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Corn production and processing into ethanol in Turkey: An analysis of the performance of irrigation systems at different altitudes on energy use and production costs

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ABSTRACT

This research aims to assess the energy input and output involved in corn production in the Elazig province of Turkey in different agricultural systems. This study is interested in energy resource allocation to analyze maize production systems since the value of production inputs and outputs is affected by economic crises as well as the country's politico-economic status. The amounts of energy used for production are still very challenging to change. The typical energy usage of the farms examined in this study is 3359,82 MJda^{-1}, 3715,74 MJda^{-1}, 5366,13 MJda^{-1} and 6456,24 MJda^{-1} according to the distance between the water sources and the farms. Of the total mean of energy, 31.06% is direct, 12, 26% is indirect, 14,38% in renewable energy and 42,30% in non-renewable energy. A kilogram of typical maize is thought to require 3,93 MJ of energy in total to produce. Energy used for irrigation makes up most of the input (37.20%), followed by sowing (22.57%) and fertilizer (16.65%). As a result of the benefit-cost ratio analysis is 0.29, the cost of corn production per decare is found to be $112.05/da in the area, with variable costs accounting for 83.17% of the total. The analysis of data reveals that the transformation of 100 kg of corn generates an energy expenditure of 2219.58 MJ and more than 50% of energy expenditure comes from the use of machines.

1. Introduction

Fossil fuel is one of the main resources used in Turkish agriculture. Energy in agriculture is significant since it helped agricultural productivity and the agro-industry to develop. The main energy sources employed in agriculture are labour forces-human, animal, and mechanical [1]. The demand for energy and natural resources is greatly increased by the expansion of trade and production opportunities brought on by fast population growth, industrialization, urbanization, and globalization [2]. Indeed, energy consumption in agriculture increases with the size of the population, the quantities of crops and agricultural land sown as well as the quality of the population's standard of living. Due to these variables, energy inputs have increased, efficiency has increased, and there is a need to speed up production and processing by reducing labor-intensive applications [3].

Worldwide agricultural production has grown quickly in recent years [4]. New seed types and enhanced production inputs were developed to achieve this result [5]. However, there is still work to be done in terms of farm energy management. According to Ref. [6], energy resources are not utilized effectively on farms, even though energy in agriculture presents enormous prospects for rural development and tools to lessen the negative effects of climate change. Mechanized agriculture produces high yields with relatively little labour input, mostly because it has access to a lot of inexpensive fossil energy [7]. Fossil fuel production in agriculture has made it possible to increase farm size and output while simultaneously replacing labour. Fuels, insecticides, fertilizers, and

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irrigation are the primary inputs and energies utilized in agricultural production [8]. Energy does, in fact, play a significant role in the social and economic development of communities. However, there is now a lack of management of the rural energy in agriculture development policy [9]. Direct and indirect energy requirements for agriculture are separated into two categories. In contrast to indirect energy, which is used in the production, packaging, and transportation of fertilizers, pesticides, and agricultural machinery, direct energy is used in the land preparation, irrigation, intercropping, threshing, harvesting, and transportation of agricultural inputs and agricultural products [10]. The Turkish economy depends heavily on the agricultural production sector, particularly the subsector that produces grains.

The grain production sub-sector represents Turkey's largest job provider and actively contributes to the country's GDP, imports and exports [11]. As a result of Turkey's rising energy consumption over the past few years, the issue surrounding the use of energy in Turkish agriculture has gotten worse. Since there is no way to increase the amount of arable land, producers' only option to improve total production if the rise in energy consumption in the agricultural sector continues will be to employ more inputs [12]. Among grains, maize is a top choice because it is utilized for human consumption, animal feed, and industrial food production. Also, because of its nutritional value and socioeconomic significance, maize's relevance is growing yearly. In Turkey, it ranks third in the production of cereals, behind wheat and barley [13]. Turkey's average maize yield in 2020 was between 700 and 1000 kg/decare, compared to the global average of 580 kg/decare [14]. For instance Ref. [15], reported an average total energy input of 51.1 GJ ha-1, a production of 243.9 GJ ha-1, and an average cost total production of $3477 ha-1 for maize cultivation in Iran [16]. stated that each step requires different forms of energy, such as direct energy (e.g., electricity, diesel, and natural gas) and indirect energy (e.g., fertilizer, pesticide, and water). Despite Turkey's yields being far higher than those worldwide for maize, domestic production cannot keep up with demand. Thus, greater energy resource allocation is essential to maximize output rates.

Optimizing the usage of energy sources during the processing of maize is equally crucial to production levels. In fact, some of the maize grown in Turkey is processed as well for a variety of uses. Its transformation into ethanol is one of the most frequent. Pharmaceutical, medicinal, and cosmetic businesses employ corn-based ethanol [17]. A considerable impact on the unit selling price of ethanol as well as on the entire production chain will result from optimizing the use of energy sources during the processing of corn.

The objective of this study is to analyze the performance of irrigation systems at different altitudes on energy consumption and maize production costs in Turkey, specifically in the province of Elazig. The levels of energy usage during the conversion into ethanol were also assessed. To determine the impact of these heights on the levels of energy consumption during the execution of the technical itinerary for maize production, the performance of the irrigation systems was examined at various elevations.

2. Literature review

Several studies have been part of the analysis of the importance (through efficiency, usefulness, etc.) of energy sources and irrigation systems in agriculture through impact studies. For example [18], used eco-exergoenvironmental toxicity indices to assess the impact of irrigation systems in sunflower production. They highlight the need for implementing sustainable practices suitable for sunflower production systems. The study compares different techniques and their potential impacts on the environment, with the aim of providing information on best practices that balance environmental concerns and energy efficiency.

Like maize cultivation, wheat cultivation is also a crucial agricultural activity that plays an important role in the fight against global food insecurity. Several studies have looked at energy consumption and the economic profitability of production systems [19–21]. Life cycle analysis as well as modeling techniques have emerged as valuable tools to assess and predict the impacts of agricultural practices on these critical aspects [22,23]. [24] highlight the importance of life cycle analysis in assessing wheat crop performance and identify key parameters to consider when assessing energy consumption and economic viability of production systems. In their research, the authors present a comprehensive review of the various energy modeling techniques used in wheat production. To this end, they compare different approaches, such as energy flow analysis, energy efficiency ratio and energy intensity, to predict the energy consumption of wheat farms. Life cycle analysis, energy modeling techniques and economic profitability analysis are therefore essential tools for evaluating the performance of production systems in agriculture. Integrated modeling approaches, on the other hand, offer a comprehensive and synergistic means of addressing the complex interrelationships between these different aspects.

Effective and efficient energy management is crucial for the economic development of agricultural value chains [25]. In agriculture, energy is used in various forms, including fuel, electricity and lighting [26]. compared energy consumption in canola production of different farm sizes in Trakya region (Turkey), focusing on energy efficiency, productivity, specific energy, net energy, direct and indirect energy consumption, renewable and non-renewable energy consumption and benefit-cost ratios. This is the same logic as the work of [27] who analyzed the efficiency of the use of inputs with 100 canola producers in the same Turkish region. The results showed that energy efficiency increases with farm size. The study revealed an energy ratio (direct and indirect) of around 25% and a benefit-cost ratio of 2.09 for canola production. These results obtained by Ref. [27] are like those obtained by Ref. [26].

The energy consumption and economic costs of different systems (conventional tunnel system and vertical system equipped with LEDs for the healing and acclimatization of grafted watermelon plants were studied by Ref. [28]. The team conducted experiments and collected data on energy consumption, financial expenditure as well as environmental effects for the two systems during one growing season in Iran [28]. therefore evaluates the energy consumption, economic and environmental impacts of conventional tunnel systems (CTS) and LED-equipped vertical systems (LVS) for watermelon seedlings. The results show that CTS increases energy consumption and is harmful to the environment while LVS is less energy intensive and less harmful to the environment. At the end of the research, these researchers strongly recommend the use of organic fertilizers and a limitation of the pressure put on energy sources to ensure their sustainability. These suggestions are also like those made by Ref. [29].

Several studies like ours have also been conducted in Turkey. Previous research on energy use in the Turkish agricultural sector, such as that of [12,30] then from Ref. [31], provided important information on trends and patterns of energy exploitation in Turkish agriculture. These studies focused on the allocation of production inputs (labour, machinery, electricity, diesel fuel, fertilizers, seeds, etc.). They revealed an increase of about 100% in total energy intake in 1975 and the year 2000; and it is the same for the energy produced over this same time interval. The findings of these studies subsequently raised concerns about the sustainability of agricultural practices and the allocation of energy sources in Turkey. The growing disparity between energy inputs and outputs has suggested a potential link to environmental issues such as global warming and pesticide pollution. The need to optimize energy use and mitigate greenhouse gas emissions became evident considering these results [32]. focused on greenhouse vegetable production in the province of Antalya (Turkey). Their study highlighted the energy-intensive nature of cucumber production, which consumed a substantial amount of energy. This information can help identify levers for energy optimization and improved efficiency of agricultural practices in the region.

Since water is an essential resource for agricultural production, this study focuses on irrigation systems located at various altitudes to analyze the energy consumption levels as well as the costs associated with maize production. The originality of this study (although descriptive) lies in the fact that the reciprocal effect and the synergy between the variables that it highlights have not yet been treated previously. Moreover, very few studies like ours have focused specifically on maize production. However, its production actively contributes to Turkey's agricultural GDP and to ensuring the food security of urban and rural households.

3. Materials and methods

This section presents the survey plan, a description of the variables of the study, then the indicators used to evaluate the economic performance and the energy used for corn production and its transformation process to ethanol.

3.1. Study area

The province of Elazig in Turkey's Kuzova region served as the site of this investigation (Fig. 1). Elazig province, which makes up 1.2% of Turkey's total land area and is situated in the southwest of Eastern Anatolia, has a total area of 9151 km^2. It's situated in the highest part of the Euphrates Valley. The province is bordered to the east by Bingol, to the north by Tunceli (through the Keban Dam Lake), to the west and southwest by Malatya, and to the south by Diyarbakir. The plain that the city is located on is 1067 m (3501 feet) above sea level. The province used to be distinguished for its continental climate, but it has now transitioned to a temperate one. This has led to generally warmer winters, which were previously bitterly cold and covered in significant amounts of snow. The province has a rather moderate climate, according to the local climatic parameters.

3.2. Sampling method and data collection

The current study is a case study that was conducted at the Turkish Ministry of Agriculture's agricultural experimental station in the province of Elazig. The agricultural experimental site in the province of Elazig was chosen because, on the one hand, it is a part of the most significant maize producing regions and, on the other hand, it is a part of those that record the best performances. The engineers and agronomy specialists in charge of overseeing the operation of the experimental site, specifically those involved in the area designated for corn production, were surveyed and provided with a questionnaire to gather the data.

A total of 35 engineers and agronomy experts were investigated. After that, five focus groups were created, each consisting of an average of seven engineers and specialists, to help triangulate the data gathered from the individual interviews. The information gathered was connected to both the production statistics and the technical path taken by the experts in charge of maize production. Data on production altitudes, input quantities and costs, labour costs, the usage of agricultural machinery, fuel, and electricity, as well as harvest amounts and maize selling prices, are among these. The time needed for each agricultural operation, the number of people, the quantity and working time of agricultural machines, and the quantities of inputs used are all factors that go into calculating energy inputs (seeds, fertilizers, pesticides, herbicide and other chemicals). The mechanical energy utilized in the production of maize include those related to the usage of tractors and equipment that is primarily powered by diesel. The energy provided by the fuel used to power the machines was calculated based on their fuel consumption. Calculations were made regarding the electrical energy required to run the irrigation pumps.

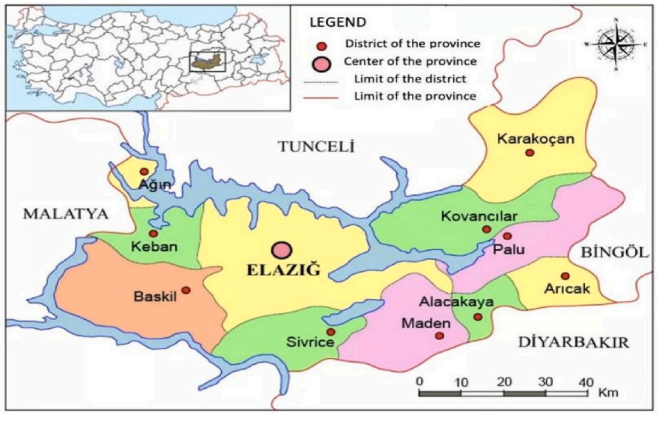


Fig. 1. Map of elazig province.
Source: Adapted from [50].

3.3. Methods and variables

The energy equivalent coefficients were calculated using data from earlier studies. The same strategy has been applied in a similar situation by Refs. [12,30–32]. Table 1 lists these sources as well as the coefficients.

The economic performance indicators were calculated once the energy quantities for each of the agricultural operations were determined. The work of Pishgar-Komleh et al. (2012) served as inspiration for the selection of these indicators. The value of the gross output, the net revenues, and the production's profit-cost ratios were all calculated for this reason. The following equations can be used to write these economic performance indicators:

$$Total\ production\ value = Corn\ yield\ \left(kgda^{-1}\right) \times Corn\ price\ \left(\$kg^{-1}\right) \quad (1)$$

$$Net\ return = Total\ production\ value\ \left(\$ha^{-1}\right) - Total\ production\ cost\ \left(\$ha^{-1}\right) \quad (2)$$

$$Benefit - cost\ ratio = \frac{Net\ return\ \left(\$ha^{-1}\right)}{Total\ production\ cost\ \left(\$ha^{-1}\right)} \quad (3)$$

Given the time and means at our disposal, data related to the production of ethanol from corn were collected from processing companies located in the province of Elazig. Five companies were looked investigated. The data gathered concerned the technical steps involved in turning corn into ethanol, the enzymes employed, and the reaction times.

Table 1
Energy content of inputs for corn production.

Inputs	Unit	Energy equivalent (MJ unit^{-1})	Reference
Human labour	h	1.96	[33–36]
Machinery			
Tractor 50 kW	h	41.4	[37–40]
Plough	h	22.8	[37–40]
Sprayer	h	23.8	[37–40]
Wagon	h	71.3	[37–40]
Pump	h	2.4	[37–40]
Fertilizers			
N	kg	60.60	[34–36,41,42]
P	kg	11.1	[34–36,41,42]
K	kg	6.7	[34–36,41,42]
Insecticides	kg	278	[43–46]
Fungicides	kg	276	[43–47]
Farmayard manure (dry matter)	kg	0.3	[34–36,41,42,48]
Diesel	l	56.31	[34,35,41,42]
Electricity	kWh	11.93	[34,35,41,42]
Water for irrigation	m3	0.63	[33,49]

From earlier study, the coefficients for the energy equivalents of the inputs used in the transformation process were calculated. Table 2 lists these sources as well as the coefficients.

All survey data was entered into Excel 2021 spreadsheets to perform energy calculations and determine economic performance measures. SPSS version 20 was used to provide the descriptive statistics.

4. Results and discussion results

4.1. Corn production and energy use

The production techniques of corn in Elagiz includes, the preparation of soil, seedling, fertilization, seeds selection, field maintenance, harvesting and storage. Among the 400 varieties of corn identified up today, numerous varieties and hybrids are cultivated in Turkey, which are recognized by their grain color (yellow, brown, black, even blue, white and yellow, white, pale yellow and dark yellow) sweet, floury [54]. They are widely used for human foods, animal feeds, industrial application. As indicated in Table 1, this section described the different steps apply in the production of corn.

Seedbed or soil selection and preparation. Corn is extremely demanding on soil, water and heat. In addition, corn can grow well in deep, loose, slightly humid, light, well-drained, fertile soils rich in organic matter, while Sour, salty and waterlogged are reported not to be suitable to produce corn. During soils preparation or Seedbed using tractors and other materials for large production area, trees, branches, plants and herbs are cut to allow enough light for better production yields, facilitate seed germination, plant control, clearing and cleaning of the plot. The plowed soil (depth 15–30 cm) allows the removal of quack grass and any other herbs, which completely crush the clods and loosen the soil in ridges or flat.

Seedling and Seeds selection. The sowing is generally performed at the beginning or at the end of the rain around August–October. The sowing can also be carried out at any time of the year after soil preparation if an irrigation system is installed on corn production field. The crop cycle of corn is estimated at 5–6 months at high altitudes while it is estimated at 3–4 months at low altitudes. Moreover, the crop cycle of corn is also reported varying based on the cultivation practices, soil composition, crop control and regions. Corn is sown at 80 × 50 cm spacings, three grains per hole (depth 3–6 cm) with a density of about 45–50 kg/ha for large seeds size and 15–30 kg/ha for small size seeds. The corn seeds before sowing are treated with a fungicide, insecticide and a repulsive to protect against diseases and attacks by soil insects, pests and predators to obtain excellent germination and optimum density. On sloping soils, the ridges are placed perpendicularly to the slope to well control erosion, while they are oriented downslope on the plains to facilitate irrigation.

Fertilization. The Fertilization of the soils highly depends on the requirements of the different varieties of seeds and the conditions of the growing area or regions. Due to their expensive nature, fertilizers and their spreading should not swallow up a large part of the production cost. The application of fertilizers is useful to obtain good yields and avoid exhausting the soil. Based on the cultivation practices and regions, some farmers or industries use organic manure alone or in combination with mineral fertilization (mineral elements N, P, K) for the development of the crop. During the preparation of the soil and the level of soil fertility, 10–30 tons of well decomposed manure are used to bury at the time of the tillage. Farmers can also apply 100–250 kg/ha of NPKSMg 15-15-15-6-1 fertilizer or complete 20.10.10 or 40.60.30 NPK fertilizer or a mixture 37 kg of urea + 130 kg of DAP + 50 kg of KCl per hectare. Fertilization can also be performed by adding compost, farmyard manure or other animal wastes at the time of plowing, at the rate of 20–50 tones (200–500,100 kg bags) per hectare. Farmers combined the sarclo-hilling 3–4 weeks after sowing with the fertilizer.

Field maintenance and plant control. This step includes the weeding, the insects and pests' management. The first weeding is carried out 15–30 days (at the stage 3–4 leave) after germination by eliminating excess and less vigorous plants to obtain a regular density (1–2 plants per hill after weeding). Regular weeding is performed to obtain a good yield, it is generally done manually or chemically via a selective herbicide. After sowing, before and during de development of corn plants, certain chemical herbicides are used at different dosages per hectare to protect the corn crops against unwanted herbs followed by slight hilling. Thereafter, a second hilling is carried out after 45 days of corn crops development. Different types of biological or chemical fungicides and insecticides prepared at different concentrations per hectare are used by Turkish farmers to treat corn crops against insects, pests and predators. The preventive protection of corn through proper crop maintenance or via the employment of biological or chemical fungicides and insecticides is significantly appropriate. However, it is necessary to ensure the economic profitability and aspects of these treatments.

Corn harvesting and storage. The harvesting of corn is commonly carried out at the time of physiological maturity corresponding to the water content of about 25–35% in grains. Corn cobs are harvested fresh or dried based on the taste and the final uses (human food, animal feeds or industries use). The dry cobs are harvested when the husks of the cobs have turned yellow, and the leaves are dried out. The harvesting is generally performed 70–85 days after sowing for the precocious varieties and 85 to 120 for the tardy varieties. Farmers and research centers reported that the minimum average yield of corn is 0.8–1.5 tons, 2–3 tons, and 4–6 tons in traditional culture, improved culture, and research station, respectively. The grains are dried on racks, and plastic sheets in dryers to significantly mitigate the water content of about 10–12%. The dried corn grains are treated with chemical substances against insects and fungi attacks. Thereafter, the corn grains are put in bags and stored in aerated places for their different industrial (starch, flour, glucose, ethanol, animal feeds) application.

Table 3 shows the energy inputs required for corn production at different altitudes in Turkey. The energy equivalent in MJ per decare for each input, including plowing, sowing, fertilization, hoeing, spraying, irrigation, harvesting, and carrying to market, was calculated. The results indicate that the energy required for corn production increases with increasing altitude. At 30 m altitude, the entire amount of energy needed to produce corn was 3359.82 MJ per decare, while at 75 m, it was 3715.74 MJ per decare. At 75–150 m altitude, the energy requirement increased to 5366.13 MJ per decare, and at 150 m or more, it further increased to 6456.24 MJ per decare.

Baran and Gökdoğan [55] stated that the highest energy input was for irrigation, with the energy required for irrigation at 150 m or more being more than six times highper than at 30 m. This suggests that irrigation is a major contributor to the energy consumption of corn production at higher altitudes. This study examined the energy intake and output related to the production of corn and processing into ethanol in the Elazig province of Turkey. The results showed that the farms under investigation's average energy use in this study is 3359.82 MJda-1, 3715.74 MJda-1, 5366.13 MJda-1 and 6456.24 MJda1 according to the distance between the water sources and the farms. Most of the energy input was nonrenewable energy (42.30%), with the dominant contribution being energy in irrigation (37.20%), followed by sowing (22.57%) and fertilizer (16.65%).

One kilogram of typical corn was produced using an estimated

Table 2
Energy content of inputs for corn processing.

Inputs	Unit	Energy equivalent (MJ unit-1)	Reference
Gasoline	kg	46.9	[51]
Diesel fuel use	l	45.6	[51]
LP gas	kg	50.0	[51]
Electricity	kW	10.97	[6]
Machinery	kg	109	[52]
Enzymes and additives	kg	0.07	[53]

Table 3
Corn production and energy use.

Energy equivalent (MJda-1)					
Input		30 m	75 m	75–150 m	150 m+
Plowing	1	157.73	157.73	157.73	157.73
	2	157.73	157.73	157.73	157.73
	3	157.73	157.73	157.73	157.73
	Total	473.19	473.19	473.19	473.19
Sowing	Machinery Rent + labor	118.78	118.78	118.78	118.78
	Seed	75	75	75	75
	Fertilizer (DAP)	800.7	800.7	800.7	800.7
	Total	994.48	994.48	994.48	994.48
Fertilization	Machinery Rent + labor	79.19	79.19	79.19	79.19
	Fertilizer (NPK)	654.2	654.2	654.2	654.2
	Total	733.39	733.39	733.39	733.39
Hoeing	Machine Rental	105.15	105.15	105.15	105.15
	Labor	0.16	0.16	0.16	0.16
	Total	105.31	105.31	105.31	105.31
Spraying	Machinery Rent + labor	158.37	158.37	158.37	158.37
	Insecticides	63.94	63.94	63.94	63.94
	Total	222.31	222.31	222.31	222.31
Irrigation		593.18	949.10	2599.49	3689.60
Harvest		158.37	158.37	158.37	158.37
Carrying to Market		79.59	79.59	79.59	79.59
Total		**3359.82**	**3715.74**	**5366.13**	**6456.24**
Energy means		**4724.48**			

amount of energy to be 3.93 MJ. The cost of corn production per decade was found to be $112,05/da in the area, with variable costs accounting for 83.17% of total. Given that the variable cost ratio is high, this suggests that extensive corn farms are being operated in the region. In the area, with variable costs accounting for 83.17% of total. Given that the variable cost ratio is high, this suggests that extensive corn farms are being operated in the region. Overall, the findings suggest that there is room for improvement in the efficiency of energy use in corn production and processing into ethanol in the Elazig province of Turkey [56]. Policymakers and farmers can exploit the study's findings to identify areas for improvement in the production process, to reduce energy input and production costs while maintaining or increasing yield. The use of machinery, such as for plowing, sowing, fertilization, hoeing, and spraying, also contributed significantly to the energy requirements for corn production. The energy input for carrying corn to market was the same across all altitudes, indicating that transportation costs do not vary significantly with altitude.

Overall, the results suggest that higher-altitude corn production requires significantly more energy inputs than production at lower altitudes. This is mainly due to the higher energy requirements for irrigation, which is necessary due to the lower availability of water at higher altitudes. The results highlight the importance of efficient irrigation systems and alternative energy sources to reduce energy consumption and production costs in corn production at higher altitudes. The results of the analysis suggest that higher altitude corn production requires more energy input due to increased irrigation needs. This increase in energy input could lead to higher production costs for corn ethanol. However, other factors such as yield, water availability, and market prices should also be considered when evaluating the profitability of corn ethanol production at different altitudes.

Table 4 shows the percentage distribution of energy use for each input in corn production at different altitudes in Turkey. The inputs considered include plowing, sowing, fertilization, hoeing, spraying, irrigation, harvest, and carrying to market.

The results of Table 4 indicate that the highest percentage of energy use is associated with irrigation, accounting for 37.20% of the total energy use on average across all altitudes. Similarly, by Ref. [15]. This is followed by sowing (22.57%) and fertilization (16.65%). The other

Table 4
Corn production Energies Equivalent (MJda-1).

Energy equivalent (MJda-1) (%)					
Input	30 m	75 m	75–150 m	150 m+	Mean
Plowing	14.08	12.73	8.82	7.33	10.74
Sowing	29.60	26.76	18.53	15.40	22.57
Fertilization	21.83	19.74	13.67	11.36	16.65
Hoeing	3.13	2.83	1.96	1.63	2.39
Spraying	6.62	5.98	4.14	3.44	5.05
Irrigation	17.66	25.54	48.44	57.15	37.20
Harvest	4.71	4.26	2.95	2.45	3.60
Carrying to Market	2.37	2.14	1.48	1.23	1.81
Total	100.00	100.00	100.00	100.00	100.00

inputs, including plowing, hoeing, spraying, harvest, and carrying to market, account for less than 10% each of the total energy use on average across all altitudes. These results contradict the conclusions of the research by Ref. [31] according to which the energy expenditure related to the use of seeds and water used for irrigation are quite low compared to other production inputs. According to Ref. [57] that the energy consumption of machines in small farms is higher. Interestingly, the percentage distribution of energy use varies with altitude. At higher altitudes, irrigation accounts for a larger percentage of energy use, while the energy use associated with sowing and fertilization decreases. This suggests that irrigation is the primary energy-intensive process that varies with altitude in corn production.

The mean energy input for corn production is 4724.48 MJ/da. One kilogram of typical corn is produced with an estimated total energy input of to be 3.93 MJ. This indicates that corn production requires a significant amount of energy input, particularly in the practice of irrigation.

4.2. Renewable and non-renewable energy

The total mean energy input of 4724.48 MJ/da, 31.06% is direct energy, 12.26% is indirect energy, 14.38% is from renewable energy sources, and 42.30% is from non-renewable energy sources. According to Ref. [32], the share of direct input energy was 42.5% of the total energy input with 57.5% for the indirect energy. In addition, not similar results by Ref. [32] an average the direct energy input remained at 15.15% of the total energy input compared to 84.59% indirect energy. Energy sources that are sufficiently quickly regenerated by natural processes are referred to as renewable energy sources. So long as the amount taken out per unit of time is not too high, they can be utilized by humans for a relatively long time. On the other side, energy sources that are scarce on Earth are referred to as nonrenewable energy sources. Human work, farmyard manure, and seeds are examples of renewable energy, while machinery, diesel fuel, chemical fertilizers, biocides, and irrigation water are examples of non-renewable energy (due to the use of electricity or diesel fuel to pump the water).

The results show that the use of non-renewable energy sources is significant in corn production, which has important implications for the environmental sustainability of this sector. Efforts to increase the use of renewable energy sources, such as wind and solar, in corn production could help to reduce the sector's reliance on non-renewable energy sources and improve its sustainability.

Table 5 provides information on the different energy forms used in corn production at different altitudes in Turkey. The table shows the amount of energy used for each energy form in megajoules per day per hectare (MJda-1) and the percentage of total energy use for each altitude. The results indicate that direct energy is the largest source of energy consumption in corn production at all altitudes, accounting for 31.06% of total energy use on average. This includes the energy used for plowing, sowing, fertilization, hoeing, spraying, harvesting, and carrying to the market. Non-renewable energy sources are the largest contributor to direct energy use, accounting for 42.3% of total energy

Table 5
Energy forms used in corn production.

Energy forms	30 m		75 m		75–150 m		150 m+		Mean
	MJda-1	%	MJda-1	%	MJda-1	%	MJda-1	%	
Direct energy	742.94	22.11	1084.43	29.18	1875.12	34.94	2454.19	38.01	31.06
Indirect energy	539.95	16.07	539.95	14.53	539.95	10.06	539.95	8.36	12.26
Renewable energy	633.56	18.86	633.56	17.05	633.56	11.81	633.06	9.81	14.38
Non-renewable energy	1443.37	42.96	1457.8	39.23	2317.50	43.19	2829.04	43.82	42.30
Total	3359.82	100.00	3715.74	100.00	5366.13	100.00	6456.24	100.00	100.00

use on average. Direct energy accounted for 31.06%, while renewable and indirect energies accounted for 14.38% and 12.26%, respectively. The mean energy required for corn production was 4799.48 MJ/ha, of which 2032.71 MJ/ha (42.3%) was from non-renewable energy sources.

Indirect energy, which includes the energy used to produce inputs such as fertilizers and machinery, accounts for 12.26% of total energy use on average. Renewable energy includes biomass, wind, and solar, while non-renewable energy includes coal, oil, and gas [59]. Renewable energy, such as biomass and solar energy, accounts for 14.38% of total energy use on average, while non-renewable energy sources, such as fossil fuels, account for 42.30% of total energy use on average. Overall, the results suggest that corn production in Turkey relies heavily on non-renewable energy sources and that efforts should be made to reduce the use of these sources and increase the use of renewable energy sources. Additionally, optimizing the use of direct and indirect energy in corn production could help to reduce energy costs and increase efficiency.

4.3. Cost analysis

The cost analysis shows that the cost of corn production per decare is $112,05 in the Elazig province of Turkey, with 83.17% of this being variable costs. The BCR is 0.28, indicating that for every unit of currency invested, the return is only 0.28 units of currency. This suggests that corn production is not very profitable in the region, and that farmers may need to explore alternative crops or more efficient production methods to increase profitability.

The cost analysis (Table 6) shows the input cost for each activity in dollar (USD) per decare for different planting distances. The total input cost includes the cost of plowing, sowing, fertilization, hoeing, spraying, irrigation, harvesting, carrying to market, other expenses, general administration expenses, and field rent. The highest input cost is observed in the 150 m + planting distance, with a total cost of $122,22/da, while the lowest input cost is observed in the 30 m planting distance, with a total cost of $98,02/da. This difference is mainly due to the higher cost of irrigation, which is necessary for the larger planting distances.

The cost of inputs for plowing, sowing, fertilization, hoeing, and spraying is almost the same for all planting distances. However, the cost of irrigation increases significantly with the increase in planting distance, as larger distances require more water for irrigation. Other expenses, general administration expenses, and field rent are also higher for larger planting distances. These expenses are related to the management of the farm and the use of the land, which increase as the planting distance increases. Overall, the cost analysis shows that the input cost per hectare increases with the increase in planting distance, mainly due to the higher cost of irrigation. However, the total cost of production should also consider the yield and energy use, as well as other economic factors such as market prices and subsidies.

Table 7 shows the cost analysis and benefit-cost ratio for corn production at different fields altitudes. The yield is assumed to be 1200 kg/da, and the price per kilogram is assumed to be $0.12/kg (30 m, 75 m, 75–150 m, and 150 m+). The variable costs, which include inputs like plowing, sowing, fertilization, hoeing, spraying, irrigation, and other expenses, increase with the field's altitudes. The total variable costs per

Table 6
Cost analyzes Input Cost.

Input cost ($/da)					
Variables		30 m	75 m	75–150 m	150 m+
Plowing	1	3	3	3	3
	2	3	3	3	3
	3	3	3	3	3
	Total	9	9	9	9
Sowing	Machinery Rent + labor	3	3	3	3
	Seed	10.56	10.56	10.56	10.56
	Fertilizer	17	17	17	17
	Total	27.56	27.56	27.56	27.56
Fertilization	Machinery Rent + labor	2	2	2	2
	Fertilizer (NPK)	8.48	8.48	8.48	8.48
	Total	10.48	10.48	10.48	10.48
Hoeing	Machine Rental	2	2	2	2
	Labor	0.1	0.1	0.1	0.1
	Total	2.1	2.1	2.1	2.1
Spraying	Machinery Rent + labor	4	4	4	4
	Insecticides	0.7	0.7	0.7	0.7
	Total	4.7	4.7	4.7	4.7
Irrigation		15	24	31	44
Harvest		4	4	4	4
Carrying to Market		2	2	2	2
Other expenses		1.6	1.8	1.8	2.2
General Administration Expenses		1.58	1.78	1.92	2.18
Field Rent		20	18	16	14
Total		**98.02**	**105.42**	**110.56**	**122.22**

Table 7
Cost Analysis and Benefit-Cost ratio.

	Unit	30 m	75 m	75–150 m	150 m+	Mean
Yield rowhead	(kg/da)	1200	1200	1200	1200	1200
Price rowhead	($/g)	0.12	0.12	0.12	0.12	0.12
Total Production Value rowhead	($/da)	144	144	144	144	144
Revolving Fund Interest rowhead		3.96	4.42	4.78	5.44	4.65
Total Variable Costs rowhead	($/da)	79.4	88.6	95.8	109.0	93.2
General Administration Expenses rowhead	($/da)	1.58	1.78	1.92	2.18	1.86
Total Fixed Costs rowhead	($/da)	21.6	19.8	18.0	16.2	18.9
Total Production Costs rowhead	($/da)	101.0	108.4	113.6	125.2	112.0
Production Cost rowhead	($/Kg)	0.084	0.090	0.094	0.104	0.092
Net Income rowhead	($/da)	43.00	35.60	30.40	18.80	31.95
Benefit-Cost Ratio rowhead		0.43	0.33	0.27	0.15	0.29

decare are $79.4 for 30 m, $88.6 for 75 m, $95.8 for 75–150 m, and $109.0 for 150 m+. The general administration expenses are relatively small and range from $1.58/da to $2.18/da. The total fixed costs, which include expenses like field rent, machinery depreciation, and interest, decrease with increasing field's altitudes and range from $16.2/da to $21.6/da.

The total production costs, which include both variable and fixed costs, range from $101.0/da to $125.2/da, with the highest cost being for the largest field's altitudes. The production cost per kilogram ranges from $0.084/Kg to $0.104/Kg, with the highest cost being for the largest field's altitudes. The net income, which is the difference between the production value and total production costs, ranges from $18.8/da to $43/da, with the highest income being for the smallest field's altitudes. The benefit-cost ratio, which is the ratio of net income to total production costs, ranges from 0.29 to 0. The benefit-cost ratio is less than one for all field's altitudes, indicating that the production costs are higher than the revenue generated, and the production is not profitable.

The analysis of the performance of irrigation systems at different altitudes on energy use and production costs in corn production and processing into ethanol in Turkey is significant for several reasons [58]. Firstly, it can help identify the most efficient irrigation systems for corn production in different regions of Turkey. This can help farmers optimize water use and reduce production costs, which can contribute to the sustainability of the agricultural sector in the country.

Secondly, the analysis can inform decisions related to the location and design of ethanol production facilities in Turkey. By understanding the energy requirements and production costs associated with different altitudes and irrigation systems, policymakers can identify optimal locations for ethanol production facilities and inform decisions related to infrastructure investments. Thirdly, the analysis can inform the development of policies related to renewable energy production in Turkey. By understanding the energy requirements and production costs of corn processing into ethanol, policymakers can identify strategies to promote the production and use of renewable energy sources in the country. Finally, the analysis can contribute to the global understanding of the potential of corn production and processing into ethanol in different climatic conditions and under different irrigation systems. This can inform international cooperation and knowledge sharing on sustainable agriculture and renewable energy production.

4.4. Corn processing in ethanol

The production of ethanol from corn in Elazig is mostly based on two basic conventional methods known as dry grind and wet mill. Among these two methods, the dry grind is reported to be the most largely applied in ethanol production industries in Turkey. Ethanol production is constituted of five main steps, including liquefaction (grinding and cooking), saccharification, fermentation, distillation and dehydration (water evaporation and recycling). Ethanol production applying the method of corn dry grind is described in this present study and its block flow diagram is shown in Fig. 2. All the data and the description of the process were obtained from Turkish corn ethanol production companies and a summary of the transformation process has been presented in the Table 8.

Pretreatment and liquefaction. Corn grains are first transferred to the grain-cleaning machine for foreign matter (metal and rocks) removal and milled. Thereafter, the corn powder containing the starch is conveyed to a liquefaction tank or reactor and blended with water to form a mash, then with steam (hot evaporator condensate) the starchy material is cooked or gelatinized to disband the amylose and amylopectin. Subsequently, enzymatic hydrolysis is conducted and enzymes, especially microbial alpha-amylase are added at a concentration of 0.04–0.08 g/g (dry basis concerning corn powder) for the liquefaction process at 80–90 °C. The pH of the medium is adjusted employing a

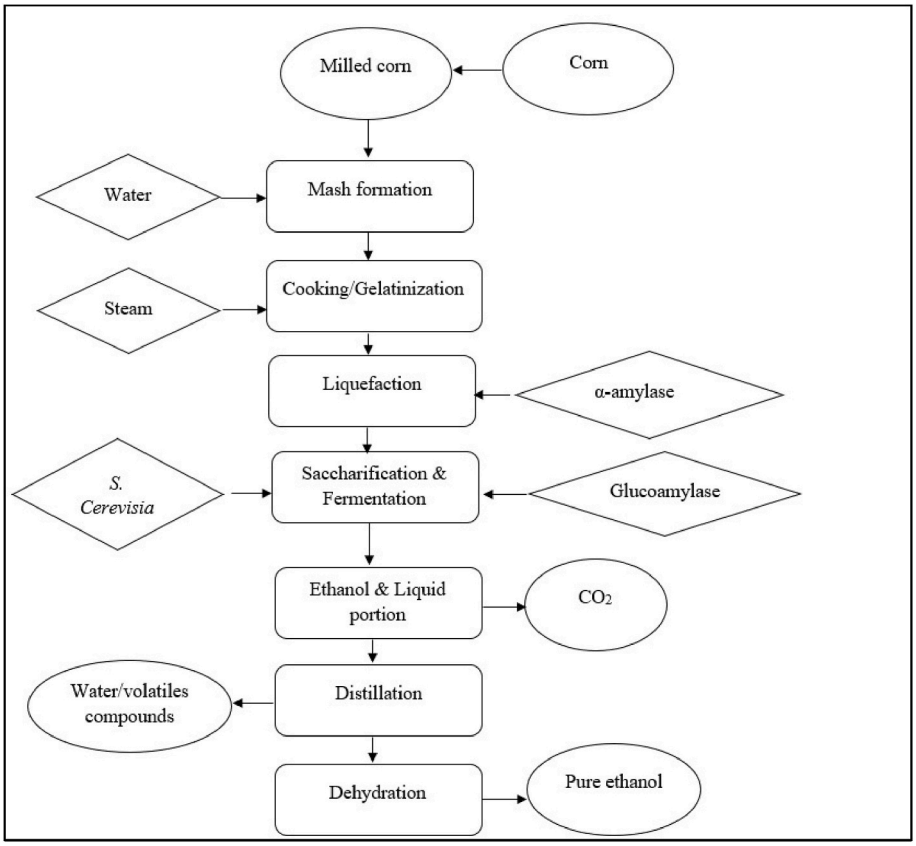


Fig. 2. Simplified representative scheme of corn ethanol production using dry mill process.

Table 8
Summary of the transformation process for 100 kg of milled corn.

Parameters	Cooking	Liquefaction	Saccharification	Fermentation	Distillation
Milled corn (Kg)	100				
Water (L)	666–800				
Temperature (°C)	100–120	80–90	50–60	20–35	78–100
Time (h)	0.5–1	2–4	48–72	48–96	2–4
Alpha amylase (g/g corn)		0.04–0.08			
Glucoamylase (g/g corn)			0.02–0.05		
***Saccharomyces Cerevisiae* (g/g corn)**				0.1–0.5	
Nitrogen Source				0.4–0.8	
pH		4–5	5–5.5	4.5–6	
Ethanol (L)				30–40	
Pure ethanol (L)					15–30

caustic, and calcium in the form of calcium carbonate (CaCO3) or other calcium salts is provided to speed up the activity of alpha-amylase. During the liquefaction process, the starch is broken down into malto-dextrin maltose, and higher oligomers or branch malto-oligosaccharides.

Saccharification and fermentation. In a fermentation reactor or tank, the gelatinized and liquified corn powder (mash) is firstly blended with slender stillage recycled from the centrifuge, heated to 85–100 °C, kept for 1020 min, and then cooled down to 50–60 °C using a circulating cool water system. The saccharification process is triggered by adding glucoamylase alone or a combination of sulfuric acid and glucoamylase. In this enzymatic hydrolysis process, microbial glucoamylase breaks down maltose and malto-oligosaccharides into glucose. Recently, alpha-amylase and alpha-glucoseamylase have been enhanced to effectively hydrolyze about 100% of the starch contained in corn grain into glucose, given that the corn is finely milled and correctly gelatinized. It is well noticed that in almost all ethanol production processes, simultaneous saccharification and fermentation (SSF) is the most used process in ethanol production industries. After all starch oligosaccharides are almost completely (99–100%) hydrolyzed into glucose molecules, yeasts, especially Saccharomyces cerevisiae (0.1–0.5 g/g) then added in the wort to convert glucose molecules into ethanol and CO2 (Reaction 1), which are regarded as the major products of the fermentation, and some minor compounds such as acetic acid, butanol, methanol, acetaldehyde and glycerol. The pH of the medium is optimized and nitrogen sources like urea and others are added to the fermenter to strengthen the activity of the yeast, and the fermentation is conducted at 20–40 for 3–5 days.

$$C6H12O6+H2O \rightarrow 2CH2OH+2CO2+C2H4O2+CH3CH2OH + CHOH+2C3H8O3 \text{ (Reaction 1)}$$

Ethanol purification. The fermented liquid portion of the slurry or beer containing the ethanol (8–12%) is purified through two distillation columns associated with a molecular sieve adsorption unit using a classical distillation/rectification system. During the purification process, more than 90% of the water in ethanol, remaining glucose residues, proteins, non-fermentative solids, and chemical substances with higher boiling points are significantly removed via the first distillation column. In an absorption column, the gases from the fermentation process predominately CO_2, are washed to recuperate 95–98% of volatile ethanol from the SSF fermenter and sent to the first distillation column. Thereafter, ethanol is purified from water using the second azeotropic distillation column, resulting in a final ethanol concentration close to 90–95%. Moreover, when a molecular sieve adsorption unit is applied, the ethanol concentration can attain 95–99%. After the distillation process, the stillage is dehydrated by evaporation and the solid residues are separated from the slurry by centrifugation. These residues can be utilized to obtain valuable by-products like corn oil and dried powder with soluble for animal feeds.

4.5. Energy use in the process

The analysis of data obtained from companies processing corn into ethanol in the province of Elazig reveals that the transformation of 100 kg of corn generates an energy expenditure of 2219.58 MJ [60]. stated that the energy consumption for corn processing into ethanol ranges from 15,000 to 20,000 BTUs per gallon of ethanol produced. However, the energy consumption can vary depending on the type of technology used for corn processing, the moisture content of the corn, and the efficiency of the process. For instance, dry-grind corn processing technology is more energyefficient compared to wet-milling technology. In companies processing corn into ethanol in Elazig more than 50% of energy expenditure (1308.01 MJ) comes from the use of machines (Fig. 3). This is mainly since machines are the main elements used in industry. This result corroborates with that of [61] According to these authors, machines are the greediest in industry in terms of energy expenditure. In terms of energy expenditure, the use of machines is followed by those related to fuels and electricity which are mainly used as energy for the operation of machines and various devices. The amount of energy required for corn processing into ethanol depends on various factors such as the type of equipment used, the efficiency of the equipment, and the quality of the corn used. All stages require energy input in the form of electricity, Gasoline, LP gas and Diesel [62]. Since enzymes and other additives are used in small quantities, their energy intake is quite low.

The use of renewable energy sources such as biomass and biogas are becoming increasingly popular in the ethanol industry. The use of renewable energy sources can reduce the carbon footprint of the ethanol production process and lower the production costs. Overall, the energy consumption in corn processing into ethanol can have a significant impact on the production costs of ethanol. Therefore, improving the efficiency of the corn processing technology and using renewable energy sources can help reduce the production costs of ethanol and make it more competitive in the market.

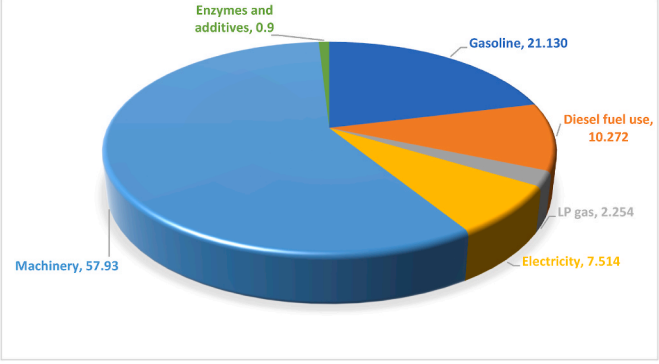


Fig. 3. Energy consumption for 100 kg of corn processing into ethanol.

5. Conclusion

Based on the information presented, it can be concluded that corn production and processing into ethanol involves significant energy and input costs. The production of corn requires both direct and indirect energy, with non-renewable sources accounting for a large portion of the total energy used. The cost analysis shows that the total production cost per hectare of corn cultivation is around $112.05, and the average yield is 1200 kg/da. In conclusion, corn production and processing into ethanol in Turkey is a complex process that involves various stages and requires significant energy input. The performance of irrigation systems at different altitudes can have a significant impact on energy use and production costs.

Efficient corn processing technology and the use of renewable energy sources can help reduce the energy consumption and production costs of ethanol. It is also important to ensure that the irrigation systems used in corn production are optimized for the local climate and altitude to ensure efficient water use. Overall, the production of ethanol from corn has the potential to contribute to Turkey's energy security and reduce its dependence on fossil fuels. However, it is important to consider the environmental and social impacts of corn production and ethanol processing, such as the use of water resources and land use changes, to ensure sustainable development.

Author contributions

SA, YEM, KFD, ISI, KFO: Writing - review & editing. SA: Project administration, Funding acquisition. YEM, KFD, ISI, OZ: Investigation, Data curation. OZ, KFO, ISI: Sampling, Investigation. SA, YEM, ISI: Project Supervision.

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Declaration of competing interest

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Data availability

Data will be made available on request.

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