frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 28 September 2023
DOI 10.3389/fenvs.2023.1186328

OPEN ACCESS

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RECEIVED 14 March 2023
ACCEPTED 13 September 2023
PUBLISHED 28 September 2023

CITATION
Abbas A, Mushtaq Z, Ikram A, Yousaf K and Zhao C (2023), Assessing the factors of economic and environmental inefficiency of sunflower production in Pakistan: an epsilon-based measure model.
Front. Environ. Sci. 11:1186328.
doi: 10.3389/fenvs.2023.1186328

Assessing the factors of economic and environmental inefficiency of sunflower production in Pakistan: an epsilon-based measure model

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Considering the growing pressure of the edible oil imports bill on Pakistan's national accounts, the significance of sunflower cultivation is gaining more attention to meet the domestic edible oil demand. Given the declining area for sunflower production, this study explored the factors of economic and environmental inefficiencies affecting sunflower growers in Pakistan. The study adopted the epsilon-based measure (EBM) model at the first stage and the Tobit truncated regression model at the second stage to precisely estimate the economic and environmental inefficiencies in the data collected from 240 sunflower growers. Results found that out of 240, 69.9% of the sunflower growers are economically inefficient, while the average environmental inefficiency of sunflower growers is 56.3%. The findings further revealed that farmers' age, cultivated land, and market distance are the driving factors of farmers' economic and environmental inefficiencies. However, formal education, farming experience, and access to agricultural extension services decreased the farmer's inefficiencies. Based on the present study's findings, diverse policy options are presented to address the problem of contraction of the area under sunflower production.

KEYWORDS

epsilon-based measure, influencing factors, economic inefficiency, environmental inefficiency, sunflower production

1 Introduction

Edible oil is an essential part of food in Pakistan, and to meet the increasing demand for edible oil, the country is forced to import it from the international market (Khan et al., 2021). Consequently, Pakistan pays a significant portion of its foreign exchange reserves to purchase edible oil due to the inadequate indigenous production of oil seeds (Raza et al., 2023). Therefore, improving the local oil seed crop production is imperative to save foreign exchange and address the country's bleak economic situation. Being a non-traditional oil seed, sunflower is considered superior to other oil seed crops due to its high oil content and natural compatibility with the agronomic environment of Pakistan (Javed et al., 2003). Thus, the expansion of sunflower cultivation can reduce the edible oil demand and supply gap in Pakistan. Moreover, keeping in view of the sunflower crop's pervasive forward and backward linkages, it possesses a prominent status in rural development. Accordingly, sunflower production growth has the potential for rural development and assures the country's economic growth. Although large-scale sunflower cultivation was introduced in the early 1970s, the area under sunflower production remained inconsistent due to various socioeconomic factors. Therefore, it is crucial to assess the factors that affect the economic and environmental inefficiencies of sunflower production systems.

Agriculture is the second largest source of nitrogen emissions after the fossil fuel industry (Kholod et al., 2020). The greenhouse gas (GHG) emission reductions associated with agricultural production caused by fertilizer applications and soil nitrous oxides are gaining significant attention from scholars across the globe (Asgharipour et al., 2016; Yue et al., 2017; Elahi et al., 2019; Lamb et al., 2021). Agriculture in Pakistan is vulnerable to climate change because of GHG emissions (Waseem et al., 2022). Therefore, sunflower cultivation is an effective technique to produce oil seeds with low GHG emissions compared to other crops (Figure 1).

Many scholars studied sunflower cultivation in Pakistan because of the importance of sunflower production. For instance, Javed et al. (2003) studied factors affecting sunflower production in Pakistan. Tabassum et al. (2020) summarized the adoption of a hybrid sunflower program in Pakistan. Shah et al. (2013) found the potential of sunflower production to increase indigenous edible oil production. Nasim et al. (2016) assessed the impact of climate change on sunflower production and its adoption in Pakistan. However, these studies have few limitations. First, the economic and environmental inefficiencies of sunflower growers were not determined. Second, and perhaps most importantly, previous literature did not consider the influencing factors of economic and environmental inefficiencies of sunflower growers to assess the constraints in sunflower production. Therefore, to fill the gap in the existing studies, it is imperative to find the factors contributing to economic and environmental inefficiencies in sunflower production in Pakistan.

The four features of the present study that contribute to existing literature are as follows: first, considering the fluctuating area under sunflower cultivation, the primary aim of the present research is to estimate economic and environmental inefficiencies of sunflower growers. The second contribution of the present study is to explore the factors contributing to economic and environmental inefficiencies in sunflower production and evaluate the main hindrances to sunflower cultivation. Adoption of a more sophisticated approach known as the epsilon-based measure (EBM) model to precisely measure the economic and environmental inefficiencies of sunflower growers is the third contribution. Fourth, after precisely calculating the farmer's inefficiencies, the current study also adopted a second-stage regression analysis by applying the Tobit truncated regression model to evaluate the factors contributing to economic and environmental inefficiencies in sunflower production. The present study also suggests viable policy options to address Pakistan's shrinking area under sunflower production.

The remainder of this article is structured as follows: Section 2 briefly presents the relevant literature to explain the research gap and discusses the significance of the selected models. Section 3 explains the selected mathematical and econometric models, along with data and variables. Section 4 is designated for the results and discussion, followed by conclusion and policy recommendation in Section 5.

2 Literature review

Sunflower, with its comparatively low greenhouse gas emissions, high drought tolerance, and high edible oil content, is one of the most important crops to tackle the problem of food security and environmentally friendly agriculture. Therefore, considering the importance of the sunflower crop to the livelihood of millions of people around the globe, agriculture economists have carried out several research studies in different parts of the world, keeping in view different research objectives. For instance, Towo and Mugisha (2013) explored the sunflower growers' technological adoption in Uganda. Based on the qualitative and quantitative data, author revealed that male sunflower growers were more proactive in adopting advanced sunflower technologies compared to female farmers in the northern parts of Uganda. Similarly, Oguz and

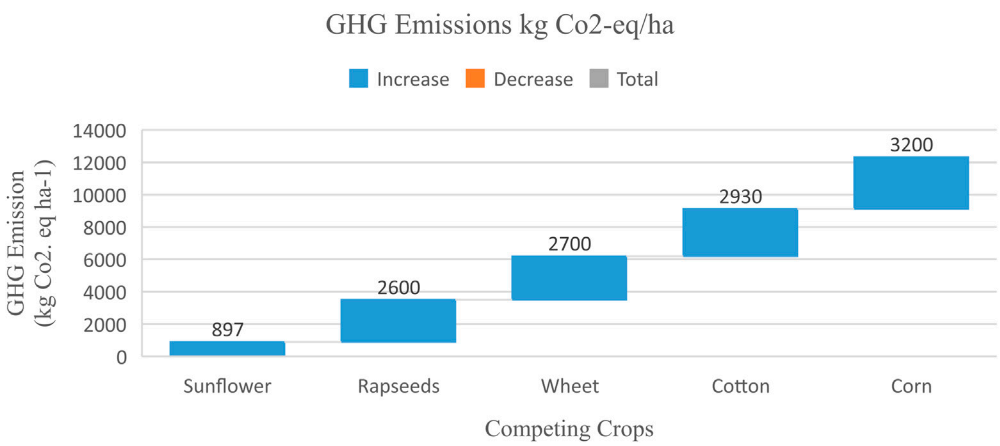

FIGURE 1
GHG emissions from competing crops.

Yener Ogur (2022) evaluated the production and energy efficiency of sunflower cultivation in Turkey and found that only one-third of the sunflower enterprises involved in the sunflower business were found to be energy-efficient in the production process, while two-thirds of the respondents were found to be energy-inefficient. The author suggested that improving the energy efficiency of the sunflower farmers would have a positive impact on economic efficiency. In another study, Mousavi Avval et al. (2011) explored the energy efficiency of sunflower enterprises and found that sunflower production can be more energy-efficient with the adoption of hybrid seeds and advanced sowing techniques. Similarly, other researchers studied the efficiency of sunflower production in different regions of the world; for example, Unakıtan and Aydın (2018) compared the economic and energy efficiency of sunflower and wheat growers in Turkey. Vorobyov et al. (2021) estimated the economic and ecological efficiencies of sunflower production in Russia. Kondratyuk (2015) calculated the production efficiency of sunflower growers considering the area under sunflower cultivation and soil fertilization. Kuts and Makarchuk (2021) estimated the economic viability of sunflower seeds in Ukraine.

Historically, the cultivation of the sunflower crop in Pakistan followed inconsistent adoption behavior due to a lack of quality seeds, fertilizers, financial hindrances, and, most importantly, a lack of cultivation information. Therefore, to suggest suitable policies, few studies have been carried out in Pakistan, keeping in mind the specific research objectives. For example, Joyo et al. (2016) carried out a research study in Sindh Province of Pakistan and evaluated the economic analysis of sunflower production and found that a large number of sunflower growers in the research zone do not have appropriate knowledge of recommended sunflower seed and variety. Shah et al. (2013) carried out a study to suggest policies to improve the production of sunflower and increase the area under sunflower cultivation in Dera Ghazi Khan (D. G. Khan) District of Punjab Province of Pakistan. The author found that approximately 80% of the farmers were sowing imported hybrid seeds, which were expensive, and it was suggested that the government introduces locally produced varieties that should be genetically modified according to the local environment and be economical. Awais et al. (2018) estimated the impact of climate change on sunflower adoption technologies in Pakistan. The findings of the research suggest that earlier and denser plantation of sunflowers can reduce the risk of production losses. Moreover, the study also suggested that as the sunflower crop is drought-resistant, skipping the second irrigation may lead to an increase in production per acre in the research zone. Sethar (2015) carried out research in Sindh Province of Pakistan to explore the comparative economic analysis of hybrid and conventional sunflower production. Although there are plenty of studies that have been carried out in different parts of the world, including Pakistan (Mandal et al., 2015; Singh et al., 2019; Abbas et al., 2021; Mushtaq et al., 2021; Wu and Ding, 2021), these studies have limitations. For example, the studies previously cited did not estimate the economic and environmental efficiency of sunflower production. Moreover, to the best of our knowledge, none of the studies explored the influencing factors of economic and technical inefficiencies in sunflower production in Punjab Province of Pakistan. Therefore, considering the area under sunflower cultivation, it was imperative to estimate the economic and environmental efficiencies, considering the GHG emissions in the analysis. Moreover, influencing factors of economic and environmental inefficiencies in sunflower production in Pakistan were explored using the epsilon-based measure model and the Tobit regression model.

There are two categories of economic and environmental efficiency calculations: single factor and total factor. The single-factor method is simpler, considering a single input with one desired output, and this technique is commonly used in various studies. However, it has a disadvantage as it does not consider the substitution effect among other inputs. As a result, the results obtained through this method may be spurious and biased. Therefore, to address these notable estimation limitations, Hu and Wang (2006) introduced the concept of total-factor efficiency. In contrast to single-factor efficiency estimations, the total-factor approach is a more refined and accurate method as it considers all inputs and outputs, including substitution effects, resulting in a comprehensive analysis of economic and environmental efficiencies. While the single-factor approach has its usefulness in certain situations, the total-factor approach is generally considered a more reliable method for economic and environmental efficiency estimation. Moreover, the total-factor energy efficiency can be determined using a parametric model, such as stochastic frontier analysis, or a non-parametric model, such as data envelopment analysis (DEA). The DEA model is a preferred method as it does not require any assumptions before analyzing the data, making it widely applicable in efficiency measurement across various fields (Wei et al., 2020; Mushtaq et al., 2021).

However, it is noteworthy that the traditional DEA models are prone to underestimating undesirable outputs, which can lead to biased and inconsistent results (Abbas et al., 2020). They operate under the assumption that all inputs, including both desirable and undesirable outputs, should be minimized to maximize overall efficiency. To ensure accurate economic and environmental efficiency measurements, Abbas et al. (2022a) recommended minimizing inputs while maximizing desirable outputs and simultaneously reducing undesirable outputs. In addition to that, the traditional DEA models employ radial or non-radial models, and their calculations may not always be entirely reliable due to the loss of critical information. The EBM model proposed by Tone and Tsutsui (2010) has emerged as a promising approach for measuring environmental efficiency. Unlike traditional methods that assume a fixed radial or non-radial direction for measuring efficiency, the EBM model allows for the possibility of measuring efficiency in both directions simultaneously. This feature provides a more flexible and accurate method of estimating environmental efficiency, which is particularly important in cases where the production process is complex and multifaceted. The EBM model has emerged as a promising approach for measuring environmental efficiency, and its benefits have been demonstrated in several recent studies. For example, Mushtaq et al. (2022) and Yang et al. (2018) adopted the EBM model to assess environmental efficiency in different fields. Thus, keeping in view the aforementioned advantages of the EBM model application, the study aims to provide a more accurate and comprehensive assessment of energy efficiency in the selected context.

Furthermore, the present study also explores the influencing factors of environmental and economic inefficiencies in sunflower production in Punjab Province of Pakistan. Although different types of mathematical or econometric models can be applied to explore

FIGURE 2
Sunflower's sampling selection zone.

the influencing factors of economic and environmental inefficiencies in sunflower production in Pakistan, it is noteworthy that the environmental and economic efficiency scores lie between 0 and 1, which makes them limited dependent variables. Therefore, adopting simple OLS, Cobb–Douglas model, or other models may lead to spurious outcomes. However, from the present literature, it is evident that the Tobit models can be more reliable in the case of the limited nature of the dependent variable to explore the factors of economic and environmental inefficiencies. Many studies applied the Tobit model to explore the factors of efficiencies or inefficiencies in different fields in different regions of the world. For instance, Wei et al. (2020) applied the Tobit model to explore factors influencing efficiencies in cotton production in Pakistan. In another study, the Tobit regression was applied to explore the factors contributing to coal consumption inefficiencies in the energy-intensive industries of China. Similarly, Liu and Lin (2018) and Ma et al. (2018) also applied the Tobit regression model to evaluate the influencing factors of efficiency in China. Thus, based on the nature of the dependent variable and the advantages of the Tobit regression model, the present study will also apply the Tobit regression model to explore the factors contributing to economic and environmental inefficiencies in sunflower production in Pakistan.

From the aforementioned discussion, it is concluded that the present research on sunflower production is very limited to Pakistan, and none of the studies estimated the economic and environmental efficiencies in Pakistan; moreover, no study was found to explore the factors contributing to the economic and environmental inefficiencies of sunflower growers. Therefore, to overcome the limitations in the existing literature, the present study, at its first stage, will estimate the economic and environmental inefficiencies in sunflower production using a more sophisticated epsilon-based measure model. Furthermore, the study is unique in that it explores the factors of economic and environmental inefficiencies applying the Tobit regression model to suggest precise policy options to help policymakers and farmers increase sunflower cultivation to meet growing edible oil demand at local levels.

3 Materials and methods

3.1 Research zone

Sunflower cultivation is a source of livelihood for many people, from cultivation to the production of edible oil. Although the sunflower crop is cultivated across different climate zones in Pakistan, southern parts, mainly Sindh and South Punjab, are considered more suitable for the sunflower crop. Therefore, considering the area under sunflower cultivation, the present study was carried out in the four sunflower-producing districts of South Punjab: D. G. Khan, Layyah, Muzaffargarh, and Rajanpur. Figure 2 depicts the research zone for sample selection.

3.2 Sampling technique

The multistage random sampling technique was applied to collect the primary data from 240 farmers cultivating sunflowers. In the first step, Punjab Province was selected, considering the area under sunflower cultivation. In the second step, using the random sampling technique, Layyah, Muzaffargarh, Rajanpur, and D. G. Khan districts were selected from Punjab Province. In the following step, one tehsil from each district was randomly selected, e.g., Tehsil Dera Ghazi Khan, from D. G. Khan District; Tehsil Lal Esan represented Layyah District; and Tehsil Kot Addu and Rajanpur represented Muzaffargarh and Rajanpur districts, respectively. Later, we selected three union councils from each selected tehsil, and one village from each selected tehsil was randomly selected. In the third step, 18–22 sunflower growers were chosen from the selected villages of each union council from these districts, depending on the respondents' availability. Prior to full-scale data collection, a pretest survey was also conducted to test the instrument's compatibility and the selected region's scope. Table 1 presents a brief summary of the sample selection zone.

3.3 Epsilon-based measure model

The EBM method, derived from DEA, was adopted to assess the environmental and economic efficiency of sunflower growers in Pakistan. DEA is a renowned, non-parametric method that measures the decision-making units' (DMU's)efficiency (Mushtaq et al., 2021). Additionally, by drawing a production frontier between inputs and outputs to assess the effectiveness of numerous inputs and outputs, DEA does not necessitate presumptions (Singh et al., 2019). However, the standard DEA model has a common shortcoming: it cannot precisely evaluate environmental efficiency when there is more than one decision-making unit on the production frontier, which may impair the integrity of the empirical findings (Mushtaq et al., 2022).

Therefore, to address the limitations in the basic DEA methods, the current study employed the input-oriented epsilon-based measure method to estimate the environmental and economic efficiency of sunflower growers in Pakistan. The EBM model is preferred over slacked-based models and CCR, as this model equally deals with radial and non-radial models. Moreover, the EBM model also considers the radial ratio of the besieged inputs compared to the

TABLE 1 Layout of random sample selection of sunflower farmers.

Province	District	Tehsil	Union council	Village	Sample	Total sample
Punjab	D. G. Khan	D. G. Khan	Wadore	1	20	240
			Samina	2	19	
			Nawan	3	21	
	Layyah	Karor Lal Esan	Chak # 98/ML	1	20	
			Chak # 90/ML	2	22	
			Samtia	3	18	
	Muzaffargarh	Kot Addu	Sanawan	1	19	
			Chak # 547/TDA	2	19	
			Budh	3	22	
	Rajanpur	Rajanpur	Piroo Wala	1	22	
			Jahanpur	2	18	
			Noorpur	3	20	

*Authors' own tabulations.

actual inputs in addition to the non-radial slacks with other inputs in the sample (Liu et al., 2017). Equation 1 represents the transition from radial to non-radial as a result of input variance.

$$\delta^* = min\,\vartheta_{\vartheta,\rho,S} - \epsilon_X \sum_{k=1}^{m} \frac{v_k^- s_k^-}{x_{k0}} Subject\ to \begin{cases} \sum_{i=1}^{n} X_i\ \rho_i + S^- = \delta X_0, \\ \sum_{i=1}^{n} Y_i\ \rho_i \geq Y_0, \\ S^- \geq 0, \\ \rho_i \geq 0, \end{cases} \tag{1}$$

where δ represents the radial efficiency value of DEA contact return to scale of the decision-making unit 0 given in subscript. v_k and s_k^- represent the weight and the slack vector of the kth non-radial input, respectively. The parameter determines the dispersion of inputs ϵ_X. ρ_k indicates the weight vector and range of the efficiency value between 0 and 1. The decision-making unit is considered efficient if the obtained efficiency score equals one. This implies that DMU lies on the production frontier, while DMU is considered inefficient if the efficiency score is less than one. Furthermore, the EBM input orientation can be mathematically expressed, as shown in Eq. 2, if $x_k = \vartheta x_{k0} - S_k^-$.

$$\delta^* = mini_{\vartheta,x,\rho,S}\,(1 - \epsilon_X)\vartheta + \epsilon_X \sum_{k=1}^{m} \frac{v_k^- s_k^-}{x_{k0}} Subject\ to \begin{cases} x_k - \sum_{i=1}^{n} X_i\ \rho_i = 0, \\ \sum_{i=1}^{n} Y_i\ \rho_i \geq Y_0, \\ S^- \geq 0, \\ \rho_i \geq 0. \end{cases} \tag{2}$$

3.4 Tobit truncated regression analysis

The sunflower growers' economic and environmental inefficiency scores are influenced not only by the weight of inputs applied and obtained outputs but also by external factors. Therefore, many researchers applied regression in the second stage of the analysis to find the inefficiency factors in different fields. For instance, Wei et al. (2020) applied Tobit regression in the second stage, to assess and explore the factors affecting the production efficiency of cotton growers. Abbas et al. (2022a) used the Cobb–Douglas production function in the second stage to find the factors affecting the production efficiency of cash and grain crops. Bonfiglio et al. (2017) measured the efficiency of arable farms and applied regression in the second stage to evaluate the influencing factors for efficiency. Therefore, following the existing literature, the present study also conducted a second-stage regression analysis to find the influencing factors of economic and environmental inefficiencies of the sunflower growers in Pakistan.

The present study took the inefficiency score gained through the EBM model as the dependent variable that lies between 0 and 1, making the dependent variable the limited variable. Tobin (1956) introduced the Tobit regression model to address the limited value problem of the dependent variable. Ma et al. (2018) believed that the use of tailed regression may lead to inconsistent and biased estimations. Thus, to overcome the limitations of these models, the present study used Tobit truncated regression analysis to find the factors contributing to economic and environmental inefficiencies of sunflower growers in Pakistan. The Tobit regression model can be mathematically expressed as given in Eq. 3:

$$Y = \begin{cases} Y^* = \alpha + \beta X + \epsilon & Y^* > 0, \\ 0, & Y^* \leq 0, \end{cases} \tag{3}$$

where X represents the vector of the independent variable. Inefficiency score is a dependent variable indicated by the symbol Y. While α and β represent intercept and regression parameters, respectively, ϵ is an error term, such that $\varepsilon \sim N(0, \sigma^2)$.

TABLE 2 Descriptive statistics of the variables used in the EBM model.

Variable	Unit	Mean	Maximum	Minimum	Standard deviation
Economic output	kg	2,124.25	2,272.42	1,976.29	148.07
GHG emissions	kg eq. CO_2	897.60	961.78	799.50	81.73
Seed	kg	5.69	2.50	1.50	2.19
Human workers	Hours	30.00	35.00	29.00	3.21
Machine hours	Hours	12.35	6.00	3.50	4.56
Irrigations	No.	6.00	9.00	4.00	2.52
Fertilizers	kg	197.60	210.00	60.00	83.25
Insect/pest chemicals	Liters	9.78	11.25	2.50	4.69
Costs and revenue					
Revenue	PKR	34,519.63	369,240.63	321,147.13	1,102.83
Land rent	PKR	88,920.00	98,800.00	83,980.00	2,258.23
Labor wages	PKR	11,090.00	13,575.00	9,550.00	2,030.90
Land preparation	PKR	18,500.00	20,550.00	14,800.00	2,914.19
Seed cost	PKR	10,000.00	15,000.00	7,500.00	2,108.35
Irrigation charges	PKR	12,356.00	15,648.00	7,410.00	4,146.58
Cost of fertilizers	PKR	15,500.00	20,000.00	0.00	2,104.53
Cost of chemicals	PKR	4,250.00	6,900.00	800.00	145.68

*Authors own tabulations.

4 Results and discussions

4.1 Descriptive statistics of the variables used in the EBM model

Table 2 presents a description of the input and output variables to evaluate the economic and environmental inefficiencies of the sunflower growers in Pakistan. The current paper considered six variables as inputs: seed rate, human workers, machine hours, fertilizers, number of irrigations, and pest/insect control chemicals. On the other hand, two variables were taken as outputs: economic output in the form of farm yield and greenhouse gas emissions, which were taken as undesirable outputs to assess the environmental efficiency of the sunflower farmers.

The greenhouse gas emissions reported in Table 2 are calculated using the mean inputs used for sunflower production. The GHG emission in sunflower production was 897.35 kg CO_2 ha^{-1}. Furthermore, Table 3 shows that nitrogen fertilizer contributed most to GHG emissions with a share of 70%, followed by potassium and fuel with 25% and 15% for sunflower production, respectively.

4.2 Economic and environmental inefficiencies in sunflower production

Table 4 shows the results obtained through the epsilon-based measure model, as presented in the second chapter of this study. The findings in Table 4 depict that, on average, 69.9% of sunflower farmers are economically inefficient, and these farmers can become efficient with similar technology and without compromising the economic output. Moreover, findings also revealed that only 8.75% of the farmers are economically less than 1% inefficient, while approximately 36% are more than 50% economically inefficient. The economic inefficiency of the sunflower growers causes a negative impact on the expansion of sunflower production in the region. Therefore, it is indispensable to find the factors contributing to economic inefficiency to address the problem of sunflower cultivation growth.

Furthermore, the results in Table 4 indicate that the average environmental inefficiency of sunflower growers is 56.3%, which reveals that most sunflower growers are highly environmentally inefficient. Moreover, 42 percent of the sunflower growers have less than 50% efficiency. The findings also revealed that only 6.25% of farmers in the sample were less than 10% inefficient, indicating that a farmer's environmental inefficiency can be reduced without compromising the economic output. Thus, it is important to find the factors contributing to environmental and economic inefficiencies in sunflower production to attract farmers to grow sunflowers in Pakistan. The findings in Table 4 are comparable with the results of the study conducted by Yousefi et al. (2017), who estimated the economic efficiency of sunflower growers in Iran.

4.3 Factors contributing to economic and environmental inefficiencies in sunflower production

Keeping in view the high average economic and environmental inefficiency scores of the sunflower growers, it

TABLE 3 GHG calculation for sunflower production.

Input	Average input (ha^{-1})	GHG emission ($Unit^{-1}$)	GHG emissions equivalents (kg CO_2 ha^{-1})
Nitrogen fertilizer (N) (kg)	120	5.27	632.4
Potassium (K) (kg)	39.5	0.57	22.51
Phosphorus (P) (kg)	37.5	0.572	21.45
Seeds (Kg)	5.69	2.025	11.52
Chemical pesticides (L)	9.7	7.7	74.69
Fuels (L)	439	0.307	134.77
Total			897.35

Authors own tabulations.

TABLE 4 Economic and environmental inefficiencies in sunflower production.

Efficiency range	Economic inefficiency		Environmental inefficiency	
	N	%	N	%
EI ≤ 0.1	21	8.75	15	6.25
0.1 < EI ≤ 0.2	24	10.00	19	7.92
0.2 < EI ≤ 0.3	63	26.25	59	24.58
0.3 < EI ≤ 0.4	42	17.50	47	19.58
0.4 < EI ≤ 0.5	59	24.58	61	25.42
EI > 0.5	31	12.92	39	16.25
Mean	69.9		56.3	
Total	240	100	240	100

EI, economic and environmental inefficiencies.

is vital to find the influencing factors of economic and environmental inefficiencies of the sunflower growers in Pakistan. Thus, at the second stage, the present study applied the Tobit regression model, as discussed previously, to find the influencing factors of economic and environmental inefficiencies in sunflower production. The results in Table 5 revealed that formal education, experience, labor productivity, farm machinery, and access to extension services had helped the farmer reduce economic and environmental inefficiencies. On the other hand, the area of cultivated land, farmer age, and market distance had accelerated the economic and environmental inefficiencies of the sunflower growers. The findings suggested that labor productivity had a regression coefficient of −0.035, which implies that 3.5% of the economic inefficiency of the sunflower growers can be reduced by improving 1% of the labor productivity. Furthermore, the formal education coefficient for environmental inefficiency is −0.15, which suggests that 1 year of additional formal education leads to a 15% decrease in environmental inefficiency. Therefore, it is important to improve labor productivity by providing technical education and strengthening sunflower cultivation skills. The results in Table 5 are in line with the findings of the study by Jariko et al. (2011), who found that areas under sunflower cultivation and formal education significantly caused an impact on sunflower production in Sindh Province of Pakistan. Javed et al. (2003) also suggested that proper formal education and skills increased sunflower production in Pakistan.

The findings of the study revealed that most sunflower farmers were economically and environmentally inefficient in their production, which has a negative impact on the expansion of sunflower cultivation in the region. The study also identified the factors contributing to economic and environmental inefficiencies among sunflower growers. The economic inefficiency of sunflower growers can be attributed to several factors, including the excessive use of fertilizers, human labor, and pest/insect control chemicals. These findings are consistent with the literature, as previous studies have also reported that farmers tend to overuse fertilizers and pesticides, resulting in increased production costs and decreased economic efficiency (Singh et al., 2019; Abbas et al., 2020; Mushtaq et al., 2021; Vorobyov et al., 2021). Similarly, the environmental inefficiency of sunflower growers can be attributed to high greenhouse gas emissions, particularly from nitrogen fertilizers. This finding is

TABLE 5 Influencing factors of economic and environmental inefficiencies in sunflower production.

variable	Unit	Economic inefficiency		Environmental inefficiency	
		Coefficient	SD	Coefficient	SD*
Cultivated land	Hectors	0.00081***	0.00061	0.00438***	0.04534
Farmer's age	Years	0.00138**	−0.00815	0.03805**	0.00947
Formal education	Years	−0.00042***	0.00057	−0.15903***	−0.41457
Sunflower-growing experience	Years	−0.00069*	0.00784	−0.09125**	0.00549
Labor productivity	No.	−0.03571**	0.04874	−0.00744***	0.02501
Farm machines	Yes/No	−0.04819	0.00018	0.20189***	0.00815
Access to extension services	Yes/No	−0.00189***	0.00915	−0.07315	0.04935
Credit accessibility	Yes/No	−0.00538***	0.20214	0.05481***	0.07691
Market distance	km	0.0058**	0.00453	0.00069***	0.28913

*, **, and *** represent the level of significance of parameters at 10%, 5%, and 1%, respectively. SD, standard deviation.

consistent with other studies that have reported nitrogen fertilizers being one of the major sources of greenhouse gas emissions in agriculture (Mohammadi et al., 2014; Vetter et al., 2017; Yue et al., 2017; Abbas et al., 2022b). The study found that improving economic and environmental efficiencies among sunflower growers requires the adoption of best practices, such as optimal use of inputs, improved crop management techniques, and reducing the use of chemical fertilizers and pesticides. These findings are consistent with the literature on sustainable agriculture, which emphasizes the importance of adopting best practices to improve economic and environmental performance in agriculture (Elahi et al., 2018; Pellegrini and Fernández, 2018; Singh et al., 2019; Wu and Ding, 2021). In conclusion, the study highlights the economic and environmental inefficiencies of sunflower growers in Pakistan. The findings stress the need for interventions to address these inefficiencies, including policy measures to promote sustainable agricultural practices, technology transfer and training, and access to finance and extension services. The factors identified in this study can serve as a basis for policymakers to design effective interventions to promote sustainable sunflower production in Pakistan.

5 Conclusion and policy implications

Based on the aforementioned findings, it is concluded that sunflower production attains a significant status in bridging the gap between edible oil demand and supply in Pakistan. However, it was important to find the causes of stagnant growth in the area under sunflower production for 40 years after its introduction. Therefore, the present study evaluated the factors contributing to economic and environmental inefficiencies of sunflower growers. In the second stage, we applied a well-designed regression model to find the factors contributing to farmers' inefficiencies in Pakistan.

The study's findings revealed that most of the farmers were economically inefficient and that most of the sunflower growers were operating well below the production frontier. Furthermore, more than 60% of the farmers were less than 50% economically efficient. Moreover, the present study also estimated the environmental inefficiency of the sunflower growers in the region. The result indicated that the farmers' environmental inefficiency score was even worse than the economic inefficiency score. Based on these findings, identifying the influencing factors of these inefficiencies became indispensable; thus, the study applied the Tobit truncated regression model.

Furthermore, inefficiency was increased due to inadequate access to extension services, and many farmers were unfamiliar with sunflower cultivation's production technology. The farmers were unaware of suitable seed varieties for their fields. In addition, sunflower growers were not well informed of the recommended dosage of chemical fertilizers for sunflower cultivation. Therefore, the poor availability of agricultural extension services was one of the main factors contributing to the farmers' economic inefficiencies in the study region. Furthermore, lack of formal education, cultivated land, and farmer's age contributed to the economic and environmental inefficiencies. However, improved labor productivity and advanced farm machinery decreased farmers' inefficiency scores. Thus, based on these findings, this study suggests improving the extension services in the region. The agriculture extension department should introduce special services, including sunflower production technology training, to address the growers' low economic and environmental inefficiencies.

Although the present study suggests feasible policy options to address the inefficiencies in sunflower production, it did not consider the other related crops cultivated in the study area to assess the comparative economic analysis. Therefore, evaluation of the economic trade of sunflower with wheat and maize in South Punjab, Pakistan, is on our agenda for future work.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

Author contributions

All authors contributed significantly to the preparation of this manuscript. Conceptualization, methodology, software, validation, formal analysis, investigation, and writing—original draft preparation, AA and ZM; resources, AA; writing—review and editing, KY, CZ, and AI; supervision, CZ. All authors contributed to the article and approved the submitted version.

Conflict of interest

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

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