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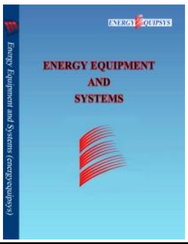

Comparison of energy consumption and greenhouse gas emission footprint caused by agricultural products in greenhouses and open fields in Iran

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ABSTRACT

Decisions can be taken to increase energy efficiency and to mitigate emission to the environment by examining the energy audit and the greenhouse gas (GHG) emission footprint of crop production in different ways and in different regions, which have comparable principles. In this study, the energy consumption and energy indices of tomato production in four regions of Iran, which include an East Azerbaijan province (open-field system), the provinces of Kermanshah, Tehran, and Isfahan (greenhouse system) were compared using data from related articles. Chemical fertilizers and the irrigation water used in tomato production in open fields, and the diesel fuel and chemical fertilizers used in tomato production in the greenhouse system were the greatest energy consumers in Iran. The energy consumption of irrigation water for tomato production in an open field was markedly higher than tomato production in a greenhouse. In this study, the GHG emission footprint inputs of machinery, diesel fuel, chemical fertilizers, chemicals, plastics, and electricity used in the production of tomatoes were calculated via coefficients related to GHG emission. The highest and the lowest greenhouse gas emission during tomato production in greenhouses in farms within the provinces of Tehran and East Azerbaijan were determined to be 13661.37 $kgCO_2eq\ ha^{-1}$ and 1274.02 $kgCO_2eq\ ha^{-1}$, respectively. Overall, tomato production in open fields leads to lower greenhouse gas emission and energy consumption per unit area, but according to the greater energy output in the cultivation of tomatoes within a greenhouse, the energy efficiency of tomato production in greenhouses was higher.

Keywords: Energy Efficiency, Energy Audit, Environment, Pollutants.

1. Introduction

The area under cultivation and the production rate of tomatoes in Iran is estimated to be about 162 hectares and 6 million tons, respectively; this is, respectively, 3.1% and 2.7% of the total harvested area and the production rate of agricultural crops. Tomato production constitutes 31% of the total vegetable production in Iran (AJMDC, 2012). According to the present energy crisis, considering the energy flow of agricultural crop production will be of great importance in the upcoming years; on the other hand, the consumption of energy resources has a direct relationship with various factors such as the

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environmental impacts, which depend on the technology used in the consumption of energy resources. In this regard, in recent years, studies exploring the review of the energy flow and environmental impact of the production of different agricultural crops have been conducted across various regions of Iran. A study was conducted to investigate the energy input and output of 19 major agricultural products in Iran between the years 1990 and 2006. During this period, the results of this study showed that energy efficiency increased from 0.95 in 1996 to 1.17 in 2006. The average energy efficiency of tomato production throughout this period was reported as 0.47 (Beheshti-Tabar et al., 2010). Many studies have been conducted on the energy audit and the greenhouse gases (GHG) emission footprint produced by agricultural products in Iran. In the investigation of GHG emission and the energy analysis of cotton production in the Golestan province, the amount of GHG emission was calculated as 1430.18 kgCO_2eq ha^{-1} and an energy efficiency of 1.58 was reported (Taheri-Rad et al., 2015).

Brentrup et al. (2001) reported that greenhouse cultivation has an advantage in that the environmental parameters which affect plant growth, including air temperature, sunlight and composition, can be controlled; however, some material inputs, especially the use of chemical fertilizers, can result in significant environmental hazards. Khoshnevisan et al. (2013) studied the environmental impacts of cucumber and tomato cultivation under greenhouses in Iran. They claimed that cucumber production in greenhouses had higher environmental burdens than that of tomatoes. Cetin et al. (2008) performed a study on the energy audit of tomato production in the open-field system in Turkey. The results highlighted that the energy use efficiency and the energy productivity were 0.8 and 0.99 kgMJ^{-1}, respectively. In another study that was carried out by Hatirli et al. (2006), the energy use efficiency and the energy productivity for tomato production in the greenhouse system in Turkey were reported as 1.2 and 0.09 kgMJ^{-1}, respectively.

The investigation of the energy audit and the GHG emission footprint of crop production in different ways and in different regions with systematic methods of comparison makes it possible to achieve the best practices and methods of production as well as to take decisions in order to increase energy efficiency and to reduce the emission of pollutants into the environment. A review of relevant literature disclosed that a comparison between energy consumption and GHG emission caused by agricultural products grown in greenhouses and products cultivated on the open fields of Iran had not been studied. Therefore, this study aimed to estimate the GHG emission caused by the consumption of inputs in the production system of tomatoes, and to compare the input and output energies as well as the energy indicators in the greenhouse and the open-field tomato production in Iran.

2.Materials and methods

2.1. Site of study

In this study, the energy consumption of tomato production in four regions of the East Azerbaijan province (open-field production), the provinces of Kermanshah, Tehran, and Isfahan (each employing greenhouse production) were evaluated. The sites of study are shown in Fig.1. The energy production of tomatoes and the energy indices in the four regions of the East Azerbaijan province (open field), and the provinces of Kermanshah, Tehran, and Isfahan (greenhouse) were compared using data from related articles.

2.2. Energy and GHG emission analysis

Data input and output energies, and energy indices were derived from previously conducted studies (Rahmati et al., 2012; Heidari and Omid, 2011; Taki et al., 2013; Raei Jadidi et al., 2010). In this study, the greenhouse gas emission inputs of machinery, diesel fuel, chemical fertilizers, chemicals, plastics, and electricity were evaluated. The GHG emission footprints for tomato production in these four regions were calculated via coefficients related to greenhouse gas emission as shown in Table 1. The GHG emission footprints of the machinery contribute to emission in manufacturing and using these inputs on the farm (Mobtaker et al.). All the calculations were performed using Microsoft Excel 2010 and JMP8.

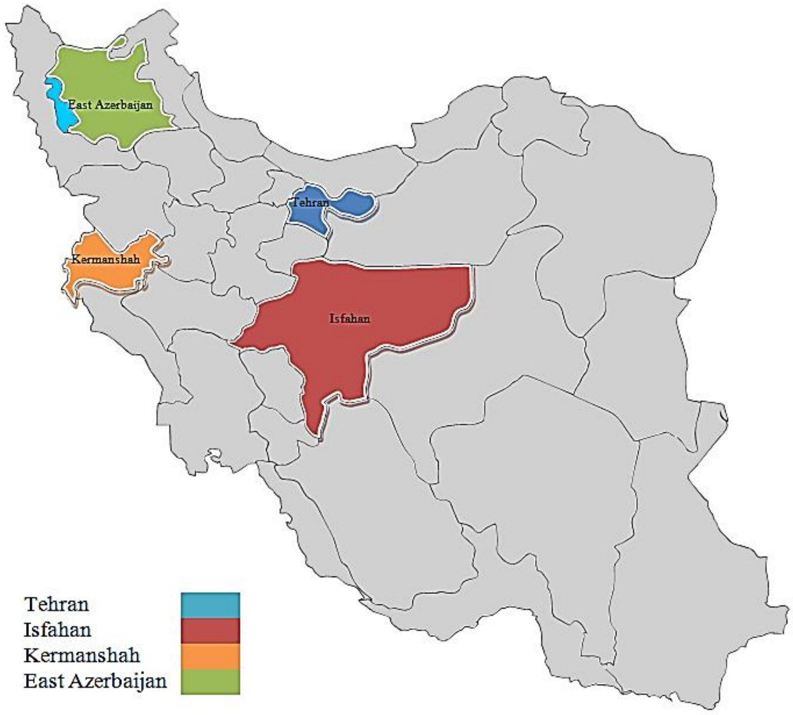

Fig.1. The studied regions

Table 1. Greenhouse gas emission coefficients of agricultural inputs

Inputs	Unit	Greenhouse gas emission coefficients (kg CO_2eq unit^{-1})	Reference
Machinery	MJ	0.071	(Dyer and Desjardins, 2006)
Diesel fuel	Li	2.76	(Dyer and Desjardins, 2006)
Nitrogen	Kg	1.3	(Lal, 2004)
Phosphate	Kg	0.2	(Lal, 2004)
Potassium	Kg	0.2	(Lal, 2004)
Fungicide	Kg	3.9	(Lal, 2004)
Insecticide	Kg	5.1	(Lal, 2004)
Herbicide	kg	6.3	(Lal, 2004)
Plastic	kg	90	(Canakci and Akinci, 2006)
Electricity	kWh	0.608	(Lal, 2004)

3.Results and discussion

3.1. Energy input-output results

The input and output energies of tomato production systems in the four regions of Iran, including the provinces of East Azerbaijan, Kermanshah, Isfahan, and Tehran are shown in Table 2. The input of chemical fertilizers was the largest consumer of energy in the East Azerbaijan province and the Kermanshah province, followed by the input of diesel fuel in Kermanshah and the input of water for irrigation in the East Azerbaijan province, which were considered as the second largest consumers of energy in tomato production. The two inputs of diesel fuel and chemical fertilizers were the greatest energy consumers of inputs in the provinces of Isfahan and Tehran. This is in agreement with Hatirli et al. (2006) and Cetin et al. (2008) who suggested that the diesel fuel and chemical fertilizers inputs were the highest consumers of energy in the production of tomatoes in the open-field and the greenhouse production systems in Turkey. Pishgar-Komleh et al. (2013), studying cucumber production in the Yazd province of Iran, and Mohammadi and Omid (2010), studying cucumber production in the Tehran province of Iran, reported that diesel fuel had the largest contributions to the total energy inputs.

The amounts of water for irrigation for tomato production in the East Azerbaijan province, the Isfahan province, the Kermanshah province, and the Isfahan province were 13222.55, 3715.69, 1062.22, and 1039.08 m^3, respectively. As observable in Table 2, the amount of water required for irrigation for tomato production in an open field is much more than the corresponding requirement for the production of tomatoes under greenhouse conditions. 20.67% of the input energy of tomato production in the East Azerbaijan province is allocated to water for irrigation. The total energy inputs for tomato production in the Tehran province, the Kermanshah province, the Isfahan province, and the East Azerbaijan province were obtained as 131634.2, 123098.6, 116768.4, and 65238.9 MJ ha^{-1}, respectively. The tomato yield in the Tehran province, the Kermanshah province, the Isfahan province, and the East Azerbaijan province were reported as 195232.05, 152341.47, 135000, and 47228.3 kg.ha^{-1}, respectively. The highest and the lowest energy outputs were reported for the Tehran province and the East Azerbaijan province. These results highlighted that the energy consumption for tomato production under the greenhouse systems was higher than that of the open-field systems. The energy consumption for tomato production in the open-field and the greenhouse systems in Turkey were reported as 45539 and 127749 $MJha^{-1}$, respectively (Hatirli et al., 2006; Cetin et al., 2008).

3.2. Energy indices

The energy indices of tomato production in these four regions are shown in Table 3. The energy efficiency of tomato production in the Tehran province, the Kermanshah province, the Isfahan province, and the East Azerbaijan province were 1.48, 0.99, 0.92, and 0.54, respectively. The results showed that the energy use efficiency of tomato production in the open-field production system in East Azerbaijan province was lower than that of the greenhouse production system in other studied regions.

Table 2. The energy audit of tomato production in Iran

	East Azerbaijan (open field)		Tehran (greenhouse)		Isfahan (greenhouse)		Kermanshah (greenhouse)	
	Energy ($MJha^{-1}$)	Percent	Energy ($MJha^{-1}$)	Percent	Energy ($MJha^{-1}$)	percent	Energy ($MJha^{-1}$)	percent
Seed	0.3	0	0.10	0	0.1	0	0.1	0
Human labor	2142.6	3.28	13342.09	10.14	11397	9.76	11045.58	8.9
Machinery	2900.9	4.45	440.66	0.33	3389	2.90	1347.19	1.09
Diesel fuel	8641.7	13.25	65521.94	49.02	47106	40.34	16258.59	13.34
Chemical fertilizers	33261.04	50.98	3160.72	24.02	28626	24.52	49141.36	39.59
-Nitrogen	26877.09	41.19	22010.11	16.72	20834	17.84	43674.4	35.19
-Phosphate	5206.1	7.98	5391.25	4.10	4615	3.95	1969.57	1.59
-Potassium	1177.8	1.80	4202.37	3.19	3177	2.72	3497.39	2.82
Biocide	268	0.41	90	6.89	1716.9	1.47	14723.93	11.86
Farmyard manure	4536.4	6.95	-	-	6425	5.50	16266.37	13.11
Electricity	-	-	2595.96	1.96	14316	12.26	14253.86	11.48
Water for irrigation	13487.9	20.67	1059.86	0.81	3790	3.25	1083.46	0.87
Plastic	-	-	9000	6.84	-	-	-	-
Total energy input	65238.9	100	131634.19	100	116768.4	100	123098.6	100
Total energy output	38581.9	-	156185.64	-	108000	-	121873.2	-

Table 3. Energy indices of tomato production in Iran

	Unit	East Azerbaijan (Open field)	Tehran (Greenhouse)	Isfahan (Greenhouse)	Kermanshah (Greenhouse)
Energy efficiency	-	0.59	0.92	1.48	0.99
Energy productivity	Kg. MJ^{-1}	0.74	1.16	1.38	1.24
Net energy	MJ. Kg^{-1}	1.35	0.86	0.72	0.81
Specific energy	MJ. ha^{-1}	-26657	-8768	63597.86	-1225.43
Direct energy	MJ. ha^{-1}	24279.29	76610	80459.99	42641.5
Indirect energy	MJ. ha^{-1}	40966.66	40158	50114.34	81478.84

The proportions of renewable and non-renewable energy in tomato production in each of the provinces of Iran are shown in Figure 2. The most used renewable energy in the production of tomatoes is related to the Kermanshah province with a total of 28395.41 MJ ha^{-1}. This is a consequence of the frequent use of farmyard manure (containing 11.3% of the input energy), which is the third most used input in this region. In addition, the highest consumption of non-renewable energy was obtained for the Tehran province (117232.14 MJ ha^{-1}), and this was a result of the high consumption of diesel fuel with an amount equalling 1445.83 L. ha^{-1}. The proportion of renewable energy for the greenhouse tomato production system was 12% (Hatirli et al., 2006).

3.3. GHG emission footprint of tomato production

The amount of GHG emission for tomato production in these four regions are provided in Table 4. While the amount of GHG emission for the production of 1000 kg of tomatoes in the Tehran province, the Kermanshah province, the Isfahan province, and the East Azerbaijan province were obtained as 69.97, 32.79, 32.09, and 26.42 kg CO_2eq. ha^{-1}, respectively, the total GHG emission footprint for tomato production in the Tehran province, the Kermanshah province, the Isfahan province, and the East Azerbaijan province were calculated as 13661.37, 4994.72, 4332.72, and 1274.02 kg CO_2eq. ha^{-1}, respectively.

Chemical fertilizers and diesel fuel, plastics and diesel fuel, diesel fuel and electricity, electricity and chemical fertilizers were the inputs that had the highest rate of greenhouse gas emission in the provinces of East

Azerbaijan, Tehran, Isfahan, Kermanshah, respectively, and among all these inputs, the input of plastic had the highest rate of greenhouse gas emission with an amount equalling 9000 kg CO_2eq ha^{-1}. Pishgar-Komleh et al. (2013) analysed the GHG emission of cucumber cultivation in the Yazd province of Iran and found that diesel fuel had the highest GHG emission, followed by electricity.

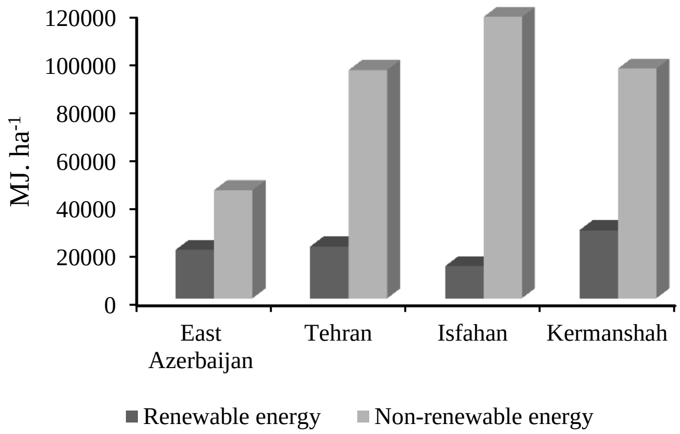

Fig.2. The share of renewable and non-renewable energy in tomato production in each of the provinces of Iran

Table 4. Amount of greenhouse gas emission during tomato production in Iran (kg CO_2eq ha^{-1})

	East Azerbaijan (Open field)		Tehran (Greenhouse)		Isfahan (Greenhouse)		Kermanshah (Greenhouse)	
		Percent		Percent		Percent		Percent
Machinery	95.69	16.17	240.62	0.23	31.29	5.56	205.96	1.19
Diesel fuel	796.90	33.25	2719.98	23.51	3211.52	62.78	423.57	15.95
Chemical fertilizers	952.83	49.69	540.7	4.34	594.67	12.48	633.10	19.08
-Nitrogen	858.43	41.47	409.5	3.17	432.61	9.45	528.28	17.19
-Phosphate	31.66	6.57	74.2	0.63	86.68	1.71	83.70	0.63
-Potassium	62.73	1.66	57	0.55	75.38	1.32	21.13	1.26
Chemicals	95.65	0.89	240.62	2.82	31.29	1.17	205.96	14.86
Electricity	0	0	729.6	3.21	438.43	16.84	2407.32	48.20
Plastic	0	0	9000	65.88	0	0	0	0
Total emissions	1274.02	100	13661.37	100	4332.72	100	4994.72	100

4.Conclusion

The aim of this study was to evaluate the energy consumption and the GHG emission footprint of tomato production in the open-field and the greenhouse systems. The results highlighted that the open-field production system had lower energy inputs in comparison to the greenhouse system. Owing to the high yield of tomato production under the greenhouse system, however, the energy efficiency of tomato production under the conditions of a greenhouse were higher than that of an open-field production system. From the evaluated results, it becomes evident that the diesel fuel consumption of open-field tomato production is the main input for improving the energy efficiency and the GHG emission footprint of production.

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