 0.49 for chili in highland, and 0.15 for lettuce. Except lettuce, this ratio in open field production was merely half that of in greenhouse production.
3. Energy productivity of greenhouse production was higher than open field production for tomato, and chili.
4. Indirect energy was the main source of energy that used in greenhouse and open field vegetables production except for the lettuce. Renewable energy sources among the inputs had a share of 33−58% of the total input, which was generally smaller than non-renewable resources for both greenhouse and open field vegetable production.

5. The benefit-cost ratio was found to be 1.43, 1.32, 1.9 and 1.07 for greenhouse tomato, chili medium land, chili highland and lettuce production. Tomato seemed to be the most profitable vegetable for greenhouse production in term of higher financial productivity.

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