



# Energy Use and Carbon Emissions of Walnut Production in Türkiye

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## Abstract

The objective of this study is to investigate the energy efficiency and greenhouse gas emissions associated with walnut production. The research will provide valuable insights into the environmental impact of walnut production. The study was conducted during the 2020–2021 agricultural season in Kahramanmaraş province of Türkiye. The study findings revealed that the energy required for walnut production includes 29,193 MJha<sup>-1</sup> (50.53%) of pesticide, 11,533 MJha<sup>-1</sup> (19.96%) of machinery, 9443 MJha<sup>-1</sup> (16.35%) of fertiliser, 3675 MJha<sup>-1</sup> (6.36%) of diesel, 1249 MJha<sup>-1</sup> (2.16%) of electricity, and 1163 MJha<sup>-1</sup> (2.01%) of farm manure energy. The total energy input and output were 57,772 MJha<sup>-1</sup> and 109,444 MJha<sup>-1</sup>, respectively. The total carbon emissions from walnut production were calculated to be 2242.23 kgCO<sub>2-eq</sub>kg<sup>-1</sup>. Of all emission sources, the use of machinery was to have the highest contribution with 56.91%.

**Keywords** Walnut · Energy use · Carbon emissions · Türkiye

## Introduction

Excessive carbon emissions resulting directly and indirectly from human activities are recognised as the primary driver of global warming (IPCC 2019). Therefore, the reduction of greenhouse gas (GHG) emissions and the deceleration of global climate change represent important environmental challenges that require the attention of all nations. Currently, many countries are signing protocols aimed at the reduction of carbon dioxide emissions within the framework of international environmental agreements. However, the means of achieving emissions reductions across all in-

dustries and how to revert to the specified goals require further elucidation.

Agricultural production has advanced in Türkiye and globally with the advent of technology and mechanisation. Consequently, the use of agrochemicals like fertilisers and pesticides has increased (Baran et al. 2017a). The utilisation of fertilisers, chemical pesticides, and negligent irrigation systems within the agricultural sector has resulted in a rise in greenhouse gas emissions, which have adverse impacts on the environment.

Conventional agricultural practices have been identified as the primary contributors to greenhouse gas emissions (IPCC 2019). According to the fifth assessment report of the IPCC, agricultural production's greenhouse gas emissions comprise 24% of the world's total emissions (Han et al. 2019).

Reducing the use of fossil resources in agricultural production systems is a vital measure in alleviating greenhouse gas emissions (Tzilivakis et al. 2005). It is a global obligation for all nations to execute the optimal strategies that diminish the potential of global warming whilst enhancing economic and environmental factors in production systems. In this context, scholarly research on enhancing greenhouse gas production and reducing global warming potential can guide policymakers in the agricultural industry (Lal et al. 2019).

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Greenhouse gas emissions originating from crop production have been the focus of a multitude of research studies. These studies have centred on calculating the quantity of agricultural GHG emissions (Johnson et al. 2007), contrasting variations in agricultural GHG emissions across diverse regions (Li et al. 2011; Wu et al. 2014), and establishing associations between crop GHG emissions and economic production (Zaman et al. 2012; Su et al. 2014), analyses of factors driving GHG emissions for different crops (Yang 2013; Tian et al. 2014), analyses of GHG emissions such as  $N_2O$  and  $CH_4$  (Zhang et al. 2011; Fang et al. 2021), and emission mitigation strategies and policies in agriculture (Peters et al. 2001; Kragt et al. 2012). Additionally, Zhang et al. (2014) have examined the components of carbon emission drivers by employing the Logarithmic Mean Division Index (LMDI) model.

Due to the geographical location of Türkiye, most of the fruits cultivated are temperate fruits. The area covered by nuts in Türkiye in 2021 was 1.35 mio.ha. 11.3% of this area was walnut and production was 325 thousand tons (Kadakoğlu et al. 2022). The aim of this study is to evaluate the energy efficiency and carbon emission levels of walnut cultivation in the Kahramanmaraş province of Türkiye, based on relevant literature. In Chap. 2, we discuss the methodology, study area, as well as data collection and analysis. Chapter 3 (Results and Discussion) presents the objective findings and corresponding analysis juxtaposed with the relevant literature. The final section comprises the study's conclusive remarks and pertinent recommendations.

## Material and Method

Kahramanmaraş province is a pivotal hub for agricultural production in Türkiye. The province is situated in the Mediterranean, Central Anatolia and South Eastern Anatolia regions, offering a diverse range of climatic and geographical conditions that enrich the agricultural product variety of the region. Notably, walnuts are at the forefront of the rich product pattern. Kahramanmaraş ranks first in Türkiye for its walnut production. The study data was gathered by conducting face-to-face interviews with walnut producers in the province of Kahramanmaraş. To determine the number of questionnaires, the following method was utilized (Newbold 1995):

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

$$D = d/t$$

$n$  represents the sample volume, whereas  $p$  indicates the number of individuals in the population with a particular characteristic as a proportion. If the specific ratio is un-

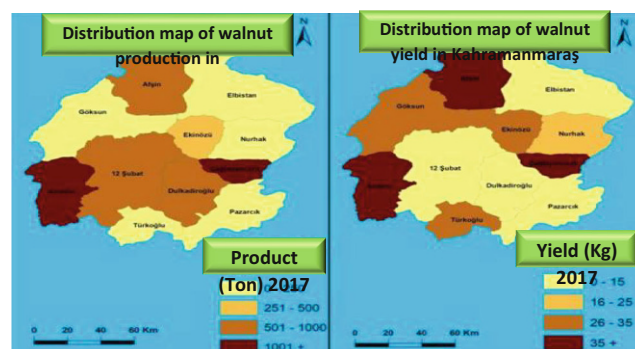


Fig. 1 Map of walnut production area in Kahramanmaraş province (Sandal et al. 2018)

known, 50% (0.5) should be assumed to achieve the maximum sampled volume. The proportion of fragments outside  $p$  can be calculated using  $q: 1-p$ , while the variance of the proportion can be determined by dividing the margin of error (%) by the table value. The  $t$  value should be employed for determining the confidence interval (with the use of the  $z$  value if the number of data exceeds 30). The acceptable error can be determined by calculating  $d$ : margin of error (%) \* mean. In order to collect primary data for the study, a total of 56 walnut producers were interviewed according to the sampling result. Figure 1 illustrates the distribution of walnut production areas in the province of Kahramanmaraş.

The selected villages for this study were chosen based on producing the highest amount of walnuts within Kahramanmaraş province.

To determine the energy equivalents and carbon emissions of walnut production, input amounts were calculated and expressed in megajoules (MJ) and  $kgC_2O$ , respectively. The carbon emissions for walnut production were calculated by first determining energy equivalence, followed by calculating carbon emission values.

To assess energy efficiency in walnut 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.

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

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

**Table 1** Standard coefficients to compute energy content of outputs and inputs in walnut production

Inputs	Unit	Energy equivalent (MJ unit <sup>-1</sup> )	References
Labour	H	1.96	Mani et al. (2007); Karağaç et al. (2011)
<i>Machinery</i>			
Tractor	H	25.4	Singh et al. (2002)
Plough	H	18.7	Singh et al. (2002)
<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)
<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	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
Walnut	Kg	11.80	Khoshroo and Mulwa (2014)
Walnut (Shell)	Kg	10.00	Baran et al. (2017b); Gündoğmuş (2013)

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

$$\begin{aligned} \text{Net energy} &= \text{Energy output} \left( \text{MJ ha}^{-2} \right) \\ &- \text{Energy input} \left( \text{MJ ha}^{-1} \right) \end{aligned} \quad (4)$$

The greenhouse gas (GHG) emissions (kgCO<sub>2-eq</sub>kg<sup>-1</sup>) for producing 1 ha of walnuts were calculated using the method developed by Hughes et al. (2011). The calculation involves finding the sum, denoted by  $\sum$ , of the product of the application ratio 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 has been devised to measure the amount of kgCO<sub>2-eq</sub> emissions spread per kg yield, using the following formula proposed by Houshyar et al. (2015). In this formula,  $I_{GHG}$  represents the GHG ratio and  $Y$  refers to the yield in kg per ha (Eren et al. 2019a).

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

$$I_{GHG} = \frac{GHG_{\text{ha}}}{Y} \quad (6)$$

**Table 2** GHG emissions coefficients in production

Inputs	Unit	GHG equivalent (kgCO <sub>2-eq</sub> unit <sup>-1</sup> )	References
Labour	H	0.36	Houshyar et al. (2015)
Machinery	MJ	0.071	Pishgar-Komleh et al. (2012); Eren et al. (2019b)
Farmyard manure	Ton	0.005	Meisterling et al. (2009)
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	L	2.760	Dyer and Desjardins (2006); Ozalp et al. (2018)
Electricity	kWh	0.608	Khoshnevisan et al. (2014)
Transportation	Kg	0.150	Meisterling et al. (2009); Eren et al. (2019b)

Table 3 EUE in walnut production

Inputs	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 (%)
<i>Labour</i>	-	-	<b>310.29</b>	<b>608.16</b>	<b>1.18</b>
Pruning	H	1.96	18.16	35.60	0.07
Soil tillage (2 times)	H	1.96	8.16	16.00	0.03
Fertilizing (Chemical and Farmyard)	H	1.96	21.00	41.16	0.08
Spraying	H	1.96	21.46	42.07	0.08
Irrigation	H	1.96	148.34	290.75	0.57
Harvesting	H	1.96	80.89	158.54	0.31
Drying	H	1.96	12.28	24.06	0.05
<i>Machinery</i>	-	-	-	<b>5119.48</b>	<b>9.97</b>
Tractor	H	25.40	171.96	4367.74	8.50
Plough (2 times)	H	18.70	40.20	751.74	1.46
<i>Pesticides</i>	-	-	-	<b>29,193.65</b>	<b>56.84</b>
Herbicides	Kg	238.00	33.36	7939.25	15.46
Fungicide	Kg	216.00	98.40	21,254.40	41.38
<i>Farmyard manure</i>	<b>Kg</b>	<b>0.30</b>	<b>3879.62</b>	<b>1163.89</b>	<b>2.27</b>
<i>Chemical fertilizers</i>	-	-	-	<b>9443.48</b>	<b>18.39</b>
Nitrogen	Kg	60.60	133.58	8094.87	15.76
Phosphorus	Kg	11.10	118.67	1317.20	2.56
Potassium	Kg	6.70	4.69	31.41	0.06
<i>Diesel</i>	<b>L</b>	<b>56.31</b>	<b>65.27</b>	<b>3675.23</b>	<b>7.16</b>
<i>Irrigation water</i>	<b>m<sup>3</sup></b>	<b>1.02</b>	<b>222.14</b>	<b>226.59</b>	<b>0.44</b>
<i>Electricity</i>	<b>kWh</b>	<b>3.60</b>	<b>347.10</b>	<b>1249.55</b>	<b>2.43</b>
<i>Transportation</i>	<b>MJ.t.km</b>	<b>4.50</b>	<b>150.83</b>	<b>678.74</b>	<b>1.32</b>
<i>Total inputs</i>	-	-	-	<b>51,358.75</b>	<b>100.00</b>
<b>Output</b>	<b>Unit</b>	<b>Energy equivalent (MJ/unit)</b>	<b>Output per hectare (unit ha<sup>-1</sup>)</b>	<b>Energy value (MJ ha<sup>-1</sup>)</b>	<b>Ratio (%)</b>
Walnut fruit	Kg	11.80	4928.13	58,151.88	53.13
Walnut shell fruit	Kg	10.00	5129.27	51,292.73	46.87
Total output	-	-	-	109,444.60	100.00

**Table 4** EUE calculations in walnut production

Calculations	Unit	Values
Walnut Fruit	kg ha <sup>-1</sup>	10,057.40
EI	MJ ha <sup>-1</sup>	51,358.75
EO	MJ ha <sup>-1</sup>	109,444.60
EUE	–	2.13
SE	MJ kg <sup>-1</sup>	5.11
EP	kg MJ <sup>-1</sup>	0.20
NE	MJ ha <sup>-1</sup>	58,085.85

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

Energy groups	Energy input (MJ ha <sup>-1</sup> )	Ratio (%)
DE	5759.54	11.21
IDE	45,599.22	88.79
Total	51,358.75	100.00
RE	834.75	1.63
NRE	50,524.01	98.37
Total	51,358.75	100.00

Energy input (EI) can be categorised into different types, including direct and indirect energy, as well as renewable and non-renewable forms. Indirect energy primarily comprises fertilisers and pesticides, while direct energy encompasses labour and animal power, diesel and electricity used in the production process. Non-renewable energy sources include petrol, diesel, electricity, chemicals, and fertilisers, as well as machinery. On the other hand, renewable energy sources include labour and animal power (Mandal et al. 2002; Singh et al. 2002). Energy balance calculations, fossil energy input types, and greenhouse gas emissions of inputs are provided in Table 3, 4, 5 and 6, respectively.

**Table 6** GHG emissions in walnut 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 (%)
Labour	H	0.700	310.29	217.20	12.16
Machinery	MJ	0.071	5,119.48	363.48	20.34
Farmyard manure	Ton	0.029	3.88	0.11	0.01
Herbicides	Kg	6.30	33.36	210.16	11.76
Fungicide	Kg	3.90	98.40	383.76	21.48
Nitrogen	Kg	1.300	133.58	173.65	9.72
Phosphorus	Kg	0.200	118.67	23.73	1.33
Potassium	Kg	0.200	4.69	0.94	0.05
Diesel	L	3	65.27	180.14	10.08
Electricity	kWh	0.608	347.10	211.04	11.81
Transportation	Kg	0.15	150.83	22.62	1.27
Total	–	–	–	1786.84	100.00
GHG ratio (per kg)	–	–	–	10.18	–

## Discussion

The walnut yield in the farms interviewed was determined to be 4928.13 kg/ha for the 2021 production season. Energy inputs in walnut production include 29,193.65 MJ ha<sup>-1</sup> (56.84%) for pesticides, 5119.48 MJ ha<sup>-1</sup> (9.97%) for machinery, 9443.48 MJ ha<sup>-1</sup> (16.35%) for fertilisers, and 3675.23 MJ ha<sup>-1</sup> (7.16%). The distribution of energy inputs showed 7.16% from diesel, 2.43% from electricity, 2.27% from organic fertilisers, 1.32% from transport, 1.18% from labour, and totaling an energy input (EI) of 51,358.75 MJ ha<sup>-1</sup>. The energy inputs of the agricultural system were evaluated and are reported in Table 3. The energy output (EO) for the system was 109,444.60 MJ ha<sup>-1</sup>. Unlike the findings of the study, Banaeian and Zangeneh (2011) (41.50%) and Gündoğmuş (2013) (46.70%) determined that the energy consumed by fertilisers in walnut production is the highest. Similarly, in other research on agricultural production, Ozkan et al. (2007) recorded 27.64% of electricity used in grape production, Akdemir (2022) noted 32.40% of energy spent on fertiliser application, Gündoğmuş (2006) found 44.99% of electrical energy utilised in organic apricot production, and Sattari-Yuzbashkandi et al. (2014) discovered that 43% of energy was used in their study. In grape production, Baran et al. (2017a) reported that diesel energy constituted the largest share with 37.21% in organic grape production, accounting for 64% of the electrical energy. Meanwhile, Özbek et al. (2023) found that chemical fertiliser energy had the largest share with 49.68% in lemon production.

In Table 4, the yield of fruit, energy input (EI), energy output (EO), energy use efficiency (EUE), sustainability index (SE), energy productivity (EP) and net energy (NE) were determined to be 10,057.40 kg ha<sup>-1</sup>, 51,358.75 MJ ha<sup>-1</sup>, 109,444.60 MJ ha<sup>-1</sup>, 2.13, 5.11 MJ kg<sup>-1</sup>, 0.20 kg MJ<sup>-1</sup> and 58,085.85 MJ ha<sup>-1</sup>, respectively, for walnut production. In

previous studies, EUE was calculated by Ozkan et al. (2007) for field grapes as 5.10, by Oğuz et al. (2019) for nectarines as 1.86, by Baran et al. (2017b) for walnuts as 0.61, and by Demir and Gökdoğan (2023) for peaches as 0.99.

Table 5 displays the energy inputs based on various types, including DE, IDE, RE and NRE, for walnut production. Walnut production's overall energy inputs, as listed in Table 5, consist of DE (11.21%; 5759.54 MJ ha<sup>-1</sup>), IDE (88.79%; 45,599.22 MJ ha<sup>-1</sup>), RE (1.63%; 834.75 MJ ha<sup>-1</sup>) and NRE (98.37%; 50,524.01 MJ ha<sup>-1</sup>). In walnut production, NRE energy inputs are significantly higher than RE energy inputs.

Similarly, several studies on walnut (Banaeian and Zangeneh 2011; Gündoğmuş 2013; Baran et al. 2017b), kiwifruit (Mohammadi et al. 2008), apple (Gokdogan and Baran 2017), plum (Karamürsel et al. 2023) and almond (Yılmaz and Bayav 2023) have observed that the non-renewable energy ratio surpasses the RE ratio.

Table 6 provides data on the greenhouse gas emissions produced by walnut production. The research shows the total greenhouse gas emissions to be 1786.84 kgCO<sub>2-eq</sub>ha<sup>-1</sup> (1.78 t CO<sub>2-eq</sub>ha<sup>-1</sup>). It was found that fungicide usage accounted for the highest value in total GHG emissions at 383.76 kgCO<sub>2-eq</sub>ha<sup>-1</sup> (21.48%). The use of machinery ranks second at 363.48 kgCO<sub>2-eq</sub>ha<sup>-1</sup> (20.34%), while labour ranked third with 217.20 kgCO<sub>2-eq</sub>ha<sup>-1</sup> (12.16%). The ratio of greenhouse gas emissions (per kilogram) was determined to be 11.85. Previous research by Özbek et al. (2023) found that the overall greenhouse gas emissions from lemon production totaled 2650.96 kgCO<sub>2-eq</sub> per hectare. Ozalp et al. (2018) determined that the total greenhouse gas emission of pomegranate production was 1416.1 kgCO<sub>2-eq</sub>ha<sup>-1</sup>, while Saltuk et al. (2022) calculated a total emission of 3794.26 kgCO<sub>2-eq</sub>ha<sup>-1</sup> for orange production.

## Conclusions

Energy use efficiency (EUE), EUE parameters, greenhouse gas emissions and greenhouse gas ratio were calculated in walnut production for this study. The research findings and recommendations, which have contributed to existing literature, are summarised below. Total energy input (EI) was 51,358.75 MJ ha<sup>-1</sup>, while total energy output (EO) was 109,444.60 MJ ha<sup>-1</sup>. In addition, total greenhouse gas emissions were calculated as 1786.84 kgCO<sub>2-eq</sub>ha<sup>-1</sup> (1.78 t CO<sub>2-eq</sub>ha<sup>-1</sup>). Walnut production is a profitable activity in terms of energy use due to a higher amount of energy output than input.

The energy utilisation efficiency (EUE), specific energy (SE), energy productivity (EP) and net energy (NE) were 2.13, 5.11 MJ kg<sup>-1</sup>, 0.20 MJ kg<sup>-1</sup> and 58,085.85 MJ ha<sup>-1</sup>, respectively. As the EUE is greater than 1, net energy

is positive, thus making walnut production profitable in terms of EUE. EI can be categorised as follows: 11.21% (5759.54 MJ ha<sup>-1</sup>) were direct energy inputs (DE), 88.79% (45,599.22 MJ ha<sup>-1</sup>) were indirect energy inputs (IDE), 1.63% (834.75 MJ ha<sup>-1</sup>) were renewable energy inputs (RE), and 98.37% (50,524.01 MJ ha<sup>-1</sup>) were non-renewable energy inputs (NRE). Pesticides were the primary energy input used in production, accounting for 29,193.65 MJ ha<sup>-1</sup> (56.84%). To increase the proportion of RE inputs in the total EI for walnut production, it is crucial to decrease NRE inputs. The research findings indicate that the largest proportion of greenhouse gas (GHG) emissions, at 33.24%, is attributed to the pesticides sector, with a value of 593.92 kgCO<sub>2-eq</sub>ha<sup>-1</sup>. The GHG ratio per kilogramme of walnut production was calculated at 0.18, meaning that 0.18 kgCO<sub>2</sub> is emitted per 1 kg of walnut harvested.

In conclusion, while walnut production can be a profitable activity in terms of energy use and efficiency, it is crucial for the ecological life cycle's continuity to utilise and/or increase renewable energy (RE) inputs in order to ensure the environmental sustainability of walnut production. Therefore, as the ratio of renewable inputs and energy use efficiency increases, the ratio of non-renewable inputs and greenhouse gas emissions decreases. To improve efficiency in energy use and reduce greenhouse gas emissions, it is necessary to decrease the usage of pesticides, fertilisers and fossil fuels and opt for renewable energy sources in electricity consumption, according to research findings.

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

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