Gorgan University of Agricultural Sciences and Natural Resources

Environmemtal Resources Research (ERR)

Print ISSN: 2783-4832
Online ISSN: 2783-4670

Assessment of energy use efficiency and life cycle environmental impact of almond and walnut production: a case study in Shahrekord, Iran

Mehrdad Salimi Beni[1], Mohammad Gholami Parashkoohi[2*], Babak Beheshti[3], Mohammad Ghahderijani[4], Hossein Bakhoda[4]

[1] Ph.D. Candidate, Department of Agricultural Systems Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
[2] Associate Professor, Department of biosystem engineering, Takestan Branch, Islamic Azad University, Takestan, Iran
[3] Associate Professor, Department of Agricultural Systems Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
[4] Assistant Professor, Department of Agricultural Systems Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

Article Info

Article type:
Research Article

Article history:
Received: April 2023
Accepted: July 2023

Corresponding author:
mohammad.gholami@iau.ac.ir

Keywords:
Energy use
Environmental impact
Human health
Sustainability

Abstract

In order to improve almond and walnut production, a study was conducted in Shahrekord, a city in central Iran, focusing on the rural agricultural lands. Shahrekord exhibits a diverse climate, which facilitates the cultivation of various agricultural and horticultural products across different areas. The study aimed to enhance the production of almond and walnut crops in this region. Selecting similar gardeners with comparable characteristics and production histories ensured a reliable research sample. One of the primary production challenges in the area is the labor-intensive manual harvesting process that is widespread in the region. To gather data for the study, questionnaires and face-to-face interviews were employed. Additionally, energy consumption was assessed by calculating the inputs utilized. The study determined that the total energy consumption for almonds and walnuts amounted to 29,430.56 MJ ha^{-1} and 15,309.28 MJ ha^{-1}, respectively. According to the LCA results, the resource category had the highest environmental impact, whereas human health had the lowest. Previous research on almond and walnut production indicated that almond production had higher greenhouse gas emissions than walnut production. Additionally, the resources category had a greater impact on almond production than on walnut production in terms of pollutants. These findings highlight the importance of carefully evaluating the environmental impact of different agricultural practices and identifying ways to reduce their impact to promote sustainable agriculture.

Cite this article: Salimi Beni, Mehrdad; Beheshti, Babak; Gholami Parashkoohi, Mohammad; Ghahderijani, Mohammad; Bakhoda, Hossein. 2023. Assessment of energy use efficiency and life cycle environmental impact of almond and walnut production: a case study in Shahrekord city, Iran. *Environmental Resources Research*, 11(2), 195-208.

DOI: 10.22069/ijerr.2024.21546.1407
Publisher: Gorgan University of Agricultural Sciences and Natural Resources

Introduction

The production of agricultural goods heavily depends on non-renewable resources like fossil fuels. There are rising concerns that the continuous and excessive use of these inputs may eventually deplete the agricultural sector's production capacity. This could lead to a cessation of the growth in food production that has been observed in recent decades. The utilization of finite and non-renewable resources has raised apprehensions about environmental issues caused by agricultural activities, such as pollution, deforestation, soil fertility loss due to erosion and over-exploitation, as well as concerns regarding intensive agriculture (Payandeh et al., 2021). Up until now, the majority of approaches, tools, and techniques in the sustainability toolbox have concentrated on attaining incremental enhancements in environmental performance. However, this is frequently inadequate to achieve the significant level of improvement needed to meet the necessary requirements (Elalami et al., 2022). The scarcity of resources and energy has prompted particular emphasis on the method of allocation and the management of their consumption. Various categories of energy are taken into account in farm energy analysis. The shift of the conventional agricultural system towards modern technology for agricultural products has prompted agricultural units to adopt appropriate energy and environmental guidelines and principles in the current era (Unakıtan and Aydın, 2018).

The cultivation area plays a crucial role in estimating costs and determining the energy efficiency of natural facilities in horticultural product cultivation and production. Ultimately, it contributes to increasing the yield per hectare (Feyzbakhsh et al., 2018; Kaab et al., 2021). The profitability of investing in walnut and almond orchards is evident from the high nutritional value, increasing global demand, and high selling prices of these products. Almond and walnut trees are resistant to cold and drought. Optimal seed growth relies on several factors such as soil type, irrigation amount, proper sunlight, sufficient humidity, and the use of animal and chemical fertilizers. Consequently, their cultivation depends on geographical conditions (Baer et al., 2016). Recent statistics reveal that the cultivated area of almonds and walnuts in Iran is 75,553 ha and 53,504 ha, respectively. Walnut production amounts to 386,976.51 tons per year, while almond production is 163,568.2 tons per year. These products play a significant role in Iran's dry food ration (FAO, 2020).

Energy flow reports on input and output in product production are instrumental in achieving sustainable agricultural development. Studying energy flow can illuminate previously unknown aspects of the production process not addressed in other management approaches, such as mechanization or economic methods (Ghasemi-Mobtaker et al., 2020; Tutak and Brodny, 2022). The energy ratio of various agricultural systems is impacted by the product type and materials utilized in production. As a result, the energy ratio is critical in identifying shortcomings and plays a pivotal role in sustaining production stability, optimizing economic benefits, preserving fossil fuel reserves, and curbing air pollution (Ghritlahre and Prasad, 2018). Designing optimal cultivation patterns through input and output energy analysis of production systems is not scientifically feasible without evaluating the efficiency and effectiveness of energy consumption (Unakıtan and Aydın, 2018). As a food supplier, agriculture is linked to all three elements of water, soil, and air, which can lead to pollution and alterations in these environments. There has been a recent focus on assessing the repercussions of these changes (Younis et al., 2021). Each agricultural product requires a specific input and a particular quantity of it based on a country's environmental and geographical conditions and the type of product (Bacenetti et al., 2018). Life cycle assessment (LCA) is increasingly being used to present scientific evidence of improved environmental performance. These assessments usually involve comparing new product designs with existing products or a comparable reference to demonstrate an incremental improvement in the eco-efficiency of a system's products or that they are leading in eco-efficiency performance. This approach enables a more objective and rigorous assessment of environmental impact and promotes sustainable practices (Wang et al., 2021).

The assessment of energy use efficiency and the life cycle environmental impact of almond and walnut production in Shahrekord city, Iran, is crucial for several reasons. Firstly, almond and walnut production play a significant role in the agricultural sector of Shahrekord City, contributing to its economy and livelihoods. However, the energy consumption associated with these production processes can have substantial environmental consequences. Secondly, understanding the energy use efficiency and life cycle environmental impact is essential for sustainable agricultural practices. By assessing these factors, we can identify areas of improvement and implement effective strategies to reduce energy consumption and minimize environmental burdens. Additionally, Shahrekord City is located in Iran, a region that may be vulnerable to climate change and water scarcity. Therefore, analyzing the energy use efficiency and environmental impact of almond and walnut production can help identify sustainable practices that ensure long-term viability in the face of these challenges. Overall, conducting this assessment is necessary to promote sustainable agricultural practices, minimize environmental impacts, and secure the future of almond and walnut production in Shahrekord City, Iran. The proposed plan aims to identify bottlenecks and expected performance related to significant dry fruits, such as almonds and walnuts. By analyzing the data, the plan aims to provide necessary solutions to optimize the utilization of existing potentials in various regions, with a focus on reducing energy consumption and environmental emissions.

Materials and Methods

Sample collection conditions

In order to implement the techniques aimed at improving almond and walnut production, rural agricultural lands in Shahrekord, Iran were chosen. The region has a varied climate, which enables the cultivation of a diverse range of agricultural and horticultural products. With a combination of hot and cold weathers, Shahrekord provides suitable conditions for the growth of fruit trees that thrive in warm climates, such as pomegranates, as well as trees that are resilient to colder temperatures, like almonds and walnuts.

To facilitate the establishment of orchards, farmers in the region have adopted the use of machinery for planting seedlings. To determine the sample size for the study we used Cochran's formula (Equation 1), which is based on reliable statistical data obtained from credible sources (Cochran, 1977). The selected gardeners displayed similar characteristics and had identical production histories. The process of manual harvesting, which required a significant amount of human labor in the region, played a vital role in almond and walnut production. Data collection was conducted through the administration of questionnaires and conducting face-to-face interviews.

$$n = \frac{\frac{z^2 pq}{d^2}}{1 + \frac{1}{N}\left(\frac{z^2 pq}{d^2} - 1\right)} \qquad (1)$$

where n is the required sample size, N is the number of farms in the target community, namely 80, Z is the reliability coefficient (equal to 1.96, which indicates a confidence level of 90%), p is the proportion of the population with a certain trait, q (p-1) and d are the permissible deviation of the error ratios from the population average. Considering the population of farmers in the region and setting 0.5 for p and q and 0.05 for the d parameters, the sample size for almond and walnut production was estimated equal to 70 and 60, respectively.

Energy consumption

Various factors, including human labor, machinery, diesel fuel, gasoline fuel, chemical fertilizers, farmyard manure, biocides, and electricity, were considered when evaluating the inputs and outputs of almond and walnut production. To determine the equivalent energy of these inputs and outputs, the energy values of different sources were used as a reference point. This approach facilitated a more precise evaluation of the energy efficiency of almond and walnut production, aiding in the identification of areas for improvement to reduce energy consumption and optimize resource utilization (Brentrup et al., 2004; Feyzbakhsh et al., 2018; Ghorbani et al., 2011).

To calculate the input and output energy values of each resource, the consumption of each resource was multiplied by its equivalent energy value. This research component encompasses various energy indicators that provide a comprehensive understanding of agricultural production systems. These indicators, including energy ratio, energy productivity, net energy addition, and specific energy, are essential measures in the energy analysis process. The study utilized these indicators to accurately evaluate the energy efficiency of almond and walnut production and identify opportunities for improving resource utilization (Beigi et al., 2016; Kaab et al., 2023).

To determine the fuel consumption of machines, agricultural operations were first divided into various stages. The duration of machine operation during each stage was calculated separately, starting from the beginning of each operation until the end of almond and walnut production stages on each farm. Based on the operator's work experience in previous years, the amount of fuel consumed was estimated using the following formula (Naseri et al., 2020).

$$FT = t \times FG$$

where FT is the fuel needed to carry out the agricultural operations at the level of one hectare (liters per ha), t is the duration of the machinery operation (hours per ha) and FG is the fuel required by the tractor in one hour of operations (liters per hour).

The researchers regarded energy ratio as the benchmark for technological advancement and identified efficiency indicators such as energy ratio, net energy addition, and energy efficiency as crucial for assessing and analyzing energy consumption in the agricultural sector. The following equations were utilized to estimate the energy indices (Elalami et al., 2022).

$$\text{Energy use efficiency} = \frac{\text{Output energy (MJ)}}{\text{Input energy (MJ)}} \quad (3)$$

$$\text{Energy productivity} = \frac{\text{Production (kg)}}{\text{Input energy (MJ)}} \quad (4)$$

$$\text{Specific energy} = \frac{\text{Input energy (MJ)}}{\text{Production (kg)}} \quad (5)$$

$$\text{Net energy} = \text{Output energy (MJ)} - \text{Input energy (MJ)} \quad (6)$$

LCA

Mitigating carbon dioxide and other greenhouse gas emissions is crucial for achieving sustainable development and addressing environmental concerns. The primary greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), contribute to the greenhouse effect, trapping heat in the atmosphere and leading to climate change. To combat the damaging effects of climate change and create a more sustainable future, it is crucial to reduce greenhouse gas emissions (Nabavi-Pelesaraei et al., 2019b). LCA is a valuable instrument for assessing the environmental impacts of products throughout their entire life cycle, which includes resource extraction, material production, parts production, final product assembly, product use, and disposal management. By enabling a comprehensive analysis of a product's environmental effects, LCA considers all stages of its life cycle and identifies areas for improvement to minimize its environmental impact. LCA evaluation of a product's life cycle can facilitate the development of more sustainable products and promote environmentally responsible practices (Houshyar and Grundmann, 2017). The LCA process comprises four distinct steps. The initial step is to establish the assessment's goal and scope. It is crucial to specify the LCA's goal and scope clearly and ensure that it is aligned with its intended application. For instance, in this study, the objective is to compare the environmental emissions associated with dried fruit production systems. The study's scope, including the system boundary and level of detail, is determined by the topic and the intended use of the LCA. The depth and breadth of the LCA can vary depending on the specific purpose of the assessment (Zeng et al., 2011). The reference stream is defined by the selected operational unit. To ensure a valid comparison between systems, it is crucial to base the comparison on similar functions. The same operational units can be quantified as reference flows. Alternatively, systems that perform the same function can be added to the boundary of other systems to make them more comparable. The chosen processes must be documented and described in detail (de Vries and de Boer, 2010). The functional unit is defined as one ton of product. The second stage involves conducting a life cycle inventory. Figure 1 illustrates the study system's boundary. The inventory analysis stage encompasses the collection of input/output data related to the system under study, including the necessary data required to meet the study's defined objectives (Wowra et al., 2021). The third stage of the LCA process is referred to as the Life Cycle Impact Assessment (LCIA). The LCIA stage is intended to provide additional information that can aid in the evaluation of the life cycle inventory of a product system. This information is essential to better comprehend the environmental significance of the product system and its potential impacts. The LCIA stage encompasses a range of impact categories, such as climate change, water use, and human toxicity, which offer a comprehensive overview of the potential environmental impacts of a product system. The results of the LCIA stage enable decision-makers to identify areas where improvements can be made to reduce environmental impact and promote sustainability (Renouf et al., 2010). The final stage of the LCA process is life cycle interpretation. This stage involves reviewing the results of both the life cycle inventory (LCI) and life cycle impact assessment (LCIA) and drawing conclusions, making recommendations, and decisions based on the defined goal and scope of the study. The life cycle interpretation stage encompasses an evaluation of the LCI and LCIA outcomes, identifying areas where improvements can be made to reduce environmental impact and increase sustainability. The results of this stage provide valuable information for decision-makers and stakeholders, enabling them to make informed decisions concerning product design, production, and management with the aim of minimizing the environmental impact of products and promoting sustainable practices (Nabavi-Pelesaraei et al., 2019a).

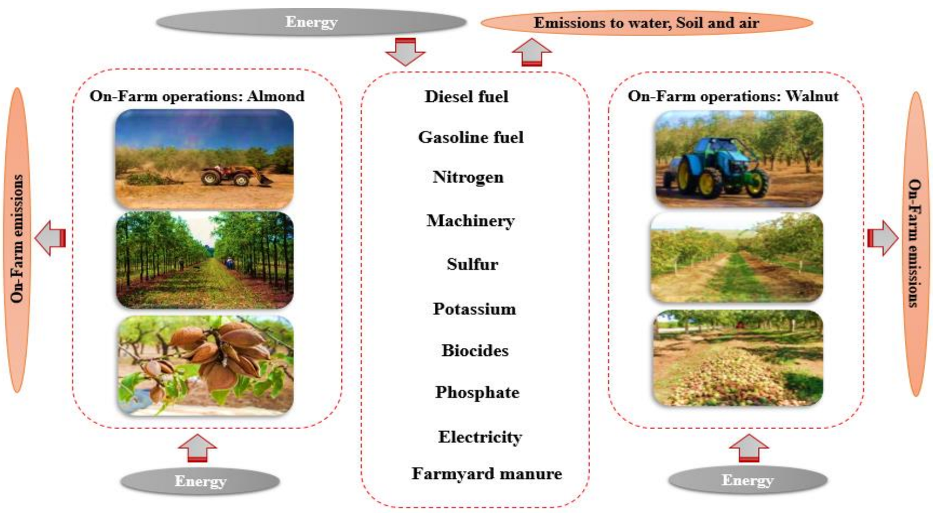


Figure 1. Selected boundaries for environmental impacts.

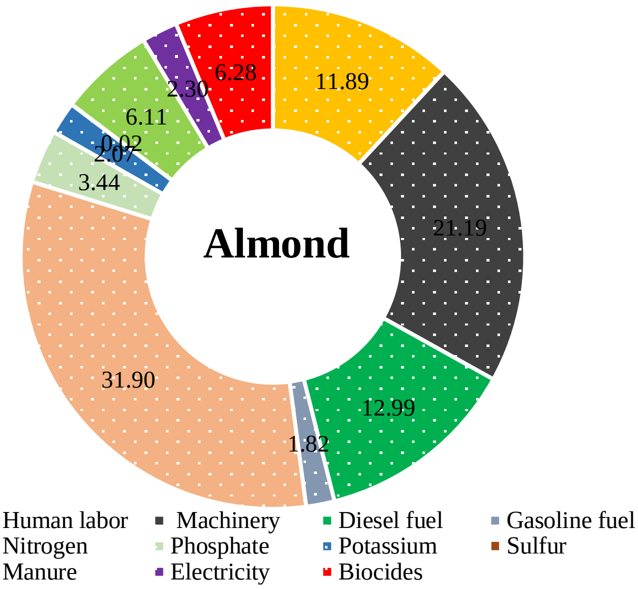
Results and Discussion

Energy use analysis

The provided information highlights a comparison of energy consumption and production for almond and walnut products. Table 1 shows that the total energy consumption for almonds is 29430.56 MJ ha^{-1}, while for walnuts, it is 15309.28 MJ ha^{-1}. However, walnuts have higher production energy, accounting for 54901.05 MJ ha^{-1}, compared to almonds. The significance of walnut production in the region depends on the input supply conditions for farmers. If the inputs required for walnut production are readily available and affordable, it may make walnut production more appealing. The discussion emphasizes the need to analyze the consumption of inputs separately, as shown in Figure 3. In almond production, nitrogen contributes to over 30% of the energy share, indicating its high energy demand. On the other hand, in walnut production, diesel fuel accounts for 21.19% of the energy share, suggesting its significant role. To enhance nitrogen use efficiency in almond production, it is crucial to apply fertilizers at the right time and in the correct amount, based on the plant's needs during the growing season. This approach can help reduce the energy required for machinery and ensure accurate and effective use of nitrogen fertilizer. Overall, the discussion highlights the different energy consumption levels and input requirements between almond and walnut production. It also emphasizes the importance of optimizing input usage to enhance energy efficiency and reduce environmental impacts. Gundogmus (2013) has reported human labor and machinery consumption to be 1305.19 and 37.26 h ha^{-1} in walnut orchards. Also, diesel fuel consumption in pistachio production has been reported to be in the range of 41.82–48.54 L ha^{-1} (Külekçi and Aksoy 2013).

Table 1. Amounts of energy inputs-outputs in almond and walnut production.

Items	Almond		Walnut	
	Unit per ha	Energy use (MJ ha^{-1})	Unit per ha	Energy use (MJ ha^{-1})
1. Human labor (h)	1785.18	3498.96	1119.45	2194.12
2. Machinery (kg)	99.47	6237.28	36.35	2279.14
3. Diesel fuel (L)	67.89	3823.36	54.03	3042.61
4. Gasoline fuel	11.57	536.14	0.00	0.00
5. Chemical fertilizers (kg)				
(a) Nitrogen	141.94	9388.04	108.86	1354.30
(b) Phosphate (P_2O_5)	81.28	1011.24	247.95	2764.64
(c) Potassium (K)	38.33	607.75	30.28	337.65
(d) Sulfur	4.44	4.98	4.00	4.48
6. Farmyard manure	5994.15	1798.24	4267.73	1280.32
7. Biocides (kg)	15.39	1846.95	12.61	1514.00
8. Electricity (kwh)	56.46	677.56	44.83	538.00
Total energy use (MJ)		29430.56		15309.28
B. Output (kg)				
1. Almond	1656.00	39876.48		
2. Walnut			2099.46	54901.05



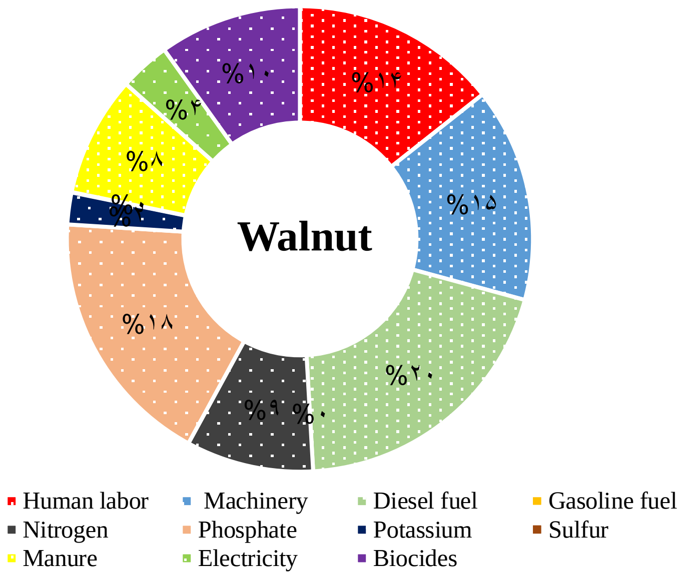


Figure 3. Shares of energy sources in different production of almond and walnut.

Table 2, compares the energy indices for almond and walnut production. Firstly, it states that the energy ratio of walnut production is considered to be very satisfactory. This suggests that the energy output from walnut cultivation is proportionally higher than the energy input. On the other hand, the energy ratio for almond cultivation is higher, indicating that more energy is available to consumers from growing almonds compared to the energy input. Additionally, it highlights that walnut production has higher energy productivity. This means that less energy is needed per kilogram of crop in walnut cultivation compared to almond production. This indicates a higher efficiency in energy use for walnut production. Lastly, the information mentions that walnut production has the highest net energy level, which is 39591.76 MJ ha^{-1}, with a positive outcome. This suggests that the energy output from walnut cultivation exceeds the energy input, resulting in a net energy gain. Overall, the discussion highlights the differences in energy indices between almond and walnut production. Walnut production seems to have better energy efficiency and productivity, resulting in higher energy output relative to energy input.

Table 2. Energy indices in almond and walnut production.

Items	Almond	Walnut
Energy use efficiency (ratio)	1.35	3.59
Energy productivity (kg MJ^{-1})	0.05	0.13
Specific energy (MJ kg^{-1})	17.89	7.34
Net energy gain (MJ ha^{-1})	10445.91	39591.76

According to Figure 4, almond production requires more energy input compared to walnut production. This suggests that almond cultivation consumes a higher amount of energy throughout the production process. Figure 4 also highlights that nitrogen fertilizer is the input that contributes to the highest energy consumption in both almond and walnut production. This indicates that the use of nitrogen fertilizer plays a significant role in energy demand for both crops. Furthermore, the figure suggests that walnut production demonstrates better energy productivity in terms of final crop output compared to almond production. This means that the energy input invested in walnut production leads to a higher output of crops compared to the energy input in almond production. Thus, walnut production is considered to be a more efficient use of energy. Overall, the discussion underscores the differences in energy input between almond and walnut production and emphasizes the importance of considering energy productivity when evaluating the efficiency of agricultural practices.

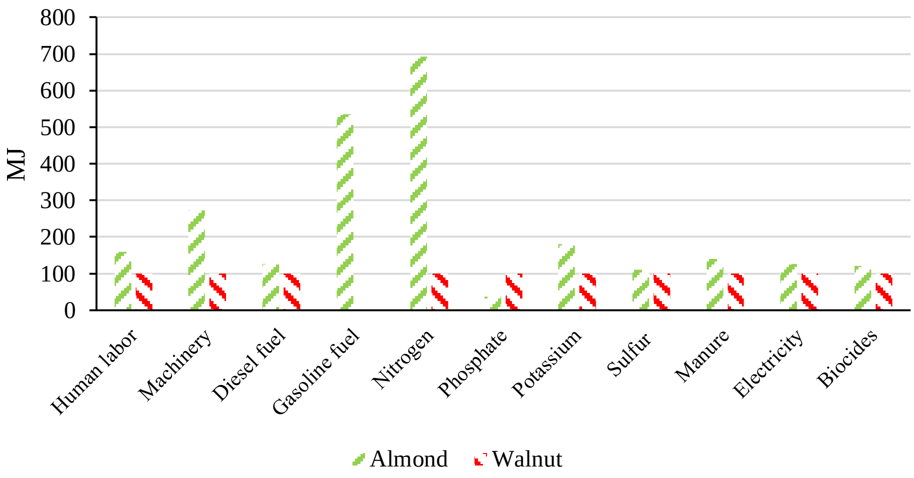


Figure 4. Comparison of energy inputs in production of almond and walnut.

LCA analysis

The stage of data collection and analysis is a crucial component of the LCA process, involving the gathering of accurate data pertinent to the defined functional unit. Data may be obtained from public or other reference sources and should encompass all activities within the system boundary, including upstream and downstream processes. The inventory flow can be categorized into various groups based on the scope of the analysis. Data quality must be assessed, and uncertainties need to be identified and addressed in the analysis.

Concerning walnut and almond production, on-farm emissions primarily arise from the use of chemical fertilizers and diesel fuel. However, walnut production exhibits lower levels of diesel fuel pollutants due to reduced diesel fuel usage, while almond production tends to have a higher prevalence of contaminants associated with diesel fuel. It is essential to gather precise data on the usage of these inputs to accurately assess their environmental impact and identify strategies to minimize their impact in the future.

Table 3. On-farm per hectare emissions of almond and walnut production in Shahrekord.

Items	Almond	Walnut
1. Emissions by diesel fuel to air (kg)		
(a). Carbon dioxide (CO_2)	284.84	226.67
(b). Sulfur dioxide (SO_2)	0.09	0.07
(c). Methane (CH_4)	0.01	0.009
(d). Benzene	0.0006	0.0005
(e). Cadmium (Cd)	0.000001	0.000001
(f). Chromium (Cr)	0.000005	0.000004
(g). Copper (Cu)	0.00015	0.0001
(h). Dinitrogen monoxide (N_2O)	0.01	0.008
(i). Nickel (Ni)	0.000006	0.000005
(j). Zink (Zn)	0.00009	0.00007
(k). Benzo (a) pyrene	0.000003	0.000002
(l). Ammonia (NH_3)	0.0018	0.001
(m). Selenium (Se)	0.000001	0.000001
(n). PAH (polycyclic hydrocarbons)	0.0003	0.0002
(o). Hydro carbons (HC, as NMVOC)	0.25	0.20
(p). Nitrogen oxides (NOx)	4.05	3.22
(q). Carbon monoxide (CO)	0.57	0.45
(r). Particulates (b2.5 µm)	0.40	0.32
2. Emissions by fertilizers to air (kg)		
(a). Ammonia (NH3) by chemical fertilizers	17.23	13.21
3. Emissions by fertilizers to water (kg)		
(a). Nitrate	18.85	14.46
(b). Phosphate	1.77	39.31
4. Emission by N_2O of fertilizers and soil to air (kg)		
(a). Nitrogen oxides (NOx)	29.80	22.86
5. Emission by human labor to air (kg)		
(a). Carbon dioxide (CO_2)	1249.63	783.61
6. Emission by heavy metals of fertilizers to soil (mg)		
(a). Cadmium (Cd)	8216.05	163621.10
(b). Copper (Cu)	20850.99	375835.45
(c). Zink (Zn)	185567.79	3485156.19
(d). Lead (Pb)	780340.57	866210.46
(e). Nickel (Ni)	19559.64	366149.62
(f). Chromium (Cr)	112665.65	2250649.44
(g). Mercury (Hg)	74.93	1274.39

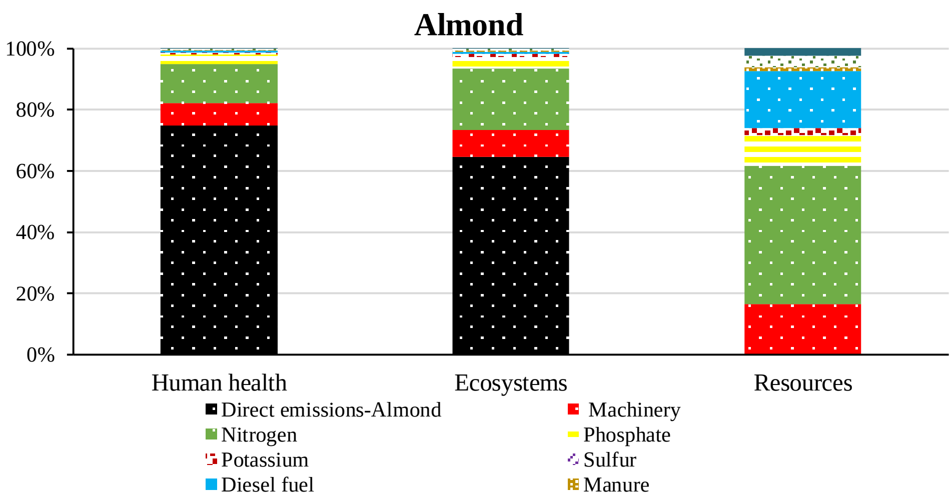
Table 4 presents the results of the damage assessment for various almond and walnut production scenarios, using the ReCiPe 2016 method. The data reveals that the resources category has the highest environmental impact, while human health has the lowest. Almond production has been the subject of more extensive research than walnut production, showing that almond production has higher greenhouse gas emissions compared to walnut production. Also, the resources category has a more significant impact on almond production than on walnut production in terms of pollutants. These findings emphasize the importance of carefully evaluating the environmental impact of different agricultural practices and identifying ways to reduce their impact to promote sustainable agriculture. Another study conducted by Mostashari-Rad et al. (2021) using the ReCiPe 2016 method found that citrus, hazelnut, kiwifruit, tea, and watermelon had a higher impact on the release of resources categories than on ecosystem and human health categories. In terms of greenhouse gas emissions, Litskas et al. (2017), Bosco et al. (2011), and Point et al. (2012) reported values of 0.155 kg CO2eq, 0.15 to 0.3 kg CO2eq, and 0.8 kg CO2eq, respectively. Nutrient management was identified as a significant contributor to ozone layer depletion, global warming, freshwater aquatic ecotoxicity, and acidification, accounting for 49%, 65%, 79%, and 92% of the impacts, respectively.

Table 4. Damage per one ton of almond and walnut production.

Items	Unit	Almond	Walnut
Human health	DALY [a]	0.10	0.93
Ecosystems	species.yr [b]	0.0001	0.0005
Resources	USD2013	109.01	78.80

[a] DALY: disability adjusted life years. A damage of 1 is equal to: loss of 1 life year of 1 individual, or 1 person suffers 4 years from a disability with a weight of 0.25.
[b] species.yr: the unit for ecosystems is the local species loss integrated over time.

Figures 5 depict the contribution of each input to emissions in almond and walnut production. Both production methods have significant direct emissions that have a considerable impact on human and ecosystem health, accounting for over 60% of emissions in both crops. Among the inputs, nitrogen fertilizer has the most significant impact on resources, accounting for over 40% of the total impact. Proper nitrogen fertilizer management is crucial for the growth and yield of crops, and researchers and farmers should prioritize its appropriate use. In many parts of the world, regulations are in place to control the use of chemical fertilizers in agriculture to prevent excessive amounts of elements from entering the environment. This not only serves to protect the environment and human health but also has economic benefits such as cost reduction, improved efficiency, and resource conservation. Steenwerth et al. (Steenwerth et al., 2015) have proposed two fertilizer management methods: mineral fertilizer and compost fertilizer. To minimize environmental impacts and ensure sustainable agricultural production, it is essential to consider the appropriate use of fertilizers and adopt efficient farming practices.



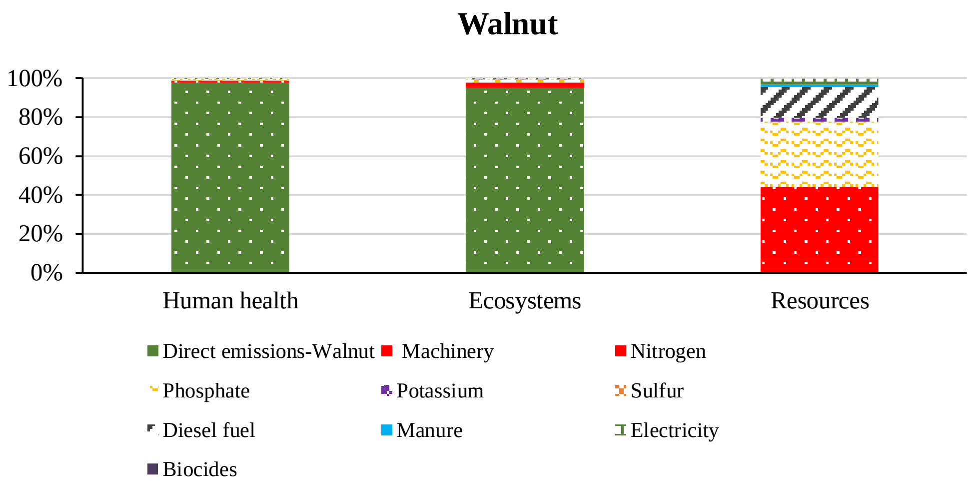


Figure 5. Contribution of different inputs in the damage categories for almond and walnut production.

Conclusions

This case study offers a comprehensive evaluation of the energy use efficiency and life cycle environmental impact associated with almond and walnut production. By analyzing energy consumption patterns and identifying environmental hotspots, this study provides valuable insights that can enhance the sustainability of these crops. Like other produce, considering energy use efficiency and assessing environmental damage are also crucial for almonds and walnuts production. Energy use efficiency measures the effectiveness of the production process by comparing input and output energy, while damage assessment evaluates the environmental impact on ecosystems and human health. Accurate prediction and assessment of these factors are essential for improving energy use efficiency and minimizing environmental harm throughout almond and walnut production. Recent research findings indicate that almond production generates a higher rate of greenhouse gas emissions compared to walnut production. Specifically, almond production consumes approximately 29,430.56 MJ ha^{-1} of energy, whereas walnut production consumes 15,309.28 MJ ha^{-1}. Through life cycle assessment (LCA), it was determined that the resources category has the most substantial environmental impact, while human health is the least affected. The study highlights the significant contribution of manual harvesting, which is labor-intensive, to the overall energy consumption in almond and walnut production. This observation suggests that the adoption of mechanized harvesting techniques has the potential to enhance energy use efficiency. Furthermore, the research identifies several critical environmental hotspots, including greenhouse gas emissions, water consumption, and land use. These findings underscore the importance of implementing sustainable practices in almond and walnut production to mitigate environmental impacts. Strategies such as optimizing harvesting methods and adopting efficient irrigation techniques can help reduce energy consumption and minimize greenhouse gas emissions. By addressing these key environmental hotspots, the overall sustainability of almond and walnut production can be enhanced.

The results of this study emphasize the significance of incorporating sustainable practices into almond and walnut production. It is recommended to optimize irrigation methods and adopt integrated pest management strategies to alleviate environmental pressures. Furthermore, the study proposes the exploration of renewable energy sources and the optimization of resource utilization in these agricultural practices. To achieve these sustainability objectives, it is suggested to implement efficient machinery and equipment while adopting environmentally friendly techniques. By doing so, farmers can minimize energy inputs, mitigate environmental impacts, and enhance the overall sustainability of their almond and walnut production operations.

References

Bacenetti, J., Lovarelli, D., Tedesco, D., Pretolani, R., and Ferrante, V. 2018. Environmental impact assessment of alfalfa (*Medicago sativa* L.) hay production. Science Total Environment. 635, 551–558.

Baer, D.J., Gebauer, S.K., and Novotny, J.A. 2016. Walnuts Consumed by Healthy Adults Provide Less Available Energy than Predicted by the Atwater Factors. Journal of Nutrition. 146, 9–13.

Beigi, M., Torki-Harchegani, M., and Ghanbarian, D. 2016. Energy use efficiency and economical analysis of almond production: a case study in Chaharmahal-Va-Bakhtiari province, Iran. Energy Efficiency. 9, 745–754.

Bosco, S., Bene, C. Di, Galli, M., Remorini, D., Massai, R., and Bonari, E. 2011. Greenhouse gas emissions in the agricultural phase of wine production in the Maremma rural district in Tuscany, Italy. Italian Journal of Agronomy. 6, e15–e15.

Brentrup, F., Küsters, J., Lammel, J., Barraclough, P., and Kuhlmann, H. 2004. Environmental impact assessment of agricultural production systems using the life cycle assessment (LCA) methodology II. The application to N fertilizer use in winter wheat production systems. Europian Journal of Agronomy. 20, 265–279.

Cochran, W.G., 1977. The estimation of sample size. Sampl Technologies. 3, 72–90.

de Vries, M., and de Boer, I.J.M. 2010. Comparing environmental impacts for livestock products: A review of life cycle assessments. Livest Science.

Elalami, D., Fertahi, S., Aouine, M., Benali, W., Ibnyasser, A., Lyamlouli, K., and Barakat, A. 2022. Comparison of pretreatment effects on sugar release, energy efficiency and the reuse of effluents. Industrial Crops. 189, 115769.

FAO, 2020. Food and Agricultural Organization Statistical Yearbook http://www.fao.org.

Feyzbakhsh, M.T., Alizadeh, P., and Sheikh, F. 2018. Energy Input and Energy Output of Rained Wheat and Barley and Its Implication for Global Warming: Case of Aqqala in Golestan Province. Iran Journal of Energy. 21, 33–50.

Ghasemi-Mobtaker, H., Kaab, A., and Rafiee, S. 2020. Application of life cycle analysis to assess environmental sustainability of wheat cultivation in the west of Iran. Energy. 193, 116768.

Ghorbani, R., Mondani, F., Amirmoradi, S., Feizi, H., Khorramdel, S., Teimouri, M., Sanjani, S., Anvarkhah, S., and Aghel, H. 2011. A case study of energy use and economical analysis of irrigated and dryland wheat production systems. Applied Energy. 88, 283–288.

Ghritlahre, H.K., and Prasad, R.K., 2018. Exergetic performance prediction of solar air heater using MLP, GRNN and RBF models of artificial neural network technique. Journal of Environment Management. 223, 566–575.

Gundogmus, E. 2013. Modeling and sensitivity analysis of energy inputs for walnut production. Actual Problems of Economics. 2, 188–197

Houshyar, E., and Grundmann, P., 2017. Environmental impacts of energy use in wheat tillage systems: A comparative life cycle assessment (LCA) study in Iran. Energy. 122, 11–24.

Kaab, A., Sharifi, M., and Moradi, H. 2021. Analysis of energy indicators and environmental impacts of dryland cantaloupe production with life cycle assessment approach (case study: ilam). Journal of Agricultural Machinery. 11(2), 491-504.

Kaab, A., Ghasemi Mobtaker, H., Sharifi, M., 2023. A study of changes in energy consumption trend and environmental indicators in the production of agricultural crops using a life cycle assessment approach in the years 2018-2022. Iranian Journal of Biosystems Engineering. 54 (3), 1-18.

Külekçi, M., and Aksoy, A. 2013. Input–output energy analysis in pistachio production of turkey. Environ. Program in Sustainable Energy. 32, 128–133.

Litskas, V.D., Irakleous, T., Tzortzakis, N., and Stavrinides, M.C. 2017. Determining the carbon footprint of indigenous and introduced grape varieties through Life Cycle Assessment using the island of Cyprus as a case study. Jouranl of Clean Production. 156, 418–425.

Mostashari-Rad, F., Ghasemi-Mobtaker, H., Taki, M., Ghahderijani, M., Kaab, A., Chau, K., and Nabavi-Pelesaraei, A. 2021. Exergoenvironmental damages assessment of horticultural crops using ReCiPe2016 and cumulative exergy demand frameworks. Journal of Clean Production. 278, 123788.

Nabavi-Pelesaraei, A., Kaab, A., Hosseini-Fashami, F., Mostashari-Rad, F., and Kwok-Wing, C., 2019a. Life Cycle Assessment (LCA) Approach to Evaluate Different Waste Management Opportunities, in: Advances in Waste-to-Energy Technologies. CRC Press, pp. 195–216.

Nabavi-Pelesaraei, A., Rafiee, S., Mohtasebi, S.S., Hosseinzadeh-Bandbafha, H., and Chau, K. 2019b. Comprehensive model of energy, environmental impacts and economic in rice milling factories by coupling adaptive neuro-fuzzy inference system and life cycle assessment. Journal of Clean Production. 217, 742–756.

Naseri, H., Parashkoohi, M.G., Ranjbar, I., and Zamani, D.M. 2020. Energy-economic and life cycle assessment of sugarcane production in different tillage systems. Energy. 119252.

Pahlavan, R., Omid, M., and Akram, A. 2012. Energy input–output analysis and application of artificial neural networks for predicting greenhouse basil production. Energy. 37, 171–176.

Payandeh, Z., Jahanbakhshi, A., Mesri-Gundoshmian, T., and Clark, S., 2021. Improving Energy Efficiency of Barley Production Using Joint Data Envelopment Analysis (DEA) and Life Cycle Assessment (LCA): Evaluation of Greenhouse Gas Emissions and Optimization Approach. Sustain. 13, 6082-3.

Point, E., Tyedmers, P., and Naugler, C. 2012. Life cycle environmental impacts of wine production and consumption in Nova Scotia, Canada. Journal of Clean Production. 27, 11–20.

Renouf, M.A., Wegener, M.K., and Pagan, R.J. 2010. Life cycle assessment of Australian sugarcane production with a focus on sugarcane growing. International Journal of Life Cycle Assess. 15, 927–937.

Steenwerth, K.L., Strong, E.B., Greenhut, R.F., Williams, L., and Kendall, A. 2015. Life cycle greenhouse gas, energy, and water assessment of wine grape production in California. International Journal of Life Cycle Assess. 20, 1243–1253.

Tutak, M., and Brodny, J. 2022. Renewable energy consumption in economic sectors in the EU-27. The impact on economics, environment and conventional energy sources. A 20-year perspective. Journal of Clean Production. 345, 131076.

Unakıtan, G., and Aydın, B. 2018. A comparison of energy use efficiency and economic analysis of wheat and sunflower production in Turkey: A case study in Thrace Region. Energy.149, 279–285.

Wang, X., Ledgard, S., Luo, J., Chen, Y., Tian, Y., Wei, Z., Liang, D., and Ma, L. 2021. Life cycle assessment of alfalfa production and potential environmental improvement measures in Northwest China. Journal of Clean Production. 304, 127025.

Wowra, K., Zeller, V., and Schebek, L. 2021. Nitrogen in Life Cycle Assessment (LCA) of agricultural crop production systems: Comparative analysis of regionalization approaches. Science Total Environment. 763, 143009.

Younis, S.A., Kim, K.H., Shaheen, S.M., Antoniadis, V., Tsang, Y.F., Rinklebe, J., Deep, A., and Brown, R.J.C. 2021. Advancements of nanotechnologies in crop promotion and soil fertility: Benefits, life cycle assessment, and legislation policies. Renewable and Sustainable Energy Reviews. 152, 111686.

Zeng, Y., Ji, X.J., Lian, M., Ren, L.J., Jin, L.J., Ouyang, P.K., and Huang, H. 2011. Development of a temperature shift strategy for efficient docosahexaenoic acid production by a marine fungoid protist, Schizochytrium sp. HX-308. Applied Biochemistry and Biotechnology. 164, 249–255.