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An Analysis of Energy input-output and Emissions of Greenhouse Gases from Agricultural Productions

Reza ABDI[1] Morteza TAKI[2*] Mohammad AKBARPOUR[1]

[1] Department of Agricultural Machinery Engineering, University of Tabriz, IRAN

[2] Young Researches Club Shahreza Branch, Islamic Azad University, Shahreza, IRAN

***Corresponding Author**
e-mail: mtaki88@ms.tabrizu.ac.ir

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Abstract

The aim of this study was to examine the energy use patterns and energy input–output analysis of some field crops and vegetables in the Esfahan province of Iran. The data were collected using a face-to-face questionnaire method. The results indicated that total energy input for wheat, corn silage, cucumber and tomato production was to 69373, 109659, 152553 and 147108 MJha–1, respectively. Among all inputs involved, fertilizer and machinery had the highest energy values per 1 hectare for field crops; furthermore, diesel fuel had the highest share of total energy consumption for vegetable productions. The value of energy ratio for cultivating wheat, corn silage, cucumber and tomato crops were calculated at 0.74, 2.55, 0.46 and 0.73, respectively. The results of CO2 emission analyzes showed that the total amount of CO2 emission for wheat, corn silage, cucumber and tomato production was 2.07, 4.35, 4.99 and 4.66 tones ha-1, respectively. In the research area, greenhouse operators are still increasing the amount of inputs used in vegetable production. However, the timing of any applications and use of the inputs are not significant issues for the Iranian greenhouse producer. This inevitably leads to problems associated with energy use such as global warming, nutrient loading and pesticide pollution, as indicated above. Therefore, there is a need to develop a new policy to force producers to use all inputs on time and enough undertake more energy–efficient practices.

Keywords: Energy utilization; Field crop; Vegetable; Energy ratio

INTRODUCTION

Agriculture is both a producer and consumer of energy. It uses large quantities of locally available non-commercial energy, such as seed, manure and animate energy, as well as commercial energies, directly and indirectly, in the form of diesel, electricity, fertilizer, plant protection, chemical, irrigation water, machinery etc. Efficient use of these energies helps to achieve increased production and productivity and contributes to the profitability and competitiveness of agriculture sustainability in rural living [1]. Energy input–output relationships in cropping systems vary with crops being grown in sequence, by type of soils, nature of tillage operations for seedbed preparation, nature and amount of organic manure, chemical fertilizer, plant protection measures, harvesting and threshing operations and, finally, yield levels [2].

Cetin and vardar [3] studied on differentiation of direct and indirect energy inputs in agro industrial production of tomatoes. Erdal et al. [4] have studied on energy consumption and economical analysis of sugar beet production. Damirjan et al. [5] studied the energy and economic analysis of sweet cherry production. Alam, et al. [6] studied the energy flow in agriculture of Bangladesh for a period of 20 years. Satori et al. [7] studied the comparison of energy consumption on two farming system of conservation and organic in Italy. In recent years, Data Envelopment Analysis (DEA) as a non-parametric method has become a central technique in productivity and efficiency analysis applied in different aspects of economics and management sciences. Although within this context, several researchers have focused on determining efficiency in agricultural units and various products ranging from cultivation and horticulture to aquaculture and animal husbandry for example: surveying the quantity of inefficient resources which are used in cotton production in Panjab in Pakistan [8], reviewing energy performance used in paddy production [9], surveying improving energy efficiency for garlic production [10], evaluation and development of optimum consumption of energy resources in greenhouse cultivation in Tehran province [11], checking the efficiency and returning to the scale of rice farmers in four different areas of Panjab state in India by using Non-parametric method of data envelopment analysis [12], determination of the amount of energy consumption in wheat cultivation of Fars province with the approach of data envelopment analysis [13]. A further comparative review of frontier studies on agricultural products can be found in [14-18].

The Esfahan region is one of the most important agricultural production areas in Iran. Different geographical and climatic characteristics increase the variety of crop patterns, and irrigated farms have an important economical value in the province. The farmers grow many agricultural products, such as field crops, vegetables, fruits, flowers, etc. The main objective of this research was to investigate the energy use patterns, examine the greenhouse gas emission and analyze the energy input–output in the cultivation of some field crops and vegetables in Esfahan province of Iran.

MATERIALS AND METHODS

Case Study and Data Collection

This study was conducted in Esfahan province of Iran. This province is located within 30° 42' and 34° 30' north latitude and 49° 36' and 55° 32' east longitude. Data were collected through personal interview method in a specially designed schedule for this study. The collected data belonged to the 2009/10 production year. Before collecting data, a pre-test survey was conducted by a group of randomly selected farmers. The required sample size was determined using simple random sampling method. The equation is as below [19]:

$$n = \frac{\sum N_h S_h}{N^2 D^2 + \sum N_H S_h^2} \quad (1)$$

where n is the required sample size; N is the number of total population; N_h is the number of the population in the h stratification; S_h is the standard deviation in the h stratification, S_h^2 is the variance in the h stratification, D^2 is equal to $\frac{d^2}{z^2}$; d is the precision, $(\bar{x} - \bar{X})$ (5%) is the permissible error and z is the reliability coefficient (1.96, which represents 95% reliability). Thus the sample size for field crops and vegetables were found to be 65 and 30, respectively. Consequently, based on the number of field crops producers and vegetable greenhouses in each village the 65 field crops farmers and 30 greenhouses from the population were randomly selected.

Energy Equivalents of Inputs and Output

Energy is primarily used in agricultural operations for autumn tillage, seedbed preparation, sowing, planting, hoeing–weeding, bund making (ridging), irrigation, fertilizer application, spraying, harvesting–threshing and transportation. The energy equivalents given in Table 1 were used to calculate the input amounts. The production energy of tractors and agricultural machines was calculated by using the following equation [20]:

$$M_{pe} = \frac{G \; M_p}{TW} \quad (2)$$

Where M_{pe} is the energy of the machine per unit area, MJha^{-1}, G is the mass of machine, kg; M_p is the energy consumption for production 1 kg of machine, MJkg^{-1}; T is the economic life, h; and W is the effective field capacity, hah^{-1}.

The Diesel energy requirement was determined on the basis of fuel consumption, l h^{-1}. The data were converted into energy units and expressed in MJha^{-1}. The following equation was used in the calculation of fuel consumption [21]:

$$FC = P_m \times R \times SFC \quad (3)$$

Where FC is the fuel consumption, l h^{-1}; P_m is the tractor power, kW; R is the loading ratio, decimal; and SFC is the specific fuel consumption (0.300 l kWh^{-1}).

In this study the fuel requirements of water pumps (stationary type) and combine harvesters were measured by the following method: the fuel tank of the engine was completely filled before starting the field test, and the quantity of fuel required to fill the tank after performing the field test was measured using a 1 L graduated cylinder. Thus, the fuel consumed during the test was determined [21].

Table.1. Energy equivalences of inputs and outputs

Energy source	Units	MJ	References
1. Human power	-		-
Man	h	1.96	[22]
Woman	h	1.57	[22]
2. Chemical fertilizer	-	-	-
N	kg	66.14	[22]
P_2O_5	kg	12.44	[22]
K_2O	kg	11.15	[22]
3. Diesel fuel	L	47.8	[23]
4. Tractor	kg	93.61	[23]
5. Agricultural machinery	kg	62.7	[23]
6. Combine	kg	87.63	[23]
7. Chemical poison	kg	-	-
Herbicides		238	[24]
Fungicides		216	[24]
Insecticides		101.2	[24]
8.Farmyard manure	kg	0.3	[25]
9.Nylon	kg	60	[23]
10. Seed	-	-	-
11. Water for irrigation	m^3	1.02	[24]
Wheat	kg	15.7	[24]
Corn Seed (hybrid)	kg	100	[26]
Tomato	unit	1.00	[27]
Cucumber	unit	1.00	[24]
12. Electricity	kWh	11.93	[24]
Wheat	kg	15.7	[24]
Corn Seed (hybrid)	kg	100	[26]
Tomato	kg	1.00	[27]
Cucumber	kg	1.00	[24]
13. Output	-		-
Wheat	kg	14.7	[24]
dry matter corn silage	kg	8	[26]
Tomato	kg	0.8	[28]
Cucumber	kg	0.8	[28]

Based on the energy equivalents of the inputs and output (Table 1), the energy ratio (energy use efficiency), energy productivity, specific energy and net energy gain were calculated [29]:

$$\text{Energy ratio} = \frac{\text{Energy Output (MJ ha}^{-1})}{\text{Energy Input (MJ ha}^{-1})} \quad (4)$$

$$\text{Energy productivity} = \frac{\text{Yield (kg ha}^{-1})}{\text{Energy Input (MJ ha}^{-1})} \quad (5)$$

$$\text{Specific energy} = \frac{\text{Energy input (MJ ha}^{-1})}{\text{Yield (kg ha}^{-1})} \quad (6)$$

$$\text{Net energy} = \text{Energy Output (MJ ha}^{-1}) - \text{Energy Input (MJ ha}^{-1}) \quad (7)$$

The output-input energy ratio (energy use efficiency) is one of the indices that show the energy efficiency of agriculture. In particular, this ratio, which is calculated by the ratio of input fossil fuel energy and output food energy, has been used to express the ineffectiveness of crop production in developed countries [30]. An increase in the ratio indicates improvement in energy efficiency, and vice versa. Changes in efficiency can be both short and long term, and will often reflect changes in technology, government policies, weather patterns, or farm management practices. By carefully evaluating the ratios, it is possible to determine trends in the energy efficiency of agricultural production, and to explain these trends by attributing each change to various occurrences within the industry [30].

RESULTS AND DISCUSSION

Energy Use Pattern

The components of the energy use pattern for cultivating the field crops and vegetables are shown in Table 2.

Vegetable Productions

As it can be seen in the Table 2, 315 kg nitrogen, 371 kg Phosphate, 285 kg potassium, 21 tons of farm fertilizer, 985 l diesel fuel, 3716 m^3 water, 9.7 kg chemical spraying agents, 5815 h human power, 52 h machinery, 1200Kwh electrical energy per hectare are used for the production of tomato in Esfahan province of Iran. The average tomato output were found to be 135000 kg ha^{-1} in the enterprises that were analyzed. The energy equivalent of this is calculated as 108000 $MJha^{-1}$. finally, the energy used in the production of tomato consists of 2% chemicals, 10% human power, 3% machinery, 30% fertilizers, 40% fuel (diesel), 12% electricity and 3% water inputs. The highest energy input is provided by diesel fuel.

As indicated in the table2, about 10 kg chemicals, 871 kg chemical fertilizer and 14.2 tones manure were used in greenhouse cucumber production on a hectare basis. The use of human power and machinery were 3789 and 40hha^{-1}, respectively. Average cucumber yield was 88123 kg ha^{-1}. The total energy input was calculated 124447 $MJha^{-1}$. Diesel fuel was the energy input in the total with a share of 45%. This was followed by fertilizers (25%) and electricity (20%). The distributions of inputs used in the production of cucumber and tomato are given in Fig 1. Mobtaker et al. [31] applied a parametric method to establish relationship between the yield and total energy input for alfalfa production in Iran. Their result showed that the total energy input for various processes in the alfalfa production was calculated to be 810.57 $GJha^{-1}$ and machinery energy was the most significant input affecting the output level.

Omid et al. [32] concluded that the input energy for cucumber production was to be 152908 $MJha^{-1}$ and the average inputs energy consumption was highest for diesel fuel, total chemical fertilizer and electricity. Similar results have been reported in the literature that the energy input of diesel fuel and chemical fertilizers has the biggest share of the total energy input in agricultural crops production [4, 27, 33, 34].

Table.2. The physical inputs used in the production of tomato, cucumber, wheat and corn silage and their energy equivalences

Particulars	Field crops				Vegetables			
Inputs	Wheat		Corn silage		Cucumber		Tomato	
	Amount	MJ	Amount	MJ	Amount	MJ	Amount	MJ
1. Chemicals	23 kg	5474	30 kg	6460	10.1 kg	1754	9.7 kg	1717
Herbicides	23 kg	5474	20 kg	4760	2.5 kg	595	3.1 kg	737
Fungicides	-	-	6 kg	1296	3.4 kg	734	2.7 kg	584
Insecticides	-	-	4 kg	404	4.2 kg	425	3.9 kg	394.9
2. Human power	192 h	378	871 h	1707	3789 h	7426	5815 h	11397
3. Machinery	89 h	5580	497 h	32251	40 h	2592	52 h	3389
4. Fertilizer	316 kg	13724	550 kg	20073	871 kg	26352	971 kg	28626
Nitrogen fertilizer	183 kg	12103	250 kg	16535	295 kg	19511	315 kg	20834
Phosphate	108 kg	1343	150 kg	1866	325kg	4043	371 kg	4615
Potassium	25 kg	278	150 kg	1672	251 kg	2798	285 kg	3177
5. Manure	-	-	10 ton	3031	14.2 ton	4304	21 ton	6425
6. Seeds	277 kg	4348	32.1 kg	3210	0.15 kg	0.12	0.1 kg	0.1
7. Diesel fuel	208 l	9983	207 l	9862	1165 l	55687	985 l	47106
8. Electricity	-	-	-	-	2056 kWh	24528	1200 kWh	14316
9. Water	9498 m^3	9688	6403 m^3	6532	1769 m^3	1804	3716 m^3	3790
Total energy input	-	69373	-	109659	-	152553	-	147108
Yield	3500 kg	51450	35000 kg	280000	88123 kg	70498	135000 kg	108000

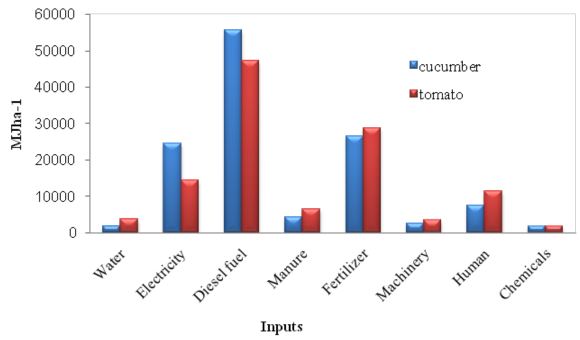

Fig.1. Comparison between energy inputs consumption for tomato and cucumber.

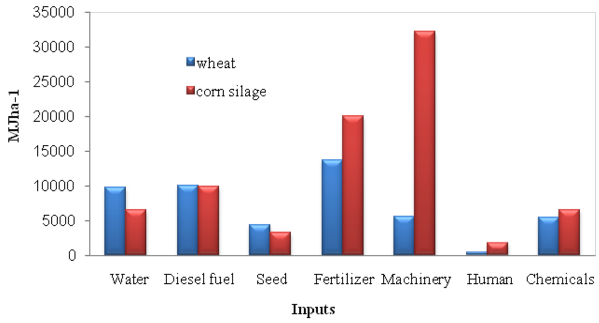

Fig.2. Comparison between energy inputs consumption for wheat and corn silage.

Field Crop Productions

For the corn silage as it can be seen in the Table 2, 250 kg nitrogen, 150 kg Phosphate, 150 kg potassium, 10 tons of farm fertilizer, 207 l diesel fuel, 6403 m^3 water, 30 kg chemical poisons, 871 h human power and 497 h machinery per hectare are used for the production of corn silage in Esfahan province of Iran. The average corn silage output was found to be 35000 kg ha^{-1}. The energy equivalent of this is calculated as 280000 $MJha^{-1}$. The energy used in the production of corn silage consists of 7.77% chemical poisons, 2.04% human power, 38.8% machinery, 24.5% chemical fertilizers, 11.85% diesel fuel, 3.64% manure and 7.85% water inputs. The highest energy input is provided by machinery.

For the wheat crop, the total energy requirement consumed in various energy sources was calculated to be 69373 $MJha^{-1}$. The fertilizer application was found to be the highest energy source in total inputs, with a share of 28%. It was followed by diesel fuel (20%) and water for irrigation (19%). All of the field operations are performed using agricultural implements. So, the share of human power usage remained at the level of 0.7%. Also, seeds and chemical energies were found to be low, with shares of 8% and 11%, respectively. The average yield of the wheat crop was determined to be 3500 kg ha^{-1}. The share of energy consumption for all inputs was shown in Fig.2

The results of corn silage were similar to Pishgar Komleh et al. [26] where machinery and chemical fertilizer were major energy inputs. Amanlou et al. [35] found chemical fertilizers as the highest energy consumer that followed by diesel fuel and fertilizers for corn silage production in Zanjan province of Iran. With lack of enough studies in forage crop the results of this study were compared to other crops. Yilmaz et al. [36] found that fertilizers and machinery energy consumption of cotton production was high. Pervanchon et al. [37] found machinery and fertilizers inputs as highest energy consumer in potato production with share of 48% and 33%, respectively. In a similar study [13], total energy inputs for wheat production in Fars province of Iran were reported to be 38589 $MJha^{-1}$. The results showed that the most energy consuming input for wheat production in the different farms investigated was fertilizer and chemicals.

Energy Indices in Field Crops and Vegetables

The energy ratio (energy use efficiency), energy productivity, specific energy, net energy gain and the distribution of inputs used in the production of wheat, corn silage, tomato and cucumber production according to the direct, indirect, renewable and non-renewable energy groups, are given in Table 3.

Table.3. Energy output–input ratio and type of energy forms for crop field and vegetables productions

Items	Unit	Cucumber	Tomato	Wheat	Corn silage
Energy ratio	-	0.46	0.73	0.74	2.55
Energy productivity	$kgMJ^{-1}$	0.58	0.92	0.05	0.32
Specific energy	$MJkg^{-1}$	1.72	1.08	20	3.1
Net energy	$MJha^{-1}$	-82055	-39108	-17923	170341
Direct energy [a]	$MJha^{-1}$	87641.4	76611	20049	18101
Indirect energy [b]	$MJha^{-1}$	35002.12	40157.4	29126	65025
Renewable energy [c]	$MJha^{-1}$	11730.52	21613.8	14414	7984
Non- renewable energy [d]	$MJha^{-1}$	110913	95154.5	34761	75142
Total energy input	$MJha^{-1}$	152553	147108	69373	109659
Energy output	$MJha^{-1}$	70498	108000	51450	280000

[a] include human power, fuel, water for irrigation and electricity power
[b] include the Chemical poisons, fertilizers, seeds and machinery
[c] include human power, seeds and manure fertilizers
[d] include fuel, electricity, Chemical poisons, water for irrigation, fertilizers and machinery

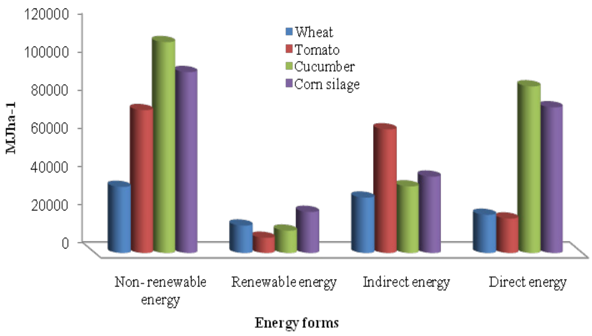

Fig.3. Comparison between the share of energy forms for field crops and vegetable productions.

The ratio of renewable energy including the energies of human power, seed and farm fertilizer inputs, within the total energy in all productions is very low (Fig. 3). Renewable energy resources (solar, hydroelectric, biomass, wind, ocean and geothermal energy) are inexhaustible and offer many environmental benefits over conventional energy sources. Each type of renewable energy also has its own special advantages that make it uniquely suited to certain applications [38].

The use of renewable energy offers a range of exceptional benefits, including: a decrease in external energy dependence; a boost to local and regional component manufacturing industries; promotion of regional engineering and consultancy services specializing in the use of renewable energy, decrease in impact of electricity production and transformation; increase in the level of services for the rural population; creation of employment, etc [39]. Within the enterprises that were analyzed, the share of non-renewable energy for wheat, corn silage, cucumber and tomato production was 70%, 91%, 89% and 81%, respectively. Several researchers have found similar results that the share of non-renewable energy is greater than that of renewable energy consumption [40].

The energy ratio in table 3 was calculated as 0.74 and 2.55 for wheat and corn silage and 0.46 and 0.73 for cucumber and tomato production. The results of Amanlou et al. [35] and Pishgar Komleh et al. [26] researches indicated 1.63 and 2.27 for energy ratio value of corn silage in Iran. The higher value of energy ratio for wheat and corn silage in this region can be explained by the efficiency of irrigation kennel and optimization of chemical fertilizer that affect in total energy consumption. The results of table 3 showed that the energy ratio was low for vegetable production in Esfahan Province. The reason of low energy ratio in this research in comparison with other researches may be including: low yield, using high energy inputs consumption, not being insulate for roof and walls, etc. It is clear that the use of renewable energy in this region is very low, indicating that tomato and cucumber production depends mainly on fossil fuels. By raising the crop yield, decreasing energy inputs consumption, insulate the roof and walls, use of renewable energy and optimization of energy consumption the energy ratio can be increased. Other authors reported similar results for vegetable production such as 0.69 [41], 0.76 [40] and 0.64 [29].

Energy productivity for wheat, corn silage, cucumber and tomato production was calculated 0.05, 0.32, 0.58 and 0.92 MJkg^{-1}, respectively. The net energy of field crops and vegetables was positive and negative, respectively. It indicates that in field crops energy is gained (net energy is greater than zero) and in vegetable productions energy is losses. In literature, similar results have been reported [2, 4]. Pishgar Komleh et al. [26] studied energy efficiency, energy productivity, specific energy and net energy for corn silage which amount of above indices were reported as 2.27, 0.28 kgMJ^{-1}, 3.76 MJ kg^{-1} and 79452 MJ ha^{-1}, respectively.

Greenhouse Gas Emission for Field Crops and Vegetable Productions

In this research GHG emissions were the scope of this analysis and the corresponding amount was calculated. The diesel fuel combustion can be expressed as fossil CO_2 emissions with equivalent of 2764.2 gL^{-1} [26]. Also, the machinery and fertilizer supply terms can be expressed in terms of the fossil energy required to manufacture and transport them to the farm with CO_2 equivalents of 0.071 TgPJ^{-1} and 0.058 TgPJ^{-1} for machinery and chemical fertilizers, respectively [26].

Table 4 shows the CO_2 emission for wheat, corn silage, tomato and cucumber production in actual energy use. Results of this table indicated that vegetable productions are mostly depending on diesel fuel sources. Diesel fuel had the highest share (64.33% and 58.37% for cucumber and tomato) followed by machinery and chemical fertilizer. As it can be seen in Table 4, the total amount of CO_2 emission was 4.99 and 4.66 tones ha^{-1} for cucumber and tomato, respectively. As it can be seen, in corn silage and wheat production, machinery and chemical fertilizer had the highest share of total CO_2 emission. Finally, table 4 showed that the CO_2 emission for vegetable productions is more than field crops.

Table.4. Amount of greenhouse gas emission for wheat, corn silage,tomato and cucumber production

Input	Equivalent (Tg (CO_2) PJ^{-1})	Quantity of CO_2 emission (ton)			
Inputs		Wheat	Corn silage	Tomato	Cucumber
Diesel fuel	0.0578	0.57 (27.54%)	0.57 (13.10%)	2.72(58.37%)	3.21 (64.33%)
Machinery	0.071	0.39 (18.84%)	2.28 (52.42%)	0.24 (5.15%)	0.18 (3.61%)
Chemical fertilizer and poison	0.058	1.11 (53.62%)	1.50 (34.48%)	1.70 (36.48%)	1.60 (32.06%)
Total	-	2.07	4.35	4.66	4.99

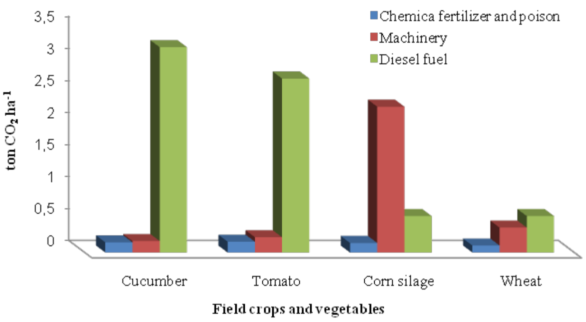

Fig.4. Comparison between the field crops and vegetables to produce CO2

Using ethanol and biodiesel as biofuel is essential in the 21st century to reduce the high GHG emissions. Field operations with minimum machinery use (especially tillage operation) and machinery production are needed to be considered to reduce the amount of CO_2. Eady et al. [42] applied the Life cycle assessment modeling of complex agricultural systems with multiple food and fibre co-products. They reported that amongst the crops, estimates of emissions for the cereal grains averaged 202 kg CO_2-e/tonne grain, canola 222 kg CO_2-e/tonne and lupins 510 kg CO_2-e/tonne, when modeled to include the benefits of the mixed farming system. Gunady et al. [43] used the Life Cycle Assessment for evaluating the global warming potential of the fresh produce supply chain for strawberries, romaine/cos lettuces and button mushrooms in Western Australia. Results showed that the life cycle GHG emissions of strawberries and lettuces were higher than mushrooms due to intensive agricultural machinery operations during the on-farm stage. Mushrooms, however have significantly higher GHG emissions during pre-farm stage due to transport of peat, spawn, and compost.

CONCLUSION

Based on the results of this paper it can be stated that:

1. The total energy requirements for cultivating the field crops and vegetables were found in the range of 69373–109659 MJ ha^{-1} and 147108–152553 $MJha^{-1}$, respectively. In energy sources, the fertilizer and machinery had the maximum energy values for field crops and diesel fuel had the highest share of total energy consumption for vegetable productions.

2. The values of the energy ratio for cultivating the field crops and vegetables varied in the range of 0.74–2.55 and 0.46–0.73, respectively. Also, the values of specific energy consumption for wheat, corn silage, cucumber and tomato cultivation were found to be 20, 3.1, 1.72 and 1.08 $MJkg^{-1}$ respectively.

3. In this research the ratio of renewable energy within the total energy in all productions is very low. The share of non-renewable energy for wheat, corn silage, cucumber and tomato production was 70%, 91%, 89% and 81%, respectively.

4. The results of CO_2 emission analyzes showed that the diesel fuel had the highest share of total CO_2 emission for vegetable productions. The total amount of CO_2 emission was 2.07, 4.35, 4.99 and 4.66 $tonha^{-1}$ for wheat, corn silage, cucumber and tomato, respectively.

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