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Modeling GHG emission and energy consumption in selected greenhouses in Iran

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Abstract
It is crucial to determine energy efficiency and environmental effects of greenhouse productions. Such study can be a viable solution in probing challenges and existing defects. The aims of this study were to analyze energy consumption and greenhouse gas (GHG) emissions for pepper production using biological method inside greenhouses which used natural gas (NG) heating system in Esfahan province. Data were collected from 22 greenhouse holders using a face to face questionnaire method, in 2010-2011. Also, functional area was selected 1000 m^2. Total energy input, total energy output, energy ratio, energy productivity, specific energy, net energy gain and total GHG emissions were calculated as 297799.9 MJ $area^{-1}$, 3851.84 MJ $area^{-1}$, 0.013, 0.016 kg MJ^{-1}, 61.85 MJ kg^{-1}, -293948 MJ $area^{-1}$ and 14390.85 kg CO_2 equivalent $area^{-1}$, respectively. Result revealed that replacing diesel fuel with NG will not be an effective way of reducing energy consumption for greenhouse production. However, it is crucial to focus on energy management in order to enhance the energy and environmental indices. One way to supply adequate input energy and a reduction in GHG emissions is the utilization of renewable and clean energy sources instead of NG and diesel fuel. Also, it is suggested to adopt solar greenhouses in the region and to supply electricity from non-fossil sources seriously

Keywords: Greenhouse pepper; Natural gas; Diesel fuel; Energy consumption; GHG emissions.

1. Introduction
Providing suitable situation, greenhouse cultivation is able to produce the most amount of yield at the lowest possible space in each geographic and climatic region. Thus, matched supply with market demand will be carried out for agricultural production considering population growth, urban sprawl and lack of enough agricultural lands. However, it is crucial to determine energy efficiency and environmental effects of agricultural productions inside greenhouses and it can be a viable solution in probing challenges and improving the current situation. In addition, analysis of energy consumption and its environmental effects are important components of management approaches in every manufacturing system, considering that energy management is the key factor of all sustainable development programs. It is, therefore, necessary to consider that balancing achievements of production and development opposite their effects on environment is one of continuous challenges for governments.
Energy inputs directly effects on marginal production cost and thus on farmers' profit. After implementing a comprehensive program on targeted subsidies in Iran, farmers have been paying more attention to energy inputs management, because with the real price of energy carriers, maximum

production and sufficient economical profit would be only depended on correct management practices of using these inputs. On the other hand, their greenhouse gas (GHG) emissions would have massive and irreversible environmental impacts such as climate change and global warming for the whole of human society. According to the researches conducted by Intergovernmental Panel on Climate Change (IPCC) carbon dioxide (CO_2) is the most important contribution to global warming [1]. Changes in concentration of GHGs and aerosols will cause changes in global and regional scale of air temperature, rain fall and other parameters that ultimately will lead to changes in soil moisture, floods and droughts in some regions of the world [2]. Iran is the 8th country in global CO_2 emission after China, U.S., India, Russia, Japan, Germany and Canada [3]. In addition, empirical results suggest a unidirectional Granger causality running from GDP and two proxies of energy consumptions (petroleum products and natural gas (NG) consumption) to carbon emissions, and no Granger causality running from total fossil fuels consumption to carbon emissions in the long run. The results also show that carbon emissions, petroleum products, and total fossil fuels consumption do not lead to economic growth, though gas consumption does [4].
Many researches were carried out to analyze energy consumption of greenhouse agricultural productions, but little research has examined the environmental impacts of energy consumption. In a previous study on energy consumption of greenhouse tomato and cucumber conducted in Tehran province, authors advised that to decline the proportion of non-renewable energy resources to produce these greenhouse agricultural productions and also, it is better to replace chemical fertilizers with green fertilizers and diesel fuel with solar energy and NG [5]. The results of analyzing greenhouse cucumber production energy efficiency in Esfahan province revealed that over use of fossil fuel inputs can be avoided by using renewable energies such as solar energy, insulation of walls, ceiling and windows to prevent heat losses, temperature choice, optimum moisture and utilizing automation systems inside greenhouses [6]. In addition, the results of analyzing energy efficiency of greenhouse tomato production in Esfahan province revealed that decreasing of diesel fuel consumption, electricity and chemical fertilizers will be an effective way on energy reservation and reducing environmental risks of the region [7]. The summary of earlier studies on energy consumption of greenhouse agricultural productions is presented in Table 1. In these studies, authors did not pay attention to environmental impacts such as GHG emissions.

Table 1. Summary of results related earlier studies on energy consumption

Country	**crop**	**Main Energy Input**	**Energy productivity (kg MJ^{-1})**	**Total Energy Input (MJ ha^{-1})**	**Ref.**
Iran, Alborz province	Greenhouse tomato Greenhouse cucumber	Diesel fuel Chemical fertilizers	1.38 0.55	131634.19 141493.51	[5]
Iran, Esfahan province	Greenhouse cucumber	Diesel fuel Chemical fertilizers & Seed electricity	0.51	139311	[6]
Iran, Esfahan province	Greenhouse tomato	Diesel fuel Electricity Chemical fertilizers	0.01	21832700	[7]
Iran, Esfahan province	Greenhouse basil	Diesel fuel Electricity Chemical fertilizers	0.01	14308998	[8]
Iran, Alborz province	Greenhouse strawberry	Diesel fuel Electricity Chemical fertilizers	0.08	805376.3	[9]
Turkey, Antalia province	Greenhouse tomato Greenhouse pepper Greenhouse cucumber Greenhouse eggplant	Diesel fuel Electricity Chemical fertilizers	0.40 0.23 0.39 0.29	470951 457633 494383 499788	[10]

The aims of this study were to analyze energy consumption and GHG emissions for pepper production using biological method inside greenhouses which used NG heating system for heating greenhouse in

Esfahan province. Considering investigated greenhouses in previous studies used diesel fuel for greenhouse space heating [6-8], the present study just has been focused on commercial greenhouses consumed NG and finally their amount of GHG emissions will be compared with them. It seems necessary to analyze and compare these systems accurately, due to recommendation made by some researchers in order to decline environmental risks by replacing diesel fuel with NG [5].

2. Materials and methods

The present study was conducted in the greenhouses of Esfahan province in Iran. Esfahan province is located within 30-42’ and 34-30’ north latitude and 49-36’ and 55-32’ east longitude. The average size of commercial greenhouses surveyed here were 200 m^2 [5]. Structural and environmental conditions for greenhouse crops like tomato, cucumber, pepper and other vegetables are the same, but their cultivation periods are different in a year. For instance, cultivation period of cucumber is just four months, while it is a year for tomato and pepper. On the other hand, greenhouse holders select one or more crop to cultivate, just according to market conditions and provided greenhouse area.

Data were collected from greenhouse holders using a face to face questionnaire method, in 2010-2011. The size of required samples was estimated 22 greenhouses, using Cochran formula [9].

Input energies include machinery, diesel fuel, electricity, NG, seed, farmyard manure (FYM), chemical fertilizer, water supply for irrigation and human labor whereas the energy equivalent of produced pepper was considered as output energy. Also, functional area was selected 1000 m^2. In the studied greenhouses, chemical biocides were not used and pest control was carried out by biological methods. The data were multiplied to energy and GHG emissions coefficients presented in Tables 2 and 3.

Table 2. Energy coefficients of different inputs and outputs in pepper production

Input / Output	Unit	Energy Coefficient (MJ $unit^{-1}$)	Ref.
A. Inputs			
1. Human labor	h	1.96	[10]
2. Seed	kg	0.28	[10]
3. irrigation	m^3	1.02	[11]
4. FYM	kg	0.3	[10]
5. Chemical fertilizers	kg		
Micro		120	[10]
N		66.14	[12]
K_2O		11.15	[12]
P_2O_5		12.44	[12]
6. Machinery	kg yr [a]		
Tractor and self-propelled		9-10	[13]
Stationary equipment		8-9	[13]
Implement and machinery		6-8	[13]
7. Diesel fuel	L	47.8	[10]
8. Natural gas	m^3	49.5	[13]
9. Electricity	kWh	11.93	[13]
B. output			
Pepper yield	kg	0.8	[10]

Table 3. GHG emissions coefficients of agricultural inputs

Inputs	Unit	GHG Emissions Coefficient (kg CO_{2eq} $unit^{-1}$)	Ref.
N	kg	1.3	[14]
K_2O	kg	0.2	[14]
P_2O_5	kg	0.2	[14]
Machinery	MJ	0.071	[15]
Diesel fuel	L	2.76	[16]
Natural gas	MJ	0.051	[17]
Electricity	kWh	0.608 [b]	[18]

yr [a]: The economic life of machines (year)

b: Direct and indirect carbon emission of LNG power generation technology

Input energies and GHG emissions were calculated in MJ and kg CO_2 equivalent units, respectively. Finally, based on the energy equivalents of inputs and output, energy indices including total energy inputs and output, energy ratio, energy productivity, net energy gain and specific energy were calculated using Equations (1) to (4) [19]:

$$\text{Energy Ratio} = \text{Output energy}\left(\text{MJ ha}^{-1}\right) / \text{Input Energy}\left(\text{MJ ha}^{-1}\right) \quad (1)$$

$$\text{Specific Energy} = \text{Enrgy input (MJ ha}^{-1}) / \text{Yield (kg ha}^{-1}) \quad (2)$$

$$\text{Energy Productivity} = \text{Pepper output}\left(\text{kg ha}^{-1}\right) / \text{Input Energy}\left(\text{MJ ha}^{-1}\right) \quad (3)$$

$$\text{Net Energy} = \text{Output Energy}\left(\text{MJ ha}^{-1}\right) - \text{Input Energy}\left(\text{MJ ha}^{-1}\right) \quad (4)$$

Direct energy includes the sum of energy equivalent of human labor, electricity, NG, diesel fuel and water supply for irrigation while indirect energy equals the sum of equivalent of seed, machinery, animal and chemical fertilizers. Renewable energy equals the sum of energy equivalent of human labor, seed, machinery, FYM and water supply for irrigation whereas non-renewable energy equals the sum of energy equivalent of electricity, NG, diesel fuel, machinery and chemical fertilizers. In addition, the amount of GHG emissions of greenhouse pepper production was calculated by the sum of emission equivalents of machinery, chemical fertilizer (Micro, N, P_2O_5 and K_2O), diesel fuel, NG and electricity. After processing data and doing calculations, results were presented in Tables 4, 5 and 6.

3. Results and discussion

The total energy requirement to produce greenhouse pepper was 297799.9 MJ area^{-1} whereas it was 45763.3 MJ area^{-1} in Turkey [10]. Also, 61.85 MJ were used per kg pepper production, and just 16 g peppers are produced per MJ energy consumption in studied greenhouses while 230 g peppers are produced per MJ energy consumption in Turkey [10]. Compared with other greenhouse productions such as tomato, cucumber and vegetables in Esfahan province [5-7], the calculated energy productivity index seems reasonable due to the nature of style and bulk of pepper. In fact, pepper yield is much less than tomato and cucumber yield [10]. In contrast, compared with pepper production in Turkey [10], the energy productivity is very low and it is due to lack of appropriate management of energy inputs and low yield. Because the pepper yield of the studied greenhouses was 4814.8 kg area^{-1}, whereas it was 10598 kg in Turkey, i.e., it is more than 2 times. It is essential to note that in order to attain high yield of pepper production, the expertise of greenhouse holders is particularly important. Pepper plant pruning is one of the most difficult and specialized operations that must be performed by skilled farmers, because this operation will directly affect on pepper quality and yield.

As it is presented in Tables 4 and 5, the proportion of non-renewable and direct energy indices are 97 % and 95.7 % and the proportion of NG and electricity, as the main energy inputs, are 80 % and 13.6 %, respectively. For one year cultivation, the proportions of these two energy inputs are so high that the contribution of other consumed inputs is only 6.4 %. Despite of controlled consumption of inputs practiced by farmers, the consumption of NG and electricity to provide the appropriate conditions of off-season cultivation is very high. Major NG and diesel fuel are consumed for heating the greenhouse in winter. In addition, heat loss from greenhouse structure is similar for both diesel and NG heating systems. Therefore, high consumption of NG can be due to low efficiency of the heating system or its availability which reveal that energy management has been neglected. Also, it should be considered that the time of data collection was coincident with one of the coldest winters in the region. On the other hand, major consumption of electricity is for fan and pad ventilating systems in summer. Energy efficiency of the ventilating system is low and it is better to use other routs including greenhouse covering (shading or painting greenhouse structure), natural ventilation and solar cooling systems in order to reduce inner air temperature and enhance energy indices [20, 21]. However, result revealed that replacing diesel fuel with NG will not be an effective way of reducing energy consumption for greenhouse production.

Table 4. Energy input and output in pepper production

Input / Output	Consumption/ production (unit area^{-1})	Energy Equivalent (MJ area^{-1})	Percentage %
A. Inputs			
1. Human labor (h)	1912	3747.52	1.3
2. Seed (kg)	0.016	0.004	-
3. Irrigation (m^3)	1711	1745.22	0.6
4. FYM (kg)	10000	3000	1
5. Chemical fertilizer		9229.31	3.2
Micro (kg)	50		
N (kg)	33.5		
K_2O (kg)	61.5		
P_2O_5 (kg)	26.5		
6. Machinery		394.4	0.2
Tractor and self-propelled (kg yr ^{a})	1460		
Stationary equipment (kg yr ^{a})	100		
Implement and machinery (kg yr ^{a})	480		
7. Diesel fuel (L)	5.6	267.68	0.1
8. Natural gas (m^3)	4825	238837.5	80
9. Electricity (kWh)	3401.36	40578.22	13.6
Total energy input		297799.9	100
B. output			
Pepper yield (kg)	4814.8	3851.84	

yr ^{a}: The economic life of machines (year)

Table 5. Energy Indices for pepper production in the studied region

Item	Unit	Amount	Percentage %
Energy ratio	-	0.013	-
Energy productivity	kg MJ^{-1}	0.016	-
Specific energy	MJ kg^{-1}	61.85	-
Net energy gain	MJ area^{-1}	-293948	-
Direct energy ^{a}	MJ area^{-1}	285176.14	95.7
Indirect energy ^{b}	MJ area^{-1}	12623.71	4.3
Renewable energy ^{c}	MJ area^{-1}	8492.75	3
Non- Renewable energy ^{d}	MJ area^{-1}	289307.12	97

a) Includes human labor, electricity, NG, diesel fuel and irrigation
b) Includes seed, machinery, FYM and chemical fertilizers
c) Includes human, seed, FYM and irrigation
d) Includes electricity, NG, diesel fuel, machinery and chemical fertilizers

Table 6. GHG emission of inputs in pepper production

Input / Output	GHG Emissions Equivalent (kg CO_{2eq} area^{-1})	Percentage (%)
Chemical fertilizer	98.65	0.7
Machinery	28	0.2
Diesel fuel	15.46	0.1
Natural gas	12180.71	84.6
Electricity	2068.03	14.4
Total GHG emissions	14390.85	100

As it is presented in Table 6, the total GHG emissions in the studied greenhouses were 14390.85 kg CO_2 equivalent. The proportion of NG, electricity and other inputs were 84.6 %, 14.4 % and 1 %, respectively (Figures 1 and 2). Compared with other studies were conducted to calculate GHG emissions of farm production [16, 22], the amount of GHG emissions of greenhouse production is extremely high. Because the proportion of fossil fuel consumption for greenhouse production is extremely more than farm production. Also, considering that Iran's power stations consume fossil fuels, electricity consumption for ventilating systems in summer caused to increase its contribution of GHG emissions. Although off-season greenhouse production is necessary, the energy management and sustainable environment is crucial too. Result revealed that replacing diesel fuel with NG will be an effective way of reducing GHG emissions, but it is reasonable for this aim to replace fossil fuels with renewable energies such as solar, wind and etc. to supply adequate input energy and a reduction in GHG emissions.

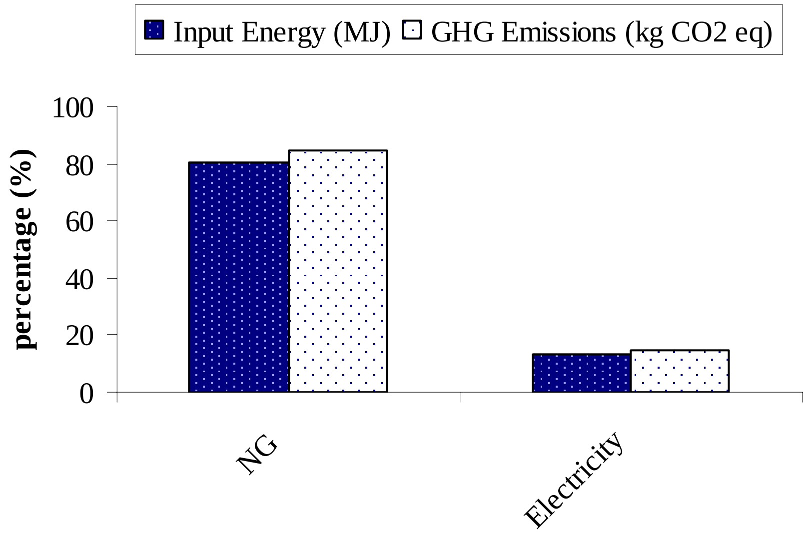

Figure 1. The proportion of NG and electricity in total input energy and GHG emissions

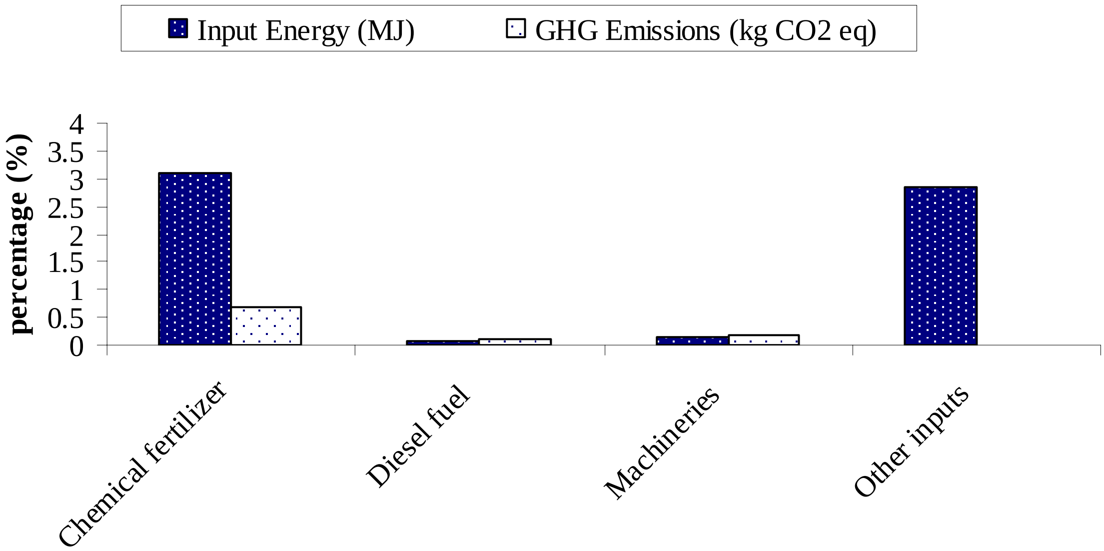

Figure 2. The proportion of inputs in energy consumption and GHG emission except NG and electricity (other inputs include human labor, seed, irrigation, FYM and micros)

4. Conclusion

Three steps are required to successfully and efficiently reduce energy consumption and GHG emissions from greenhouse production as same as farms: (i) identification of the most energy consuming and GHG polluting inputs, (ii) determining appropriate mitigation options for these inputs, and (iii) selection between these options on the basis of their cost effectiveness [23]. In this study, we investigated the option of replacing diesel fuel with NG as it is able to reduce GHG emissions of greenhouse productions. Results revealed that replacing diesel fuel with NG will not be an effective way of reducing energy consumption but it can reduce GHG emissions significantly. However, it is crucial to focus on energy management in order to enhance the energy and environmental indices.

Total energy input, total energy output, energy ratio, energy productivity, specific energy, net energy gain and total GHG emissions were calculated as 297799.9 MJ area^{-1}, 3851.84 MJ area^{-1}, 0.013, 0.016 kg MJ^{-1}, 61.85 MJ kg^{-1}, -293948 MJ area^{-1} and 14390.85 kg CO_2 equivalent area^{-1}, respectively. As it is indicated, low yield and high energy consumption were lead to weak energy indices compared with Turkey.

Finally, it is suggested to adopt solar greenhouses in the region and to supply electricity from non-fossil sources seriously. Iran has 300 sunny days and 5.5 kWh solar energy on average daily in 90 % of its area. Therefore, there are good potentials to supply adequate input energy from renewable and clean energy sources instead of fossil fuels, although this approach should be studied consciously.

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