Applied Fruit Science (2025) 67:99
https://doi.org/10.1007/s10341-025-01322-w

ORIGINAL ARTICLE

Evaluating Energy Efficiency and Carbon Emissions in Banana Cultivation: the Case of Antalya Province in Türkiye

Serhan Candemir[1] · Kemalettin Ağızan[2] · Hasan Gökhan Doğan[3] · Zeki Bayramoğlu[4]

Received: 10 February 2025 / Accepted: 1 April 2025 / Published online: 5 May 2025

Abstract
The aim of this study is to determine the energy efficiency of banana production and the carbon emissions during the production process. For this purpose, a survey study was conducted in Antalya Province, Türkiye, in the 2021–2022 agricultural production season. Within the scope of the survey study, the input elements and technical coefficients of banana producers were recorded, and the primary data of the study were collected. The research results revealed that a total of 69,045.29 MJ ha-1 energy input was used in banana production. It was calculated that the total energy input originated from 57,228.45 MJha-1 (82.89%) nitrogenous fertilizer, 5301.59 MJha-1 (7.68%) diesel input, 2147.54 MJha-1 (3.11%) machinery use, 1923.94 MJha-1 (2.79%) labor, and 1258.76 MJha-1 (1.82%) pesticide use. In total, 97.17% of the energy input is provided from non-renewable energy sources, and this result is a risk factor in terms of the sustainability of agriculture. The total carbon emission from banana production was calculated as 2371.23 kg CO2-eq for the entire production, and 0.047 kg CO2-eq per kilogram of banana. It was determined that 40.2% of the total emission was caused by nitrogenous fertilizers, 29.0% by labor, and 11.0% by diesel use. The research findings reveal that fertilization is the most important input in both energy use and carbon emissions. For the sustainability of agricultural production, it is suggested that technical norms be taken into consideration in chemical fertilizer applications and that monitoring processes be developed. In addition, directing efforts toward more environmentally friendly alternatives that can be equivalent to chemical fertilizers can be considered a solution.

Keywords Fruit · Climate change · Environment · Sustainability · Food safety

Introduction

Climate change has become a global threat in terms of its effects in environmental, economic and social dimensions. Greenhouse gas (GHG) emissions are increasing the world's average temperature, negatively affecting many areas such as agricultural production, water resources, biodiversity, and human health. The agricultural sector and climate change have a two-way interaction. Agriculture is both one of the important sectors contributing to climate change and one of the sectors most affected by climate change (Candemir et al. 2024). Fluctuations in temperatures, irregularities in precipitation regimes, and extreme weather events have negative effects on agricultural productivity. Therefore, the agricultural sector has an important role in adapting to climate change and reducing GHG.

Within the scope of combating climate change, it is important to determine the energy and amounts of inputs used in agricultural activities and the carbon equivalents of the inputs. Determining the structure of energy use and the source of carbon emissions is of critical importance in terms of measures to be taken. Energy use based on fossil resources in agricultural production is one of the largest sources of carbon emissions (Baran et al. 2017a). Increasing energy use not only harms the sustainability of agriculture, but also increases GHG emissions, leading to deepening climate change.

✉ Hasan Gökhan Doğan
hg.dogan@ahievran.edu.tr

[1] Department of Agricultural Economics, Faculty of Agriculture, Malatya Turgut Özal University, Malatya, Turkey

[2] Department of Agricultural Economics, Faculty of Agriculture, Aydin Adnan Menderes University, Aydin, Turkey

[3] Department of Agricultural Economics, Faculty of Agriculture, Kırşehir Ahi Evran University, Kırşehir, Turkey

[4] Department of Agricultural Economics, Faculty of Agriculture, Selçuk University, Konya, Turkey

Fig. 1 Study area map of Antalya province

Table 1 Energy coefficients of inputs and outputs used in banana cultivation

Inputs	Unit	Energy equivalent (MJ unit-1)	References
Labor	H	1.96	Mani et al. (2007); Karaağaç et al. (2011)
Machine power			
Tractor	H	64.8	Singh et al. (2002)
Plow	H	18.7	Singh et al. (2002)
Pesticides			
Herbicides	Kg	238	Khoshroo and Mulwa (2014); Rafiee et al. (2010); Candemir et al. (2024)
Insecticides	Kg	278	Yılmaz and Bayav (2023); Aydın and Aktürk (2018)
Organic fertilizers			
Farm fertilizer	Kg	0.30	Singh et al. (2002)
Chemical fertilizers			
N fertilizer	Kg	60.60	Singh et al. (2002); Ozalp et al. (2018)
P fertilizer	Kg	11.10	Mandal et al. (2002); Ozalp et al. (2018)
K fertilizer	Kg	6.70	Mandal et al. (2002)
Diesel	L	56.31	Singh et al. (2002)
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-1)	Reference
Banana	Kg	2.4	Strapatsa et al. 2006

Table 2 Greenhouse gas (GHG) emission equivalents of inputs

Inputs	Unit	GHG equivalent(kg$CO_{2\text{-eq}}$ unit-1)	References
Labor	H	0.700	Houshyar et al. (2015)
Machine power	MJ	0.071	Pishgar-Komleh et al. (2012); Eren et al. (2019b)
Farm fertilizer	Ton	0.029	Meisterling et al. (2009)
Herbicides	Kg	6.300	Graefe et al. (2013)
Insecticides	Kg	5.100	Sezer (2014)
N fertilizer	Kg	1.300	Lal (2004); Ozalp et al. (2018)
P fertilizer	Kg	0.200	Lal (2004); Ozalp et al. (2018)
K fertilizer	Kg	0.200	Taghavifar and Mardani (2015)
Diesel	L	2.760	Dyer and Desjardins (2006); Candemir et al. (2024)
Electricity	kWh	0.608	Khoshnevisan et al. (2014)
Transportation	Kg	0.150	Meisterling et al. (2009); Eren et al. (2019b)

Agriculture accounts for approximately 5% of global energy use and contributes significantly to the increase in GHG emissions (Platis et al. 2019). Energy use based on fossil fuels in agricultural production not only increases carbon emissions but also complicates the sustainability of this sector (Sarkodie et al. 2019). As agriculture has become technology-intensive, it has become important to analyze energy consumption dynamics and its effects on carbon emissions. Many studies have analyzed energy use and carbon emissions in agricultural production (Candemir et al. 2024; Özbek et al. 2023; Karamürsel et al. 2023; Qi et al. 2023; Kadakoğlu et al. 2022; Daizy et al. 2021; Khan et al. 2021; Liu et al. 2021; Bhatti and Fazal 2021; Gokdogan and Baran 2017).

While the energy consumption and carbon emissions of the agricultural sector originating from production are examined in many countries and products globally, regional studies are also very important to reveal the differences in producer behavior. In this context, analyzing energy use and carbon emissions in countries with high agricultural production potential, such as Türkiye, is of particular importance.

Due to the advantages of Türkiye such as its geographical location and climate conditions, many fruits can be cultivated. In Türkiye, the area covered by banana production in 2023 was 13.6 thousand hectares and the production amount was around 930 thousand tons. Approximately 50% of Türkiye's banana planting areas and amount of production are carried out in Antalya province, which is the study area (Turkstat 2024). In this study, the energy input level and carbon emission level in banana cultivation in the Antalya province of Türkiye were analyzed. The importance and purpose of the study were examined in Introduction, and the methodological background of the study, the study region, and data collection issues were discussed in Materials and Methods. Results and Discussion, the relevant analysis results were discussed and presented in the context of the existing literature. The last section which Conclusion includes the results of the study and relevant recommendations.

Materials and Methods

One of the provinces with the highest agricultural potential in Türkiye is Antalya. Antalya is located in the Mediterranean region, and its climatic conditions significantly increase its fruit and vegetable production potential. In addition, greenhouse fruit and vegetable production is widely practiced in the study area. Antalya is located in the southwest of Türkiye between 29°20′–32°35′ east longitudes and 36°07′–37°29′ north latitudes. In the study conducted in Antalya, where approximately 50% of Türkiye's banana production takes place, data were collected through face-to-face surveys conducted with banana producers. The following method was used to determine the number of surveys for the study (Newbold 1995):

$$n = Np * q/(N-1)\sigma 2 + p * q$$
$$\sigma = d/t$$

Here, n refers to the sample size; p represents to probability; q refers to the probability of not having that characteristic. To reach the maximum sample size, p and q, values were taken as 50%. t: represents the table value in the appropriate confidence interval, while d: reflects the error rate. According to 2021 data, the number of enterprises is 2300, and with the calculations made with a 15% margin of error and 90% confidence interval, it was decided to conduct the sample of the study with 32 producers (Fig. 1).

In accordance with the purpose of the study, regions where banana production is intensive in Antalya province were specially selected.

The input amounts used in production were determined and converted to energy and carbon equivalents. The energy equivalent unit and carbon equivalent unit were specified as megajoule (MJ) and kgCO2, respectively.

The following equations were used in the evaluation of energy efficiency (Mandal et al. 2002; Singh et al. 2002; Table 1 and 2);

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

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

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

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

The method used to calculate (GHG) emissions (kgCO2-eqkg-1) is given below (Hughes et al. (2011). In the formula, R(i): the proportional application of input i and EF(i): R(i) is the GHG emission equivalent of input i. In addition, the IGHG (Greenhouse Gases Per Output) equation suggested by Houshyar et al. (2015) is used to calculate the emission measurement per output (Eren et al. 2019a).

$$GHG_{ha} = \sum_{i=1}^{n} R\,(i)\,xEF\,(i) \quad (5)$$

Table 3 Energy use efficiency in banana production

Inputs	Unit	Energy equivalent (MJ unit-1)	Input used per hectare (unit ha-1)	Energy value (MJ ha-1)	Rate (%)
Labor	–	–	*981.60*	*1923.94*	*2.79*
Pruning	H	1.96	130.94	256.64	0.37
Soil tillage (twice)	H	1.96	38.13	74.73	0.11
Fertilizing (chemical and farmyard)	H	1.96	122.97	241.02	0.35
Spraying	H	1.96	17.68	34.65	0.05
Irrigation	H	1.96	270.94	531.04	0.77
Harvesting	H	1.96	388.13	760.73	1.10
Transportation	H	1.96	12.81	25.11	0.04
Machine power	–	–	–	*2147.54*	*3.11*
Tractor	H	25.40	56.44	1433.58	2.08
Plow (twice)	H	18.70	38.18	713.97	1.03
Pesticides	–			*1258.76*	*1.82*
Herbicides	Kg	238.00	2.03	483.14	0.70
Insecticides	Kg	278.00	2.79	775.62	1.12
Farm fertilizer	*Kg*	*0.30*	*879.68*	*263.90*	*0.38*
Chemical fertilizers	–	–	–	*57,228.45*	*82.89*
N fertilizer	Kg	60.60	734.01	44,481.01	64.42
P fertilizer	Kg	11.10	854.56	9485.62	13.74
K fertilizer	Kg	6.70	486.84	3261.83	4.72
Diesel	*L*	*56.31*	*94.15*	*5301.59*	*7.68*
Electricity	*kWh*	*3.60*	*235.94*	*849.38*	*1.23*
Transportation	*MJ.t.km*	*4.50*	*15.94*	*71.73*	*0.10*
Total inputs	–	–	–	*69,045.29*	*100.00*
Output	Unit	Energy equivalent (MJ/unit)	Output per hectare (unit ha-1)	Energy value (MJ ha-1)	Ratio (%)
Banana fruit	Kg	*2.4*	*50,406.3*	*120,975.12*	***100.00***
Total output	–	–	–	120,975.12	**100.00**

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

Results and Discussion

The average banana yield of the banana producers participating in the study was determined as 50,406.3 kg/ha. The energy inputs of banana production are examined in Table 3. The total energy input (EI) in banana production was calculated as 69,045.29 MJ ha-1. When the distribution of energy use in banana production by source was examined, it was 57,228.45 MJ ha-1 (82.89%) chemical fertilizers, 5301.59 MJ ha-1 (7.68%) diesel, 2147.54 MJ ha-1 (3.11%) machinery, 1923.94 MJ ha-1 (2.79%) labor, 1258.76 MJ ha-1 (1.82%) pesticides and 849.38 MJ ha-1 (1.23%) electricity. The energy output (EO) of the banana production system was calculated as 120,975.12 MJ ha-1. Unlike the study findings, Akcaoz (2011) found that the highest energy source in banana production (27.55%) was due to electricity use. On the other hand, in parallel with the study results, Gündoğmuş (2013) found that the highest energy source in walnut production (46.70%) was due to fertilizer, Özbek et al. (2023) found that energy use from chemical fertilizers (49.68%) had the highest share in lemon production, and Banaeian and Zangeneh (2011) found that energy use from chemical fertilizers (41.50%) had the highest share in walnut production.

According to Table 4, fruit yield for banana production was calculated as 50,406.3 kg ha-1, EI as 69,045.29 MJ ha-1,

Table 4 Energy efficiency coefficients for banana production

Calculations	Unit	Values
Banana fruit (yield)	kg ha-1	50,406.3
EI (energy input)	MJ ha-1	69,045.29
EO (energy output)	MJ ha-1	120,975.12
EUE (energy use efficiency)	–	2.28
SE (sustainability index)	MJ kg-1	1.36
EP (energy efficiency)	kg MJ-1	0.95
NE (net energy)	MJ ha-1	53,007.24

Table 5 Distribution of energy inputs by energy types

Energy groups	Energy input (MJ ha-1)	Rate (%)
Direct energy	8075.04	11.88
Indirect energy	59,892.25	88.12
Total	67,045.29	100.00
Renewable energy	1923.90	2.83
Non-renewable energy	66,043.39	97.17
Total	67,045.29	100.00

EO as 120,975.12 MJ ha-1, energy use efficiency (EUE) as 2.28, sustainability index (SE) as 1.36 MJ kg-1, energy efficiency (EP) as 0.95 kg MJ-1 and net energy (NE) as 53,007.24 MJ ha-1. In previous studies, energy efficiency indices calculated by Akcaoz (2011) for banana production (EP 1.00, EUE 1.90, NE 46,464.83 MJ ha-1) are similar to the study results. In addition, energy use efficiency was calculated to be between 0.61 and 1.88 in similar studies on fruit growing (Oğuz et al. 2019; Baran et al. 2017b; Demir and Gökdoğan 2023).

Direct energy (DE), indirect energy (IDE), renewable energy (RE) and non-renewable energy (RNE) values of banana production are examined in Table 5. Total energy inputs of banana production are calculated as: DE 11.88%, 8075.04; IDE, 88.12%, 59,892.25; RE, 2.83%, 1923.90; and NRE, 97.17%, 66,043.39). In many studies (Candemir et al. 2024; Atılgan et al. 2023; Yılmaz and Bayav 2023; Candemir 2020; Banaeian and Zangeneh 2011; Gündoğmuş 2013; Baran et al. 2017b; Arredondo et al. 2009; Monirahmad et al. 2022), it has been determined that the use of renewable energy in agricultural production is significantly below the use of non-renewable energy. The most important reason for this result is that fossil fuels are the main source of energy needed for agricultural practices (Hariharan 2023). However, in the agriculture of the future, it is inevitable that fossil resources will be replaced by renewable energy sources (Bathaei 2023). Meeting the energy needed by agricultural practices from renewable and environmentally friendly sources such as wind, solar and hydropower is a must for agricultural sustainability (Saidivaliyeva 2024).

Data on GHG emissions from banana production are examined in Table 6. Total GHG emissions from banana production were calculated as 2371.23 kgCO2-eqha-1 (2.37 tonCO2-eqha-1). Nitrogen fertilizer use constitutes the highest value of 954.21 kgCO2-eqha-1 (40.2%) among total GHG emissions. Carbon emission from labor ranks second at 687.11 kgCO2-eqha-1 (29%), while carbon emission from diesel use ranks third at 259.85 kgCO2-eqha-1 (11%). Carbon emission for 1 kg of banana production was calculated as 0.047 kgCO2-eqha-1. Suwan and Somjai (2022) found that carbon emission from banana production in Thailand (80%) was due to fertilization.

Conclusions

The aim of this study was to analyze the energy use and carbon emissions originating from banana production in Türkiye. For this purpose, energy efficiency indexes and carbon emissions were calculated for banana production. Since a higher amount of energy output (EO = 120,975.12 MJ ha-1) is realized than the input energy (EI = 69,045.29 MJ ha-1), banana production is a profitable production activity in terms of energy use. However, increasing energy efficiency in banana production can contribute not only to environmental sustainability but also to economic sustainability, as it will also reduce costs. In addition, the total carbon emission of banana production was calculated as 2371.23 kgCO2-eqha-1, and the carbon emission per 1 kg was calculated as 0.047 kgCO2-eqha-1.

Table 6 Greenhouse gas (GHG) emissions and distribution of inputs

Inputs	Unit	GHG co-efficient (kg CO_{2eq} unit-1)	Input used Per area (unit ha-1)	GHG emissions (kg CO_{2eq} ha-1)	Ratio (%)
Labor	H	0.700	981.58	687.11	29.0
Machine power	MJ	0.071	94.56	6.71	0.3
Farm fertilizer	Ton	0.029	879.69	25.51	1.1
Herbicides	Kg	6.30	2.03	12.79	0.5
Fungicide	Kg	3.90	2.80	10.92	0.5
N fertilizer	Kg	1.300	734.01	954.21	40.2
P fertilizer	Kg	0.200	854.56	170.91	7.2
K fertilizer	Kg	0.200	486.84	97.37	4.1
Diesel	L	2.760	94.15	259.85	11.0
Electricity	kWh	0.608	235.94	143.45	6.0
Transportation	Kg	0.15	15.93	2.39	0.1
Total	–	–	–	2371.23	100.0
GHG ratio (per kg)	–	–	–	0.047	–

Fertilizer is the primary source of both energy and carbon emission in banana production in Türkiye. Since chemical fertilizer applications are among the important factors that pose an environmental risk, it is necessary to reduce fertilizer applications and/or spread more environmentally friendly alternatives such as farm manure. When compared to other agricultural products produced in Türkiye, banana production can be said to have a profitable production system in terms of energy. In addition, in order to reduce carbon emissions, sustainable agricultural production can be supported through training and incentives for low-carbon production systems.

When the distribution of energy inputs was examined, it was determined that 97.17% of them consist of non-renewable energy sources. This result is an important risk factor not only for banana production but also for the sustainability of agriculture. In this respect, energy resources used in agriculture both in Türkiye and globally should be directed towards renewable energy resources. In order for the EU to reach its 2030 targets within the scope of the Green Deal, it is a global necessity to increase agricultural producers' access to renewable energy resources through agricultural support policies. However, as Türkiye aligns its agricultural policies with the objectives of the European Green Deal, it will increase Türkiye's competitiveness in global markets and accelerate the transition to the use of renewable energy.

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

References

Akcaoz H (2011) Analysis of energy use for banana production: a case study from Turkey. Afr J Agric Res 6(26):5618–5624 (https://api.semanticscholar.org/CorpusID:86279662)

Arredondo HI, Colorado AA, Júnior SD (2009) Ethanol production from banana fruit and its lignocellulosic residues: exergy and renewability analysis. Int J Thermodyn 12:155–162

Atılgan A, Krakowiak-Bal A, Ertop H, Saltuk B, Malinowski M (2023) The energy potential of waste from banana production: a case study of the mediterranean region. Energies. https://doi.org/10.3390/en16145244

Aydın B, Aktürk D (2018) Energy use efficiency and economic analysis of peach and cherry production regarding good agricultural practices in Turkey: A case study in Çanakkale province. energy 158:967–974. https://doi.org/10.1016/j.energy.2018.06.087

Banaeian N, Zangeneh M (2011) Modeling energy flow and economic analysis for walnut production in Iran. Res J Appl Sci Eng Technol 3(3):194–201

Baran M, Gökdoğan O, Oğuz H (2017b) Determining the energy usage efficiency of walnut (Juglans regia L.) cultivation in Turkey. Erwerbs-Obstbau. https://doi.org/10.1007/s10341-016-0301-y

Baran MF, Lüle F, Gökdoğan O (2017a) Energy input-output analysis of organic grape production: a case study from Adıyaman province. Erwerbs-Obstbau 59(4):275–279

Bathaei A (2023) Renewable energy and sustainable agriculture: review of indicators. Sustainability 15(19):14307. https://doi.org/10.3390/su151914307

Bhatti MA, Fazal S (2021) Impact of modernized agriculture and trade on carbon emissions: the role of fossil fuel and renewable energy consumption evidenced from ASEAN states. Irasd J Energy Environ 2(2):55–66. https://doi.org/10.52131/jee.2021.0202.0017

Candemir S (2020) Ekmeklik Buğday Üretiminde Enerji Kullanımı ve Etkinlik Analizi: Kahramanmaraş İli Örneği. Turk J Agric Nat Sci 7(4):896–903. https://doi.org/10.30910/turkjans.780486

Candemir S, Ağizan K, Doğan HG, Bayramoğlu Z, Akdoğan A (2024) Energy use and carbon emissions of walnut production in Türkiye. Appl Fruit Sci 66(4):1347–1354. https://doi.org/10.1007/s10341-024-01142-4

Daizy AF, Anjum MI, Arman MR, Nazia T, Shah N (2021) Long-run impact of globalization, agriculture, industrialization, and electricity consumption on the environmental quality of Bangladesh. Int J Energy Econ Policy 11(6):438–453. https://doi.org/10.32479/ijeep.11817

Demir C, Gökdoğan O (2023) Determination of energy use efficiency and greenhouse gas emissions in peach production. Int J Agric Biol Eng 16(2):165–170

Dyer JA, Desjardins RL (2006) Carbon dioxide emissions associated with the manufacturing of tractors and farm machinery in Canada. Biosyst Eng 93(1):107–118

Eren O, Baran MF, Gokdogan O (2019a) Determination of greenhouse gas emissions (GHG) in the production of different fruits in Turkey. Fresenius Environ Bull 28(1):464–472

Eren O, Gokdogan O, Baran MF (2019b) Determination of greenhouse gas emissions (GHG) in the production of different plants in Turkey. Fresenius Environ Bull 28(2A):1158–1166

Fluck RC, Baird CD (1982) Agricultural energetics. AVI, Connecticut

Gokdogan O, Baran MF (2017) Determination of energy use efficiency of some apple (Malus x domestica) production in Turkey: a case study of Eğirdir region. Erwerbs-Obstbau 59:13–18

Graefe S, Tapasco J, Gonzalez A (2013) Resource use and greenhouse gas emissions of eight tropical fruits species cultivated in Colombia. Fruits 68(4):303–314

Gündoğmuş E (2013) Modelling and sensitivity analysis of energy inputs for walnut production. Actual Probl Econ 2(140):188–197

Hariharan M (2023) Economic analysis of energy use pattern in cotton cropping system. Int J Stat Appl Math 8(5S):11–15. https://doi.org/10.22271/maths.2023.v8.i5sa.1161

Houshyar E, Dalgaard T, Tarazgar MH, Jorgensen U (2015) Energy input for tomato production what economy says, and what is good for the environment. J Clean Prod 89:99–109

Hughes DJ, West JS, Atkins SD, Gladders P, Jeger MJ, Fitt BD (2011) Effects of disease control by fungicides on greenhouse gas emissions by UK arable crop production. Pest Manag Sci 67:1082–1092

Kadakoğlu B, Bayav A, Karlı B (2022) Walnut production projection and competitiveness analysis in Turkey. Fruit Sci 9(1):8–15. https://doi.org/10.51532/meyve.1125552

Karaağaç HA, Aykanat S, Çakır B, Eren Ö, Turgut MM, Barut ZB, Öztürk HH (2011) Energy balance of wheat and maize crops production in Hacıali undertaking. 11th International Congress on Mechanization and Energy in Agriculture Congress, Istanbul, 21–23 September, pp 388–391

Karamürsel ÖF, Karamürsel D, Bayav A, Öztürk FP (2023) Economic analysis and energy efficiency of different training systems and planting densities in plum cultivation. Erwerbs-Obstbau 65:2305–2313. https://doi.org/10.1007/s10341-023-00931-7

Khan ZA, Koondhar MA, Khan I, Ali U, Tian-jun L (2021) Dynamic linkage between industrialization, energy consumption, carbon emission, and agricultural products export of Pakistan: an ARDL approach. Environ Sci Pollut Res 28(32):43698–43710. https://doi.org/10.1007/s11356-021-13738-4

Khoshnevisan B, Shariati HM, Rafiee S, Mousazadeh H (2014) Comparison of energy consumption and GHG emissions of open field and greenhouse strawberry production. Renew Sustain Energy Rev 29:316–324

Khoshroo A, Mulwa R (2014) Improving energy efficiency using data envelopment analysis: a case of walnut production. In: Managing service productivity: using frontier efficiency methodologies and multicriteria decision making for improving service performance, pp 227–240

Kitani O (1999) Energy for biological systems. In: The International Commission of Agricultural Engineering (ed) CIGR Handbook of Agricultural Engineering: Energy and Biomass Engineering, vol 5. American Society of Agricultural Engineers, pp 13–39

Lal R (2004) Carbon emission from farm operations. Environ Int 30:981–990

Liu J, Wang H, Rahman S, Sriboonchitta S (2021) Energy efficiency, energy conservation, and determinants in the agricultural sector in emerging economies. Agriculture 11(8):773. https://doi.org/10.3390/agriculture11080773

Mandal KG, Saha KP, Ghosh PK, Hati KM, Bandyopadhyay KK (2002) Bioenergy and economic analysis of soybean-based crop production systems in central India. Biomass Bioenergy 23:337–345

Mani I, Kumar P, Panwar JS, Kant K (2007) Variation in energy consumption in production of wheat-maize with varying altitudes in hill regions of Himachal Prades. India Energy 32:2336–2339

Meisterling K, Samaras C, Schweizer V (2009) Decisions to reduce greenhouse gases from agriculture and product transport: LCA case study of organic and conventional wheat. J Clean Prod 17:222–230

Monirahmad R, Mashallah S, Mahmoud AB, Amin N, Hamid M, Valiollah S (2022) Modeling and optimizing the exergy flow of tropical crop production in Iran. Sustain Energy Technol Assess 49:101683. https://doi.org/10.1016/j.seta.2021.101683

Newbold P (1995) Statistics for business and economics. Prentice-Hall International, New Jersey

Oğuz Hİ, Erdoğan O, Gökdoğan O (2019) Energy use efficiency and economic analysis of nectarine (Prunus persica var. nucipersica) production: a case study from Niğde province. Erwerbs-Obstbau 61:323–329

Ozalp A, Yilmaz S, Ertekin C, Yilmaz I (2018) Energy analysis and emissions of greenhouse gases of pomegranate production in Antalya province of Turkey. Erwerbs-Obstbau 60(4):321–329

Özbek O, Dokumacı KY, Gökdoğan O (2023) Analysis of energy use efficiency and greenhouse Gaz emissions of lemon (citrus lemon L.) production in Turkey. Erwerbs-Obstbau 65:1705–1712

Ozkan B, Kurklu A, Akcaoz H (2004) An input-output energy analysis in greenhouse vegetable production: a case study for Antalya region of Turkey. Biomass Bioenergy 26:89–95

Pishgar-Komleh SH, Ghahderijani M, Sefeedpari P (2012) Energy consumption and CO2 emissions analysis of potato production based on different farm size levels in Iran. J Clean Prod 33:183–191

Platis DP, Anagnostopoulos CD, Tsaboula A, Μενεξές Γ, Kalburtji KL, Mamolos AP (2019) Energy analysis, and carbon and water footprint for environmentally friendly farming practices in agroecosystems and agroforestry. Sustainability 11(6):1664. https://doi.org/10.3390/su11061664

Qi Y, Liu H, Zhao J (2023) Prediction model and demonstration of regional agricultural carbon emissions based on Isomap–ACO–ET: A case study of Guangdong Province, China. Sci Rep. https://doi.org/10.1038/s41598-023-39996-5

Rafiee S, Avval SHM, Mohammadi A (2010) Modeling and sensitivity analysis of energy inputs for apple production in Iran. Energy 35(8):3301–3306

Saidivaliyeva B (2024) Renewable energy and agriculture: developing a common language for technological integration. Bio Web Conf 105:6006. https://doi.org/10.1051/bioconf/202410506006

Sarkodie SA, Ntiamoah EB, Li D (2019) Panel heterogeneous distribution analysis of trade and modernized agriculture on CO_2 emissions: the role of renewable and fossil fuel energy consumption. Nat Resour Forum 43(3):135–153. https://doi.org/10.1111/1477-8947.12183

Sezer B (2014) Karbon Salınımı ve Toprak Yönetimi. www.tarim.gov.tr/ABOGM/Belgeler.

Singh H, Mishra D, Nahar NM (2002) Energy use pattern in production agriculture of a typical village in arid zone India-part I. Energy Convers Manag 43(16):2275–2286

Strapatsa AV, Nanos GD, Tsatsarelis CA (2006) Energy flow for integrated apple production in Greece. Agric Ecosyst Environ 116(3-4):176–180. https://doi.org/10.1016/j.agee.2006.02.003

Suwan C, Somjai T (2022) Carbon footprint analysis of the cultivated banana cultivation in Prachinburi Province, Thailand. In: Research, Invention and Innovation Congress https://doi.org/10.1051/e3sconf/202235502002

Taghavifar H, Mardani A (2015) Prognostication of energy consumption and greenhouse gas emissions analysis of apple production in West Azerbayjan in Iran using artificial neural network. J Clean Prod 87:159–167

Turkstat (2024) Turkish Statistical Institute, crop production statistics. www.tuik.gov.tr

Yılmaz A, Bayav A (2023) Determination of energy efficiency in almond production according to variety: a case study in Turkey. Erwerbs-Obstbau 65:971–979. https://doi.org/10.1007/s10341-022-00728-0