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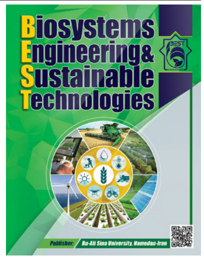

Energy Audit in Greenhouse Grown Cucumber – a Case Study in Hamedan Province, Iran

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ABSTRACT

This paper is a case study on auditing energy and water used in greenhouse-grown cucumber production. The study has been done under real conditions in Hamedan a western province of Iran with harsh winters. Here, all the procedures of production from land preparation to harvest and finally the removal of residues were recorded. The fruit produced per square meter of covered area was 10.07 kg m^{-2}. Moreover, the parameters of energy consumption, energy output, net energy gain, specific energy, energy productivity, and energy use efficiency were 5.05 MJ, 18,560 MJ, -5.03 MJ, 217.60 MJ kg^{-1}, 0.0046 kg MJ^{-1}, and 0.0037, respectively. Water productivity was also 39.42 kg m^{-3}. The indicators obtained in this study showed the effect of surrounding environmental parameters on the performance in comparison with the literature. Additionally, it is estimated that to provide solar-based electricity for this greenhouse, roughly 110 square meters of solar panels are required.

1. Introduction

Societies demand an efficient and sustainable food production system to survive (Azadi et al., 2013; Saadi et al., 2025). To achieve this goal, governments have begun to use the latest scientific findings to improve the productivity and efficiency of agricultural production (Ortiz et al., 20013) Considering the world population growth, the development of agricultural technologies has been followed by producers to meet the increasing demand for food, feed, and fiber (Khoshnevisan et al., 2013; Lak & Almasi, 2011). Moreover, scarcity of arable land as well as accessible sweet water draws the attention of producers to increase their performance in terms of production per unit of cultivated area (Ali et al., 2019) and farmers preferred to take advantage of modern agricultural techniques, especially the cultivation of crops under greenhouse covers (Gong et al., 2023; Taki & Yildizhan, 2018) in which we need more energy resources to use.

Energy consumption has influenced the development of economic sectors such as industry, transportation, and agriculture (Baruah et al., 2008) and increasing population, grappling with restricted fossil fuel sources, demand urgent attention to reduce energy consumption in different sectors of economic activity, including agriculture (Rahimi Ajdadi & Abbaspour-Gilandeh, 2011). Scarcity of natural resources, including water, soil, and energy, is a growing concern globally; while an increasingly growing world population with intensively increasing demands for these essential resources has been placing considerable pressure on the world's finite resources, resulting in a considerable shortage in many areas that threatens human life and economic development (Freedman, 2018; Wang & Azam, 2024). Thus, it is assumed that more efficient energy alternatives support sustainability (Gagnon, 2008). It is claimed that greenhouse-covered area development has been an alternative to water and energy-efficient consumption (Ghaffarpour et al., 2024; Kaur et al., 2024); as a result, growers focused on growing plants under greenhouses to produce high-quality crops in higher quantities compared to the open field region throughout the year (Rizwan et al., 2023; Saadi et al., 2025; Timonen et al., 2019). It is while, in the agricultural sector in Iran, greenhouses are among the highest users of energy sources, especially electrical power (Morovat et al., 2019; Shadidi et al., 2024).

In this manner, providing water and energy in all seasons is essential to grow crops in greenhouses (Kaur et al., 2024). Therefore, many of researches has been focused on auditing water and energy consumption in greenhouse productions.

Most of the studies reviewed in the literature are based on governmental statistics published as average data. Thus, a case study focused on detailed real data gathered during a growing season was the main source of the current study. This case study was done in a greenhouse placed in Hamedan, a mountainous region in the west of Iran with harsh winters.

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Table 1. Greenhouse characteristics

Parameter	Value	Unit	Description
Length	36	m	
Number of spans	5	-	
Spans' width	12.8	m	
Covered area	2,304	m^2	
Service corridor (space under cover with no plant)	200	m^2	
Gutters height	5.5	m	
Total height	8	m	
Cultivation bed	Soil	-	Clay 19%, Silt 50%, and Sand 31%
Irrigation system	Drip tapes	-	
Heating system	4	-	Cabinet heater each 220,000 kcal per h
Ventilation fans	7	-	140 * 140 cm2
Number of openings	10	-	2 in each span
Cladding	-	-	Double film-plastic layers

2. Experimental

In the current study, in a 2300 m^2 greenhouse placed in Bu-Ali Greenhouse Town in Hamedan province, western Iran, 4500 seedlings of cucumber (*Cucumis sativus* 'Nagene F1') have been grown since December 21, 20204 to May 13, 2025 (Table 1). In the period of their life, the data related to production inputs consumed energy in the form of gas and electricity was recorded based on the bills; furthermore, all the inputs consumed, whether as water to irrigate crops or biocides and fertilizers used in the period of growing, were also recorded. In addition, the human labor worked in the period from soil bed preparation to removal of the final residues as well as the diesel consumed to prepare the soil bed, all were recorded (Table 2).

Irrigation water energy equivalent was calculated based on the energy required to:

Providing water from a 60-meter well to the reservoir; and

Pumping water from the reservoir to the irrigation system.

3. Method

3.1. Methodology

The energy input and output were calculated based on multiplying consumed/produced values by the coefficient of energy equivalent extracted from literature (Table 2). Following the calculation equations for water efficiency, energy input, and energy use efficiency were determined (Ghasemimobtaker et al., 2010; Mandal et al., 2002; Mohammadi & Omid, 2010; Yilmaz et al., 2004):

$$\text{Net energy gain (MJ)} = \text{Total output energy} - \text{Total input energy} \quad (1)$$

$$\text{Specific energy (MJ per kg)} = \frac{\text{Energy input (MJ)}}{\text{Produced cucumber (kg)}} \quad (2)$$

$$\text{Energy productivity (kg per MJ)} = \frac{\text{Produced cucumber (kg)}}{\text{Energy input (MJ)}} \quad (3)$$

$$\text{Energy use efficiency (non-dimensional)} = \frac{\text{Energy output (MJ)}}{\text{Energy input (MJ)}} \quad (4)$$

$$\text{Water productivity (kg per m}^3\text{)} = \frac{\text{Produced cucumber (kg)}}{\text{Water consumed (m}^3\text{)}} \quad (5)$$

4. Result and Discussion

4.1. Results

The data obtained from the field study and the equivalent energies were extracted from the literature, providing a database about cucumbers grown in Hamedan greenhouses (Table 1). Based on the value of production equal to 23,200 kg cucumber fruit during the growing period, the parameters of

Table 2. Amounts of input-output water and energy

Input		Value	Unit	Energy equivalent (MJ unit^{-1})	Energy in/out (MJ)	Reference
Water		**588,500**	l			
Farmyard manure		25	ton	300	**7500**	(Hesampour et al., 2022)
Seedlings	**Total seedlings**				**182.98**	
	Seeds	0.11	kg	1	0.11	(Ahmadbeyki et al., 2023; Yilmaz et al., 2004)
	Sowing in trays	1	man-day	1.96	1.96	(Ahmadbeyki et al., 2023; Yilmaz et al., 2004)
	Growing	1	man-day	1.96	1.96	(Ahmadbeyki et al., 2023; Yilmaz et al., 2004)
	Heating gas	15	m^3	11.93	178.95	(Hesampour et al., 2022)
Fertilizers	**Total fertilizers**				**6,959.14**	
	Nitrogen	94	kg	66.14	6,217.16	(Ahmadbeyki et al., 2023; Yilmaz et al., 2004)
	Phosphate	22	kg	12.44	273.68	(Ahmadbeyki et al., 2023; Yilmaz et al., 2004)
	Potassium	42	kg	11.15	468.3	(Ahmadbeyki et al., 2023; Yilmaz et al., 2004)
Biocides		11	kg	120	**1320**	(Ahmadbeyki et al., 2023)
Labor	**Total labor**				**344.96**	
	Preparation	2	man-day	1.96	3.92	(Ahmadbeyki et al., 2023; Yilmaz et al., 2004)
	Transplanting	4	man-day	1.96	7.84	(Ahmadbeyki et al., 2023; Yilmaz et al., 2004)
	Growing	25	man-day	1.96	49	(Ahmadbeyki et al., 2023; Yilmaz et al., 2004)
	Harvesting	140	man-day	1.96	274.4	(Ahmadbeyki et al., 2023; Yilmaz et al., 2004)
	Removal	5	man-day	1.96	9.8	(Yilmaz et al., 2004)
Natural gas		96427	m^3	49.5	**4,773,137**	(Hesampour et al., 2022)
Electricity	**Total electricity**				**255,791.1**	
	Heating	20263	kWh	11.93	241,737.6	(Hesampour et al., 2022)
	Water supply	700	kWh	11.93	8351	(Hesampour et al., 2022)
	Irrigation pump	465	kWh	11.93	5,547.45	(Hesampour et al., 2022)
	Other	13	kWh	11.93	155.09	(Hesampour et al., 2022)
Diesel	Soil bed preparation	56	l	56.31	**3,153.36**	(Yilmaz et al., 2004)
Total consumed energy					**5,048,388**	
Output		**23200**	kg	**0.8**	**18,560**	(Ahmadbeyki et al., 2023)

energy consumption, energy output, net energy gain, specific energy, energy productivity, and energy use efficiency were (eq. 1 to 5), 5,048,388 MJ, 18,560 MJ, -5,029,828 MJ, 217.60 MJ kg^{-1}, 0.0046 kg MJ^{-1}, and 0.0037, respectively (Table 3). Water productivity was also 39.42 kg m^{-3} (Table 3).

As seen in the Table 3 In this study, despite the high value for water productivity equal to 39.42 kg per cubic meter of water, the indicators related to energy are not all within the ranges reported in the literature. However, the main reason is not mismanagement of this greenhouse; the data in the literature all ignore the energy required to heat a greenhouse in the winter. Moreover, the greenhouse in this study is located in a mountainous region with an altitude of 1,700 with harsh winters where heaters are working all night from November to March. Thus, ignoring the energy required to warm the greenhouse, assuming the growing was in the period with no warming system, the energy indicators can be as Table 4.

Ignoring the energy used for heating the greenhouse, the parameters of energy consumption, energy output, net energy gain, specific energy, energy productivity, and energy use efficiency were (eq. 1 to 5), 55511.03 MJ, 18,560 MJ, -36951 MJ, 2.39 MJ kg^{-1}, 0.42 kg MJ^{-1}, and 0.33, respectively (Table 3). Water productivity was also 39.42 kg m^{-3}.

4.2. Discussion

Table 4 approved that neglecting the data related to the heating system, energy indicators would be approached to the literature (Ahmadbeyki et al., 2023; Ali et al., 2019; Khessro et al., 2022; Rashidi et al., 2024; Saadi et al., 2025). However, among the inputs used to produce greenhouse-grown cucumber in the case study in Hamedan (Table۲), natural gas consumed to warm the greenhouse environment and the electricity in which the heating system shares exceed 94% have the most share in energy usage; thus, it seems that the most important management decisions in the greenhouse must be made on the heating system. Ignoring the energy consumed in the heating system, in the form of natural gas and electricity, the indicators of input, output, net energy gain, specific energy, energy productivity, and energy ratio were 55511.03 MJ, 18560 MJ, -36951 MJ, 2.39 MJ kg^{-1}, 0.42 kg MJ^{-1}, and 0.33, respectively. As a result, the climatic conditions in the region where greenhouses are established greatly influence the energy consumption. The effect of climatic conditions on energy consumption in a greenhouse was approved by Rizwan et al. (2023) (Rizwan et al., 2023).

In a survey on greenhouse-grown crops, energy consumption in cucumbers, tomatoes, eggplants, and peppers was found at 134.77 GJ ha^{-1}127.42 , GJ ha^{-1}, 98.68 GJ ha^{-1}, and 80.25 GJ ha^{-1}, respectively. Energy efficiency was 0.76, 1.26, 0.61, and 0.99, respectively (Ozkan et al., 2007). In another study, energy consumption in greenhouse-grown cucumbers in Kerman, a southern province in Iran with moderate winters, was 2,058 GJ ha^{-1}, while 1752 GJ ha^{-1} (more than 85%) was consumed for heating purposes. Thus, energy consumption may be under influenced by factors such as the crop physiological requirements, techniques of cultivation, status of mechanization, regional climate, season of growing, and the availability of agricultural inputs and energy sources (Aravindan & Kumar, 2023; Saadi et al., 2025).

As a result, analyzing energy indicators for crops grown in greenhouses is very dependent on:

- The physiological needs of crops
- The season of growing

Table 3. Production indicators.

Parameter	Value (this study)	Saadi et al., 2025 [1]		Rashidi et al., 2024	Ahmadbeyki et al., 2023	Ali et al., 2019	Khessro et al., 2022
		Quanst greenhouse	Tunnel greenhouse				
Energy consumption	5,048,388	1,120,275	1,003,032	12,221	93,243	51,400	10,679
Energy output	18,560	34,960	31,280	5,285	24,146	57,992	12,219
Net energy gain	-5,029,828	-1,085,315	-971,752	-6,936	-69,097	+6,592	+1,540
Specific energy	217.60	25.64	25.65	1.85	3.09	0.71	0.70
Energy productivity	0.0046	0.04	0.04	0.54	0.32	1.41	1.43
Energy use efficiency	0.0037	0.03	0.03	0.43	0.26	1.13	1.14
Water productivity	39.42	23.22	24.29	11.89	n*	29.49	n*

[1] - The values in the literature is based on ha. Here, the values are reported based on 2,300 square meter greenhouse is reported.

Table 4. Energy audit ignoring heating systems.

Input		Value	Unit
Farmyard manure		**7500**	**MJ**
Seedlings	**Total seedlings**	**4.03**	**MJ**
	Seeds	0.11	MJ
	Sowing in trays	1.96	MJ
	Growing	1.96	MJ
Fertilizers	**Total fertilizers**	**6959.14**	**MJ**
	Nitrogen (N)	6217.16	MJ
	Phosphate (P_2O_4)	273.68	MJ
	Potassium (K_2O)	468.3	MJ
Biocides	**Total biocides**	**1320**	**MJ**
Labor	**Total labor**	**344.96**	**MJ**
	Preparation	3.92	MJ
	Transplanting	7.84	MJ
	Growing	49	MJ
	Harvesting	274.4	MJ
	Removal	9.8	MJ
Electricity	**Total electricity**	**39382.9**	**MJ**
	Cooling	22176	MJ
	Water supply	8351	MJ
	Irrigation pump	5547.45	MJ
	Other	155.09	MJ
Diesel	**Soil bed preparation**	**3153.36**	**MJ**
Input		**55511.03**	**MJ**
Output		**18560**	**MJ**
Net energy gain		**-36951**	**MJ**
Specific energy		**2.39**	**MJ per kg**
Energy productivity		**0.42**	**kg per MJ**
Energy ratio		**0.33**	**Dimensionless**

- The climate as well as the altitude where the greenhouse is established
- The greenhouse itself in terms of structure, cladding quality, dimensions, covered area, and heating/cooling systems

Management of energy in production can play a key role in energy performance in production. Ensuring optimal growing conditions for greenhouse-grown plants, Gong et al. (2023) proposed a particle swarm optimization model predictive control (PSO-MPC) algorithm to control the greenhouse. They believe that the use of a predictive-control-model-based approach with particle swarm optimization enables the algorithm to optimize real-time controllable parameters in a greenhouse (Gong et al., 2023).

Yakub et al. (2024) suggested a hybrid renewable energy source (HRES), focusing on wind and solar power in six geopolitical zones of Nigeria. Significant variations in temperature and solar radiation across Nigeria, as revealed in the study, are claimed that affected the energy requirements of greenhouse operations significantly. The authors believed that to revolutionize the energy sector and agricultural practices in Nigeria, renewable energy resources can overcome to the challenges posed by climate change (Yakub et al., 2024).

In the place of greenhouse establishment, cold winters with cloudy weather, hot sunny summers, and winds throughout the year, make greenhouse growers pay more attention to the structural strength. While energy-saving shades are very important to use. Additionally, heaters with higher efficiency are recommended to be used. Moreover, management of the greenhouse based on good practices plays a key role in increasing the performance.

Based on the current governmental decisions towards the development of renewable energy resources in Iran, it is suggested that producers provide 80% of their electricity demand by photovoltaic panels to help the growers to use the plan exclude them from the electrical load management program[1] (Anonymous, 2024). The greenhouse of this study's electricity demand was 15 kW. Thus, it is expected to provide at least 12 kW of its electricity demand will be provided by solar panels. It is while the average radiation in Hamedan ranges from 347 to 571, with an average of roughly 463 watts per square meter with (Alamdari et al., 2013). Considering the efficiency of 23 to 24 % in current photovoltaic panels (Anonymous, 2024), it is expected that roughly 110 watt per square meter would be harvestable; thus, the greenhouse of this case study needs about 110 square meters of photovoltaic panels.

5. Conclusions

In the present paper, a case study was carried out on the energy audit of greenhouse-grown cucumber in Hamedan province, a mountainous region with harsh winters in the west of Iran. Based on the results of this study, energy indicators are very dependent on the heating system's performance. On the other hand, water productivity seemed very efficient in comparison to similar studies. Among the reasons, the harsh winter with cloudy air in December 2024 to February of 2025, as well as the small area of greenhouse coverage, might have influenced. Moreover, the physiological needs of crops, the climate, as well as the altitude where the greenhouse is established, the greenhouse internal environment in terms of structure, cladding quality, dimensions, covered area, and heating system may have effects on the energy audit.

Installation of photovoltaic panels to provide 80% of the electricity demand of this greenhouse can be an alternative to help growers use the exception of industries from the load management program (Anonymous, 2024).

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