



# Energy Use and GHG Emissions in Olive Production: A Comparison of Irrigated and Rainfall Conditions

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## Abstract

The objective of this study was to examine the energy efficiency and greenhouse gas (GHG) emissions associated with olive production under both irrigated and rainfall conditions. The findings of this research will provide valuable insights into the environmental impacts of olive production. The study was conducted in the province of Kahramanmaraş during the 2020–2021 agricultural production season. The study findings indicate that the total input energy required for olive production under irrigated and rainfall conditions is 174,331.3 MJ ha<sup>-1</sup> and 129,115.55 MJ ha<sup>-1</sup>, respectively. In olive production, the primary energy input under irrigated conditions was chemical fertilizer (38.67%), while the primary energy input under rainfall conditions was diesel fuel (38.59%). The total energy output in olive production under irrigated and rainfall conditions was calculated as 41,534.83 MJ ha<sup>-1</sup> and 29,710.55 MJ ha<sup>-1</sup>, respectively. The GHG emissions per kilogram in olive production were calculated as 0.24 kg CO<sub>2</sub> for 1 kg of olives produced under irrigated conditions and 0.20 kg CO<sub>2</sub> for 1 kg of olives produced under rainfall conditions.

**Keywords** Olive · Energy use · Carbon emissions · Türkiye · Greenhouse gas

## Introduction

It is widely acknowledged that human activities are the primary cause of excess carbon emissions, and these are leading to global warming (Yoro and Daramola 2020). Consequently, reducing greenhouse gas (GHG) emissions and mitigating global climate change represent significant environmental challenges that require the attention of all nations. Currently, many countries are signing protocols under international environmental agreements aimed at reducing carbon dioxide (CO<sub>2</sub>) emissions. However, more clarity is needed on how to achieve emission reductions across all sectors and how to meet the targets set.

Global energy use in agriculture has a significant impact on GHG emissions. While CO<sub>2</sub> emissions originate from a variety of natural sources, the increase in atmospheric emissions since the Industrial Revolution is due to human activities. Changes in agricultural land use and vegetation cover contribute approximately 20% of annual global CO<sub>2</sub> emissions. It has been demonstrated that conservation and reduced agricultural production practices can significantly reduce CO<sub>2</sub> emissions from agricultural activities (Yoro and Daramola 2020). Greenhouse gas emissions from fossil fuels are one of the main causes of climate change and lead to an ever-increasing accumulation of CO<sub>2</sub> in the atmosphere. To ensure sustainable development, these emissions should be minimized. Between 1970 and 2004, CO<sub>2</sub> emissions from the use of fossil fuels increased by approximately 80%. Concurrently, global temperatures rose by 0.5 °C. If air pollution persists at the current rate, it is estimated that temperatures will increase by 4–5 °C and sea levels by 2.2 m over the next 100 years (Strauss et al. 2021).

Agricultural production has a significant impact on natural resources, including climate, biodiversity, water, soil and the atmosphere (Rockström et al. 2009; Foley et al. 2011; Gkissakis and Damianakis 2020). These impacts depend on the farm inputs used, both in terms of quantity and quality (Tilman et al. 2002). The foundation of agricul-

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tural sustainability is the enhancement of energy efficiency in agricultural production and the reduction of GHG emissions (Yue et al. 2017). In this context, the determination of the quantity of energy utilized and carbon emissions generated during the production of agricultural products is of paramount importance for agricultural sustainability and circular ecology.

Numerous studies have been conducted with the objective of determining the energy input–output ratios and amount of GHG emissions of agricultural products. These studies include organic grape (Ağızan et al. 2024), almond (Yılmaz and Bayav 2023), organic almond (Baran et al. 2020), apricot (Hayran et al. 2023), orange (Saltuk et al. 2022), avocado (Gökdoğan et al. 2022), mandarin (Soyler et al. 2022), and plum (Baran et al. 2017). Regarding the determination of energy input–output ratios in olive production, there is a paucity of studies, with the notable exceptions of the studies by Gökdoğan and Erdoğan (2018) and Karaca and Aydın (2023). However, there is no study in which energy input–output ratios and GHG emissions are determined in olive production under irrigated and rainfall conditions.

## Materials and Methods

This study was conducted in Kahramanmaraş province, which has key olive-growing areas in Turkey. Kahramanmaraş is an important province with historical olive tree

plantations and newly established olive groves. In its basins located in the Mediterranean region, intensive olive cultivation, both table and oil, is carried out (Fig. 1).

The data of the study were collected through face-to-face surveys with olive producers in the Onikişubat district, Kahramanmaraş province, where olive cultivation is intensively carried out. In the questionnaires, all inputs, such as labor force, machine power, amount of diesel fuel, amount of chemical fertilizer and pesticide use, and amount of olive production, used by the producers in olive cultivation were recorded. A simple random sampling method (Noor et al. 2022) was used in the selection of the enterprises to be surveyed:

$$n = \frac{Np(1-p)}{(N-1)\sigma_{px}^2 + p(1-p)}$$

$D = d/t$ ,  $n$  represents the sample volume, while  $p$  represents the number of individuals with a specific characteristic in the population as a proportion. If the specific proportion is unknown, 50% (0.5) should be assumed to reach the maximum sample volume:  $1-p$ , while the variance of the proportion is determined by dividing the margin of error (%) by the table value. For clarity, abbreviations of technical terms are explained the first time they are used. The  $t$  value is used to determine the confidence limit (the  $z$  value can also be used if the number of data exceeds 30). The acceptable error can be determined by calculating  $d$ : margin of error (%) \* mean. Within the scope of the study, a total

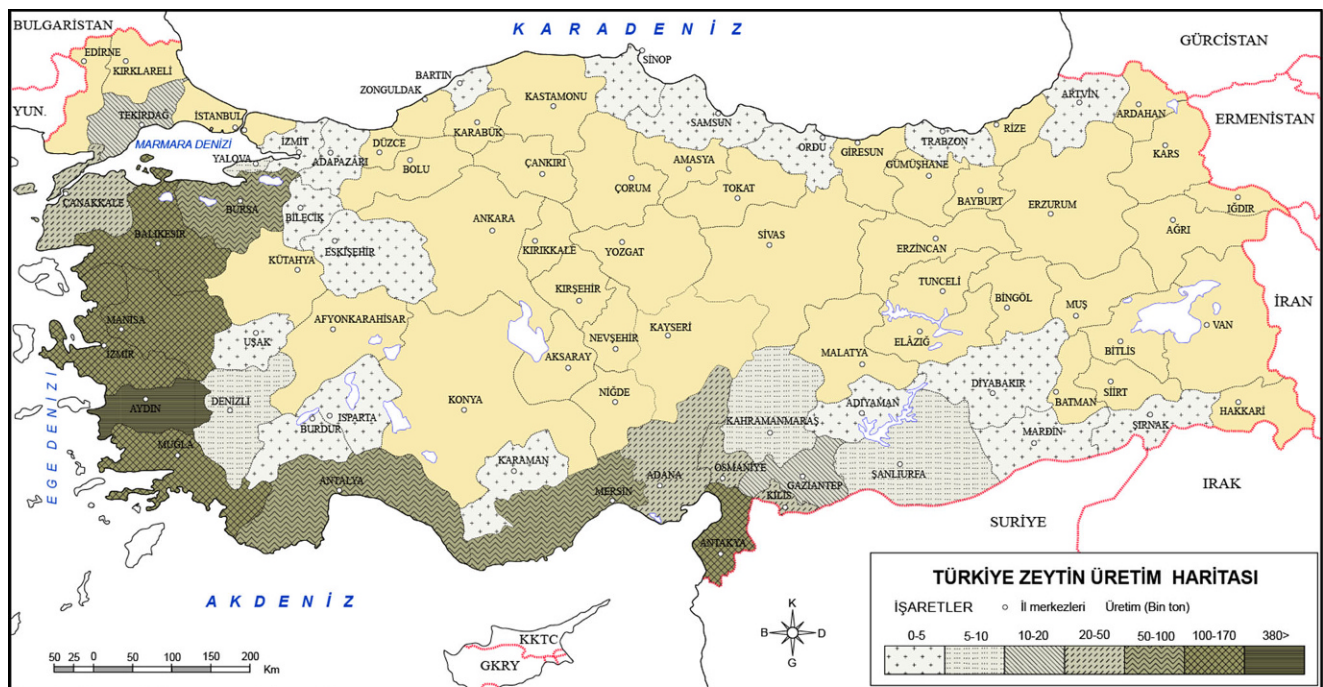


Fig. 1 Map of the study area

**Table 1** Standard coefficients for computing energy content of outputs and inputs in olive production

Inputs	Unit	Energy equivalent (MJ unit <sup>-1</sup> )	References
Human labor	H	1.96	Mani et al. (2007); Karaağaç et al. (2011)
<i>Machinery</i>			
Tractor	H	25.4	Singh et al. (2002); Akbolat et al. (2014)
Plough	H	18.7	Singh et al. (2002); Akbolat et al. (2014)
<i>Pesticides</i>			
Herbicides	kg	238	Khoshroo and Mulwa (2014) Rafiee et al. (2010)
Fungicides	kg	216	Khoshroo and Mulwa (2014) Rafiee et al. (2010)
<i>Organic fertilizers</i>			
Farmyard manure	kg	0.30	Singh et al. (2002); Ekinici et al. (2020)
<i>Chemical fertilizers</i>			
Nitrogen	kg	60.60	Singh et al. (2002); Ozalp et al. (2018)
Phosphorus	kg	11.10	Mandal et al. (2002); Ozalp et al. (2018)
Potassium	kg	6.70	Mandal et al. (2002)
<i>Others</i>			
Diesel fuel	L	56.31	Singh et al. (2002)
Irrigation water	m <sup>3</sup>	1.02	Acaroglu (1998); Azizi and Heidari (2013)
Electricity	kWh	3.60	Ozkan et al. (2004)
Transportation	MJ.t.km	4.5	Fluck and Baird (1982); Kitani (1999)
Output	Unit	Energy equivalent (MJ unit <sup>-1</sup> )	Reference
Olives	kg	11.80	Gökdoğan and Erdoğan (2018)

**Table 2** GHG emission coefficients in production

Inputs	Unit	GHG equivalent (kgCO <sub>2</sub> -eq unit <sup>-1</sup> )	References
Human labor	H	0.36	Houshyar et al. (2015)
Machinery	MJ	0.071	Pishgar-Komleh et al. (2012); Eren et al. (2019)
Farmyard manure	t	0.005	Meisterling et al. (2009); Ekinici et al. (2020)
Herbicides	kg	6.300	Graefe et al. (2013)
Fungicide	kg	3.900	Graefe et al. (2013)
Nitrogen	kg	1.300	Lal (2004); Ozalp et al. (2018)
Phosphorus	kg	0.200	Lal (2004); Ozalp et al. (2018)
Potassium	kg	0.200	Taghavifar and Mardani (2015)
Diesel fuel	L	2.760	Dyer and Desjardins (2006); Ozalp et al. (2018)
Electricity	kWh	0.608	Khoshnevisan et al. (2014); Ekinici et al. (2020)
Transportation	kg	0.150	Meisterling et al. (2009); Eren et al. (2019b)

of 53 enterprises were interviewed in Kahramanmaraş and the primary data of the study were obtained.

To determine the energy equivalents and carbon emissions of olive production, input amounts were calculated and are expressed in megajoules (MJ) and kgC<sub>2</sub>O, respectively (Tables 1 and 2). The carbon emissions for olive production were calculated by first determining energy equivalence, followed by calculating carbon emission values.

To assess energy efficiency in olive production, the energy output/input ratio, energy efficiency, and energy effectiveness coefficients were calculated using equations as outlined by Mandal et al. (2002) and Singh et al. (1997).

Net energy was calculated as the difference between total energy output and total energy input:

$$\text{Energy use efficiency} = \frac{\text{Energy output} \left( \frac{\text{MJ}}{\text{ha}} \right)}{\text{Energy input} \left( \frac{\text{MJ}}{\text{ha}} \right)} \quad (1)$$

$$\text{Specific energy} = \frac{\text{Energy input} \left( \frac{\text{MJ}}{\text{ha}} \right)}{\text{Yield output} \left( \frac{\text{kg}}{\text{ha}} \right)} \quad (2)$$

**Table 3** Descriptive statistics of the data used in the analysis

	Unit	Energy equivalent (MJ unit <sup>-1</sup> )	Input used per hectare (unit ha <sup>-1</sup> )		Energy value (MJ ha <sup>-1</sup> )		Ratio (%)	
			Irrigated	Rainfall	Irrigated	Rainfall	Irrigated	Rainfall
<i>Human labor</i>	–	–	652.96	416.24	1279.84	815.82	7.34	6.32
Pruning	H	1.96	132.17	136.79	259.06	268.10	1.49	2.08
Soil tillage (2 times)	H	1.96	26.96	22.14	52.83	43.40	0.30	0.34
Fertilizing (chemical and farmyard)	H	1.96	20.93	19.27	41.03	37.77	0.24	0.29
Spraying	H	1.96	15.43	15.00	30.25	29.40	0.17	0.23
Irrigation	H	1.96	18.78	0.00	36.81	0.00	0.21	0.00
Harvesting	H	1.96	424.78	212.50	832.57	416.50	4.78	3.23
Transportation	H	1.96	13.91	10.54	27.27	20.65	0.16	0.16
<i>Machinery</i>	–	–	27.00	16.66	1534.12	935.41	8.80	7.24
Tractor	H	62.70	23.39	14.18	1466.63	889.00	8.41	6.89
Plough (2 times)	H	18.70	3.61	2.48	67.48	46.42	0.39	0.36
<i>Pesticides</i>	–	–	–	–	1068.61	1186.71	6.13	9.19
Herbicides	kg	238.00	2.04	2.57	486.35	612.00	2.79	4.74
Insecticide	kg	216.00	2.70	2.66	582.26	574.71	3.34	4.45
<i>Farmyard manure</i>	kg	0.30	865.22	857.14	259.57	257.14	1.49	1.99
<i>Chemical fertilizers</i>	–	–	–	–	6741.53	4674.57	38.67	36.20
Nitrogen	kg	60.60	102.44	68.31	6207.81	4139.39	35.61	32.06
Phosphorus	kg	11.10	48.08	48.21	533.72	535.18	3.06	4.14
<i>Diesel fuel</i>	l	56.31	94.04	88.48	5295.34	4982.43	30.38	38.59
<i>Electricity</i>	kWh	3.60	328.26	0.00	1181.74	0.00	6.78	0.00
<i>Transportation</i>	MJ.t.km	4.50	16.09	13.21	72.39	59.46	0.42	0.46
<i>Total inputs</i>	–	–	–	–	17,433.13	129,11.55	100.00	100.00
<i>Output</i>								
Olive fruit	kg	11.80	3520.00	2517.89	41,534.83	29,710.55	100.00	100.00

**Table 4** Calculations of energy utilization efficiency in olive production

	Unit	Values	
		Irrigated	Rainfall
Olive fruit	kg ha <sup>-1</sup>	3520.00	2517.89
EI	MJ ha <sup>-1</sup>	17,433.13	12,911.55
EO	MJ ha <sup>-1</sup>	41,534.83	29,710.55
EUE	–	2.20	2.35
SE	MJ kg <sup>-1</sup>	10.25	6.15
EP	kg MJ <sup>-1</sup>	0.19	0.20
NE	MJ ha <sup>-1</sup>	24,101.70	16,799.00

$$\text{Energy productivity} = \frac{\text{Yield output} \left( \frac{\text{kg}}{\text{ha}} \right)}{\text{Energy input} \left( \frac{\text{MJ}}{\text{ha}} \right)} \quad (3)$$

$$\text{Net energy} = \text{Energy output}(\text{MJ ha} - 1) - \text{Energy input}(\text{MJ ha} - 1) \quad (4)$$

the sum, denoted by  $\sum$ , of the product of the application rate of input  $i$  (unit<sub>input</sub>ha<sup>-1</sup>), denoted by  $R(i)$ , and the GHG emission coefficient of input  $i$  (kgCO<sub>2-eq</sub>unit<sub>input</sub><sup>-1</sup>), denoted by  $EF(i)$ . However, an index was developed to measure the amount of kgCO<sub>2-eq</sub> emissions dispersed per kg of yield, using the following formula proposed by Houshyar et al.

The GHG emissions (kgCO<sub>2-eq</sub>kg<sup>-1</sup>) for the production of 1 ha of olives were calculated using the method developed by Hughes et al. (2011). The calculation involves finding

**Table 5** Energy inputs in the varieties of energy used for olive production

Energy groups	Energy input (MJ ha <sup>-1</sup> )		Ratio (%)	
	Irrigated	Rainfall	Irrigated	Rainfall
DE	7756.92	5798.25	44.50	44.91
IDE	9676.21	7113.30	55.50	55.09
Total	17,433.13	12,911.55	100.00	100.00
RE	1279.84	815.82	7.34	6.32
NRE	16,153.29	12,095.73	92.66	93.68
Total	17,433.13	12,911.55	100.00	100.00

**Table 6** Greenhouse gas (GHG) emissions in olive production

Inputs	Unit	GHG coefficient (kg CO <sub>2eq</sub> unit <sup>-1</sup> )	Input used per area (unit ha <sup>-1</sup> )		GHG emissions (kg CO <sub>2eq</sub> ha <sup>-1</sup> )		Ratio (%)	
			Irrigated	Rainfall	Irrigated	Rainfall	Irrigated	Rainfall
Human labor	H	0.36	652.98	416.23	235.07	149.84	27.70	29.54
Machinery	MJ	0.071	27.00	16.67	1.92	1.18	0.23	0.23
Farmyard manure	t	0.005	865.22	857.14	4.33	4.29	0.51	0.84
Herbicides	kg	6.3	2.04	2.57	12.85	16.19	1.51	3.19
Fungicide	kg	3.9	2.74	2.66	10.69	10.37	1.26	2.04
Nitrogen	kg	1.3	102.44	68.31	133.17	88.80	15.69	17.50
Phosphorus	kg	0.2	48.08	48.21	9.62	9.64	1.13	1.90
Diesel fuel	L	2.76	86.52	81.40	238.80	224.66	28.14	44.28
Electricity	kWh	0.608	328.26	0.00	199.58	0.00	23.52	0.00
Transportation	kg	0.15	17.39	15.54	2.61	2.33	0.31	0.46
Total	–	–	–	–	848.63	507.32	100.00	100.00
GHG ratio (per kg)	–	–	–	–	0.24	0.20	–	–

(2015). In this formula,  $I_{GHG}$  represents the GHG ratio and  $Y$  refers to the yield in kg per ha (Eren et al. 2019a):

$$GHG_{ha} = \sum_{i=1}^n R(i) \times EF(i) \tag{5}$$

$$I_{GHG} = \frac{GHG_{ha}}{Y} \tag{6}$$

EI can be divided into different types, including direct energy (DE) and indirect energy (IDE), and renewable and non-renewable forms. Indirect energy mainly includes fertilizers and pesticides, while direct energy includes human and animal labor, diesel, and electricity used in the production process. Non-renewable energy (NRE) sources include petrol, diesel, electricity, chemicals and fertilizers, and machinery. On the other hand, renewable energy (RE) sources include human and animal power (Mandal et al. 2002; Singh et al. 2003; Koctürk and Engindeniz 2009). Energy balance (EB) calculations, fossil energy input types, and GHG emissions of inputs are presented in Tables 3, 4, 5, and 6.

The average olive yield for the 2021 production season was calculated as 3520 kg ha<sup>-1</sup> under irrigated conditions and 2517.89 kg ha<sup>-1</sup> under rainfall conditions. Energy inputs in olive production under irrigated conditions were

6741.53 MJ per hectare (MJ ha<sup>-1</sup>), with 38.67% being chemical fertilizer, 30.38% diesel fuel, 8.80% machinery, and 7.34% manpower. The remaining inputs were as follows: 0.84 MJ ha<sup>-1</sup> (7.34%) manpower, 1181.74 MJ ha<sup>-1</sup> (6.78%) electricity, 1068.61 MJ ha<sup>-1</sup> (6.13%) pesticides, and 259.57 MJ ha<sup>-1</sup> (1.496%) farmyard manure. Energy inputs in olive production under rainfall conditions comprise 4982.43 MJ ha<sup>-1</sup> (38.59%) diesel fuel, 4674.57 MJ ha<sup>-1</sup> (36.20%) chemical fertilizer, and 1186.71 MJ ha<sup>-1</sup> (9.19%) pesticides. The remaining 7.24% of the energy input is attributed to pesticides, 6.32% to machinery, 1.99% to manpower, and 1.99% to farmyard manure (Table 3).

The input of human labor time was 652.96 h ha<sup>-1</sup> under irrigated conditions and 416.24 h ha<sup>-1</sup> under rainfall conditions. It was observed that in both production conditions, the highest input of human labor time is used in the harvesting stage. The machine time input was 27.00 h ha<sup>-1</sup> under irrigated conditions and 16.66 h ha<sup>-1</sup> under rainfall conditions.

While chemical fertilizer accounts for the largest proportion of 6741.53 MJ ha<sup>-1</sup> (38.67%) in olive production under irrigated conditions, diesel fuel energy represents the highest share of 4982.43 MJ ha<sup>-1</sup> (38.59%) in production under rainfall conditions. Similarly, Gökdoğan and Erdoğan

(2018) found that diesel fuel constituted the highest energy input (50.31%), while Çelik et al. (2010) found that diesel fuel was the highest energy input in organic black carrot production (35.26%). In cucumber production, Mohammadi and Omid (2010) found that diesel fuel was the highest energy input (41.94%). Baran et al. (2017) found that diesel fuel was the highest energy input in organic almond production (37.21%).

When these studies were examined, it was determined that the highest energy input was diesel fuel, since chemical fertilizers and pesticides were not used in organic production. In addition to these findings, Gündoğmus (2013) found that the highest energy input was chemical fertilizer in walnut production (43.70%) and for Akdemir (2022) it was in grape cultivation (32.40%).

Table 4 presents the values for fruit yield, energy input (EI), energy output (EO), energy utilization efficiency (EUE), sustainability index (SE), energy efficiency (EP), and net energy (NE) for the production of olive oil under conditions of drought and heat stress. In conditions of optimal growth, olive production yields 3520 kg ha<sup>-1</sup> of fruit, with an input of 17,433.13 MJ ha<sup>-1</sup> and an output of 41,534.83 MJ ha<sup>-1</sup>. The EUE is 2. The SE was calculated to be 10.25 MJ ha<sup>-1</sup>, the energy efficiency ratio (EER) was found to be 0.19 kg MJ<sup>-1</sup>, and the NE was determined to be 24,101.70 MJ ha<sup>-1</sup>. In arid conditions, the following values were obtained: 2517.89 kg ha<sup>-1</sup>, 12,911.55 MJ ha<sup>-1</sup>, 29,710.55 MJ ha<sup>-1</sup>, 2.35, 6.15 MJ kg<sup>-1</sup>, 0.20 kg MJ<sup>-1</sup>, and 16799 MJ ha<sup>-1</sup>, respectively.

In previous studies of EUE, Karaca and Aydınli (2023) estimated the energy consumption of olive oil production in Turkey at 2.83, while Gökdoğan and Erdoğan (2018) calculated the energy intensity of organic olive oil production at 2.72. In other studies on fruit production, Demir and Gökdoğan (2023) calculated a value of 0.99 for peach production, while Oğuz et al. (2019a) estimated a figure of 1.86 for wolfberry and Baran et al. (2017) determined a value of 0.61 for walnuts.

Table 5 presents the energy input required to produce olive oil under different conditions, including rainfall, humid, and refrigerated environments. These inputs are based on various energy sources, including DE, IDE, RE, and NRE. Table 5 lists the total energy inputs for olive production under irrigated conditions, with DE accounting for 44.50% (7756.92 MJ ha<sup>-1</sup>), IDE for 55.50% (9676.88 MJ ha<sup>-1</sup>), RE for 7.34% (1279.84 MJ ha<sup>-1</sup>), and NRE for 92.66% (16,153.29 MJ ha<sup>-1</sup>). The energy input for the cultivation of olive trees can be divided into three categories: DE (direct energy), RE (renewable energy) and NRE (non-renewable energy). The energy input for olive trees is 6.21 MJ ha<sup>-1</sup>, 7.34 MJ ha<sup>-1</sup>, and 1279.84 MJ ha<sup>-1</sup>, respectively. In arid conditions, the total energy inputs for olive production are 44.91% DE (5798.25 MJ ha<sup>-1</sup>)

and 55.09% IDE (7113.3 MJ ha<sup>-1</sup>). The energy inputs for olive production can be divided into three categories: DE (44.91% of the total, 5798.25 MJ ha<sup>-1</sup>), IDE (55.09% of the total, 7113.3 MJ ha<sup>-1</sup>), and NRE (93.68% of the total, 12,095.73 MJ ha<sup>-1</sup>). In olive production, the NRE energy inputs are significantly higher than the RE energy inputs. In olive production under rainfall conditions, the RE ratio is higher than in production under irrigated conditions.

The results of the studies are consistent with those observed in the production of grapes (Akdemir 2022), and oranges (Saltuk et al., 20). In the case of apple production (Gökdoğan and Baran, 2017) and walnut production (Baran et al. 2017), the NRE energy inputs were calculated to be higher than the RE energy inputs.

Table 6 presents data on GHG emissions from olive production. The study indicates that the total GHG emissions of olive production under irrigated conditions are 848.63 kgCO<sub>2-eq</sub>ha<sup>-1</sup> (0.84 tCO<sub>2-eq</sub>ha<sup>-1</sup>) and under rainfall conditions are 507.32 kgCO<sub>2-eq</sub>ha<sup>-1</sup> (0.50 tCO<sub>2-eq</sub>ha<sup>-1</sup>). The highest value of total GHG emissions was found to be generated by the human labor force in both irrigated and rainfall conditions, at 27.70% and 29.54%, respectively. The use of diesel fuel ranked second under irrigated and rainfall conditions, at 28.14% and 44.28%, respectively. The use of nitrogen fertilizer ranked third under irrigated and rainfall conditions, with values of 15.69% and 17.50%, respectively. The ratio of GHG emissions (per kilogram) was determined to be 0.24 under irrigated conditions and 0.20 under rainfall conditions. In a previous study, Ağızan et al. (2024) determined total GHG emissions to be 4411.47 kgCO<sub>2-eq</sub>ha<sup>-1</sup> in organic grape production. The results of the study by Özbek et al. (2023) indicated that the total GHG emissions were 3794.26 kgCO<sub>2-eq</sub>ha<sup>-1</sup> in orange production, while the study by Saltuk et al. (2022) revealed that the total GHG emissions were 2650 kgCO<sub>2-eq</sub>ha<sup>-1</sup> in apple production.

## Conclusion

This study calculated energy use efficiency (EUE), EUE parameters, greenhouse gas emissions, and greenhouse gas (GHG) ratio in olive production under irrigated and rainfall conditions. The findings and recommendations that contribute to existing literature are summarized here. The total energy input (EI) was found to be 17,433.13 MJ ha<sup>-1</sup> under irrigated conditions and 12,911.55 MJ ha<sup>-1</sup> under rainfall conditions, while the total energy output (EO) was calculated as 41,534.83 MJ ha<sup>-1</sup> under irrigated conditions and 29,710.55 MJ ha<sup>-1</sup> under rainfall conditions. Furthermore, total GHG emissions were calculated as 848.63 kgCO<sub>2-eq</sub>ha<sup>-1</sup> under irrigated conditions and 507.32 kgCO<sub>2-eq</sub>ha<sup>-1</sup> under rainfall conditions. It can be concluded that olive production under irrigated and rainfall

conditions is a profitable activity in terms of energy use due to the higher amount of energy output than input.

The EUE in olive production under irrigated and rainfall conditions was calculated as 2.20 and 2.35, respectively. As EUE is greater than 1, net energy is positive, and olive production is profitable in terms of EUE in both production conditions. The EI was calculated to be 44.50% (7756.92 MJ ha<sup>-1</sup>) under irrigated conditions and 44.91% (5798.25 MJ ha<sup>-1</sup>) under rainfall conditions. The direct energy input (DE) was found to be 55.50% (9676.21 MJ ha<sup>-1</sup>) under irrigated conditions and 55.09% (7113.30 MJ ha<sup>-1</sup>) under rainfall conditions, indirect energy input (IDE), 7.34% (1279.84 MJ ha<sup>-1</sup>) under irrigated conditions and 6.32% (815.82). Under rainfall conditions, renewable energy inputs (RE) accounted for 92.66% (16,153.29 MJ ha<sup>-1</sup>) of the total energy input, while under irrigated conditions, non-renewable energy inputs (NRE) comprised 93.68% (12,095.73 MJ ha<sup>-1</sup>) of the total energy input. The primary energy input of olive production under irrigated conditions was chemical fertilizer (38.67%), amounting to 6741.53 MJ ha<sup>-1</sup>, while the primary energy input under rainfall conditions was diesel fuel (38.59%), amounting to 4982.43 MJ ha<sup>-1</sup>. The GHG emission rate per kilogram of olive production was calculated as 0.24 kgCO<sub>2</sub> under irrigated conditions and 0.20 kgCO<sub>2</sub> under rainfall conditions. This indicates that 0.24 kgCO<sub>2</sub> is emitted per 1 kg of olives harvested under irrigated conditions and 0.20 kgCO<sub>2</sub> is emitted per 1 kg of olives harvested under rainfall conditions.

In conclusion, although olive production under irrigated and rainfall conditions is a profitable activity in terms of energy use and efficiency, it is crucial for the continuity of the ecological life cycle to use and/or increase RE inputs to ensure the environmental sustainability of olive production.

**Conflict of interest** Z. Bayramoğlu, S. Candemir, K. Ağızan and H.G. Doğan declare that they have no competing interests.

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