Investigation of energy inputs and CO_2 emission for almond production using sensitivity analysis in Iran

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Abstract: The objective of this study is to examine input–output energy and CO_2 emission of almond production in Shahrekord region, Iran. This article presents a comprehensive picture of the current status of energy consumption and some energy indices like energy use efficiency, energy productivity, specific energy and net energy gain. Sensitivity analysis of energy was carried out using the marginal physical productivity (MPP) technique. For this propose data were collected from 29almond farms using a face to face questionnaire. The results revealed that total energy input for almond production was found to be 106.61GJ/ha where the electricity was the major energy consumer (59.58%). The direct energy shared about (50.98%) whereas the indirect energy did (49.02%). Energy use efficiency, energy productivity, and net energy were 0.37, 0.016 kg/MJ, and -67350.16MJ/ha, respectively. The regression results revealed that the contribution of energy inputs on crop yield (except for farmyard manure and water energies) was insignificant. Water energy was the most significant input (0.674) which affects the output level. The results also showed that the impacts of direct, indirect and renewable energies on yield are significant. The GHG emissions were indicated a high CO_2 output in diesel fuel consumption.

Keywords: energy use, energy efficiency, cobb–douglas, almond

Citation: Salehi, M., A. Maleki, H. G. Mobtaker, S. Rostami, and H. Shakeri. 2016. Investigation of energy inputs and CO_2 emission for almond production using sensitivity analysis in Iran. Agric Eng Int: CIGR Journal, 18(1):158-166.

1 Introduction

Tree planting could be considered as an investment for farmers by inhibiting natural resource degradation in soil and water. Almond trees play a significant role in the protection of soil and water with strong roots on sloping lands, mainly regions with high rates of soil erosion (Pattanayak and Mercer, 1998). Almond has a long history in Iran, known historically as one of the first countries to cultivate almonds. This product rank first among tree nuts and are very useful food products because of their content of numerous beneficial nutritive and bioactive compounds, such as total lipid (49.22g/100g),oleic acid (60.4%), linoleic acid(17.4%), fibre (12.2g/100g)and vitamin E (26.22 mg/100g) (Mexiset al., 2009).

Besides water, food, education, diseases and environmental issues, energy has become one of the main priorities of humankind during the last century. In developing countries, energy is the fundamental factor for population fulfillment and development purposes. Technology advancement and social-economic development are in debt of fossil fuel consumption and this fact that fossil fuel resources run out soon has become one of the main concerns of humankind (Hosseini et al., 2013).

Agricultural activities necessitates employing different types of energy inputs and energy carriers and all processes involving production, transportation, formulation, storage, distribution and application of these materials as well as combustion of fossil fuels in different field operations emit CO_2 and other greenhouse gases into

Received date: 2015-08-26 **Accepted date:** 2016-01-07
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the atmosphere (Lal, 2004). More energy consumption causes numerous environmental problems of which global warming and greenhouse gases (GHG) are regarded as the most important ones.

The need to increase food production has resulted in the increased consumption of energy and natural resources because farmers have little knowledge of or few incentives to use more energy efficient methods (Esengun et al., 2007). Intensive energy consumption and reducing the known energy resources are the key factors to develop the philosophy of optimum energy consumption. Optimum use of energy helps to achieve a high level of production and contributes to the economy, profitability and competitiveness of agricultural sustainability of rural communities (Singh et al., 2002). Energy input–output analysis is usually used to evaluate the efficiency and environmental impacts of production systems. It is also used to compare the different production systems (Salehi et al., 2014). Many researchers have studied energy analysis and relationship between inputs and yield to determine the energy efficiency of plant production (Kuesters and Lammel, 1999; Hatirli et al., 2006; Esengun et al., 2007;Iriarte et al., 2010;Abdi et al., 2013; Ebrahimi and salehi., 2015).

Hetz (1998) studied the utilization of energy in the production of fruits in Chile in order to improve the efficiency of its use. He found that the energy ratio of fruit production was in the 0.44–2.22 range. Ozkan et al. (2004) examined energy use of citrus production in Antalya province of Turkey and found that energy ratios for orange, mandarin and lemon were .25, 1.17 and 1.06, respectively. Kizilaslan (2009) investigated the energy use for cherries production in Turkey. The results indicated that majority of this energy (42%) was provided by farming fertilizer consisting of nitrogen, potassium and phosphorus. The 58% of this energy was provided by chemicals, labour, machinery, diesel fuel, electricity. There are other studies looking to the energy use in the production of fruit (Gezer et al., 2003; Strapatsa et al., 2006; Esengun et al., 2007; Banaeian et al., 2010).

Based on the literature, there was no study on energy use and GHG emissions for almond production in Iran. So, the present study investigated the energy consumption and CO_2 emission in almond production in Shahrkord region, Iran. Also the relationship between energy inputs and yield was studied using Cobb–Douglas production function. In last part of study the relationship between energy form and yield was studied.

2 Materials and methods

The research was done in Shahrekord region (32°27′06″N, 50°54′38″E) of Chaharmahal-Bakhtiari province, Iran, because of its major contribution to almond production in Iran, with 18.24% of the total production. The average annual rainfall, temperature and elevation from sea level in the research area are 321.5 mm, 11.5℃, and 2060 m, respectively. Data were collected from 29 almond orchards by using a face-to face questionnaire in the production period of 2013-2014. The face-to-face interview, also called an in-person interview, is probably the most popular and oldest form of survey data collection. The sample size was calculated using the Cochran method (Kizilaslan, 2009):

$$n = \frac{N(s \times t)^2}{(N-1)d^2 + (s \times t)^2} \tag{1}$$

where n is the required sample size; s, the standard deviation; t, the t value at 95% confidence limit (1.96); N, the number of holding in target population and d, the acceptable error (permissible error 5%).

The inputs for the almond production in this area included human labor, machinery, diesel fuel, chemical fertilizers, farmyard manure, electricity, biocides and irrigation water; while outputs were almond and green shell. The energy equivalent may thus be defined as the energy input taking into account all forms of energy in agricultural production. The irrigation water energy indicates the energy for manufacturing the materials for the dams, canals, pipes, pumps and other equipments.

The input energy was divided into direct and indirect and renewable and non-renewable forms (Esengun et al., 2007). Direct energy constituted of human labor, diesel fuel and electricity, whereas, indirect energy include chemical fertilizers, biocides, farmyard manure, water for irrigation and machinery. Renewable energy consists of human labor, water and farmyard manure and non-renewable energy includes machinery, diesel fuel, electricity, chemical fertilizers and biocides. The units in Table 1 were used to calculate the energy equivalent of input in almond production.

Table 1 Energy equivalent of inputs and output in agricultural production

Inputs/Output		Units	Energy coefficients, MJ/unit	Reference
	Inputs			
1.	Human labor	H	1.96	Yilmaz et al., 2005
2.	Machinery	H	62.7	Singh, 1998
3.	Diesel fuel	L	56.31	Canakci et al., 2006
4.	Electricity	kWh	11.93	Hatirli et al., 2005
5.	Chemical fertilizers	kg		Esengun et al., 2007
a)	Nitrogen (N)		66.14	
b)	Phosphate (P_2O_5)		12.44	
c)	Potassium (K_2O)		11.15	
6.	Micro elements	kg	10	Singh and Mittal, 1992
7.	Farmyard manure	kg	0.3	Yilmaz et al., 2005
8.	Biocides	kg		Singh and Mittal, 1992
a)	Insecticides		101.2	
b)	Herbicides		238	
9. Water for irrigation		m^3	1.02	Acaroglu et al., 1998
	Outputs			
1.	Almond	kg	24.08	Singhand Mittal, 199
2.	Green shell	kg	18	Singh and Mittal, 1992

The input and output were calculated per hectare and then, these input and output data were multiplied by the coefficient of energy equivalent. Following the calculation of energy input and output values, the energy indexes of almond were calculated (Mandal et al., 2002; Ozkan et al., 2011). These indexes are showed in Table 2.

Table 2 Indices of energy in agriculture production (Mandal et al., 2002; Ozkan et al., 2011)

Indicator	Definition	Unit	
Energy use efficiency	$\frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$	Ratio	(2)
Energy productivity	$\frac{\text{Yield (kg/ha)}}{\text{Energy input (MJ/ha)}}$	kg/MJ	(3)
Specific energy	$\frac{\text{Energy input (MJ/ha)}}{\text{Yield (kg/ha)}}$	MJ/kg	(4)
Net energy gain	Energy output (MJ/ha) – Energy input (MJ/ha)	MJ/ha	(5)

The amounts of greenhouse gas (GHG) emissions from inputs in almond production per hectare were computed using CO_2 emissions coefficient of agricultural inputs (Table3). GHG emissions were calculated by multiplying the input application rates (diesel fuel, chemical fertilizers, machinery, pesticides and electricity) by their corresponding emission coefficients.

Table3 Greenhouse gas (GHG) emission coefficients of agricultural inputs

Inputs	Unit	GHG Coefficient (kg CO_2 eq./ unit)	Reference
Machinery	MJ	0.071	Dyer and Desjardins, 2003
Diesel fuel	L	2.76	Dyer and Desjardins, 2003
Electricity	kWh	0.608	
Chemical fertilizers	Kg		
a)Nitrogen (N)		1.3	Lal, 2004
		0.2	Lal, 2004
b)Phosphate (P_2O_5)			
c) Potassium (K_2O)		0.2	Lal, 2004
Biocides	Kg		
a) Insecticides		5.1	Lal, 2004
b) Herbicides		6.3	Lal, 2004

In order to obtain a relationship between inputs and yield, a mathematical function needs to be specified. For this purpose Cobb–Douglas production function was selected; because it produced better results (yielded better estimates in terms of statistical significance and expected signs of parameters). The Cobb–Douglas production function is frequently used in both energy and economics studies to show the relationship between input factors and the level of production (Singh et al., 2004; Mobtaker et al., 2010). The Cobb–Douglas production function is expressed as:

$$Y = f(x)\exp(u) \quad (6)$$

This function has been used by several authors to examine the relation between energy inputs and yield (Singh et al., 2004; Hatirli et al., 2006; Mobtaker et al., 2010). The linear form of Equation (6) can be written as:

$$\ln Yi = \alpha_0 + \sum_{j=1}^{n} \alpha_j \ln(x_{ij}) + e_{i(i=1,2.3,\ldots,n)} \quad (7)$$

Where Y_i denotes the yield level of the i'th farmer, X_{ij} is the vector inputs used in the production process, α_0 is the constant term, α_j represents coefficients of inputs which are estimated from the model and e_i is the error term.

Using Equation (7), the effect of energy inputs on almond yield for each input was studied. On the other hand, almond yield (endogenous variable) was assumed to be a function of human labor, diesel fuel, oil, machinery, chemical fertilizers, biocides, electricity and farmyard manure energy (exogenous variables).

Similarly, the effect of direct, indirect, renewable and non–renewable energies on production was also studied. For this purpose, Cobb–Douglas function was determined as Equations (8) and (9):

$$\ln Yi = \beta_0 + \beta_1 \ln DE + \beta_2 \ln IDE + e_i \quad (8)$$

$$\ln Yi = \gamma_0 + \gamma_1 \ln RE + \gamma_1 \ln NRE + e_i \quad (9)$$

Where$Yi$is the ith farmer's yield,β_0 and γ_0 are the constant terms, β_i and γ_i are coefficients of exogenous variables and e_i is the error term. *DE*, *IDE*, *RE* and *NRE* are direct, indirect, renewable and non–renewable energies respectively.

In the last part of study marginal physical productivity (MPP) method, based on the response coefficients of the inputs was utilized to analyze the sensitivity of inputs on almond output. The MPP of a factor input indicates the change in the output with a unit change in the factor input in question, keeping all factors constant at geometric mean level. The MPP of various inputs were computed using regression coefficients (α_j) of various energy inputs as given by (Singh et al., 2004; Pishgar–Komleh et al., 2012):

$$MPP_{xj} = \frac{GM(Y)}{GM(Xj)} \times \alpha_j \quad (10)$$

Where MPP_{xj} is marginal physical productivity of jth input, α_j is regression coefficient of jth input, $GM(Y)$ is geometric mean of yield, and $GM(X_j)$ is geometric mean of jth input.

Basic information on energy inputs and almond yield were entered into Excel's spreadsheet and simulated using SPSS 19 software.

3 Results and discussion

3.1 Input-output energy use in almond production

As it can be seen in the Table 4, 1719.95 h of labor, 93.82 L of diesel fuel and40.08 h of machinery per hectare are used for the production of almond in Shahrekord region. The total energy input for various processes in the almond production was calculated to be 106.61GJ/ha. The average almond output were found to be 1305 kg/ha in the enterprises that were analyzed. The energy equivalent of this is calculated as 3.14GJ/ha. The highest energy input is provided by electrical (5324.76 kWh) followed by chemical fertilizers. Electricity used for irrigation proposes. The shares of nitrogen and phosphorus energy were 85% and 8%, respectively, from the total energy of chemical fertilizer used. Kizilaslan (2009) calculated the energy inputs for cherries production in Tokat Province of Turkey as 48.7 GJ/ha. In another study Nabavi-Pelesaraei et al. (2013b) concluded that the input energy for peanut production in north Iran were to be 19248.04 MJ/ha.

Table 4 Amounts of inputs and output with their equivalent energy

Inputs, unit	Quantity per unit area, ha	Total energy equivalent, GJ/ha	Percent,%
A. Inputs			
Human labor , h	1719.95	3.37	3.17
Machinery , h	40.08	2.51	2.37
Diesel fuel , L	93.82	5.28	4.95
Chemical fertilizers , kg	446.66	15.77	15.21
Farmyard manure , kg	26322.41	7.90	7.4
Electricity , kWh	5324.76	6.35	59.59

Biocides , kg	11.99	2.14	2
Water for irrigation	5555.12	5.67	5.31
Total energy input, GJ	-	106.61	100
B. Output			
1. Almond , kg	1305	3.14	
2. Green shell , kg	434	7.83	

The inputs energy consumption was least for biocides (2.14GJ/ha) which accounted for about 2% of the total energy consumption. The share of almond input can be seen in last column of Table 4. With respect to the obtained results, the shares of energy consumption in almond production consist of 59.58% electricity, 14.78% fertilizers,7.4% Farmyard manure, 5.31% water,4.95% diesel fuel, 3.16% human labor, 2.35% machinery and 2% biocides.

Energy use efficiency, energy productivity, specific energy and net energy gain are listed in Table 5. Energy use efficiency in almond production was calculated as 0.37, showing the inefficiency use of energy in the almond production. It is concluded that the energy use efficiency can be increased by raising the crop yield and or by decreasing energy input consumption. Several authors have been reported the energy use efficiency for different crops such as1.06 for lemon (Ozkan et al., 2004)0.96 for cherries (Kizilaslan, 2009), 1.16 for apple (Rafiee et al., 2010) and1.84 for orange (Nabavi-Pelesaraei et al., 2014).

The average energy productivity of almond was 0.016 kg/MJ. This means that 0.016 units output was obtained per unit energy. The specific energy and net energy gain of almond production are 61.27 MJ/kg and -67350.16 MJ/ha, respectively. Net energy is negative (less than zero). Therefore, it can be concluded that in almond production, energy is being lost. Also the distribution of inputs used in the production of almond according to the direct, indirect, renewable and non-renewable energy groups, are given in Table 5.

It is seen that the ratios of direct energy resources are more than indirect energy (73.02% and 26.98%). Also the ratios of non-renewable energy are more than renewable energy (84.12% and 15.88%). Therefore, it is clear that almond production depended on non-renewable energy consumption. Similar results have been reported by other researchers for different crop (Demircan et al., 2006; Erdal et al., 2007; Kizilaslan, 2009).

Table 5 Some energy parameters in almond production

Items	Unit	Quantity
Energy use efficiency	-	0.37
Energy productivity	Kg/MJ	0.016
Specific energy	MJ/kg	61.27
Net energy gain	MJ/ha	-67350.16
Direct energy [a]	MJ/ha	77844.55 (73.02%)
Indirect energy [b]	MJ/ha	28761.98 (26.98%)
Renewable energy [c]	MJ/ha	16934.05 (15.88%)
Non-renewable energy [d]	MJ/ha	89672.48 (84.12%)
Total energy input	MJ/ha	106606.54 (100%)

Note: a Includes human labor, electricity, diesel fuel and water.
b Includes machinery, chemical fertilizers, farmyard manure and biocides.
c Includes human labor, farmyard manure and water.
d Includes diesel fuel, electricity, chemical fertilizers, biocides and machinery.

3.2. GHG emissions of almond production.

Agricultural GHG emissions account 10%-12% of all manmade GHG emissions and contribute significantly to global warming and environmental protection strategies have thus to integrate emission reduction measures from this source (Brownea et al., 2011). The results of GHG emission of almond production are shown in Table 6. The total GHG emissions were calculated as 4047.46 kgCO_2eq./ha. The shares of different parameters are demonstrated in Figure1. The greatest shares in GHG emissions correspond to diesel fuel (79.99%) and Nitrogen (6.51%), respectively, followed by machinery (6.4%). The main reason of high diesel fuel GHG emissions is that most of the machinery in the almond production were old or were not properly repaired and maintained. As mentioned before, using new equipment in almond production and having regular programs for repair and maintenance can be considered in order to reduce the amount of diesel fuel consumption and its emission in this stage. Pathak and Wassmann (2007) reported a total emission of 1038 kgCO_2eq./ha for wheat production. Soni et al. (2013) calculated the total CO_2 emission of transplanted rice about 1100 kgCO_2eq./ ha.

Table 6. Greenhouse gas emissions of inputs in almond production

Inputs	Average (kg CO_2 eq./ha)	Max	Min
Machinery	178.45	534.2	0
Diesel fuel	258.93	702.42	103.5
Electricity	3237.45	5928	449.92
Chemical fertilizers			
a) Nitrogen (N)	263.48	910	110.5
b)Phosphate (P_2O_5)	21.906	66	0
c) Potassium (K_2O)	17.95	75	0
Biocides			
a) Insecticides	26.8	63.75	0
b) Herbicides	42.47	378	0

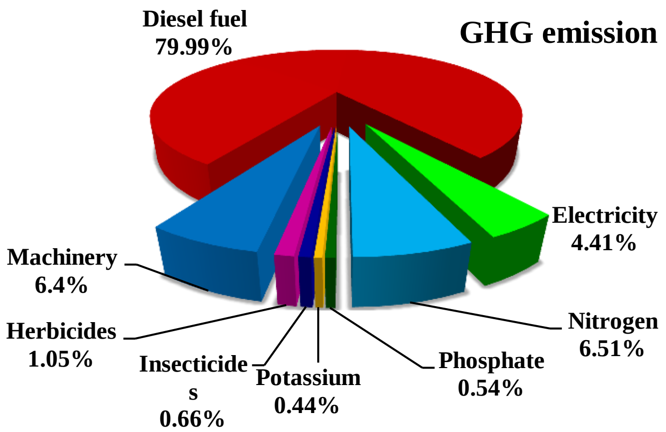

Figure1 The portions of different inputs in CO_2 emission

3.3 Sensitivity of energy inputs, DE, IDE, RE and NRE

In order to estimate the relationship between energy inputs and almond yield, Cobb–Douglas production function was chosen and assessed using ordinary least square estimation technique. The R^2 value was determined as 0.99 for Equation (7), implying that around 0.99 of the variability in the energy inputs was explained by this model. Regression results for Equation (7) were estimated and are shown in Table 7. As can be seen from Table 7, all exogenous variables had a positive impact and were found statistically significant on almond yield (expected diesel fuel, machinery, and chemical fertilizers). It can be seen from Table 7 that for almond production, water had the highest impact (0.674) among other inputs and significantly contributed on the yield at 1% level. This indicates that with an additional use of 1% for of this input would lead to 0.674% increase in almond yield. The second important input was found to be the farmyard manure with 0.331 elasticity and significantly contributed on the yield at 1% level.

Table7Sensitivity of inputs

Endogenous variable: yield	Coefficient	t–ratio	MPP
Exogenous variables			
Equation(7): ln $Y_i=\alpha_1 \ln X_1+\alpha_2 \ln X_2+\alpha_3 \ln X_3+\alpha_4 \ln X_4+\alpha_5 \ln X_5+\alpha_6 \ln X_6+\alpha_7 \ln X_7+\alpha_8 \ln X_8+e_i$			
Diesel fuel	-0.069	-0.434	-0.55
Electricity	0.019	0.224	0.01
Human labor	0.222	1.005	2.78
Machinery	-0.013	-0.696	-0.71
Farmyard manure	0.331	3.635*	1.94
Chemical fertilizers	-0.069	-0.336	-0.18
Biocides	0.159	1.719	4.03
Water	0.674	4.137*	4.55
R^2	0.99		

Note: *indicates significance at p<1% level.

This indicates that with an additional use of 1% for of this input would lead to 0.331% increase in almond yield. Rafiee et al. (2010) estimated an econometric model for apple production in Iran and they reported that the inputs of human labor, farmyard manure, chemical fertilizers, water for irrigation and electricity had significant impacts on yield. Royanet al., 2012 reported that Chemical fertilizers and farmyard manure had significant influence on peach yield.

For the Equations (8) and (9) the statistic variables are presented in Table 8. As can be seen, regression coefficients of direct, indirect and renewable energies are significant. The energy obtained from existing inputs was divided into two direct and indirect forms. The assessed trends of both forms of energy were positive, indicating the positive impacts on the output level. Impact of indirect energy (0.695) was more than that of direct energy (0.311). The regression coefficient for renewable energy (0.919) was significant at 1% level. It is concluded that impact of renewable energy was higher than that of nonrenewable energy in almond production. The R^2 value was 0.99 for both these estimated models.

Table 8Sensitivity of direct, indirect, renewable and non-renewable energies

Endogenous variable: energy output	Coefficient	t–ratio	MPP
Exogenous variables			
Equation(8): ln $Yi=\beta_1 \ln DE+\beta_2 \ln IDE+ei$			
Direct energy	0.311	3.712*	0.17

Indirect energy	0.695	7.565*	1
R^2	0.99		
Equaton(9): $\ln Yi=\gamma_1 \ln RE+\gamma_2 \ln NRE+ei$			
Renewable energy	0.919	8.946*	2.15
Non-renewable energy	0.144	1.636	0.06
R^2	0.99		

Note: * Indicates significance at$p$<1% level.

In the last part of the research, the marginal physical productivity (MPP) method, based on the response coefficients of the inputs was utilized to analyze the sensitivity of energy inputs on almond yield. The MPP of a factor implies the change in the total output with a unit change in the factor input, assuming all other factors are fixed at their geometric mean level. As shown in Table 7, the major MPP was drown for water energy (4.55), followed by biocides energy (4.03). This indicates that additional utilize of 1MJ for each of the water and biocides energy would result in an increase in yield by 4.55kg and 4.03 kg, respectively. Also the MPP of Diesel fuel, Machinery and Chemical fertilizers energy were found to be -0.55,-0.71 and -0.18; a negative value of MPP of inputs mentions that additional units of inputs are contributing negatively to production, i.e. less production with more input (Erdalet al., 2007).

According to the result of Table 8,the MPP of direct, indirect, renewable and non-renewable energy was found to be 0.17, 1, 2.15 and 0.06, respectively. This indicates that an additional use of 1 MJ of each of direct, indirect, renewable and non-renewable energy would lead to an additional increase in yield by 0.17, 1, 2.15, 0.06 kg, respectively. It is concluded that impact of renewable energy was higher than that of non-renewable energy in almond production, which is in agreement with the literatures for different crops (Yilmaz et al., 2005; Tabatabaieet al., 2013).

4 Conclusions

The aim of this study was to analyze impact of a particular energy input level on almond yield in Shahrekord region, Iran. Based on the results of the investigations, the following conclusions were drawn:

(1) Total energy input for almond production was found to be 106.61GJ/ha and energy output was calculated as 39.26GJ/ha. Electricity showed as the most energy consuming input followed by chemical fertilizers and farmyard manure .

(2) Energy use efficiency, energy productivity, and net energy were 0.37, 0.016 kg/MJ, and -67350.16MJ/ha, respectively.

(3) The total GHG emissions were calculated as 4047.46 kg CO_2eq./ha. Diesel fuel with a share of 79.99% played the most important role on the total GHG emission and it was followed by Nitrogen (6.51%), and machinery (6.4%).

(4) The ratios of non-renewable energy are more than renewable energy (89% and 11%). Therefore, it is clear that almond production depended on non-renewable energy consumption.

(5) The impact of energy inputs could have positive effect on yield (except for diesel fuel, machinery and chemical fertilizers energies).

(6) The MPP value of water energy (4.55) was the highest, followed by biocides energy (4.03).

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