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Energy use pattern and greenhouse gas emission in systems for greenhouse vegetable production

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Abstract. *Algeria has experienced a notable agricultural development driven by a prosperity in market gardening in plastic greenhouses due of the favorable climatic conditions and the government's policy. For that, a survey has been conducted in order to determine the energy use pattern for greenhouse vegetable production, also to estimate the greenhouse gas (GHG) emission for this system of production in Biskra province, Algeria. The results revealed that the total energy required for vegetable protected production is 119.68 GJ per hectare where the infrastructure was the highest energy consumer followed by the electricity and fertilizers with a share of 22%, 20% and 19%, respectively. The energy use efficiency (energy ratio) was calculated as 0.82, showing the inefficiency use of energy in the protected vegetable production. The inputs of farmyard manure, followed by infrastructure and electricity in greenhouse vegetable production generated the highest proportion of gas emissions with values 35%, 33% and 23%, respectively. According to these results, management of electricity and diesel fuel consumption are possible using solar energy to decrease total GHG emission in greenhouse vegetable production in Biskra province.*

Keywords: protected vegetable, greenhouse, energy pattern, Biskra province, Algeria

Introduction

In the two last decades, Algeria has experienced a notable agricultural development driven by a prosperity in market gardening in plastic greenhouses due of the favorable climatic conditions and the government's policy (Nourani and Benchiekh, 2017). As a result of this development, Biskra province becomes the first producer of early vegetables nationally (Allache et al., 2015) where the surface occupied by the greenhouse has increased by 528.52% over the last 20 years (Belhadi et al., 2016).

Taking into account the limited natural resources and the impact of using different energy sources on environment and human health; it is substantial to investigate energy use patterns in agriculture (Samavatean, 2011). Therefore, research efforts have emphasized energy and economic analysis of various agricultural productions for planning resources in the ecosystem (Singh et al., 2002). While several works across the world have been conducted to estimate the energy use in greenhouse vegetable production, such as: Ozkan et al. (2004), Elings et al. (2005), Campiglia et al. (2007), Djevic and Dimitrijevic (2009), Ozkan et al. (2011), Pahlavan et al. (2011), Heidari and Omid (2011), Bojacá et al. (2012), Baptista et al. (2012) and Hedau at al. (2014), in Algeria there is only the work by Nourani and Benchikh (2017).

Global warming is one of the most important issues in recent century, where there is scientific agreement that this phenomenon poses one of the major environmental challenges in the future (Pishgar-Komleh et al. 2012). While the bulk of the so called greenhouse gases originate from fossil fuel consumption (Pathak and Wassmann, 2007), agricultural GHG emissions account for 10 to 12% of all manmade GHG emissions (Brownea et al., 2011). Thus, an understanding of the emissions expressed in kilograms of carbon equivalent (kg CE) for different farm operations is essential to identify C-efficient alternatives such as biofuel and renewable energy sources for seedbed preparation, soil fertility management, pest control and other farm operations (Lal, 2004). Several researches have been conducted on energy and GHG emissions in different agricultural crops productions, showing that chemical fertilizers have the largest share in GHG emission.

Pishgar-Komleh et al. (2012) examined the energy consumption and CO_2 emission of potato production in three different farm sizes in Esfahan province of Iran. They concluded that the total energy consumption and GHG emission is 47 $GJ.ha^{-1}$ and 99 2.88 kg $CO_2eq.ha^{-1}$, respectively. The most significant energy consumer was chemical fertilizers (49%), especially nitrogen (40%), followed by seed with a share of 24%. In a similar study, Soltani et al. (2013) analyzed energy use and GHG emissions in various wheat production scenarios in North-Eastern Iran and to identify measures to reduce energy use and GHG emissions. They estimated that averages of total energy input and output were 15.58 and 94.4 $GJ.ha^{-1}$, respectively and the average across scenarios, GHG emissions of 1137 kg $CO_2eq.ha^{-1}$ and 291 kg $CO_2eq.ha^{-1}$. In another study that was carried out by Mohammadi et al. (2014) the energy flow in farming systems, in the north of Iran, across farm size with their corresponding GHG emissions was compared.

Rajaeifar et al. (2014) performed a research on energy-economic life cycle assessment (LCA) and greenhouse gas emissions analysis of olive oil production in Iran. Theirs results revealed that the total energy consumption through the olive oil life cycle

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was 20344 MJ.ha^{-1} while the total GHG emissions were estimated at 1333 kg.ha^{-1}(CO_2eq). In another research, emissions of greenhouse gases generated by the agricultural activities carried out in Medellin - Colombia were estimated by Guerra et al. (2016) and they found 63.1 and 66 Gg CO_2eq for 2009 and 2011, respectively.

Considering the fact that there is no published work in terms of energy consumption with estimation of GHG emissions of greenhouse vegetable production in Algeria, this study is aimed to analyze the energy use pattern and estimate of GHG emissions generated by the greenhouse vegetable production in Biskra province, southern Algeria.

Material and methods

Description of study area

Biskra province is located at the foot of the southern slope of the Aures massif, where there are two valleys that run through this massive. Biskra is at the Eastern part of Algeria, the first step and the door of the Saharan region. In addition to the water and soil resources which allowed the practice of oasis agriculture, this pivotal position made Biskra a natural relay of the North-South flows. Biskra has a hot desert climate, with very hot and dry summers and mild winters with annual rainfall averaging between 120 and 150mm/year. The average annual temperature is 20.9°C. According to Rekibi (2015), Biskra province occupies over 32% of the national production of protected crops which make it the first producer of early vegetables in Algeria. In addition, no document published estimates the GHG emissions from the infrastructure input. For this reason, this study has been carried out in this region.

Data collection

An investigation was conducted in Biskra province during the season 2014-2015. The study employed face-to-face personal interviews using questionnaires which contain sections providing the economic characteristics, practices and management of the farm. The data have been collected from 65 farmers which present 5% of greenhouse vegetable growers from the six most productive municipalities, namely: M'ziraa, Ainnaga, SidiOkba, Elaghrous, Doucen and Lioua. In this area, the vegetables produced most extensively are tomato, cucumber, eggplant and pepper.

Energy use measurement

Energy requirements in agriculture are divided into two groups, direct and indirect (Samavatean, 2011). In this study, direct energy includes human labor, diesel, water for irrigation and indirect energy includes seeds, fertilizers, farmyard manure, chemicals, machinery and infrastructure. Based on the energy equivalents of the inputs and outputs (Table 1), the metabolisable energy was calculated. Renewable energy (RE) consists of human labor, seed, manure and water for irrigation, whereas non-renewable energy (NRE) includes machinery, diesel fuel, electricity, infrastructure, fertilizers and chemicals.

Table 1. Energy equivalent factors used

Energy source	Unit	Energy equivalent (MJ unit^{-1})	Reference
Inputs			
Human labor	h	1.96	Singh et al. (2002)
Machinery	h	62.7	Singh et al. (2002)
Diesel oil	L	45.4	Bojacá et al. (2012)
Infrastructure	kg		
Steel		33	Medina A et al. (2006)
Polyethylene		9.9	Medina A et al. (2006)
Synthetic fiber		1.2	Medina A et al. (2006)
PVC		11.6	Medina A et al. (2006)
Fertilizers	kg		
N		60.6	Ozkan et al. (2004)
P_2O_5		11.1	Ozkan et al. (2004)
K_2O		6.7	Ozkan et al. (2004)
Farmyard manure	kg	0.3	Bojacá et al. (2012)
Pesticides	kg		
Fungicides		216	Mohammadi and Omid (2010)
Insecticides		101.2	Mohammadi and Omid (2010)
Plant materials			
Plantlets	unit	0.2	Bojacá et al. (2012)
Water for irrigation	m^3	0.63	Bojacá et al. (2012)
Electricity	kWh	3.6	Ozkan et al. (2004)
Output			
Tomato, cucumber, eggplant, pepper	kg	0.8	Ozkan et al. (2004)

Energy flow analysis

To analyse the energy flow, energy ratio (energy use efficiency) (ER), energy net (EN) and energy productivity (EP) indices were calculated as follows:

Output-Input ratio (ER) = Energy output (MJ/ha) / Energy input (MJ/ha),

Energy productivity (EP) = Total output (MJ/ha) / Energy input (MJ/ha),

Energy Net (EN) = Energy output (MJ/ha) - Energy input (MJ/ha),

Specific energy = Energy input (MJ/ha) / Vegetable output (kg/ha),

Energy intensiveness = Energy input (MJ/ha) / Cost of cultivation ($/ha).

Greenhouse gas emission (GHG) estimation

Using machinery in different farm activities, such as: production, transport, formulation, storage, distribution and application of agricultural inputs, needs the fossil fuel energy, which, as a result, emits CO_2 and other GHGs in the atmosphere. Then, an understanding of the emission expressed in kg CO_2 equivalent for different agricultural practices is a necessary step toward identifying environmentally efficient alternatives such as biofuel and renewable energy sources. The present paper focused on estimation of CO_2 emission in greenhouse vegetable production (Lal, 2004). In the current study, the amounts of GHG emissions that can be produced by inputs in different farm operations were estimated by using CO_2 emission coefficient of farm inputs. The coefficients of GHG emission for agriculture inputs are presented in Table 2. The calculation is based on multiplying the amount of energy consumed from each input item in the CO_2 emission coefficient.

Table 2. GHG emission coefficients of agricultural inputs

Input	Unit	GHG Coefficient ($kgCO_2eq.unit^{-1}$)	Reference
1. Machinery	MJ	0.071	Nabavi-Pelesaraei et al. (2014)
2. Diesel fuel	L	2.76	Nabavi-Pelesaraei et al. (2014)
3. Chemical fertilizers	kg		
a. Nitrogen		1.3	Nabavi-Pelesaraei et al. (2014)
b. Phosphate (P_2O_5)		0.2	Nabavi-Pelesaraei et al. (2014)
c. Potassium (K_2O)		0.2	Nabavi-Pelesaraei et al. (2014)
4. Farmyard manure	kg	0.126	Pishgar-Komleh et al. (2013)
5. Infrastructure	kg		
a. Steel		0.768	Hammond and Jones (2008)
b. Polyethylene		2.4	Daniel Posen et al. (2017)
c. Synthetic fiber		1.5	Daniel Posen et al. (2017)
d. PVC		2.2	Daniel Posen et al. (2017)
6. Biocides	kg		
a. Insecticides		5.1	Nabavi-Pelesaraei et al. (2014)
b. Fungicides		3.9	Nabavi-Pelesaraei et al. (2014)
7. Electricity	kWh	0.608	Nabavi-Pelesaraei et al. (2014)

Results and discussion

The data were collected from 65 vegetable protection growers in Biskra province. The average size of greenhouses is around 2.1ha with a range from 0.25 up to 12.75ha. All of the surveyed greenhouses were plastic houses and metallic structures. Also the data showed that almost all superficies covered by greenhouse were irrigated using a drip irrigation and about 73% of the visited farms were privately owned and 27% rented.

Energy consumption results

The summarized information on energy use pattern and yield value of vegetable production is presented in Table 3 along with the percentage distribution of energy inputs.

The results revealed that the total energy required for vegetable protected production is 119.68GJ per hectare. Compared to another study, in Turkey, the consumption of energy by cucumber, tomato, eggplants and pepper were 134.77, 127.32, 98.68 and 80.25 $GJ.ha^{-1}$, respectively (Ozkan et al., 2004). In central Italy the total energy requirements for producing the greenhouse vegetable crops were found in the range of 64.232–142.835 $GJ.ha^{-1}$ (Campiglia et al., 2007). These results indicate that the energy consumption for vegetable greenhouse production is different from one region to another with light variation. Among the different energy sources the infrastructure is the highest energy consumer followed by electricity and fertilizers with a share of 22%, 20% and 19%, respectively. This result is in accordance with that found by A. Medina et al (2006) where the highest portion of the energy use in Colombia comes from the greenhouse construction with 41.29% of the total energy use and the major part of this energy is attributed to the steel.

Table 3. Amounts of inputs and output energy in protected vegetable production

Energy source	Quantity per unit area (ha)	Total energy equivalent (MJ unit^{-1})	Share, %
Input			
Human labor (h)	3457.03	6775.78	5.66
Machinery (h)	31.38	1967.25	1.64
Diesel oil (l)	129.02	5857.41	4.89
Infrastructure (kg)			
Steel	146.68	4840.31	4.04
Polyethylene	2082.54	20617.14	17.23
Synthetic fiber	105.81	126.97	0.11
PVC	130.82	1517.46	1.27
Fertilizers (kg)			
N	278.86	16899.13	14.12
P_2O_5	354.66	3936.76	3.29
K_2O	274.50	1839.16	1.54
Farmyard manure (kg)	47742.54	14322.76	11.97
Pesticides (kg)			
Fungicides	10.30	2224.12	1.86
Insecticides	96.47	9762.64	8.16
Plant materials			
Plantlets (units)	17232	3446.35	2.88
Water for irrigation (m^3)	3154.00	1987.02	1.66
Electricity (kWh)	6544.84	23561.42	19.69
Output			
Tomato, cucumber, eggplant, pepper (kg)	122095.24	97676.19	

The proportion of energy input of farmyard manure, pesticides, human labor, diesel oil, plantlets, water and machinery used for protected vegetable (tomato, cucumber, eggplant, pepper) growing were 12%, 10%, 6%, 5%, 3%, 2% and 1%, respectively. In similar works, in Antalya (Turkey), the results indicated that the bulk of energy consumed by greenhouse winter crop tomato production was consumed in fertilizer (38.22%), electricity (27.09%), manure (17.33%) and diesel-oil (13.65%) (Ozkan et al., 2011), while, among input energy sources, diesel fuel and fertilizers contained the highest energy with 54.17% - 49.02% and 21.64% -24.01%, respectively (Heidari and Omid, 2011). This comparison shows that each region has specificity in terms of energy inputs sharing.

The fertilizers and manure required to fertilize the soil is 48650.56 kg.ha^{-1} with, nearly, a third of total energy consumed (31%), this observation is a common belief that increased use of fertilizer and manure will increase the yield. 3457.03h of human power and 31.38h of machine power are required per hectare of vegetable production in the research area. The crop itinerary is mainly similar for all the greenhouse crops; moreover, it is carried out generally by human labor energy (6%) compared to machinery energy (1%). The source of human labor in the investigated farms is from either family members or mainly from hired (seasonal) labors. Also, 5857.41 MJ.ha^{-1} of diesel fuel is consumed generally for machinery purposes and most of the machineries are mainly rented.

Energy indices analysis

Table 4 presents the energy use efficiency, energy productivity, specific energy, net energy and energy intensiveness of protected vegetable production.

Table 4. Energy parameter in greenhouse vegetable production

Items	Unit	Protected vegetable production
Energy input	MJ ha^{-1}	119681.69
Energy output	MJ ha^{-1}	97676.19
Yield	kg ha^{-1}	122095.24
Energy use efficiency		0.82
Specific energy	MJ kg^{-1}	0.98
Energy productivity	kg MJ^{-1}	1.02
Net energy	MJ ha^{-1}	-22005.50
Energy intensiveness	MJ \$$^{-1}$	2.09

Energy use efficiency (energy ratio) was calculated as 0.82, showing the inefficiency use of energy in the protected vegetable production. Other results found for protected vegetables, such as 0.66 for tomato (Pahlavan et al., 2011), 0.76 for cucumber, 0.61 for eggplant, 0.99 for pepper (Ozkan et al., 2004), 0.32 for tomato, 0.31 for cucumber, 0.23 for eggplant, 0.19 for pepper (Canakci and Akinci, 2006) have been reported for different crops, showing the inefficient use of energy, thus it is concluded that the energy ratio can be increased by raising the crop yield and/or by decreasing energy input consumption. Similar results such as 0.68 for tomato (Bojacá et al., 2012), for cucumber and tomato were calculated as 0.69 and 1.48, respectively (Heidari and Omid, 2011) 0.8 for winter crop tomato (Ozkan et al., 2011).

The average energy productivity of protected vegetable is 1.02 kg MJ^{-1}. This means that 1.02kg of tomato, cucumber, pepper or eggplant output is obtained per unit energy. The specific energy, net energy and energy intensiveness of protected vegetable production are 0.98MJ kg^{-1}, -22005.50 MJ ha^{-1} and 2.09 MJ $\$^{-1}$, respectively. Net energy is negative (less than zero). Therefore, it can be concluded that in protected vegetable production, energy is being lost and this result is similar to that obtained by other researchers such as Ozkan et al. (2004), Canakci and Akinci (2006) and Pahlavan et al. (2011). Parallel studies obtain 0.31 MJ kg^{-1} (Ozkan et al., 2004), 12380.3 MJ/t (Hatirli et al., 2006) and 0.94 kg/MJ (Ozkan et al., 2011) for the specific energy of corn production.

Total mean energy input as direct, indirect, renewable and nonrenewable forms are given in Figure 1.

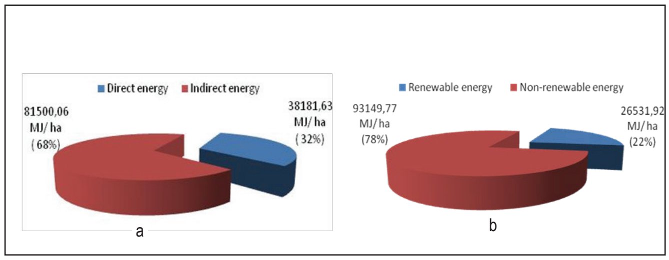

Figure1. Different form of energy contribution a) direct and indirect form; b) renewable and non-renewable form

The total energy input consumed could be classified as direct energy (31.90%), indirect energy (68.10%) and renewable energy (22.17%) and non-renewable energy (77.83%). A number of resultants, in the same cultivation system, revealed that for tomato in Turkey indirect energy (41.54%) is less than that of direct energy (58.18%), and renewable energy (81.60%) is greater than that non-renewable energy (18.12%) (Ozkan et al., 2011), while for the same crop and region the results show that the share of direct input energy is 59% in the total energy input compared to 41% for the indirect energy. On the other hand, non-renewable and renewable energy contributed to 88 and 12% of the total energy input, respectively (Hatirli et al., 2006).

GHG estimation

The results of greenhouse gas emission of greenhouse vegetable production are shown in Table 5.

Table 5. Amount of GHG generated

Input	Amount of GHG ($kgCO_2eq.ha^{-1}$)	Share, %
1. Machinery	139.67	0.82
2. Diesel fuel	356.10	2.09
3. Chemical fertilizers		
a. Nitrogen	362.52	2.12
b. Phosphate (P_2O_5)	70.93	0.42
c. Potassium (K_2O)	54.90	0.32
4. Farmyard manure	6015.56	35.24
5. Infrastructure		
a. Steel	112.65	0.66
b. Polyethylene	4998.10	29.28
c. Synthetic fiber	158.72	0.93
d. PVC	287.80	1.69
6. Biocides		
a. Insecticides	492,00	2.88
b. Fungicides	40.17	0.24
7. Electricity	3979.26	23.31
Total emission	17068.37	100

This research focused on calculation of GHG emissions issues from the greenhouse cultivation system where a small number of articles was found in literature on this topic. Because of that, in the present article, the similar works have been taken into account for comparison. In addition, no work conducted in the same subject matter takes into account the GHG emission generated by infrastructure input.

The total CO_2eq emission per hectare was determined as 17068.37 kg CO_2eq.ha^{-1}. In a similar study, the amount of GHG emissions was calculated as 82.724 kg CO_2eq.ha^{-1} for greenhouse cucumber production (Pishgar-Komleh et al., 2013). For the greenhouse strawberry production, GHG was calculated as 35083.5 kg CO_2eq.ha^{-1} (Khoshnevisan et al., 2014). Farmyard manure has the highest contribution in GHG emission with the share of 35.24% of total emission. Infrastructure was the second important input in producing GHG emission with percentage of 32.52%. Electricity also has significant share in total emission of protected vegetable production in the province with share of 23.31% of the total emission. Pishgar-Komleh et al. (2013) reported that the contribution of diesel fuel had the highest value with 61% in greenhouse cucumber production in Yazd province.

Percentage distribution of total emission of GHG for greenhouse vegetable production is illustrated in Figure 2. Results are in agreement with the finding that electricity had significant contribution in total emission of greenhouse strawberry and cucumber production in Iran with values 54% (Khoshnevisan et al., 2014) and 19% (Pishgar-Komleh et al., 2013). Thus, management of electricity and diesel fuel consumption are possible using solar energy to decrease total GHG emission in greenhouse vegetable production in Biskra province.

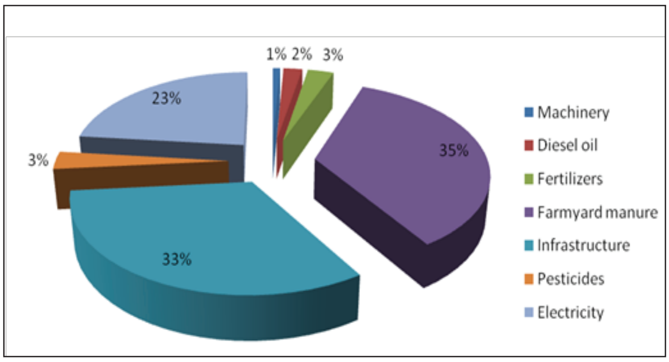

Figure 2. Percentage distribution of total emission of GHG for greenhouse vegetable production

Conclusion

This work was aimed to analyse the energy use pattern and to estimate the GHG emission for the protected vegetables in Biskra province. The results revealed that total energy required for vegetable protected production is 119.68 GJ per hectare with and among the different energy sources the infrastructure was the highest energy consumer followed by electricity and fertilizers with a share of 22%, 20% and 19%, respectively. Energy use efficiency (energy ratio) was calculated as 0.82, showing the inefficiency use of energy in the protected vegetable production. All farmers use least machinery labor energy per hectare compared to the human energy labor, thus we could say that the itinerary crop is similar for all the greenhouses visited. The total CO_2eq emission per hectare was determined as 17068.37 kg CO_2eq.ha^{-1}. Farmyard manure has the highest contribution in GHG emission with the share of 35.24% of the total emission followed by infrastructure (32.52%) and electricity (23.31%). As recommendations, the below propositions could enhance the control of energy flow and decrease GHG emissions in protected vegetable production, namely: Providing information, by a qualified employer, to farmers for changing their wrong behaviors and the controlled input. Improving pest management using an integrated fighting method (IPM) instead of using pesticides. Finally, management of electricity and diesel fuel consumption are possible using solar energy to decrease total GHG emission in greenhouse vegetable production in Biskra province.

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