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Evaluation and comparison of energy use efficiency among cucumber greenhouses

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Introduction: Construction of agricultural greenhouses can be considered as one of the appropriate solutions to meet the growing food demands. However, high energy use in greenhouse productions on the one hand and energy limitation on the other hand are fundamental challenges facing mankind. The present study aims to measure and compare energy efficiency based on the components of energy use sustainability (Environmental Norms, Environmental Beliefs, Environmental Values, Technical Management, Technical Knowledge, Education Level, Greenhouse's Work Experience, Cost-Effectiveness and Educational-Extension Service) among greenhouse cucumber growers.

Methods: The statistical population included cucumber production greenhouse owners in Kerman Province, Iran. Out of the total population, 356 cases were selected as a sample using two-stage cluster sampling method. The data collection tool in this study was a researcher-made questionnaire. The questionnaire validity was confirmed via the content validity method and its reliability was confirmed through the pilot test. The data obtained from the questionnaire was recorded, calculated, and analyzed by SPSS24, Excel2019, and Deap software.

Results and discussion: The results showed that the average energy efficiency in the studied units was 0.72 (out of 1), so that 21 and 335 greenhouses used energy efficient and inefficient, respectively. According to the components of energy use sustainability, a significant difference was observed between efficient and inefficient greenhouses, so that the energy efficient greenhouses have a high level of related components. It is suggested that the decision-makers, stakeholders, and active policy makers in the field of greenhouse crops should consider all the components of energy use sustainability, so that the developed policies and programs can cover all dimensions and take into account different aspects of energy use sustainability. As the results of this study can serve as a reference for other similar areas.

KEYWORDS

energy efficiency, greenhouse cucumbers, technical management, technical knowledge, cost-effectiveness, educational- extension service

1 Introduction

The agricultural sector supplies food to the growing population of the earth and raw materials required for the industrial sector. There are many people, especially in rural communities, who depend on agriculture for income and employment, and a significant amount of the income of developing countries is related to the agricultural sector (Yazdani et al., 2019). Agricultural activities, however, have destructive effects on the surrounding environment such as deterioration of water and soil resources, air pollution, and the reduction of ecological diversity (Nabizadeh et al., 2018). Limitation of water and land, as well as the increase of the world's population, have always attracted subjects for farmers to provide more food per unit area (Taki et al., 2012a). Therefore, a sustainable system with high productivity should be a priority in order to satisfy the food demands of the growing human population, and one of the appropriate ways to overcome this problem is to use new agricultural methods such as greenhouse structures.

Greenhouses are important infrastructures to meet the increasing demand for food (Kozai et al., 1997). They are the foundation of a protected cultivation system (Baeza et al., 2013), in geographical locations where the soil, climate, and social conditions are not optimal or even where it is impossible to grow and harvest any plant, they make it possible for vegetables, fruits, and flowers to grow and be harvested (Zabeltitz, 1990). Greenhouses also protect the crop from pests, insects, and extreme climate conditions such as heavy rains or draft animals and wind. It is a significant expectation that greenhouses are feasible and sustainable in terms of ecological and socioeconomic status (Bot, 2001). Despite the benefits of greenhouse cultivation, this agricultural system depends on huge resources of energy and fossil fuels (directly and indirectly) (Taki et al., 2012b). Energy intensive operations in greenhouse production and energy limitation are fundamental challenges of mankind for increasing production system performance. Therefore, it is very important to check the amount of energy use and efficiency in greenhouse production (Esfanjari Kenari et al., 2015), as low energy efficiency not only leads to energy wastage, but also causes serious environmental contamination (Liu et al., 2020). Knowledge of the energy flow in an agricultural system and its related factors allows us to develop a more accurate picture of the system in terms of energy production, resource consumption, and system efficiency. Moreover, the energy-intensive inputs are specified and the system's reliance on the inputs is determined according to the limited energy resources, which is effective in future decisions to design sustainable ecosystems in the direction of sustainable development (Koohkan, 2017). Undoubtedly, it cannot be claimed that a non-balanced system in terms of energy consumption and production has a constant and sustainable state for energy (Asgharipour et al., 2012). Accordingly, most of the developed and developing countries have measured the energy input per unit area for the production of various agricultural crops and have attempted to optimize their agricultural systems for energy consumption by calculating the energy efficiency index (Nasirian et al., 2006). In this regard, the optimal energy consumption in agriculture can minimize environmental problems, prevent the destruction of resources, and strengthen sustainable agriculture as an economic production system as well (Kizilaslan, 2009). The first step for optimal use of available resources is to evaluate the energy efficiency in the production process (Taki et al., 2012c). As the increase in demand for food productions due to the population growth has led to excessive use of chemical fertilizers, agricultural machinery, insecticides and other production inputs, which ultimately causes environmental problems and threatens public health. The efficient energy use minimizes environmental problems, prevents the destruction of natural resources, and promotes sustainable agriculture as a production and economic system (Erdal et al., 2007).

Some of the factors affecting energy increasing efficiency are: management, modification of consumer behavior, modification of environmental norms, beliefs and values (Barber et al., 2009; Miafodzyeva et al., 2010; Viscusi et al., 2011; Thanh et al., 2012; Sadeghi Shahedani and Khoshkhouy, 2015; Salehi et al., 2017; Bondari et al., 2020; Behroozeh et al., 2024). Technical management of agricultural inputs consumption is one of the important topics in sustainable agriculture, because although the indiscriminate and unplanned consumption of agricultural inputs increases the yield and improves the quality of crops, it brings destructive effects that should not be ignored (Nuthall, 2006; Mohtashami and Zandi Daregharibi, 2018). Energy consumption management is based on learning and knowledge of energy consumption (Huo et al., 2022). The use of energy resources in alignment with technical management is therefore vital to optimal energy consumption (Iqbal and Kim, 2022). Thus, managing energy consumption through technical knowledge and information of energy generation and consumption can significantly improve energy economy (Shahpasand, 2016; Wang et al., 2022). On the other hand, the values, beliefs, and norms of farmers have a significant impact on their environmental behavior regarding the use of agricultural inputs (Wensing et al., 2019). This is because values are general goals that serve as principles and guides in people's lives, influencing various environmental behaviors (Gao et al., 2017). In general, individuals with environmental values are more likely to engage in pro-environmental behaviors, such as those that reduce energy consumption (Steg et al., 2014; Behroozeh et al., 2023). Environmental values, beliefs, and norms act as key components in the adoption of sustainable production methods by agricultural greenhouse growers (Hall et al., 2009). Norms also refer to a moral obligation or duty that encourages individuals to engage in specific behaviors and are a primary predictor of intention and behavior (Wan et al., 2017). Environmental beliefs indicate a willingness to protect the environment, such as the acceptance of using clean energy (Xia et al., 2019; Wang et al., 2020). This is because environmental beliefs are a system of attitudes that determine an individual's behavior toward the environment and serve as a frame of reference in interacting with the environment (Corral-Verdugo et al., 2003).

In addition, the application and use of agricultural inputs is different between farmers who use extension and educational services, and farmers who do not use these services (Salehi et al., 2020). Accessibility to extension and educational services in line with the application of agricultural inputs has positive effects on agricultural productivity (Emmanuel et al., 2016). In order to achieve more sustainable farming, farmers may need to relearn and subsequently change their attitudes (Šūmane et al., 2018) through extension education (Polat, 2015) to overcome the resource-consumption approaches that have long been dominant and are deeply ingrained in the thinking and practices of many farmers (Sáenz et al., 2024). In general, the impact of extension and educational services in agriculture is positively and significantly correlated with agricultural productivity (Haq, 2012). This is because farmers who use extension and educational services achieve higher technical efficiency in agriculture compared to those who do not benefit from these services (Dinar et al., 2007; Anik and Salam, 2017). In general, the goal of agricultural extension services is to improve farmers' knowledge, which helps increase crop production and technical efficiency (Biswas et al., 2021). In this context, low educated and low experienced farmers, compared to their more educated and experienced counterparts, tend to use more than the recommended optimal amounts of chemical fertilizers and agricultural inputs due to their limited access to information (Adesina, 1996; Ade Freeman and Omiti, 2003). In fact, farmers with higher levels of education tend to have higher technical efficiency (Haider et al., 2011; Rahman et al., 2012). Because years of experience and education enrich farmers' knowledge, leading to improved technical efficiency (Athukorala, 2017). Additionally, the benefits of increased productivity because of the consumption of agricultural inputs have a positive relationship with the intensity of their consumption, while education has a negative relationship with it (Waithaka et al., 2007; Haq, 2015).

Agricultural production system contributes 14% of the net global CO_2 emissions (Cooper et al., 2011) from greenhouse gases (GHG) (Pishgar Komleh et al., 2011), and leading to the release of 30–50% of insecticides in the air (Khoshnevisan et al., 2014). In general, the energy consumed for various agricultural activities includes land preparation, irrigation, planting, fertilization, pest control, harvesting, processing, transportation, and distribution of agricultural products (Mirzabaev et al., 2023). This has contributed to global warming since the 1950s (Masson-Delmotte et al., 2021). The global climate is warming, and various studies (Outhwaite et al., 2022) have confirmed that this is due to human activities that emit greenhouse gases (GHGs). Agricultural greenhouse gas emissions account for 40 to 60 percent (Omotoso and Omotayo, 2024) of total anthropogenic greenhouse gas emissions, contributing to global warming and drought (Brownea et al., 2011; Khoshnevisan et al., 2013). Therefore, reducing global warming is a major challenge for energy consumption management, as a significant portion of global warming and climate change results from the combustion of fossil fuels that releases greenhouse gases (Meyer, 2010). Greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are released by various human activities, including deforestation, disruption of natural land use, industrial operations, and unsustainable agricultural practices (such as excessive use of energy resources, pesticides, fertilizers, etc.), as well as the use of fossil fuels like coal, oil, and petroleum products (Scott et al., 2023). For this reason, land degradation through the emission of greenhouse gases is a significant driver of climate change (Tione et al., 2022). Therefore, the efficient use of energy in agricultural production systems, including greenhouse cultivation, as a crop production system with energy compression, is the highest priority to achieve energy use sustainability (Ghorbani et al., 2011). Accordingly, energy analysis in agriculture plays a significant role in the development of human's perspective toward agricultural ecosystems and improves the quality of decisions and planning in the management and development of the agricultural sector (Rathke and Diepenbrock, 2006). The statistics of the Agricultural Jihad Organization indicate that the area of greenhouses in Iran has increased from 3,380 hectares to 6,630 hectares during 2003–2011. According to the above statistics, the production of greenhouse cucumbers, which is one of the main greenhouse crops in the world, has increased rapidly in the country, and therefore, after China and Turkey, Iran ranked in third place with production of more than two million tons of cucumbers annually (Heidari and Omid, 2011). According to the agricultural statistics of 2016, the cultivated area of greenhouse crops in Iran was 8,820 hectares, among which the cultivated area of cucumber, tomato, pepper, strawberry, and eggplant was 72.8, 8.1, 5, 5.2, and 2.6% of the total area under cultivation in greenhouses, respectively (Agricultural Statistics, 2015). Cucumber is the most commonly greenhouse vegetable worldwide (Nassiri and Singh, 2009) and is a warm-season plant and grows quickly at 24–29°C (Marr, 1995). Since Kerman province has a unique climate, it is considered as one of the largest natural greenhouses in Iran, where it allows to grow all kinds of greenhouse vegetables (Saei, 2019) and it is the largest producer of greenhouse cucumbers in Iran (Mehrabi Basharabadi, 2008). According to the literature and in order to achieve the objectives in the study, it is concluded that the consumption of agricultural inputs and as a result, achieving the energy use efficiency depends on several factors, based on which the conceptual framework is designed and analyzed (Figure 1). Because many studies have investigated energy consumption from the point of view of technical issues (Giampietro et al., 1992; Nassiri and Singh, 2009; Fartout Enayat et al., 2017); In several instances where the impact of non-technical factors on energy input usage has been examined, the research has focused more specifically on the consumption of particular inputs, such as fertilizers and chemicals (Gün and Kan, 2009; Zhou et al., 2010; Ataei-Asad and Movahedi, 2021). Accordingly, the main objective of this study is to measure and compare energy use efficiency among cucumber greenhouse growers. To save energy, improve energy use efficiency, and increase resource productivity, a better understanding of sustainable energy use models can enhance economic performance and reduce environmental impacts. Although numerous studies have been conducted on energy use efficiency in agriculture, only a limited number have specifically analyzed energy use efficiency in cucumber greenhouses based on sustainable energy use components. Furthermore, many of these studies have not compared energy-efficient and inefficient greenhouses based on sustainable energy use components. Therefore, in this study, to achieve the main research objective, the energy use efficiency in the greenhouses under investigation will first be examined and assessed. Subsequently, energy-efficient and inefficient greenhouses will be compared and analyzed based on sustainable energy use components. This innovative approach not only aids in identifying the best energy use practices but also provides solutions for optimizing energy use based on sustainable energy use components.

Therefore, the present study specifically examines the energy use situation in the cucumber greenhouse by considering components such as Environmental values, Environmental beliefs, Environmental norms, Technical knowledge of the greenhouse, Technical management of the greenhouse, The use of the educational- extension services, Education level, Benefit/Cost and Greenhouse's work experience. Consequently, the necessity of measuring and comparing the energy use efficiency in cucumber cultivation greenhouses according to the components of the energy use sustainability is felt because it helps managers and executives to understand the difference in energy use efficiency in cucumber cultivation greenhouses based on these components, and if required, design programs to strengthen and benefit from these components for the greenhouse owners. Therefore, it is required to measure and compare the energy use efficiency among cucumber cultivation greenhouses in order to make energy use sustainability programs in agricultural greenhouses effective. To that end, the present study investigated the energy use efficiency among the cucumber growers in Kerman province, Iran with the aim of measuring the energy use efficiency and comparing it based on the components of energy use sustainability (Figure 1).

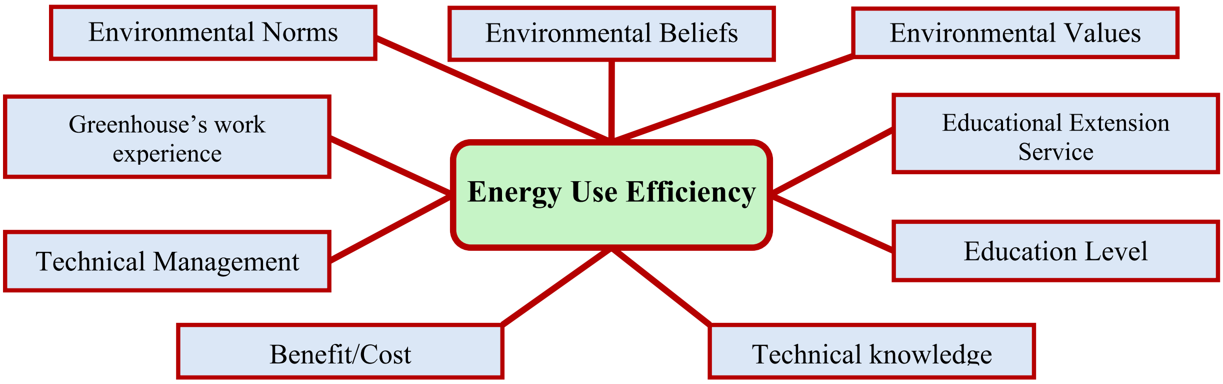

FIGURE 1
Study's conceptual model.

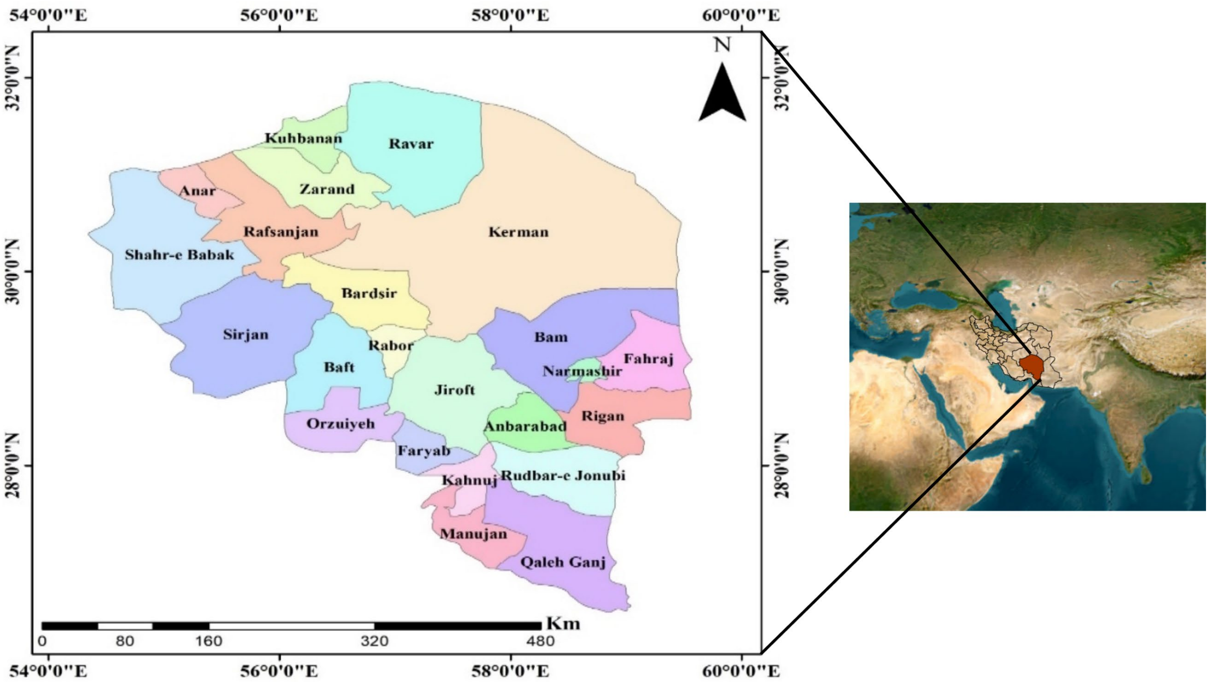

FIGURE 2
The site of the study area.

2 Materials and methods

The present study is practical purposefully, it is a survey research in terms of data collection, and descriptive for data analysis, which was conducted in greenhouse cucumber production farms in Kerman province, Iran (Figure 2) in the crop year of 2020–2021 (From the middle of September 2020 to the middle of June 2021). The population studied were the greenhouse cucumber growers ($N = 4{,}946$), whose number was obtained through the resources available in the Agricultural Jihad Organization of the province. The two-stage cluster sampling method was used considering the wide distribution of cucumber production greenhouses in different cities of the province and the coverage of 92.81% of cucumber production greenhouses in Jiroft, Kahnuj, Anbarabad, and Ghalae-Ganj counties among all the production greenhouses in the province. In the first step, the studied area was divided into two high-density (counties with cultivated area above 100 ha) and low-density (counties with cultivated area less than 100 ha) clusters in terms of cultivated area; and in the second step, Jiroft was selected from the high-density cluster and Kerman was selected from the low-density cluster. These two counties were selected due to the diversity of the climate. The number of samples in each cluster was also selected using the proportional assignment method. In addition, Krejcie and Morgan's (1970) table was used to determine the sample size ($n = 356$).

The data collection tool in this study was a researcher-made questionnaire, including eight main items as follows:

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1. **Energy use efficiency:** It is the level of energy used (MJ) to produce a unit of crop in term of energy (Demircan et al., 2006), i.e., this index shows how much energy has been harvested for each mega Joule of energy consumed per hectare for production purposes. The larger the ratio, the higher the energy efficiency (Singh et al., 2004; Banaeian et al., 2011; Ghorbani et al., 2011). Accordingly, the level of energy use of a greenhouse cucumber cultivation period was investigated using questionnaires prepared including information on the application value of agricultural inputs (Irrigation water, Fertilizers, Chemical pesticides, Machinery, Fuel, Manpower, Plastic, Seeds, and Electricity). In order to measure the energy use efficiency among cucumber growers, the level of energy available in all inputs and outputs was estimated using their energy equivalents recorded in Table 1, and then the energy efficiency index was calculated using Deap software and using the DEA (Data Envelopment Analysis) method [that was first introduced by Charnes et al. (1978)]. A comparison of the average factors affecting energy use in two groups of efficient and inefficient (Nassiri and Singh, 2009) greenhouses was made by dividing the evaluated greenhouses based on the energy use efficiency.
2. **Environmental values:** They include the basic orientation of an individual in the field of environment and show the worldview of people toward the natural world (Schultz and Zelezny, 1998; Barr et al., 2003). Accordingly, environmental values with twelve items (1- In my view, human beings hold superior rights to utilize the environment compared to other living beings such as plants and animals. 2- Farmers are entitled to utilize the environment in any way they see fit to enhance agricultural productivity. 3- I prioritize agriculture over environmental concerns. 4- I believe the key to human survival lies in increasing production rather than maintaining the health of natural resources. 5- The marketability and perceived quality of products are paramount considerations in greenhouse management. 6- I am of the opinion that chemical residues in fruits and vegetables do not pose risks to human health. 7- I prioritize human welfare over the protection of animal and plant species. 8- I prioritize increasing agricultural output for human sustenance over environmental preservation. 9- My primary objective in farming is to maximize production and profits. 10- I assert my right to utilize agricultural inputs to their maximum extent in pursuit of maximizing profits. 11- The management of my greenhouse and my methods are my exclusive prerogative, and I reject any interference or supervision from others. 12- Given the current economic climate, considerations for the environment or collective interests are not feasible for me) were investigated.
3. **Environmental beliefs:** They are a system of attitudes determining an individual's behavior toward the environment and are the frame of reference in interacting with the environment (Corral-Verdugo et al., 2003). Consequently, environmental beliefs with twelve items (1- I believe that nature possesses inherent resilience to counteract the impacts of modern industrialization. 2- The ingenuity of humanity assures us that we will not render the Earth uninhabitable. 3- The purported environmental crisis facing humanity has been overly sensationalized. 4- Human survival does not hinge on aligning ourselves with nature. 5- I am of the opinion that haphazard use of agricultural inputs does not exacerbate environmental conditions in the area. 6- I do not subscribe to

TABLE 1 Energy equivalents of inputs and output in cucumber production.

Inputs and outputs	Unit	Energy equivalent (MJ unit^{-1})	Ref.
A. Inputs			
1. Human labor			
(a) Man	h	1.96	Bojaca and Schrevens (2010)
(b) Woman	h	1.57	Bojaca and Schrevens (2010)
2. Machinery			
Leveler	h	4.703	Nassiri and Singh (2009)
Bund Former (Tractor)	h	2.063	Nassiri and Singh (2009)
Bund Former (Manual)	h	0.502	Nassiri and Singh (2009)
Cultivator	h	3.135	Nassiri and Singh (2009)
M.B. plough	h	2.508	Nassiri and Singh (2009)
Disk Harrow	h	7.336	Nassiri and Singh (2009)
Sprayer	h	0.502	Nassiri and Singh (2009)
3. Fuel			
(a) Gasoline	L	56.31	Nassiri and Singh (2009) and Ghochebeyg et al. (2010)
(b) Gas	m^3	49.5	Kitani et al. (1999) and Khoshnevisan et al. (2013)
(c) Petrol	L	48.23	Nassiri and Singh (2009)
4. Chemical fertilizers			
(a) Nitrogen (N)	kg	66.14	Heidari and Omid (2011) and Ozkan et al. (2007)
(b) Phosphate (P2O5)	kg	12.44	Heidari and Omid (2011) and Ozkan et al. (2007)
(c) Potassium (K2O)	kg	11.15	Heidari and Omid (2011) and Ozkan et al. (2007)
5. Farmyard manure	kg	0.30	Bojaca and Schrevens (2010)
6. Chemicals	kg	120	Canakci and Akinci (2006) and Khoshnevisan et al. (2013)
7. Water for irrigation	m^3	1.02	Ghochebeyg et al. (2010)
8. Electricity	kWh	11.93	Ghochebeyg et al. (2010), Nabavi-Pelesaraei et al. (2014), and Pishgar-Komleh et al., 2012
9. Seed	kg	1	Ghochebeyg et al. (2010)
10. Plastic	kg	158.2	El-Helepi (1997)
B. Output			
1. Cucumber	kg	0.8	Ozkan et al. (2007) and Canakci and Akinci (2006)

the notion that environmental issues such as water and soil pollution can be attributed to agricultural input usage. 7- Assertions regarding phenomena like climate change are exaggerated. 8- Concerns about the environment are unwarranted as future generations will possess greater capabilities to address present challenges. 9- The responsibility for addressing environmental crises lies solely with the government. 10- I disclaim any responsibility for mitigating environmental issues stemming from the use of chemical pesticides in agriculture. 11- It is not incumbent upon me to divulge information about energy use sustainability in my greenhouse to other greenhouse owners. 12- If others make no efforts to protect the environment, I would feel no responsibility to do so.) were evaluated.

4. **Environmental norms:** They are formal and informal rules that express the type of behavior (environmental behavior) and individual relationships in the community (Vesely and Klöckner, 2018). In this regard, environmental norms with four items [1- I believe that the implementation of environmentally friendly practices in greenhouse cultivation and the adoption of eco-conscious interventions have limited impact on environmental conservation. 2- I strongly feel that adherence to environmental principles and regulations is not merely a choice but a mandatory obligation. 3- It is my view that concern over environmental pollution is unwarranted, as technological advancements will inevitably resolve such issues. 4- From my perspective, humans possess the capability to manipulate the environment to suit their requirements] were investigated.
5. **Technical management:** Greenhouse management includes planning, directing, and controlling the operations before cultivating, harvesting, producing, and supplying (Hanan et al., 2012). Technical management with 11 items including 1- Which cases have you analyzed to optimize fuel consumption in greenhouse design? 2- What measures do you implement to minimize energy waste within the greenhouse? 3- In a fan-and-pad cooling system, where is the fan positioned within your greenhouse? 4- What are your greenhouse's temperature settings for daytime and nighttime operation? 5- What cooling mechanisms do you employ to reduce temperatures inside the greenhouse? 6- How do you prevent energy wastage, particularly concerning light and heat? 7- What method do you use to ensure even heat distribution throughout the greenhouse? 8- What types of heating equipment is utilized in your greenhouse? 9- What type of air circulation system is installed within the greenhouse? 10- What fuel source is used for heating the greenhouse? 11- Are there any subsidies available for the purchase of fuel? were evaluated in this study.
6. **Technical knowledge:** Technical knowledge is a set of principles for the application of agricultural inputs, which includes the two dimensions of "knowledge of application" and "knowledge of environmental benefits" (Abtew et al., 2016). Accordingly, measurement and analysis of technical knowledge were conducted with 17 items including: 1- What issues arise for cucumbers when excessive nitrogen fertilizer is applied before flowering? 2- At which stage of cucumber growth was nitrogen fertilizer administered? 3- What are the impacts of applying phosphate fertilizers on cucumbers? 4- Which elements' proportion is crucial for regulating both vegetative and reproductive growth in cucumber plants? 5- Where are ticks most active during the cold season? 6- What factors contribute to reductions in sulfur levels in plants? 7- How does ensuring the appropriate moisture level benefit plant growth? 8- What type of fertilizer should be fully applied to the soil before planting? 9- If harvest time is expected within the next eight days and chemical intervention is necessary in the greenhouse, what is the maximum pre-harvest interval for the chemical to be used? 10- How does light intensity affect plant development? 11- What impacts do elevated EC levels have on cucumber plants? 12- What is the primary limiting factor for greenhouse cultivation? 13- What is the EC level of the soil in which cucumbers are grown? 14- What is the soil pH for cucumber cultivation? Additionally, which elements are used to, respectively, increase and decrease soil acidity? 15- How frequently, in what forms, and on what occasions do you conduct soil sampling and testing? 16- What methods do you employ for non-chemical control of cucumber downy mildew? 17- What strategy do you employ to enhance the volume of cucumber plant roots?
7. **Educational extension services:** Educational extension services are responsible for disseminating technological knowledge to farmers (Singh and Meena, 2019) and helping them improve agricultural practices and increase management skills (Wanigasundera and Atapattu, 2019). In this study, 12 items including 1- Do the experts of Agricultural Jihad (Iranian public agricultural organization who responsible to supply extension and educational services) or the related research center visit your greenhouse during the cultivation period? 2- Do the experts from the Agricultural Jihad or the related research center visit your greenhouse on a monthly basis? 3- Do the experts from the Agricultural Jihad or the related research center offer you services related to cucumber greenhouses? 4- Do the experts from the Agricultural Jihad or the related research center provide you with training regarding cucumber greenhouses? 5- Are you a member of online groups related to greenhouses? 6- Have you so far received advisory services and counseling through virtual groups about the greenhouses for growing cucumber? 7- Have you used educational- extension books regarding the greenhouses for growing cucumber? 8- Have you used educational- extension journals regarding the greenhouses for growing cucumber? 9- Have you used educational- extension films regarding the greenhouses for growing cucumber? 10- Do the information resources cover your information needs about greenhouses for growing cucumber? 11- Do you have access to appropriate information resources about the greenhouses for cultivating cucumber? 12- Have you taken part in the educational classes and workshops regarding the greenhouses for growing cucumber? were used to evaluate the benefit of promotional-educational services.
8. **Individual characteristics:** A demographic survey of greenhouse cucumber growers was conducted by considering the income from cucumber cultivation, the cost of cucumber cultivation, the level of cucumber cultivation experience, and the level of education.

The questionnaire validity was confirmed via the content validity method by expert professors and its reliability was confirmed through the pilot test. In addition, the number of studied greenhouse owners was obtained through the resources available in the Agricultural Jihad Organization. The steps of conducting the research are shown in Figure 3. The data obtained from the questionnaire was recorded, calculated, and analyzed by $SPSS_{24}$, $Excel_{2019}$, and Deap software.

3 Results and discussion

Table 2 presents the demographic characteristics of greenhouse owners. It illustrates that the average area of land dedicated to cucumber cultivation in the surveyed region is 12,952.3 square meters. Moreover, the average duration of greenhouse cucumber cultivation is reported as 8.8 years, with a standard deviation of 3.6. The respondents' average educational attainment stands at 11.1 years, with a standard deviation of 5.2. Furthermore, the study reveals that 6% (22 individuals) of participants are female, while 94% (334 individuals) are male.

The findings concerning the technical management of individuals studied in cucumber cultivation within greenhouses, aimed at optimizing energy use, reveal that the average technical management score among greenhouse owners (9.83) falls below the intermediate level. This deficiency stems from a lack of essential information and knowledge necessary for efficient greenhouse management and optimal energy use. For instance, owners neglect crucial solutions for greenhouse design to minimize fuel use and prevent energy waste. Additionally, they fail to regulate greenhouse temperatures adequately throughout the day and night, and they do not employ suitable cooling and heating systems to maintain favorable conditions for plant growth (Table 3). Consequently, the greenhouse manager's decisions regarding greenhouse unit implementation and management, as well as agricultural input utilization, do not result in efficient energy use. In fact, energy use sustainability in agriculture cannot be achieved solely through technology for environmental protection but requires changes in behavior, improved management, and enhanced knowledge of farmers about energy use and identifying the factors affecting it (Bourdeau, 2004). This is because sustainability in energy use and energy systems management helps enhance energy use efficiency (Behroozeh et al., 2022). Furthermore, the technical knowledge of greenhouse owners (with a mean score of 13.65) regarding cucumber cultivation in greenhouses falls below the intermediate level. This deficiency primarily arises from their limited understanding of various agricultural inputs' proper usage during the cultivation process. This includes aspects such as observing the latent period, soil sampling and testing, the effects of high electrical conductivity (EC) on cucumber, non-chemical methods for plant disease control, and regulating optimal plant temperature. Often, this lack of knowledge leads to haphazard and unprincipled input usage, thereby decreasing energy efficiency in cucumber-growing greenhouses (Table 3). Therefore, excelling in greenhouse crop production requires an increase in technical knowledge (Hall, 2003). Thus, achieving energy use efficiency requires utilizing technical knowledge for sustainability in energy use (Anderson, 2010; Croppenstedt, 2005).

The findings regarding individuals' environmental values in relation to efficient energy use in cucumber-growing greenhouses indicate that the average value among greenhouse owners (21.87) falls below the intermediate level. This discrepancy arises from the owners prioritizing agricultural activities for sustenance over environmental protection. They perceive increased production as more crucial for human survival than preserving healthy natural resources. This is because values are defined based on what people believe is fundamentally right or wrong (Gursoy et al., 2013). Environmental values are conceptualized as fundamental guides in people's lives (Hedlund, 2011) and play a crucial role in efficient energy use (Shove and Walker, 2014). In fact, values act as informational filters that lead individuals to selectively accept or seek out information (Salehi et al., 2018). For this reason, environmental values play a significant role in the decision-making of agricultural unit managers and in the management of the use and application of resources in agricultural activities. Similarly, the results concerning individuals' environmental beliefs regarding energy-efficient cucumber cultivation reveal that the average value of greenhouse owners' environmental beliefs (22.56) is

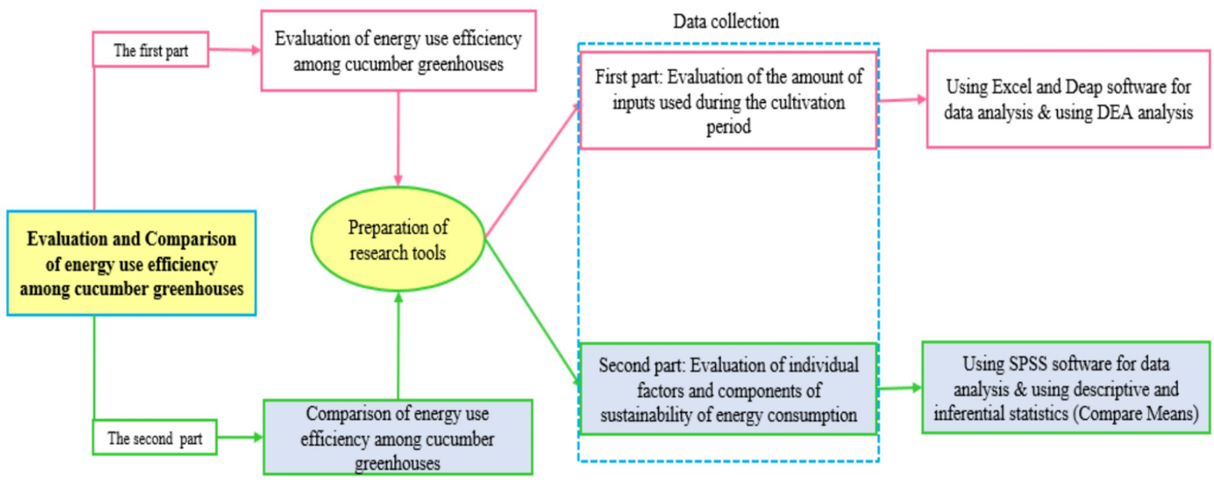

FIGURE 3
Research methodology flow chart.

TABLE 2 The demographic properties of the studied greenhouse owners.

	Minimum	Maximum	Mean	Standard deviation
Area of cucumber-cultivated (m^2)	2000	40,000	12952.3	11,109. 8
Greenhouse's work experience (year)	4	16	8.8	3.6
Education level (year)	5	22	11.1	5.2
Gender	Female	22		
	Male	334		

TABLE 3 Descriptive statistics of energy use sustainability components.

Component	Range	Mean	Standard deviation
Technical management of the greenhouse	0–21	9.83	3.61
Technical knowledge of the greenhouse	0.40	13.65	6.53
Environmental values	12–48	21.87	9.95
Environmental beliefs	12–48	22.56	6.92
Environmental norms	4–16	8.51	1.97
The use of the educational-extension services	0–12	4.45	1.63
Cost amount (Per hectare)	-----	119,342.6	-----
Income amount (Per hectare)	-----	180,380.9	-----
Profit amount (Per hectare)	-----	61,038.4	-----
Profit-cost ratio (Per hectare)	-----	0.55	-----

lower than the intermediate level. This is because some owners believe that if others do not contribute to environmental protection, they themselves bear no responsibility in this regard. Moreover, they hold the belief that human survival does not necessitate harmony with nature. However, environmental beliefs play an important role in decision-making and the management of the use and application of inputs in agricultural activities (Howley et al., 2015). This is because environmental beliefs are a system of attitudes that determine an individual's behavior toward the environment and serve as a reference framework in interactions with the environment (Corral-Verdugo et al., 2008). The findings concerning the environmental norms of participants involved in energy-efficient practices within cucumber-growing greenhouses reveal that the average score for greenhouse owners' environmental norms (8.51) falls below the moderate threshold. This suggests that individuals who endorse human intervention in environmental alteration for human benefit tend to have lower environmental norm scores. Moreover, interventions aimed at promoting environmentally friendly practices within greenhouse cultivation appear to have limited impact on overall environmental protection efforts (Table 3). Since norms provide meaningful values and orientations of others (Schwartz, 1977). And are generally defined as rules and standards perceived by members of a group that guide or constrain social behavior without the enforcement of laws (Cialdini and Trost, 1998). Therefore, energy use is influenced by social and environmental norms (Shove, 2010).

Similarly, the utilization of educational and extension services among participants striving for energy efficiency in cucumber-growing greenhouses indicates a modest average score (4.45) among greenhouse owners. This score falls below the moderate range, indicating a lack of substantial engagement with educational resources. Specifically, greenhouse owners exhibit minimal utilization of educational materials such as books and journals, infrequent participation in online discussions related to greenhouse practices, and limited access to educational programs offered by agricultural experts and research institutions in the region (Table 3). Considering that the main lever for promoting agriculture among farmers is education, educating farmers has significant benefits and substantial economic impacts (Nguyen and Cheng, 1997). Farmers with higher levels of education have better access to the knowledge, information, and innovations needed for their professional activities. They are also more capable of analyzing the information they receive and selecting the best approach for managing their farms (Uematsu and Mishra, 2010). Therefore, continuous education over time facilitates the enhancement of knowledge and acquisition of new skills in the process of empowering farmers toward sustainable energy use. Thus, as a prerequisite, it contributes to the development of theoretical capabilities and practical competencies in the field of greenhouse cultivation. Therefore, the rationale behind agricultural extension systems for agricultural development is based on the necessity of continuously implementing training programs for audiences. Over time, this approach aims to enhance their practical, technical, and social awareness, thereby improving their capacities, capabilities, and competencies as trained individuals. Because education is a key factor in agricultural development, and training specialized and research-oriented human resources is the most important factor for advancing agriculture (Cantley, 2004). Therefore, successful greenhouse management requires access to educational and extension services (Behroozeh et al., 2022). Because the goal of agricultural extension is to improve agricultural operations by promoting knowledge about technologies, operations, and the technical management of modern farming practices to farmers (Fabusoro et al., 2008).

The findings from Table 3 reveal that the average cost per hectare for operating cucumber-growing greenhouses amounts to approximately $119,342.6. Additionally, the average income and profit per hectare are reported as $180,380.9 and $61,038.4, respectively. Notably, the profit-cost ratio stands at 0.55, indicating that the economic viability of the greenhouses is modest. A higher ratio suggests a more favorable economic justification for investing in and operating these greenhouses. Because there is a close relationship between agricultural activities and energy use, and the productivity and profitability of this sector depend on its energy use (Karimi et al., 2008). Therefore, efficient energy use contributes to increased production and productivity, and supports the profitability and sustainability of agriculture (Singh et al., 2004).

According to the mentioned topics and the energy equivalent of inputs and outputs of greenhouse production (Table 1), as well as the amount of energy use, the energy equivalent of inputs used to produce greenhouse cucumbers in the greenhouses of Kerman province, Iran, was calculated during one cultivation period. The results presented in Table 4, show that the total energy of inputs for cucumber production in one cultivation period and the total energy of the produced crop in one cultivation period are 667,442,186 and 23,780,391 MJ/ha, respectively. Analyzing the amount of inputs use per unit area show how much of each input per hectare is used for greenhouse cucumber production. According to the results of Table 4, the highest level of energy consumed in the studied greenhouses is related to the fuel at the rate of 819,739 MJ/ha, which is used to heat the greenhouse and as fuel for tools and machinery. Due to the nature of greenhouse operations and off-season crop cultivation, fuel inputs often account for the largest share of energy use. Other researchers (Zalaghi et al., 2021) have also found in their studies on energy in agricultural greenhouses that fuel inputs account for the highest proportion of energy use in greenhouse crops.

As aforementioned, DEA method was used to calculate the energy efficiency of the studied units. According to the results of Table 5, the mean energy use efficiency is 0.72, indicating low energy efficiency in the studied greenhouses. Twenty-one greenhouses are in an efficient state and 335 greenhouses are in an ineffective state for energy use, which indicates the inefficient use of agricultural inputs in greenhouse production. In this regard, some researchers found the excessive use of agricultural inputs by farmers (Benli and Kodal, 2003; Nassiri and Singh, 2009; Ghorbani et al., 2020).

According to the results in Table 6, showing the application level of different inputs in the minimum optimal use combination, by reaching the optimal level of use, an average of 492,730.3 MJ/ha is saved in energy use. This issue indicates that greenhouse growers of cucumbers are not effectively minimizing energy use for optimal use. Therefore, there is significant potential to enhance the efficiency of greenhouse operators, as optimizing input use can maximize their efficiency.

The student's t-test was used to compare the mean energy use efficiency among cucumber greenhouses based on the components of energy use sustainability (Table 7). According to the Cohen's scale [Cohen's *d* (Cohen, 2013) is a standardized effect size for measuring the difference between two group means]. There is a significant difference between efficient and inefficient greenhouse owners in terms of environmental norms, environmental beliefs, environmental values, technical management, technical knowledge, education level, greenhouse's work experience, cost-effectiveness, and the benefit of educational-extension services. As mentioned in Table 7, the components of energy use sustainability are significantly higher among the group of greenhouses with energy use efficiency. In this regard, several researchers found the importance of environmental norms (Miafodzyeva et al., 2010; Viscusi et al., 2011; Thanh et al., 2012), environmental beliefs (Sadeghi Shahedani and Khoshkhouy, 2015; Salehi et al., 2017), environmental values (Barber et al., 2009; Bondari et al., 2020), technical management (Nuthall, 2006; Mohtashami and Zandi Daregharibi, 2018), technical knowledge (Mohammad-Rezaei and Hayati, 2018; Huo et al., 2022), education level (Adesina, 1996; Ade Freeman and Omiti, 2003; Wang, 2010), greenhouse's work experience (Ade Freeman and Omiti, 2003; Ganji et al., 2018), cost-effectiveness (Shahan et al., 2008; Taghinazhad and Ranjbar, 2019), and the benefit of educational-extension services (Keshavarz and Mousavi, 2018; Salehi et al., 2020) in their research on resource sustainability and environmental protection. In general, if cucumber greenhouse growers believe that excessive use of agricultural inputs can worsen environmental conditions in the region, and if they make efforts to preserve the environment and feel responsible in this regard; then management of individuals in agricultural greenhouses will not seek to harm the environment through the use and application of agricultural inputs. To the extent that individuals recognize their equality with other living beings in terms of using the environment, prioritize agriculture in a balanced way with respect to the environment, avoid exploiting the environment for increased production, and do not excessively use agricultural inputs to maximize profits, then energy use behavior in agricultural greenhouses will align with the efficient and effective use of energy resources (Mousavi-Avval et al., 2011; Zangeneh et al., 2010).

TABLE 4 The amount of energy consumed by each of the inputs.

Input	Average amount of use per unit area (MJ/ha)
Human labor	10,287.2
Electricity	239,724
Water for irrigation	12,466
Fuel	819,739
Chemicals	9,918
Chemical fertilizers	8,747
FYM	8,530
Machinery	123.6
Plastic	765,299
Seed	1.03

4 Conclusion and implications

In this study, measuring and comparing the energy use efficiency in cucumber greenhouses was evaluated by focusing on the comparison of efficient and inefficient greenhouses based on the components of energy use sustainability (Figure 1) in the study area; and since the comparison of energy use efficiency is influenced by the components of energy use sustainability, the detailed identification of these components was first addressed based on the fundamental studies in this field. Accordingly, the distinguishing components of effective and ineffective greenhouses were compared and investigated in nine dimensions, e.g., "environmental norms," "environmental beliefs," "environmental values," "technical management," "technical knowledge," "education level," "greenhouse's work experience," "cost-effectiveness," and "the benefited of educational-extension services." The results showed the significance of all these nine components in comparing the energy use efficiency in the studied greenhouses. Because greenhouse owners with energy efficiency exhibited a high level of these components related to energy use. However, despite the lack of energy efficiency (Table 5) in cucumber production in most of the greenhouses studied, the

TABLE 5 Energy efficiency indicators in studied greenhouses.

Efficiency	Maximum	Minimum	Mean	Standard deviation	=1% (Efficient)	<1% (Inefficient)
Energy use efficiency	1	0.45	0.72	0.13	21	335

TABLE 6 The amount of different inputs in the minimum-optimal combination.

Input	Input current level (MJ/ha)	The optimal level of use (MJ/ha)	Excess use energy (MJ/ha)
Chemical fertilizers	8747.1 ± 4501.3	6371.1 ± 1345.1	2,376 ± 4515.8
Human labor	10287.2 ± 1002.3	8117.6 ± 1467.9	2169.6 ± 1509.7
Chemicals	9,919 ± 1068.4	7955.5 ± 1411.6	1963.5 ± 1507.2
Electricity	239,724 ± 16009.7	187679.1 ± 36827.8	52044.9 ± 35534.7
Water for irrigation	12466.2 ± 897.9	9816.8 ± 1794.6	2649.4 ± 1840.6
FYM	8530.9 ± 3895.3	6166.8 ± 2872.9	2364.1 ± 2554.1
Fuel	819739.1 ± 10,117,276	576387.1 ± 685797.8	243,352 ± 539892.1
Seed	1.03 ± 0.2	0.8 ± 0.16	0.23 ± 0.2
Machinery	123.6 ± 34.6	97.2 ± 35	26.4 ± 22.2
Plastic	765299.5 ± 124273.8	579515.3 ± 116,341	185784.2 ± 155945.2
Total	1874837.6 ± 1025856.4	1382107.3 ± 727546.2	492730.3 ± 600633.1

Mean ± SD.

TABLE 7 Comparison between efficient and inefficient cucumber greenhouses based on the components of energy use sustainability.

Component	Energy use efficiency	Frequency	Mean	Standard deviation	*t*	sig	Cohen's *d*
Environmental Norms	Efficient	21	12	0.01	37.44	0.001	2.89
	Inefficient	335	8.29	1.81			
Environmental Beliefs	Efficient	21	30.9	6.94	5.96	0.001	1.31
	Inefficient	335	22.04	6.59			
Environmental Values	Efficient	21	31.1	4.65	9.94	0.001	2.17
	Inefficient	335	21.29	4.37			
Technical Management	Efficient	21	17	0.01	43.18	0.001	3.33
	Inefficient	335	9.38	3.23			
Technical knowledge	Efficient	21	1	0.01	4.23	0.001	0.46
	Inefficient	335	0.95	0.22			
Education Level	Efficient	21	21.9	0.44	42.41	0.001	3.48
	Inefficient	335	10.45	4.63			
Greenhouse's work experience	Efficient	21	15.9	0.44	37.91	0.001	3.3
	Inefficient	335	8.39	3.18			
Cost-Effectiveness	Efficient	21	1.02	0.09	23.04	0.001	3.33
	Inefficient	335	0.52	0.19			
Educational -Extension Service	Efficient	21	8	0.01	49.17	0.001	3.80

high price of greenhouse cucumbers has made cultivating this crop economically viable. It is also worth noting that the reduction in energy efficiency in cucumber production is due to the low cost of energy inputs in the country and the abundant availability of these resources. In this regard, making the prices of inputs more realistic and ensuring farmers' access to agricultural inputs according to their needs will play a significant role in rationalizing farmers' behavior in the use of these inputs.

The results of energy use for cucumber production greenhouses during one-year cultivation period showed that the total energy input in cucumber production is 667,442,186 MJ/ha. The most energy use of inputs was related to fuel. This can be due to the high use of this input especially in the cold season to keep the greenhouses warm and the need of the cucumber crop for a relatively high temperature to grow. Accordingly, replacing the method that can reduce the amount of fuel use in the greenhouse, such as modern heating devices which provide the required heat for the greenhouses by using the hot water flow system, can reduce fuel use and consequently reducing the total energy of inputs used in the greenhouse.

The results indicated that a high percentage of the studied greenhouses did not have the required efficiency and the increase in the input use in the above units exceeded the increase in the production of these units and caused a decrease in energy efficiency, which resulted in irreparable damages to the environment due to improper use of resources. Therefore, it is suggested that by improving management operations in the optimal use of inputs such as fuel and fertilizers and the technical knowledge of greenhouse owners about the importance of energy use, and conducting production units in line with the rational and timely energy use and energy saving methods, they should take steps in the direction of reducing energy losses and increasing performance per surface unit. This is because the average score for the technical management of greenhouse operators (Table 3) is below the average level. This situation stems from a lack of sufficient information on greenhouse management and principles of optimal energy use. Furthermore, the average technical knowledge of greenhouse owners (Table 3) is also below the average level. This issue is due to their relatively low awareness about the use and application of various agricultural inputs throughout the growing period.

Considering that only a few greenhouse units have 100 percent efficiency, and there is a difference in energy use sustainability components between high-efficiency and low-efficiency production greenhouses. Therefore, policymakers aiming to improve energy efficiency should focus on strategies that enhance environmental values, beliefs, and norms, and institutionalize them among greenhouse owners. This is because, according to the research results, the average values, beliefs, and environmental norms of greenhouse operators (Table 3) are below the average level. For this purpose, field extension and agricultural education agents can be utilized. Considering that the average level of utilization of educational and extension services (Table 7) in the study area is below the average level. Agricultural managers should provide educational and extension services by expanding successful methods used in efficient units and enhancing management knowledge and experience among units. They should train other units on the optimal use of resources through exemplary units. In addition, the expansion of educational classes related to identifying the types of pests and diseases and timely diagnosis of these factors and how to use inputs such as chemicals and pesticides which are required for these situations can effectively affect the efficiency of these units. Hence, it is suggested that the decision-makers, stakeholders, and active policy-makers on greenhouse crops should consider all the components of energy use sustainability, so that the policies and plans developed can cover all dimensions and take into account different aspects. Consequently, the results of this study can apply as a reference for other similar areas.

5 Limitations and avenues for future research

Numerous notable constraints were encountered during the research process. Initially, it is important to highlight that the assessment of energy use sustainability in agricultural greenhouses focused specifically on cucumber cultivation. A sample group consisting of greenhouse cucumber growers was selected to facilitate the comparison and measurement of sustainability indicators. This approach aimed to offer fresh insights into sustainable energy use criteria, which could potentially be valuable for other greenhouse operators, including those cultivating tomatoes, eggplants, strawberries, and similar crops.

Moreover, spatial restrictions coupled with the limited accessibility to other greenhouse owners, exacerbated by the COVID-19 outbreak, were primary factors contributing to the unavailability of pioneering farmers engaged in diverse greenhouse crop cultivation. Consequently, future research endeavors are advised to explore sustainable energy use components among farmers cultivating crops such as eggplants, tomatoes, strawberries, and similar produce. This exploration could greatly contribute to recognizing disparities and thus facilitate more targeted agricultural policy formulation across different regions and a wider spectrum of greenhouse crop varieties. Secondly, the components utilized in this study have been derived from a literature review; endeavors have also been made in this study to utilize the most prevalent components; however, it should be noted that components for energy use sustainability, akin to the notions of stability and sustainability, are highly dynamic. Hence, future researchers may employ alternative components for energy use sustainability in agriculture depending on the scope of their investigations.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent was obtained from the patients/participants or patients/participants legal guardian/next of kin to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

SB: Data curation, Formal analysis, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. DH: Conceptualization, Investigation, Supervision, Writing – review & editing. EK: Investigation, Methodology, Supervision, Writing – review & editing. SN: Formal analysis, Methodology, Software, Validation, Writing – review & editing. KR-M: Formal analysis, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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