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ORIGINAL ARTICLE

Energy cycle assessment of bioethanol production from sugarcane bagasse by life cycle approach using the fermentation conversion process

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Abstract

Researchers are developing new techniques for clean fuel production due to environmental problems such as global warming. In this respect, bioethanol is considered among the most important renewable fuels. This study aims to investigate the energy cycle and estimate the potential environmental effects of ethanol production from sugarcane bagasse in Iran. To this end, ethanol's life cycle assessment (LCA) was conducted based on the "cradle to gate" approach. This assessment includes three stages of sugarcane farming, transportation to the factory, and bioethanol production. This study defines three scenarios for bioethanol production from sugarcane bagasse using the fermentation conversion process: fermentation, bagasse burning for electricity, and combined bioethanol and electricity production. The third scenario was chosen as the best. However, in environmental analysis, it showed the most negative effects on environmental indicators, especially in cases of abiotic depletion and global warming potential. Scenario 1 showed better results than the others. The results showed that electricity, diesel fuel, and nitrogen fertilizer had the greatest environmental impact in the mentioned process. Moreover, by replacing fossil fuels with clean energies, more energy efficiency and less environmental consequences can be achieved because fossil fuels cause air pollution leading to acid rain, eutrophication, damage to forests, and harm to wildlife. Our results show that the bioethanol production process using sugarcane bagasse as feedstock requires 27.13 MJ/L input energy, while the total output energy is 40.44 MJ/L. Energy indices were calculated, with values of 1.49, 0.037, 27.13, and 13.31 for energy ratio, efficiency, intensity, and net energy addition, respectively.

Keywords Life cycle assessment (LCA) · Bioethanol · Bagasse · Biofuels · Sustainability · Renewable energy

1 Introduction

The estimated world population in 2050 is 1.5 times the current population, making the need for sustainable production methods for energy greater than ever. However, 85% of current energy needs are met by burning fossil fuels like oil, natural gas, and limited coal resources, which raises concerns about depletion of fossil fuel reserves and environmental pollution from carbon emissions [1].

The direct consumption of fossil fuels may lead to greenhouse gas (GHG) emissions. In this respect, CO_2, NO_X, and SO_2 are among the most important GHGs with severe global challenges due to their persistent impact on the environment and ecosystem, especially on climate change [2]. GHG emissions emitted in Iran has been recently exceeded the Kyoto Protocol thresholds. Accordingly, more efficient use of fossil fuels and increasing the use of renewable energy sources have been the subject of intense interest in Iranian scientific societies. One of the oldest industries in Iran is the sugar industry. According to the Iranian sugar factories syndicate (ISIF), this industry is among the most energy-intensive sectors. In Iran, this industry supplies its energy needs from fossil fuels. As a result, national energy strategies are shifting towards using renewable and sustainable energy sources, such as biodiesel, bioethanol, and biohydrogen, which are mainly produced from plant residues, to achieve energy security in an environmentally friendly manner [1, 3].

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One fundamental difference between biofuels and fossil fuels is that biofuels typically have a higher oxygen content, ranging from 10 to 45%, while fossil fuels have no oxygen content. This difference in oxygen content can contribute to the relative levels of pollution associated with each type of fuel. Fossil fuels are generally considered more polluting because they lack oxygen and produce higher levels of harmful emissions when burned [4, 5].

Considering the higher oxygen content of biofuels compared to fossil fuels, utilizing agricultural waste for biofuel production has the potential to offer a more sustainable and environmentally-friendly energy source. As the agricultural industry grows, there is an increasing amount of agricultural waste being produced annually. This waste can serve as a low-cost source for biofuel production, providing an opportunity to convert waste materials into useful energy sources while also reducing the environmental impact of agriculture [6].

In a study conducted by Shakiba et al., corn stalk, sewage sludge, and sawdust were used as agricultural waste to produce biofuel [7]. Najafi et al. conducted research on the potential of bioethanol production from agricultural waste in Iran [8]. Meanwhile, Azadbakht et al. studied the production of biofuels using agricultural waste, livestock, and slaughterhouse waste in Golestan province, Iran [9]. Another example of agricultural waste is sugarcane bagasse, which is abundantly found in sugarcane plantations. One of the ways in which bagasse can be utilized is for the production of bioethanol, which is widely recognized as one of the most commonly used biofuels [10].

Bioethanol (C_2H_5OH) is a colorless, biodegradable liquid with low toxicity that causes little pollution if spilled. When bioethanol is mixed with diesel, due to the presence of oxygen in this mixture, the diesel burns completely and emits less pollution. E10 is a term referring to the 10:90 mixture of ethanol and diesel. This fuel is very common in the USA, as no change in car engines is made to consume it. Also, bioethanol can be used as a substitute for methyl tert-butyl ether (MTBE), which is commonly used as an octane booster in gasoline to replace lead additives for environmental reasons [11–14].

Ethanol production methods include ethylene hydration, ethanol production from CO_2 and fats, and fermentation. The first generation of biofuels, which are produced from sources rich in sugar and starch, are produced in two or three stages. In this method, sugar plants such as sugarcane are converted into bioethanol with two stages of fermentation and distillation. Besides, plants rich in starch produce the final product with three steps, including hydrolysis, fermentation, and distillation. However, in the second generation of biofuels, including lignocellulosic materials, the physical and chemical pretreatment stage is also added to the production steps of bioethanol. The reason for using these lignocellulosic materials is their protective lignin layer, as it makes hydrolysis and fermentation difficult. Lignocellulosic materials consist of three parts, namely, cellulose, hemicellulose, and lignin [15–18].

The raw materials for bioethanol production are:

- Plants rich in sugar such as sugar beet, sugar cane, and sweet sorghum
- Plants rich in starch include wheat, barley, corn, sorghum seeds, rye, potatoes, and cassava.
- Energy-generating plants such as willow, and fir
- Forest debris
- Paper industry wastes
- Agricultural waste such as sugarcane bagasse, straw and stalks, and corn leaves [19–23]

Bagasse or sugarcane residue is one of the most important by-products of sugar production from sugarcane, which is obtained after sugarcane extraction in the form of small pieces of straw chips (fiber) mixed with the cork tissue of the straw core (called peat) and is straw yellow in color with the humidity is about 50%, and 30% of the weight of sugarcane is bagasse. This material has high fiber and nitrogen and low digestibility, and the amount of its constituent elements is different according to the different types of sugarcane and according to the age of the sugarcane, the way it is harvested, and finally the recovery and extraction efficiency in the mills [24].

The average sugarcane production per hectare is approximately 100 tons, and in Khuzestan, it has been found that approximately 32 tons of bagasse is left over after extracting syrup from sugarcane. Both bagasse and sugarcane leaves contain significant amounts of cellulose and hemicellulose, which can be broken down into sugar monomers like glucose and galactose through enzymatic or chemical polymerization processes [25, 26].

Bagasse, which has no nutritional value, is often burned as waste in Iran. This issue is the advantage of the second-generation biofuels over the first generation, as a result of which the raw material of biofuel does not compete with food products and does not increase the price of food products [1].

Concerns about environmental pollution and energy and material scarcity have led to developing environmental-based life cycle product approaches. Life cycle assessment (LCA) has undergone significant developments in both methodology and applications since proposing the first LCA model in the 1960s. Today, LCA is defined as “a tool to assess the potential environmental impacts and resources used throughout the product’s life cycle, i.e., from the acquisition of raw materials, through the stages of production and use, to waste management” [27–29].

Literature shows numerous LCA studies on bioethanol generation with a wide variety of results and objectives, such as energy consumption, GHG emissions, land use, economic viability, and water footprint. Also, these studies use different variables for different purposes. Some efforts focus on using bagasse, sugarcane, and corn as feedstock to produce ethanol from energy balance, land use, and global warming perspectives. Some others have studied GHG emissions and water input using switchgrass and corn stover as feedstock [30–32]. Furthermore, some authors have investigated the cultivation and processing of sugarcane, maize, wheat, and sugar beet for bioethanol production [33, 34].

In the last decade, many LCA studies have been conducted on these fuels to reveal and compare the advantages and disadvantages of different methods and fossil fuels [35–37]. A distinction between these studies is that bagasse is considered waste and burned. Alexiades et al. (2017) evaluated a low-carbon route to produce bioethanol from sugar beet. The carbon intensity (CI) for sugar beet ethanol produced from the simulated path is 25.5 g of CO_2e/MJEtOH, which is 44% less than the average ethanol produced in that state. Finally, the total pollution emission in this simulation is 71% less than diesel in cars [38]. Lask et al. (2018) evaluated miscanthus as a raw material for bioethanol production. Ethanol obtained from miscanthus resulted in lower impacts related to GHG emissions, fossil resource depletion, natural land conversion, and ozone depletion [39]. Hasanli et al. (2018) have also examined the potential of bioethanol production from wheat straw in Iran. This study simulated the ethanol production process from wheat straw using Designer SuperPro software. The Monte Carlo simulation (MCS) results showed that the risk of the biorefinery of the main scenario with a medium to high selling price is acceptable. Also, they showed that the risk of suffering from a low selling price of ethanol could be reduced by increasing the plant size [40]. Comparing bioethanol production from cassava, sugar cane molasses, and rice husk, Rathnayake et al. (2018) offered a comprehensive LCA comparison based on indirect process data from simulations and minimal changes in other settings such as process feedstock type and waste recycling options. The results showed that bioethanol production from cassava provides the best values of net energy ratio (1.34), renewability (5.16), and reduction of GHG emissions (410 kg CO_2eq/1000 L). LCA results from net energy analysis and environmental impact assessment, including identification of GHG emissions and sensitivity analysis, have been comprehensively used in the literature [41].

For the first time in Iran, Amin Salehi et al. (2013) compared and ranked the energy conversion technologies and reported that two competing technologies (i.e., anaerobic digestion (AD) and gasification) are the most effective ones in this regard. Also, it was found that the optimum method for bagasse processing is an AD with subsequent biogas combustion in a combined heat and power (CHP) plant [42].

Gonzalez et al. (2022) examined gas emissions from producing white sugar and its by-products from sugar beet. Using a cradle-to-gate assessment, particulate matter emissions (PM), global warming potential (GWP), marine eutrophication potential (MEP), and freshwater eutrophication potential (FEP) were determined without allocation and with economic and energy allocation. The results of the scenario without allocation revealed that cultivation was responsible for a large share of emissions. In addition, applying the allocation strategy lowered the emissions for white sugar, as this strategy considers the by-products separately. Overall, in applying economic allocation compared to energy allocation, all considered by-products had low emissions regarding the low economic value of the by-products. Furthermore, replacing natural fossil gas with softwood chips as the primary energy source at the factory showed considerable potential (45%) for lowering sugar production's carbon footprint [43].

Mohammadi et al. (2020) investigated three conversion options for bagasse and characterized them using different environmental key figures. Overall, the combustion option was found as the optimum promising method compared to gasification and AD, especially when saving GHG emissions and regarding the export potential of surplus electricity to the grid [3].

In 2023, Santoyo-Castelazo et al. employed a comprehensive and sturdy LCA method to evaluate the environmental impacts linked with creating bioethanol from sugarcane bagasse, which could potentially be blended with gasoline for use in vehicles. The LCA analysis examined the entire life cycle of bioethanol production, including stages such as raw material extraction, transportation, sub-product material extraction, bioethanol production, biofuel use, and biorefinery construction and decommissioning [44].

In 2018, Maga et al. examined different technological alternatives for producing ethanol and quantified their potential environmental impacts. They compared first-generation ethanol made from sugarcane to stand-alone second-generation ethanol, as well as an integrated first- and second-generation ethanol production. Their findings suggest that utilizing bagasse and trash for ethanol production in Brazil could significantly reduce several environmental impacts and minimize land use [45]. In 2019, Amezcua-Allieri and co-authors performed a techno-economic and environmental analysis of the process of generating steam and electricity from sugarcane bagasse. The goal of the study mentioned is to identify the necessary auxiliary supplies and services, assess the cost, and evaluate the environmental impact of energy production. They compare the use of fuel oil and grid electricity to the utilization of sugarcane bagasse for energy self-sufficiency. The study evaluates the technical efficiency and economic profitability while establishing a sustainable design through the use of LCA. To achieve this, the authors conducted both techno-economic and LCA analyses to determine the cost and environmental impact of supplying heat and electricity in the sugar production process through two different scenarios: the use of fuel oil or sugarcane bagasse. The economic analysis revealed that the use of bagasse as a solid fuel is more cost-effective than fuel oil, resulting in lower costs of producing energy in the form of steam and electricity [46].

This study addresses the gaps identified in previous literature on the life cycle assessment of bioethanol production from sugarcane bagasse. One such gap is the simultaneous evaluation of energy efficiency and environmental indicators, which has not been addressed in previous studies. Additionally, a combination scenario for optimizing bioethanol production has not yet been investigated.

The aim of this research is to assess the feasibility of producing bioethanol from the residues of native sugarcane fields in Khuzestan province in a manner that generates a positive net energy balance and minimizes negative environmental impacts. To achieve this, life cycle assessment (LCA) was utilized to evaluate the environmental burden in abiotic depletion, global warming potential, ozone layer depletion, human toxicity potential, photochemical oxidation, acidification potential, eutrophication potential, and abiotic depletion of fossils fuels of the bioethanol production process across its various stages. The findings of this study help address the research questions related to the feasibility of bioethanol production from sugarcane residues. To date, no studies in Iran have examined the environmental impact and energy cycle of ethanol production from sugarcane bagasse simultaneously. Furthermore, the scenarios developed in this study were based on proposed plans from industry decision-makers and have provided valuable insights for making informed choices.

2 Research methodology

The life cycle assessment (LCA) is a technique used to evaluate possible environmental consequences of a product or process by examining the energy and material flows that are released into the environment during its entire life cycle. The ISO 14040, 2006 standard provides a framework for carrying out an LCA, which involves four key phases as follows:

1. Goal and scope definition
2. Life cycle inventory
3. Impact assessment (Results)
4. Interpretation (Discussion)

The following four phases will be described in detail in the context of the specific topic being addressed in this study [3, 47].

Table 1 is a thorough investigation that examines various methodologies and their intended goals and resultant effects through the use of case studies within the literature, with the primary aim of making comparative analyses.

2.1 Goal and scope

The increase in global energy consumption and its cost, coupled with the finite nature of fossil fuel reserves and the associated environmental pollution, has underscored the importance of exploring alternatives to these non-renewable sources of energy. The search for clean, affordable, and sustainable fuel has become imperative. This research aims to analyze the energy cycle of bioethanol production from sugarcane bagasse. Along with this goal, the environmental impacts of this process are also assessed. To this end, three stages of bioethanol production including sugarcane farming, bagasse transportation, and conversion process are investigated. The project's first stage was performed in 2019 in Mirza Kuchak Khan Agro-industry in Khuzestan, the main pole of sugarcane production in Iran. Also, the required data were collected, followed by conducting the second and third stages of simulations. In analyzing the input and output energy of a product, in most of its life cycle, we do not only suffice the final product with the highest value because the by-products also allocate a share of the system's input and output energy.

2.1.1 Allocation method

When analyzing the energy input and output of a product, it is common to only evaluate the final product with the highest value, while disregarding the secondary products that also contribute to the input and output energy of the system throughout its life cycle. In the case of sugarcane agriculture, bagasse is a significant by-product that cannot be ignored, and some of the input energy of the system must be allocated to bagasse. Therefore, the mass allocation method is used to allocate input and output energy. The mass allocation method distributes the consumed energy flow based on the mass ratio of the produced products. This method is commonly used for input-output energy analysis because it can produce acceptable results with ease.

2.1.2 System boundary

System boundary of this study was from the cradle to the gate. In this way, the research begins with the agriculture of the raw material for the production of bioethanol. All input and output data to the system are calculated. After that, its output product (bagasse) is transferred to the factory which is converted into ethanol by the fermentation processes. Similarly, for other scenarios, in the scenario of burning bagasse, the first and second stages are the same,

Table 1 A comparative analysis of different method and their objectives and outcomes through case studies in the context of the literature

Authors	Goal	Raw material	Result
Omto et al. (2009)	Assessing the life cycle of bioethanol production from sugarcane	Sugar cane	The life cycle of ethanol involves substantial use of non-renewable resources, including a significant input of renewable resources such as water consumption during the industrial phases, particularly due to the sugarcane washing process; moreover, the harvesting phase contributes the most to global warming
Sanchez et al. (2017)	Life cycle evaluation of sweet sorghum stalks in four scenarios	Sweet sorghum	In the combined scenario, the highest energy rate of 1.89 was achieved
Alexiades et al. (2017)	Carbon output reduction in the sugar beet bioethanol production cycle	Sugar beet	There is a 40% reduction associated with 25.5 g of carbon emissions per megajoule of energy produced
Ding et al. (2018)	Assessing the life cycle of bioethanol production from soluble sugar in the stem of sweet sorghum	Sweet sorghum	Compared to gasoline, sorghum stalk ethanol offers advantages in energy consumption, with 85% less fossil energy and 44% less global warming potential
Lask et al. (2018)	Comparing various pretreatment methods for producing bioethanol from miscanthus	Miscanthus	Hot water and dilute sulfuric acid pretreatment method proved to be the most effective, while sodium hydroxide showed the poorest results in the production of bioethanol from miscanthus
Hassanali et al. (2018)	Assessing the potential for producing bioethanol from wheat straw	Wheat straw	The wheat straw and enzyme costs were found to be the main drivers of operating cost, and the biorefinery risk was deemed acceptable with a medium to high selling price for the bioethanol produced
Ratnayake et al. (2018)	Comparing bioethanol production using various raw materials	Cassava, sugarcane molasses and rice hulls	Among the different ingredients, cassava exhibited better results with a net energy of 1.34

but in the third stage, instead of producing ethanol, bagasse is burned and produces electricity. The generated electricity is the output of the system. In the combined scenario, both the above steps are done.

Figure 1 presents the life cycle stages of bioethanol production and the input and output boundaries of the system.

Figure 2 starts from the sugarcane farming stage and ends with bioethanol production. All processes are in the boundary system. The outputs of each stage, the input is the next stage, and only in the last stage there are final outputs, which are ethanol and electricity.

The functional unit is a basic unit used in life cycle assessment calculations where input values are collected and calculated during the second stage of the life cycle. The functional unit is determined based on the product being studied and the purpose of the study and can be expressed in various forms such as product mass, surface area, or number. In evaluations of energy consumption, the

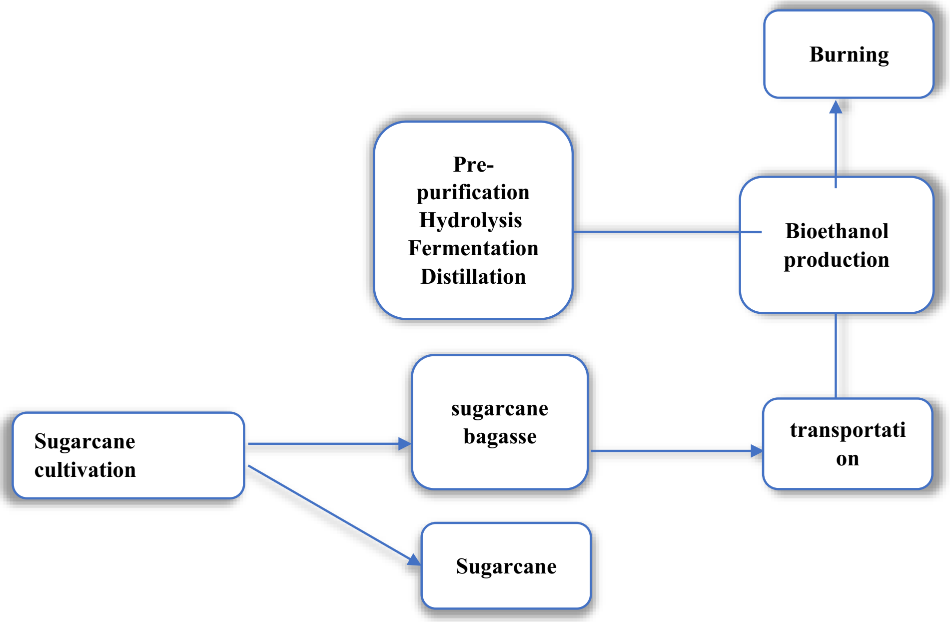


Fig. 1 Bioethanol production processes at the boundary system of this study

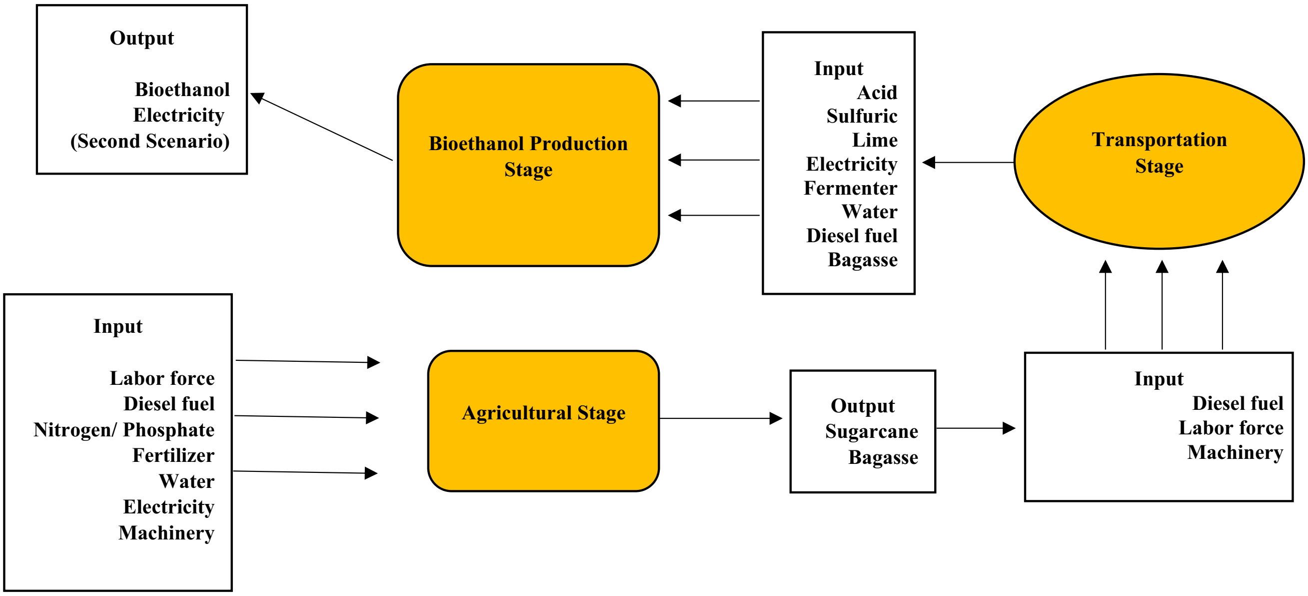


Fig. 2 Schematic of inputs and outputs of the system in this research

operational unit is typically considered to be a megajoule. For this particular study, the operational unit is a megajoule.

2.2 Technical description

2.2.1 Energy extraction processes

In this study, three scenarios were defined for extracting energy from sugarcane bagasse in the sugarcane agro-industry, and the results were compared.

In Khuzestan, Iran, in each hectare of sugarcane fields, approximately 85 tons of sugarcane is produced, with 26.31 tons of bagasse remaining as residue. It takes 3.318 kg of bagasse to produce 1 L of ethanol. As a result, the production of ethanol from one hectare of sugarcane cultivation yields approximately 7929 L of ethanol.

Bioethanol production After harvesting the sugarcane crop and separating the bagasse in the field, the bagasse residue from sugarcane harvesting is transported to the ethanol production plant via a 28-ton truck, covering a distance of 15 km. The truck used in the transportation adheres to Euro 3 emission standards. The decision to transport the bagasse by road was based on the proximity of the farm to the factory, as well as the unavailability of other transportation options such as train tracks.

In the factory, they are divided into smaller pieces by a shredder and pre-purified with sulfuric acid. Due to the higher efficiency of the simultaneous hydrolysis and fermentation process, this method has been chosen for the first scenario of bioethanol production. Next, the produced ethanol is dewatered in the distillation towers and sent to the combustion engine with a purity of over 90% to obtain energy.

Burning bagasse This scenario was created to extract energy from sugarcane bagasse by burning bagasse and producing electricity from heat. The remaining bagasse after agricultural operations is transported to a distance of 15 km from the farm and is burned in a suitable power plant with the highest possible efficiency to generate electricity. This scenario was selected to compare the amount of energy produced in multi-step processes after bioethanol production with the energy released after burning bagasse. In addition to the energy consumption in the scenarios, their environmental effects are also evaluated, and the optimal scenario is presented in different sectors.

Simultaneous bioethanol production and bagasse burning In this energy production scenario, the electricity required for bioethanol production is obtained from sugarcane bagasse by burning bagasse.

Comparing these scenarios provides important results regarding the production energy of the bioethanol process in its life cycle.

2.2.2 Life cycle assessment (LCA)

The LCA analysis was conducted following the method recommended by the International Standardization Organization (ISO 14040-14044, 2006) [24, 25].

After performing the input and output flow calculations, the environmental effects of different parts of the process are evaluated in the second stage of the LCA. In this study, these effects were investigated through EPD 2018. Input and output data were imported into the Simapro software and analyzed through EIA using the EPD 2018 method. The effect sections used in this study are given in Table 2.

2.3 Data collection

The data used in this research were taken from Mirza Kuchak Khan Agro-industry in Khuzestan, the main pole of sugarcane production throughout Iran. These data include information about cultivated land, chemical poisons (herbicides, pesticides, and chemical fertilizers) used in the land, fuel and electricity consumption, machinery and manpower, irrigation water, and the amount of final product and bagasse.

2.3.1 Life cycle inventory

Energy coefficients Energy inputs and outputs during the life cycle of bioethanol production are specified in Table 3. The energy indices in this study are measured using the energy equivalent of inputs and outputs.

Direct energy consumption

$$DE = \frac{\rho g H Q}{\eta 1 \eta 2} \tag{1}$$

where DE denotes direct energy consumption (J/ha), ρ is water density (1000 kg/m^3), g is gravity acceleration (9.8 m/s^2), H shows total dynamic height plus pressure friction

Table 2 Impact category and unit of measurement for each section

Impact category	Symbol	Measurement unit
Abiotic depletion	ADP	Kg sb eq
Global warming potential	GWP	Kg Co_2 eq
Ozone layer depletion	ODP	Kg CFC-11 eq
Human toxicity potential	HTP	Kg 1.4-DCB eq
Photochemical oxidation	Pho	kg C_2H_4 eq
Acidification potential	AP	Kg SO_2 eq
Eutrophication potential	EP	Kg PO_4^{-3} eq
Abiotic depletion of fossils fuels	ADP(ff)	MJ

Table 3 The energy content of inputs and outputs

Input/output	Unit	Energy content (MJ/unit)	Reference
Inputs			
a) Agriculture			
1. Labor force	h	1.96	[48]
2. Diesel fuel	L	47.8	[49]
3. Herbicide	kg	85	[49]
4. Chemical fertilizer	kg		
Nitrogen		78.1	[50]
Phosphate		17.4	[50]
5. Irrigation water	m^3	1.02	[51]
6. Electricity	kWh	3.6	[51]
7. Machinery	h	545	[52]
b) Transportation			
1. Diesel fuel	L	47.8	[49]
2. Labor force	h	1.96	[48]
c) Bioethanol production			
1. Sulfuric acid	kg	2.2-	[53]
2. Lime	kg	0.53	[54]
1. Electricity	kWh	3.6	[51]
3. Water	m^3	1.02	[51]
4. Diesel fuel	L	47.8	[49]
Output			
Bagasse	kg	9.6	[55]
Bioethanol	L	21.2	[56]
Heat	MJ	1	

Functional units: 1 MJ

loss (m), and Q is the total flow of water used in the cropping season (m^3/ha). Also, ŋ1 is the pumping efficiency in decimal form (a function of the vertical height of the lift, speed, and water flow), which is often considered equal to 0.9–0.7. Finally, Ŋ2 is the total efficiency of energy and power conversion in decimal form, which is often considered equal to 0.20–0.18 for electric pumps [49].

It is noteworthy that the indirect irrigation energy (including equipment, raw materials, well drilling, and construction of all irrigation system facilities) was not included in the system regarding the boundaries of the current LCA. The reason for neglecting these boundaries is the long life of the equipment used and the small energy allocation of this equipment for each ton of cultivated crops [49].

In Iran, the useful life of agricultural machinery is at least 15 years. For example, the area studied in this article is 14,000 hectares, where 85 tons of sugarcane are produced per hectare, and the annual yield is 1,190,000 tons. If this number is multiplied by the useful life of the machines, the result is 17,850,000 tons. It is clear that the energy allocated from machines to each ton of product is negligible. Furthermore, Lampridi et al. have calculated the amount of energy consumed by the machines, which supports this claim [57].

Energy indicators In order to review and compare different results in the energy debate, it is necessary to use energy indicators. Some of the continuous and important energy indicators that provide a comprehensive understanding of the state of energy flow in the production of a product include energy ratio (ER), energy productivity (EP), specific energy, and net energy gain (NEG).

$$ER = \frac{Output\ energy}{Input\ energy} \tag{2}$$

$$EP = \frac{\text{Product performance (liters per hectare)}}{Input\ energy} \tag{3}$$

$$EI = \frac{\text{Energy input}}{\text{Product performance (liters per hectare)}} \tag{4}$$

$$NEG = Input\ energy - Output\ energy \tag{5}$$

where ER is the energy ratio, EP is energy productivity (liters per megajoule; L/MJ), EI is energy intensity (MJ/L), and NEG is the net energy gain (MJ/ha). Net energy gain refers to the amount of energy that is gained or lost throughout the life cycle of a product or process.

ER is a dimensionless value that expresses the ratio between the energy of the output products and the total energy spent in the production factors.

EP is the ratio of the amount of product produced to the energy consumed. This ratio expresses the amount of product produced per unit of energy consumed in L/MJ. EI (MJ/L) is the inverse of EP and shows the energy consumption to produce one product unit.

To calculate the environmental indicators at each stage of bioethanol production, the analyze function was utilized. The compare function was used to compare different scenarios. The choice of these calculation methods was based on the specific results required in each section.

3 Results and discussion

In this study, the energy flow in each stage of bioethanol production (i.e., sugarcane farming, bagasse transportation to the bioethanol production site, and bioethanol production) was calculated. To this end, energy analysis and environmental assessment are performed, followed by comparing energy extraction processes. All LCA studies include limitations that affect the results. In this study, the authors have encountered limitations, some of which have been resolved by determining the boundaries of the system, but the significant ones are as follows: Studies in Iran have been done, but some of the modeling data were from European databases, which make the results less accurate for the study area. Also, the lack of access to data related to the cost of the processes and the possibility of economic analysis of the defined scenarios were not available and were among the limitations of the study.

3.1 Energy analysis

3.1.1 Energy analysis in the field sector of sugarcane production

Human power allocates a small share of sugarcane farming operations. Meanwhile, the largest share is related to electricity, with 31,838.4 MJ of energy associated with irrigating 29,000 m^3 of water per hectare. The results show that the water consumption for each kg of sugarcane is 341 L, which is less than many products, including wheat; the amount of water required to produce 1 kg of wheat ranges from 500 to 4000 L, depending on various factors [58]. The total energy required for sugarcane production was 117,860 MJ/ha, which is a lower amount than a similar study [59] on sugarcane cultivation. This result is due to the difference in the equivalent of electrical energy consumed in agriculture.

Figure 3 shows the allocation of each input to the total energy consumption in sugarcane production in the studied area. As can be seen, the largest share is related to electricity, followed by irrigation water and nitrogen fertilizer. Also, the labor force, herbicides, and phosphate chemical fertilizers have a small share of the energy consumption of sugarcane farming operations.

The high share of electricity input is related to the energy consumed to provide irrigation water for the sugarcane crop. The high water requirement of the sugarcane crop and the pumping of water on a large scale have led to consuming a high amount of energy in the form of electricity. The information collected from the studied area shows that the average water required for each hectare of sugarcane cultivation is between 28,000 and 30,000 m^3.

The second stage of the life cycle of bioethanol production from sugarcane bagasse is bagasse transportation from the farm to the factory. The energy consumed in this step is presented in Table 4. This energy is analyzed in MJ, and the distance between the factory and the farm is considered to be 15 km. About 26 tons of bagasse is produced per hectare of cultivation.

Table 4 Amount of inputs and energy consumption of inputs in the transportation phase (per one hectare)

Title	Unit	Average consumption (per hectare)	Average energy consumption (per hectare)
Labor force	h	25	49
Diesel fuel	L	15	717
Machinery	h	0.67	365
Total	MJ	-	1131

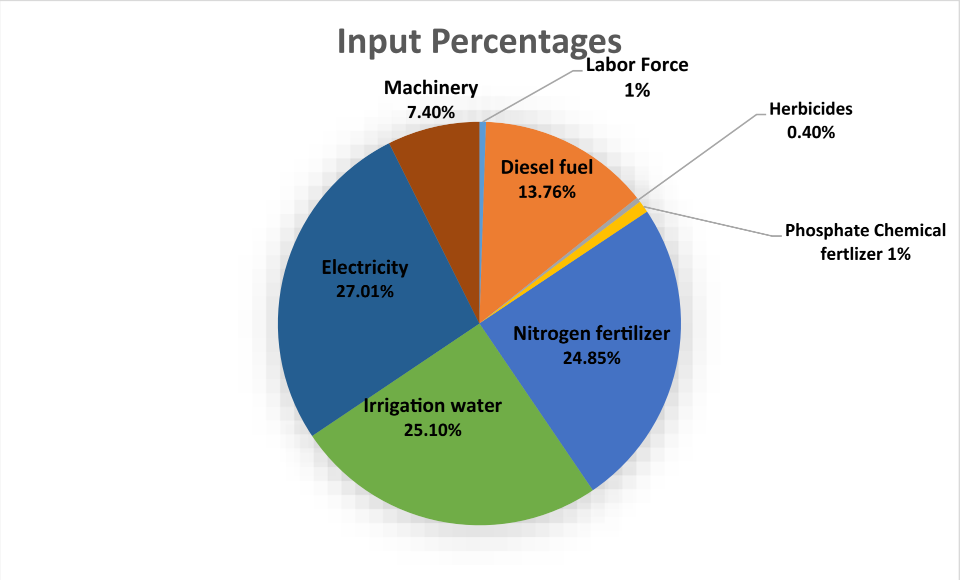


Fig. 3 The share of different inputs from the total energy consumption in sugarcane production

In this study, the functional unit used as the basis for all calculations is 1 MJ. For instance, in Table 3, it is found that each hour of labor is equivalent to 1.96 MJ, while Table 4 shows that the amount of manpower required for the transportation phase for each hectare is 25 h, which translates to 49 MJ when converted to the functional unit. All calculations were initially done for one hectare of agricultural land, and the results were then multiplied by the total area of agricultural land. This approach was taken to simplify the calculations.

As shown in Table 3, the highest energy consumed in the transportation sector is diesel fuel, which has a share of 63% of the total energy consumption, followed by machinery and labor force with 32% and 5% of other energy consumption, respectively.

3.1.2 Energy analysis in the bioethanol production stage

At this stage, bagasse is pretreated. Among many pretreatment methods, the most common is acid pretreatment, which separates the lignin layer from bagasse with a dilute H_2SO_4 solution and prepares it for hydrolysis and fermentation. Simultaneous hydrolysis and fermentation are more efficient for bioethanol production [60]. Table 5 shows the amount and energy consumption of each input considered for bioethanol production. The largest share of energy consumption in bioethanol production belongs to diesel fuel, i.e., 9.56 MJ/L of ethanol. After that, the electricity input of 2.849 MJ greatly contributes to this process. Overall, the main inputs of the production stage are diesel fuel and electricity, which have 77% and 23% shares, respectively, and other inputs have a negligible percentage in the energy input of the system.

Table 5 Amount and energy of consumed inputs in the bioethanol production process [61]

Title	Unit	Amount (per 1 L of ethanol)	Energy (megajoule per liter of ethanol)
Input			
Sulfuric acid	kg	0.146	0.321-
Lime	kg	0.030	0.016
Electricity	MJ	2.849	2.849
Fermenter	g	1.63	0.022
Water	L	6.525	0.007
Diesel fuel	L	0.2	9.56
Bagasse	kg	3.318	-
Total input energy	MJ		12.133
Output			
Ethanol	L	1	21.2

3.1.3 Energy analysis at the boundary of the conversion of bagasse to ethanol system

The largest share of energy flow is related to sugarcane agriculture, with 14.86 MJ, the main product of which is sugarcane, and bagasse is the waste of this process. After the agricultural sector, the factory sector has a large share of the energy intensity entered into the system border, and the transportation sector includes a small share due to the factory's proximity to the sugarcane plantation.

Figure 4 shows the allocation of different parts of energy input to the system. The agricultural sector has the largest allocation (i.e., 54.8%), followed by the factory sector (44.7%), and the transportation sector (i.e., 0.5%) of the total energy used to produce 1 L of ethanol.

The system's EP was 0.037 L/MJ, suggesting that 37 mL of bioethanol is produced for each MJ of energy input to the system. In the inverse state of EP, the EI shows that 27.13 MJ was used to produce 1 L of ethanol. Finally, the NEG was found to be 13.31 MJ. This value was calculated in the case that the equivalent energy of sugarcane production was calculated as the output energy. If sugarcane energy is ignored, NEG will be equal to − 5.93 MJ.

Energy indicators (i.e., ER, EP, EI, and NEG) in bioethanol production per 1 L of bioethanol production are shown in Table 6.

Using bagasse to produce bioethanol is cost-effective in terms of energy input and output to the system. Also, it makes sugarcane farming by-products very valuable.

3.2 Life cycle impact assessment (LCIA)

In this section, the environmental impacts of each of the agricultural, transportation, and bioethanol production processes are examined. Next, environmental indicators are presented during the life cycle, and the allocation of each process to the environmental indicators is determined. Input and output data were imported into the Simapro software version 9.0.0.48 and database Ecoinvent3 and analyzed through EIA using the EPD 2018 method.

EIA of the sugarcane farming stage During the sugarcane farming stage, the use of fossil fuels in agricultural machinery and the application of pesticides and herbicides have negative effects on the environmental indicators studied. For instance, the electricity consumed for field irrigation, which is generated from fossil fuels in power plants, has a detrimental impact on the global warming index.

Several agricultural activities such as agrochemical manufacturing and packaging, mechanized operations, fertilizer and pesticide applications, pre-harvest burning, and irrigation can result in pollutant emissions, including GWP,

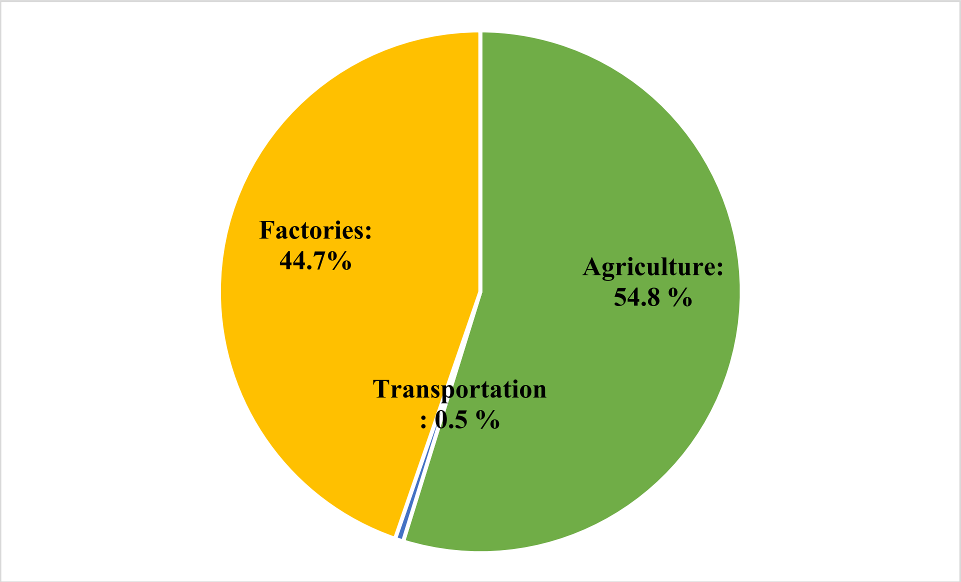


Fig. 4 Energy share of different sectors of the bioethanol production system

Table 6 Energy indicators in the bioethanol production from sugarcane bagasse (per liter of ethanol)

Title	Unit	Value
Total input energy	MJ	27.13
Total output energy	MJ	40.44
ER	-	1.49
EP	L/MJ	0.037
EI	MJ/L	27.13
NEG	MJ	13.31

acidification, and eutrophication. Additionally, irrigation can lead to significant water consumption.

Figure 5 presents the simulation and EIA results of the input and output data of the agricultural stage of sugarcane cultivation. As can be seen, nitrogen fertilizer and electricity in sugarcane cultivation have the most destructive environmental effects. Electricity is 65% effective in reducing the ozone layer, 71.1% in reducing fossil fuel resources, 60.9% in photochemical oxidation, 62.3% in global warming, and 56.1% in acidification potential. In addition, nitrogen fertilizer is 81.2% effective in reducing natural resources and 65.7% in eutrophication.

Electricity use in agriculture is a significant contributor to global warming due to its reliance on fossil fuels for energy generation, fertilizer production, irrigation, and processing and transportation of agricultural products. This reliance on fossil fuels releases greenhouse gases into the atmosphere, which contributes to global warming. To address this issue, it is important to explore sustainable farming practices and alternative renewable energy sources to reduce the impact of agriculture on global warming.

Also, the use of nitrogen fertilizers in sugarcane farming can contribute to abiotic depletion through soil acidification, nitrate pollution, eutrophication, and energy consumption. These impacts can cause the depletion of minerals and nutrients in the soil, negatively impact water resources, and contribute to the depletion of non-renewable energy resources. Sustainable agricultural practices and regulation of fertilizer use are important in mitigating the impact of nitrogen fertilizers on abiotic depletion in sugarcane farming.

EIA of bagasse transportation stage According to the system boundaries, it is not only diesel fuel that causes environmental pollution. In this respect, the infrastructure factors, such as the maintenance of the machines and the mobile parts of the trailers and containers, have harmful environmental effects, which are included in this section.

Upstream effects related to rail and truck vehicles and infrastructure manufacturing, maintenance, and roadway end-of-life account for 20% of transport impacts [62].

The EIA results of this section are shown in Fig. 6. As can be seen, fuel consumption and maintenance of transportation machinery have the greatest EIA.

In the current research, fuel consumption and maintenance of transportation vehicles had the greatest impacts. In this regard, Anna W. Larsen et al. reported that using diesel in collection trucks might be the highest critical environmental burden from the waste collection due to exhaust gases emission from the combustion process [63].

Diesel fuel has the largest EIP in areas of acidification potential with 37.7%, in abiotic depletion of fossil fuels with 71.4%, in water scarcity with 38.4%, and in ozone layer depletion with 84.5%. Maintenance of machinery also contributes the most to eutrophication at 35.7%, global warming at 38%, photochemical

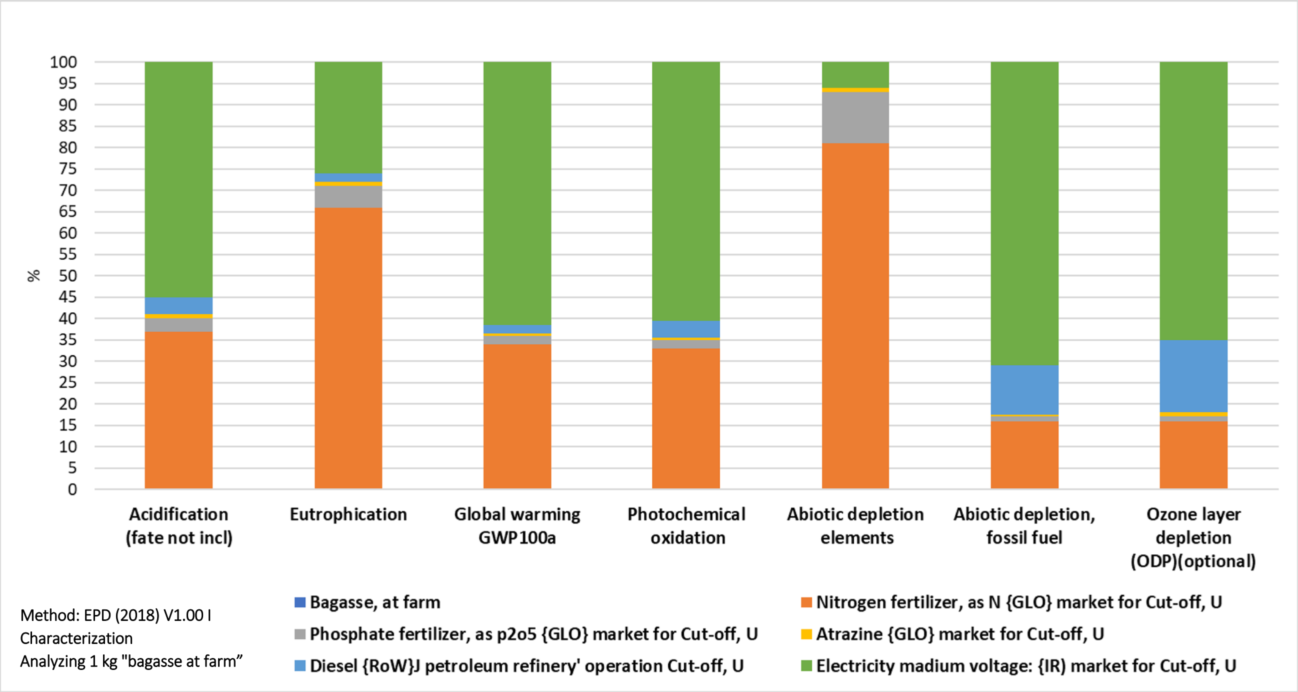


Fig. 5 The share of each consumption input in the environmental indicators in the agricultural stage

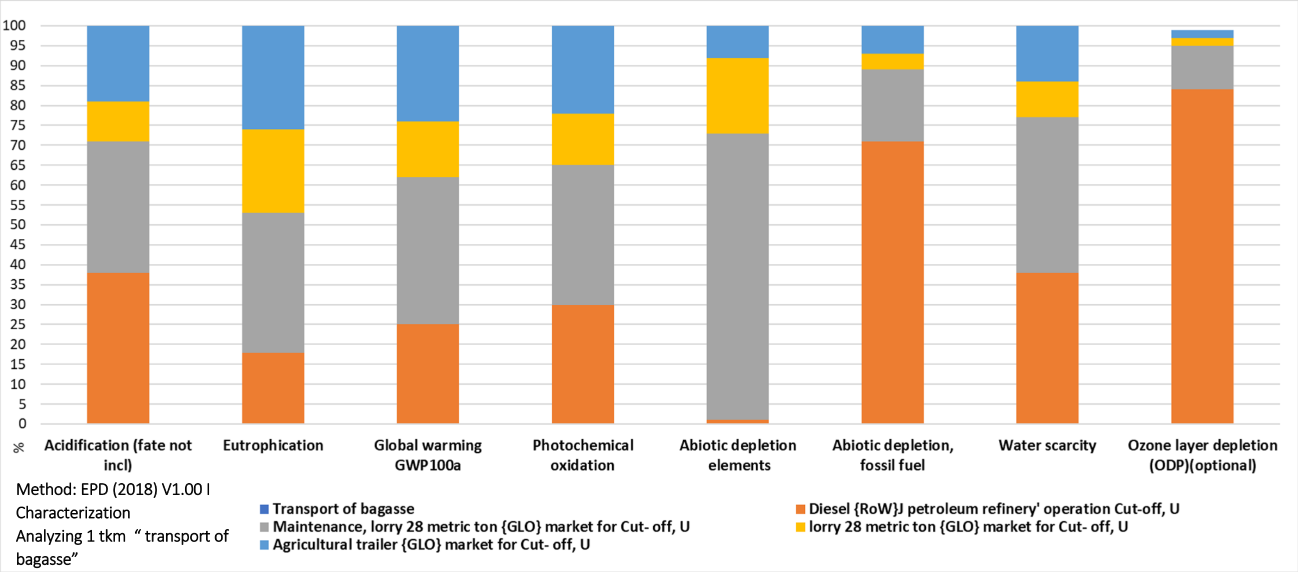


Fig. 6 The share of each consumption input in the environmental indicators in the transportation stage

oxidation at 35.4%, and the abiotic depletion of elements at 72.6%. Because the agricultural trailer and its tracker travel a long distance during their life cycle, their allocation to the environmental impact is less than the other two factors.

The use of diesel transportation of bagasse can contribute to the depletion of the ozone layer through the emissions of CFCs and particulate matter, as well as through energy consumption. Alternative, sustainable transportation methods such as electric or biofuel-powered vehicles can help reduce the impact of transportation on ozone depletion, while reducing greenhouse gas emissions and improving air quality. So, considering these reasons, diesel has the highest contribution on ozone layer depletion.

The maintenance of lorries used in transportation trucks for sugarcane farming can contribute to abiotic depletion through the use of non-renewable resources, waste generation, and energy consumption. Sustainable maintenance practices, such as the use of biodegradable lubricants and proper waste disposal methods, can help reduce the impact of maintenance on abiotic depletion. Additionally, exploring alternative, sustainable transportation methods can also help reduce the impact of transportation on abiotic depletion.

Although replacing fossil diesel with biodiesel fuel offers many environmental benefits, it also involves some disadvantages. Using biodiesel is beneficial as it saves fossil energy and produces a lower amount of GHG. However, it has negative effects such as ecotoxicity, acidification, and inorganic respiratory impacts. The higher environmental score for the GHG impact is because rapeseed assimilates CO_2 during its growth. In this respect, each ton of fossil diesel can release about 2.8 tons of CO_2 into the atmosphere, slightly higher than 1 ton of biodiesel (i.e., 2.4 tons of CO_2). Concerning inorganic respiratory impacts, biodiesel has a considerable effect, mainly due to the increase in vehicles' NO_x exhaust emissions. Certainly, the biodiesel impacts are considerably lower than those of diesel, mainly because of sharp declines in CO_2 [64].

In the current research, the largest EIA is related to ozone layer depletion, while Hannah Hyunah Cho et al. reported the largest EIA for CO_2 emissions.

EIA of bioethanol production stage As shown in Fig. 7, electricity and diesel fuel have more destructive effects due to their higher consumption than other inputs. In the "Energy analysis" section, these two inputs consumed more energy than others.

The environmental impacts of electrical energy generation contribute a large share of the total environmental burdens identified in product LCAs, across a wide range of product types impacts [65].

Electricity has the greatest allocation in acidification potential at 68.8%, global warming at 80.9%, photochemical oxidation at 68.8%, and abiotic depletion of elements at 73.2%. Diesel fuel also has the largest share in ozone layer depletion and abiotic depletion of fossil fuels, with 62% and 48.4%, respectively. However, in the eutrophication index, process water consumption has a share of 63.8%, which is more than other consumption inputs of this sector. Overall, it is concluded that using biofuels offers great environmental advantages in terms of non-renewable energy. Also, using this energy source, global warming does not alter regarding the allocation methods in the DDGS product system [66].

The use of water in bioethanol production can contribute to eutrophication through nutrient runoff, waste disposal, energy consumption, and water scarcity. Sustainable water management practices, such as the use of recycled water and efficient irrigation systems, can help reduce the impact of water use on eutrophication in bioethanol production. For more clarification, bioethanol production requires a significant amount of water, which can exacerbate water scarcity in regions that are already experiencing water stress. This can impact local ecosystems and contribute to eutrophication by reducing the volume and quality of available water.

Electricity used during bioethanol production can contribute to acidification due to the release of sulfur dioxide and nitrogen oxides from fossil fuel combustion. The manufacturing and transportation of equipment for bioethanol production, as well as waste management practices, can also contribute to acidification if non-renewable energy sources are used. To mitigate these impacts, renewable energy sources should be

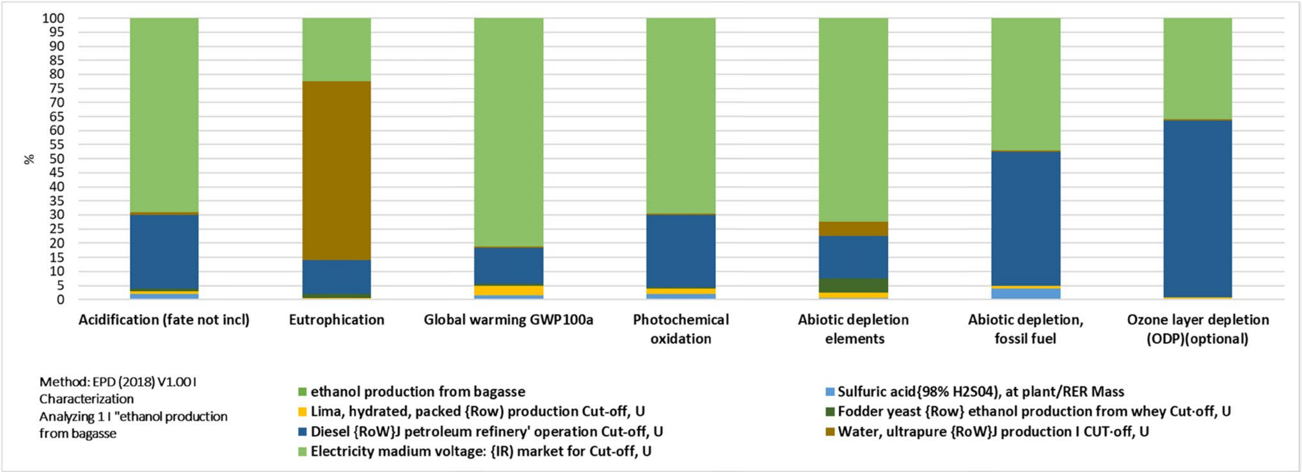


Fig. 7 Allocation of each consumed input in the environmental indicators in the bioethanol production stage

used and electricity consumption reduced during bioethanol production. Proper waste management and equipment manufacturing and transportation can also help reduce acidification.

In the present current research, the largest allocation is related to global warming. The most significant allocation in the current research is attributed to global warming. This finding is consistent with the conclusion reached by Santoyo-Castelazo et al. that the use of biofuels in vehicles, as well as their production stages, has a significant impact on global warming potential (GWP). The study determined that the GWP impact of biofuel production is approximately 26.7 kg CO_2-eq/L. [44].

3.3 Scenario assessment

In this study, three scenarios were considered. The first scenario involved producing bioethanol from sugarcane bagasse, which was then burned to generate electricity. The second scenario involved simultaneously producing bioethanol and electricity from bagasse. These scenarios were chosen because of the large amount of bagasse generated in the Khuzestan province of Iran, which is typically burned in open air, resulting in significant energy waste. By comparing the option of producing electricity from burned bagasse with the production of bioethanol, the study aimed to identify the most efficient approach. The third scenario proposed a combined option to increase the overall efficiency of bioethanol production.

3.3.1 First scenario (base case/process): producing bioethanol from sugarcane bagasse

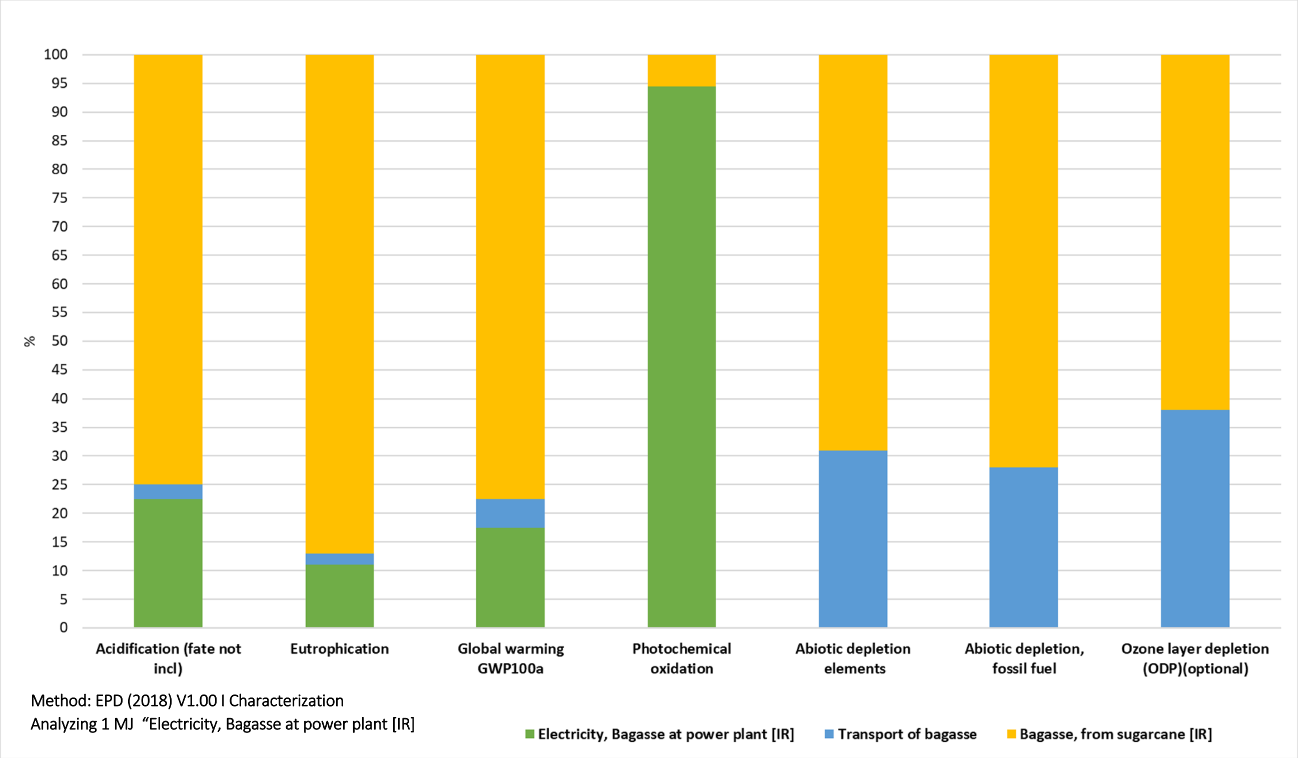
The base scenario produces bioethanol using sugarcane bagasse, which is considered waste in sugarcane fields.

3.3.2 The second scenario: producing energy from burning bagasse

This scenario's first and second stages are the same as the base scenario. In this scenario, the inputs of the agricultural and transportation stages are the same as the base scenario. After the bagasse reaches the factory, it is burned to produce electricity instead of bioethanol. Because bagasse is a by-product of sugarcane farming, a high amount of energy is consumed in sugarcane farming.

In bagasse combustion, 76% of the steam produced is used to manufacture sugar [65].

Figure 8 presents the EIA results of the second scenario. The agricultural stage has the greatest environmental impact. In this stage, acidification potential contributes



Method: EPD (2018) V1.00 I Characterization
Analyzing 1 MJ "Electricity, Bagasse at power plant [IR]

Fig. 8 The allocation of each stage of the life cycle of electricity production from bagasse in environmental indicators to 74.4%, eutrophication to 87%, global warming to 78%, abiotic depletion of elements to 69.2%, abiotic depletion of fossil fuel to 71.4%, and ozone layer depletion to 61.7% of the impacts. The electricity generation stage also has the largest share in the photochemical oxidation sector, with 94.4%. In total, the two indicators of the abiotic depletion of natural resources and the ozone layer depletion in this process had a small allocation to the environmental effects of this process.

The production of electricity from sugarcane bagasse can contribute to a high level of photochemical oxidation due to the burning of bagasse, land use changes associated with sugarcane cultivation, and energy consumption. To reduce these impacts, it is important to use sustainable land use practices, minimize the burning of bagasse by using more efficient power plant technologies, and reduce energy consumption and emissions during the production and transportation of bagasse. For more clarification, the burning of sugarcane bagasse to generate electricity can release a variety of air pollutants, including volatile organic compounds (VOCs) and nitrogen oxides (NO_x), which can contribute to photochemical oxidation when they react with sunlight in the atmosphere.

The results of the bagasse electricity production system in (Ramjeawon 2008) research indicated that producing 1 GWh of electricity from bagasse requires about a land area of 203 ha, using 224,000 m^3 of water, and producing 15,385 t of sugarcane and 4615 t of bagasse. In this process, about 261,000 MJ of fossil fuel is consumed. The agriculture step (i.e., sugarcane cultivation and harvest, and herbicides fertilizers manufacturing) accounts for the largest share of this energy consumption. Using fossil fuel energy involves releasing a global warming potential of 35,600 kg per GWh of electricity. The net avoided emission of CO_2 because of using bagasse as an energy source is about 310,000 t. This value is equivalent to 15% of all fossil fuel emissions in Iceland [65].

Compared to the present study, wherein the largest allocation is related to eutrophication, in Toolseeram Ramjeawon's research, the net avoided emissions of CO_2 are much less when using fossil fuel emissions.

3.3.3 The third scenario: producing bioethanol and burning bagasse at the same time

In this scenario, the amount of electricity required to produce bioethanol from sugarcane bagasse is obtained by burning bagasse. The difference between the third and base scenario is in the bioethanol production stage, which eliminates electricity consumption and makes the bioethanol production process more efficient. In this scenario, the mixing percentage is determined so that for the bioethanol production from sugarcane bagasse, there is no need to use grid electricity, and all the energy consumed is obtained from burning bagasse. Hence, the energy analysis of this scenario shows better indicators than those for the base research scenario.

Figure 9 presents the life cycle stages of bioethanol production in environmental indicators in this scenario. In the acidification potential index, the allocation of bioethanol production is 30%, transportation is 0.63%, agriculture is 52.3%, and bagasse burning is 17.1%. In the eutrophication sector, the allocation of the production stage is 33.6%, transportation 0.63%, agriculture 41.1%, and bagasse burning 24.7%. Also, in the global warming index, the allocation of the production stage is 32.1%, transportation is 0.46%, agriculture is 59.1%, and electricity generation from bagasse is 8.37%. In the photochemical oxidation index, the allocation is 5.21% for the production stage, 0.13% for transportation, 8.36% for the agricultural stage, and 86.3% for the electricity production from the bagasse. These values suggest excessive pollution in this index in the bagasse burning stage. In the abiotic depletion of natural resources, the allocation of the production stage is 4.28%, the transportation stage is 4.62%, the agriculture stage is 79.2%, and bagasse burning is 11.9%. In the fossil fuel reduction index, which is directly affected by fuel and electricity consumption, the production stage contributes 49.8%, transportation 1.04%, agriculture 46.3%, and electricity production from bagasse 2.87%. The last index evaluated in this research is ozone layer depletion, in which the allocation of the bioethanol production stage is 54%, transportation is 1.21%, agriculture is 42.3%, and bagasse burning is 2.51%.

3.3.4 Choosing the best scenario

Table 7 shows the energy indicators of each scenario.

(1): In the second scenario, because there is no product (bioethanol), the energy indicators for 1 ha of sugarcane field are considered instead of 1 L of ethanol. The third scenario shows the highest ER and EP. However, among the environmental indicators, the results are different (Fig. 10). This scenario shows a higher degree of abiotic depletion of natural resources, abiotic depletion of fossil fuel resources, and ozone layer depletion in terms of global warming indicators. In addition, the second scenario also has more destructive effects on the indices of potential acidification, eutrophication, and photochemical oxidation than other scenarios.

Overall, the base scenario can be chosen as the best scenario in terms of the environment in this research.

In the following, these scenarios are compared based on human health indicators, ecosystems, and resources. The results show that in the human health index, the second scenario (electricity production from bagasse) has the highest score, followed by the third scenario with about 75% of it, and the base scenario (i.e., bioethanol production from sugarcane bagasse) with 60% compared to the second scenario.

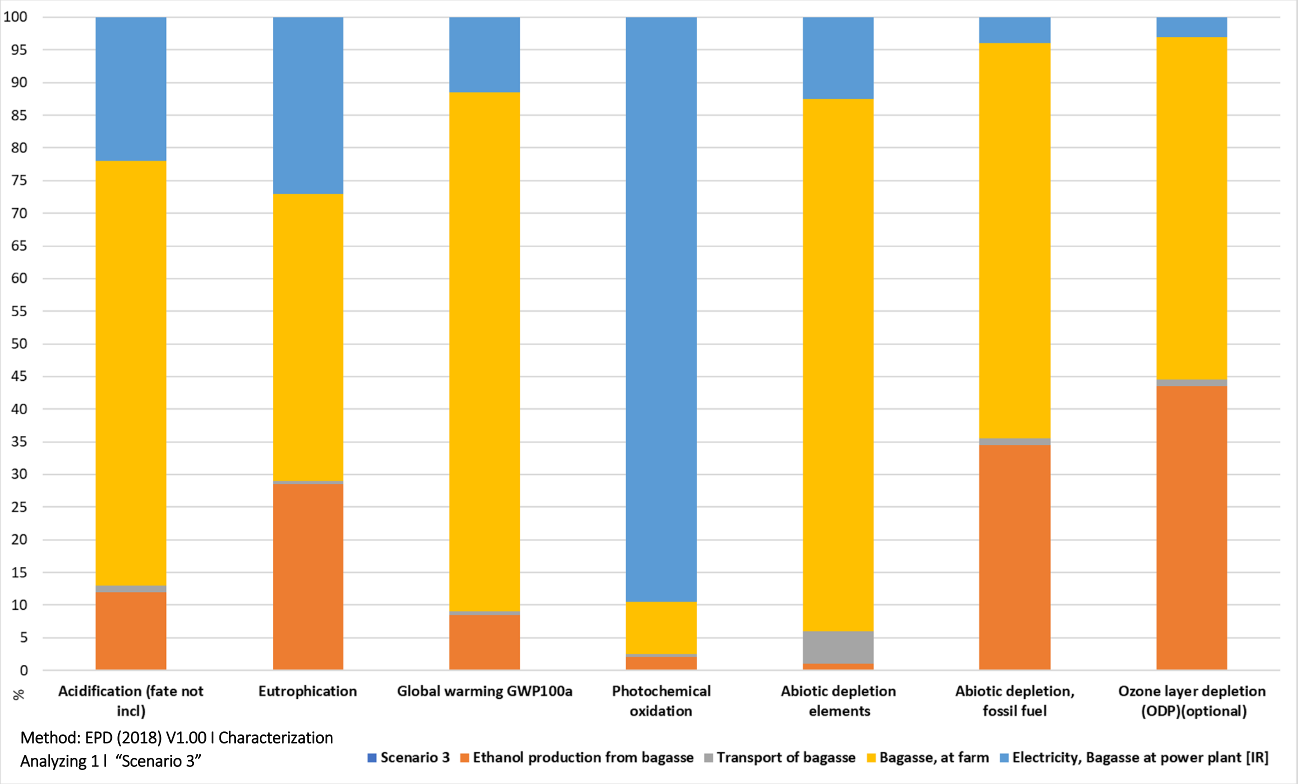


Fig. 9 Allocation of each life cycle stage of bioethanol production in environmental indicators

Table 7 Energy indices of the scenarios

Title	Unit	Base scenario	Scenario 2	Scenario 3
The total input energy	MJ	27.130	118’991.0	24.284
The total output energy	MJ	40.440	161’474.0	40.440
ER	-	1.490	1.360	1.670
EP	MJ/L	0.037	-	0.041
EI	L/MJ	27.130	-	24.284
NEG	MJ	13.310	42’483.0	16.156

The third scenario has the highest score in the ecosystem index, suggesting that it brings the most destructive effects to the ecosystem. The next ranking is for the base scenario, whose index is above 90%. But the second scenario, unlike human health, shows a value of less than 50% in the ecosystem index.

Figure 11 illustrates the resource, human health, and ecosystem indices for each scenario. As depicted in the figure, scenario 3 demonstrates the greatest impacts on three indices, with a difference only slightly smaller than that of the base scenario. In contrast, scenario 2, which involves direct energy generation from burning bagasse, exhibits the lowest utilization of natural resources, accounting for less than 25% of the utilization seen in scenario 3. Overall, the three scenarios are ranked as follows:

1. The third scenario (bioethanol production and electricity in the form of a mixture)
2. The second scenario (production of electricity from bagasse)
3. Base scenario (bioethanol production from bagasse)

As mentioned in the energy analysis, the third scenario had the best energy efficiency. However, after the environmental analysis, this scenario was ranked as the worst when using the total environmental indicators.

4 Conclusion

Numerous industrial and non-industrial uses of ethanol have encouraged researchers to try various methods to produce this valuable matter. In this regard, sugarcane bagasse is found in large quantities in sugarcane fields and

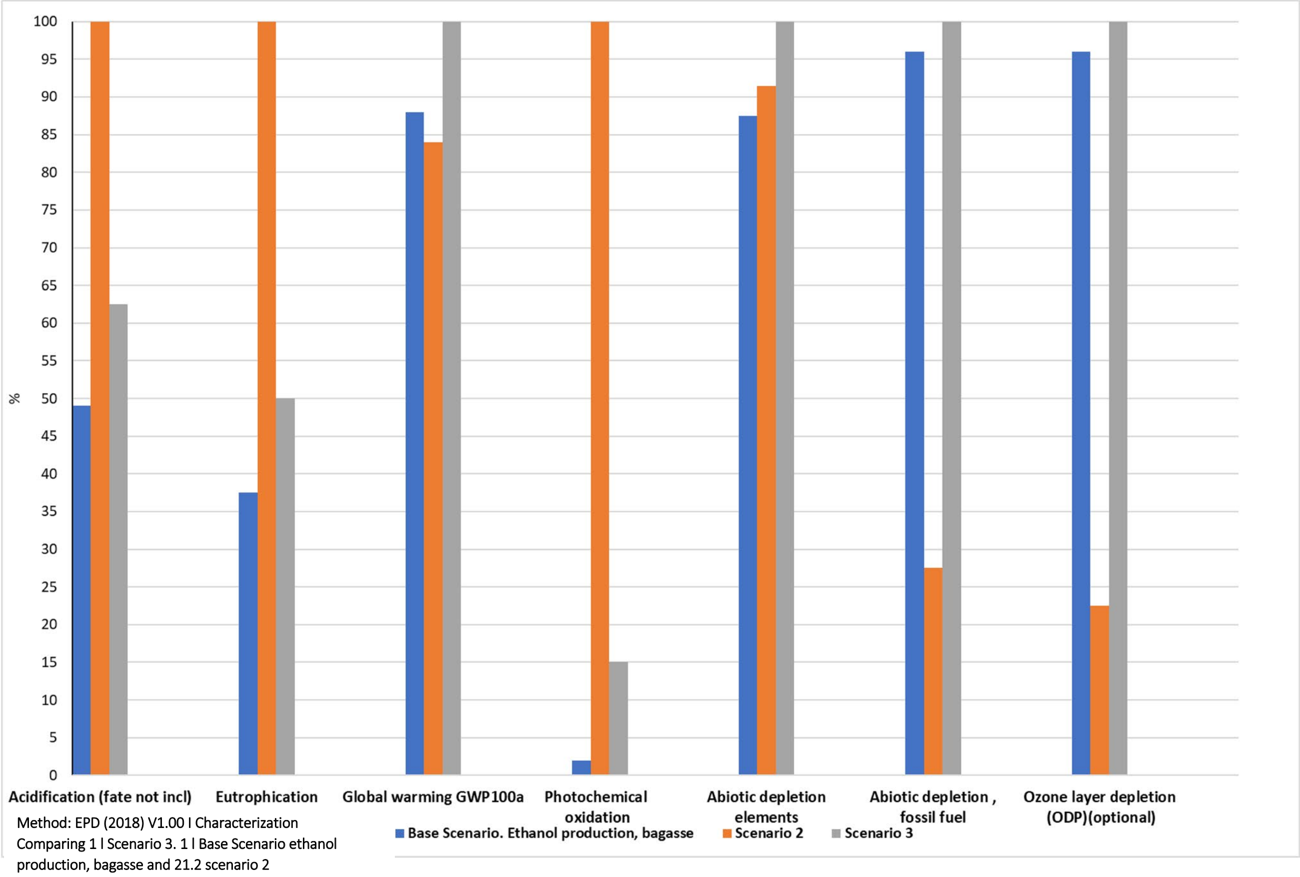


Fig. 10 Comparison of base scenario and scenarios (2) and (3) in environmental indicators

has multiple uses. The current research investigates energy and environmental issues for three energy extraction scenarios from sugarcane bagasse. The results showed that energy indices for bioethanol production, including ER, EP (liter/MJEI (MJ/L), and NEG (MJ), were calculated to be 1.49, 0.037, 27.13, and 13.31, respectively. Comparing the bioethanol production from bagasse with the extraction of electricity from sugarcane bagasse and the bioethanol production simultaneously with the extraction of electricity, the third scenario (mix scenario) showed the highest energy efficiency in energy analysis.

In the environmental assessment, the third scenario showed the most indicators in the sectors of global warming, abiotic depletion of elements, abiotic depletion of fossil fuel resources, and ozone layer depletion. Besides, the base scenario (bioethanol production from bagasse) had lower effects in all indicators than other scenarios. The negative environmental effects of the investigated process on human health and the ecosystem were much more than its effect in the field of natural resource consumption.

The biggest allocation to the life cycle of bioethanol production from sugarcane bagasse is related to using fossil fuel and electricity in various processes, which can be reduced by replacing clean energy with energy consumed from fossil fuels. In other words, fossil fuels have the largest contribution to the harmful environmental effects of the bioethanol production process, whether they are involved directly or used for the production of electricity. To reduce these negative effects, it is necessary to replace fossil fuels with clean fuels. However, this replacement could potentially reduce the production of bioethanol.

Future research suggestions include exploring and comparing ethanol production from various raw materials, such as wheat straw and corn, in different regions. Additionally, finding ways to reduce energy consumption in the bioethanol production process to increase productivity is recommended. Since the current research only defined the boundary until the production of bioethanol, future studies could investigate the use of bioethanol fuel in combustion engines and exhaust pollutants to obtain more accurate results on both energy and environmental issues.

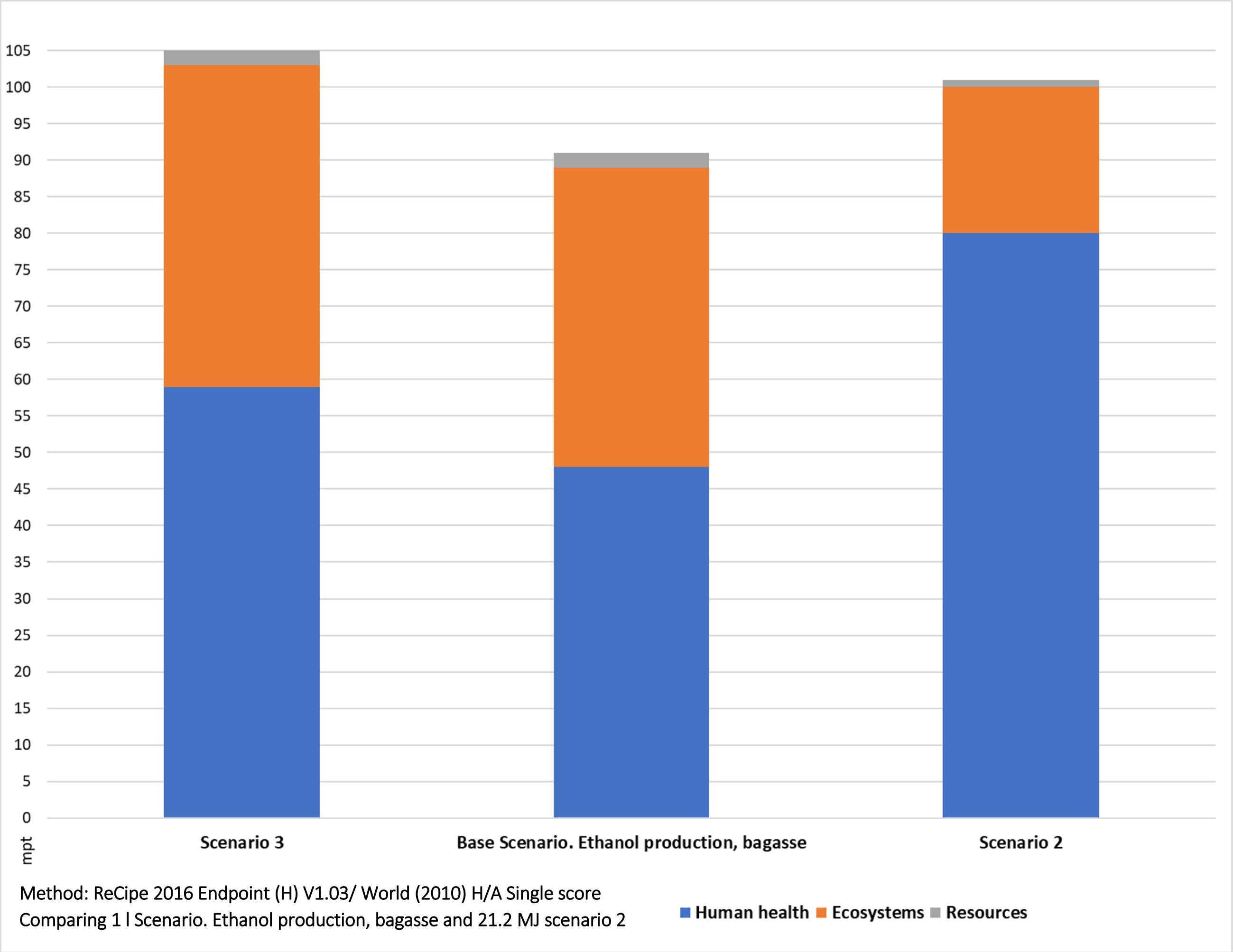


Fig. 11 Evaluation of environmental indicators in different scenarios: a comparative analysis

Data availability The datasets generated during and/or analyzed during the current study are not publicly available due to ethical concerns but are available from the corresponding author on reasonable request.

Author contribution Arman Satari Dibazar, Arash Aliasghar, Asal Behzadnezhad, Aria Shakiba, and Maryam Pazoki contributed to the design and implementation of the research, to the analysis of the results, and to the writing of the manuscript.

Declarations

Competing interests The authors declare no competing interests.

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