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Investigation of the energy use and environmental emissions assessment in the cultivation of soybean and peanut: A case study

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Abstract

This research aims to explore the energy usage and environmental impact of cultivating soybean and peanut, with a specific focus on a case study. The cultivation of these crops is crucial for agricultural production, and understanding their energy use and potential damage is essential for sustainable farming. The results of this study will be valuable for farmers, policymakers, and researchers working towards sustainable agricultural production. The study reveals that soybean production in Ardabil province of total energy was 43170.20 MJ ha^{-1}, also, output energy was 40417.28 MJ ha^{-1}, while peanut production requires 28677.36 MJ ha-1 of total energy and produces 28677.36 MJ ha^{-1} of output energy. The results of the Life Cycle Assessment (LCA) show that emissions on farms are closely related to the inputs used in soybean and peanut production. Diesel fuel and chemical fertilizers are the main sources of emissions in both systems, with soybean farming showing higher levels of diesel fuel pollutants due to reduced usage compared to peanuts. The distribution of emissions from different sources in soybean and peanut production is highlighted in the study. Both methods of production have a significant impact on human health, with soybean responsible for 70% of emissions and peanuts contributing 65%. Diesel fuel and nitrogen fertilizer have the most significant environmental impact, accounting for over 50% of the overall impact. Proper management of nitrogen fertilizer is essential for maximizing crop growth and yield, making it a top priority for researchers and farmers.

Keywords: Energy use, Life Cycle Assessment (LCA), Peanut, Soybean

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بررسی مصرف انرژی و ارزیابی انتشارات زیست‌محیطی در کشت سویا و بادام زمینی: مطالعه موردی

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چکیده

هدف این تحقیق بررسی مصرف انرژی و تأثیر زیست محیطی کشت سویا و بادام زمینی، با تمرکز خاص بر یک مطالعه موردی است. کشت این محصولات برای تولید کشاورزی بسیار مهم است و درک مصرف انرژی و آسیب احتمالی آن‌ها برای کشاورزی پایدار ضروری است. نتایج این مطالعه برای کشاورزان، سیاست گذاران و محققانی که در راستای تولید پایدار کشاورزی تلاش می‌کنند ارزشمند خواهد بود. این بررسی نشان می‌دهد که تولید سویا در استان اردبیل با انرژی کل ۴۳۱۷۰/۲۰ مگاژول در هکتار و همچنین انرژی خروجی ۴۰۴۱۷/۲۸ مگاژول در هکتار و تولیدبادام زمینی‌به ۲۸۶۷۷/۳۶ مگاژول در هکتارکل انرژی نیاز دارد و ۲۸۶۷۷/۳۶ مگاژول در هکتار انرژی تولید می‌کند. انرژی خروجی نتایج ارزیابی چرخه زندگی (LCA) نشان می‌دهد که انتشار گازهای گلخانه‌ای در مزارع ارتباط نزدیکی با نهاده‌های مورد استفاده در تولید سویا و بادام زمینی دارد. سوخت دیزل و کودهای شیمیایی منابع اصلی انتشار در هر دو سیستم هستند، به طوری که کشاورزی سویا به دلیل کاهش مصرف در مقایسه با بادام زمینی، سطوح بالاتری از آلاینده‌های سوخت دیزل را نشان می‌دهد. توزیع انتشار گازهای گلخانه‌ای از منابع مختلف در تولید سویا و بادام زمینی در این مطالعه برجسته شده است. هر دو روش تولید تأثیر قابل توجهی بر سلامت انسان دارند، به طوری که سویا مسئول ۷۰ درصد انتشار گازهای گلخانه‌ای و بادام زمینی ۶۵ درصد است. سوخت دیزل و کود نیتروژن بیشترین تأثیر زیست‌محیطی را دارند و بیش از ۵۰ درصد از تأثیر کلی را تشکیل می‌دهند. مدیریت صحیح کود نیتروژن برای به حداکثر رساندن رشد و عملکرد محصول ضروری است و آن را در اولویت اول برای محققان و کشاورزان قرار می‌دهد.

واژه‌های کلیدی: مصرف انرژی، ارزیابی چرخه زندگی، بادام‌زمینی، سویا

1. Introduction

The production of crucial food items and the economic growth heavily depend on cultivating soybeans and peanuts. Yet, these activities have a notable ecological footprint and demand a large energy input. It is crucial to focus on energy efficiency and assess environmental metrics in the cultivation of soybeans and peanuts to promote sustainable agricultural methods. This includes identifying strategies to reduce energy consumption in various tasks and systems (Altieri et al., 2012; Ghasemi-Mobtaker et al., 2020; Simpeh et al., 2022). Utilizing renewable energy sources can assist businesses and individuals in decreasing their dependence on fossil fuels and overall energy usage. Furthermore, adopting energy-efficient transportation options such as carpooling, utilizing public transportation, and using fuel-efficient vehicles can further improve energy efficiency. Ultimately, prioritizing energy efficiency is crucial for reducing energy consumption, saving money, and lessening environmental harm (Savelli and Morstyn, 2021). Significant improvements in energy efficiency across various societal sectors require a combination of technological advancements, changes in behavior, and policy initiatives. Evaluating environmental indicators involves a thorough assessment of different environmental aspects to understand its current state and possible consequences (Ruparathna et al., 2016). This evaluation encompasses the analysis of air and water quality, biodiversity, land use, and other elements that impact the overall environmental well-being. Environmental indicators serve as tools for gauging and tracking environmental changes over time, offering crucial insights for decision-making and policy formulation. The assessment of these indicators involves the gathering of data, trend analysis, and identification of potential areas requiring attention or enhancement (Singh et al., 2012). Environmental assessments can be carried out at different levels, ranging from local to global, and can aid in pinpointing areas that require intervention to safeguard the environment and advance sustainability. Through the evaluation of environmental indicators, stakeholders can gain a deeper understanding of the environment's condition and make well-informed choices to counteract environmental decline and support conservation initiatives (Lyche Solheim et al., 2019). Alluvione et al. (2011) investigated energy flows in a wheat-maize-soybean-maize rotation across three distinct cropping systems: low-input integrated farming (LI), integrated farming following European Regulations (IFS), and conventional farming (CONV). Their findings suggest that aligning nitrogen fertilization with actual crop needs and adopting minimum tillage are the most efficient approaches for decreasing energy inputs, accounting for 64.7% and 11.2% of the total reduction, respectively. Nabavi-Pelesaraei et al. (2021) conducted a study to assess the exergoenvironmental efficiency of using solar technologies for sunflower oil production in Iran. The energy analysis revealed that the production of 1 ton of sunflower oil necessitates around 180,354 MJ of energy and generates approximately 39,400 MJ. Taherzadeh-Shalmaei et al. (2023) conducted a study to investigate energy consumption and environmental emissions in the mushroom production industry. They utilized an energy audit analysis and a life cycle assessment (LCA) to achieve this. The energy audit analysis showed that the total input energy for mushroom production was 1022537.82 MJ ha^{-1}, while the total output energy was only 11125.94 MJ ha^{-1}. This resulted in an energy use efficiency rate of 0.01, indicating substantial energy imbalance and inefficiency.

In the context of producing essential food products and boosting the economy through soybean and peanut farming, it is crucial to address the significant environmental impact and energy consumption associated with these practices. Prioritizing energy efficiency and evaluating environmental indicators are key steps towards ensuring sustainable agricultural practices in this sector. The literature review highlights existing research emphasizing the importance of minimizing energy usage, utilizing renewable energy sources, and implementing energy-efficient transportation methods to reduce environmental impact and enhance sustainability in agriculture. The identified knowledge gaps in the literature point towards the need for a comprehensive investigation into the energy use and environmental emissions specifically related to soybean and peanut cultivation. While previous studies have examined the environmental impact of agricultural practices in general, there is a lack of specific focus on the energy consumption and emissions associated with these two crucial crops. This research aims to address this gap by conducting a detailed case study on soybean and peanut cultivation, providing valuable insights into their energy efficiency and environmental sustainability. The novelty of this work lies in its specific focus on soybean and peanut crops, offering a unique perspective on the energy consumption and emissions of these important agricultural products. By exploring innovative techniques and technologies, such as precision agriculture and alternative energy sources, this research aims to contribute to the advancement of sustainable farming practices in the soybean and peanut industry. The findings from this study can inform decision-making processes for farmers, policymakers, and other stakeholders, guiding them towards more sustainable crop production practices and environmental conservation efforts. Overall, this research not only adds to the existing body of knowledge on sustainable agriculture but also provides practical insights and solutions for improving the energy efficiency and environmental sustainability of soybean and peanut cultivation. By bridging the gap between energy consumption, environmental impact, and agricultural practices, this work aims to drive positive change towards a more sustainable and efficient farming sector. The novelty of this work lies in its comprehensive investigation of the energy use and environmental emissions associated with the cultivation of soybean and peanut crops. While there have been previous studies on the environmental impact of agricultural practices, this research specifically focuses on the energy consumption and emissions of two important crops, soybean and peanut. By conducting a case study on these specific crops, the researchers are able to provide valuable insights into the energy efficiency and environmental sustainability of soybean and peanut cultivation. This information can help farmers, policymakers, and other stakeholders make informed decisions about crop production practices and sustainability initiatives. Additionally, the researchers may also explore innovative techniques and technologies that can help reduce energy consumption and emissions in crop cultivation. This could include the use of precision agriculture, sustainable farming practices, and alternative energy sources. Overall, this work contributes to the growing body of research on sustainable agriculture and provides valuable information for improving the environmental performance of crop cultivation.

2. Materials and methods

2.1. Case study regine

This research was conducted in Parsabad, Moghan, a city located in the Ardabil province of northwest Iran. Positioned on the southern bank of the Aras River and to the west of the Caspian Sea, Parsabad is situated between 39 ´ and 12° to 39 ´ and 42° north latitude, and 47 ´ and 10° to 48 ´ and 21° east longitude from the Greenwich meridian (Ministry of Jihad-e-Agriculture of Iran, 2021). Figure 1 displays the location of Ardabil province, this region holds significant importance in the field of agriculture in Iran. The study involved determining a sample size of 150 farmers using Equation 1 to evaluate their awareness and attitudes towards input consumption and crop production. The sample size was calculated based on similar studies and the formula for cross-sectional studies, with a significance level of p=0.05 and an accuracy of d=0.07 (Cochran, 1977). Data was gathered using a standardized questionnaire, which was designed based on previous research with minor adjustments. The questionnaire comprised three main sections: personal information and background, irrigation methods, and awareness of water conservation practices.

Fig. 1. Geographical status of the investigated region in Ardabil province, Iran.

$$n = \frac{\frac{z^2 pq}{d^2}}{1 + \frac{1}{N}\left(\frac{z^2 pq}{d^2} - 1\right)} \qquad (1)$$

The required sample size (n) is determined by the number of farms per target population (N), the reliability coefficient (z) which equals 1.96 representing a 95% confidence level, the estimated proportion of an attribute in the population (p) which equals 0.5, the complement of the estimated proportion (q) which also equals 0.5, and the permitted error ratio deviation from the average population (d) which equals 0.05.

2.2. Energy

Energy use analysis involves evaluating and understanding how energy is utilized within a system, building, or organization. This includes gathering and analyzing data on energy consumption, identifying usage patterns and trends, and assessing the effectiveness of energy systems and equipment. The aim is to identify areas for improvement and develop strategies to reduce energy consumption, increase efficiency, and lower costs. This may involve conducting audits, using monitoring systems, and implementing energy-saving technologies and practices. Key steps in energy use analysis may involve examining energy inputs, outputs, and coefficients related to production (Altieri et al., 2012). The energy inputs, outputs, and coefficients for soybean and peanut production are shown in Table 1.

Table 1
Energy inputs-outputs and coefficients in the production of soybean and peanut.

Items	Unit	Energy equivalent (MJ unit^{-1})	References
A. Inputs			
1. Human labor	h	1.96	(Kaab et al., 2019)
2. Machinery	kg yr	62.7	(Ordikhani et al., 2021)

3. Diesel fuel	kg	56.31	(Molaee Jafrodi et al., 2022)
4. Chemical fertilizers	kg		
(a) Nitrogen		66.14	(Taherzadeh-Shalmaei et al., 2021)
(b) Phosphate (P_2O_5)		12.44	(Khalaj et al., 2023)
(b) Potassium (K)		11.15	(Kaab et al., 2023)
5. Farmyard manure	kg	0.3	(Nabavi-Pelesaraei et al., 2019b)
6. Biocides	kg	120	(Kaab et al., 2019)
7. Electricity	kWh	11.93	(Mohammadi Kashka et al., 2023)
8. Soybean seed	kg	23.20	(Maysami, 2013)
9. Peanut seed	kg	25.00	(Nabavi-Pelesaraei et al., 2013)
*B. Output*s	kg		
1. Soybean		23.20	(Maysami, 2013)
2. Peanut		25.00	(Nabavi-Pelesaraei et al., 2013)

We have identified four key energy indicators (Equations 2 to 5) to evaluate energy efficiency, energy productivity, energy intensity, and net energy gain. The energy consumption efficiency index measures the amount of energy harvested per MJ ha^{-1} of energy used for production, with a higher ratio indicating better energy efficiency. The energy productivity index shows the output achieved kg MJ^{-1} of input energy. The specific energy index calculates the ratio of total energy input to product performance, with a higher value indicating greater energy wastage. Finally, the net energy index evaluates the net energy output (Kaab et al., 2019).

$$\text{Energy efficiency} = \frac{\text{Output Energy}}{\text{Input Energy}} \tag{2}$$

$$\text{Energy Productivity} = \frac{\text{Production}}{\text{Input Energy}} \tag{3}$$

$$\text{Energy intensity} = \frac{\text{Input Energy}}{\text{Production}} \tag{4}$$

$$\begin{aligned}\text{Net Energy Gain} = {} & \text{Output Energy} \\ & - \text{Input Energy}\end{aligned} \tag{5}$$

2.3. LCA

LCA is a method used to evaluate the environmental impact of a product or process from its creation to its disposal. The goal of LCA is to identify and measure the environmental effects of a product or process, including its carbon emissions, energy usage, water consumption, and waste production (Elyasi et al., 2022; Taherzadeh-Shalmaei et al., 2023). During the inventory analysis phase, data is gathered on the inputs and outputs of the product or process, such as raw materials, energy use, emissions, and waste generation. The impact assessment phase involves assessing the potential environmental impacts of these inputs and outputs, such as greenhouse gas emissions, water pollution, and resource depletion (Nabavi-Pelesaraei et al., 2019a). Interpreting the results of LCA analysis is critical for identifying opportunities for improvement and guiding decision-making. Businesses, governments, and organizations commonly use LCA analysis to inform decisions about product design, manufacturing processes, and waste management strategies. It can also be used to compare the environmental performance of different products or processes and identify areas for improvement to minimize environmental impacts (Kaab et al., 2020). Figure 2 shows how the stages of LCA define the parameters of soybean and peanut production systems. The steps of LCA, as outlined by Azizpanah et al. (2023), include: 1. Establishing the goal and scope of the LCA study by defining the functional unit (FU), system boundaries, and impact categories to be assessed; 2. Collecting data on the inputs and outputs of the product or process under study, including raw materials, energy consumption, emissions, and waste generation; 3. Evaluating the environmental effects of the resources used and the waste produced using life cycle impact assessment tools like ReCiPe or similar methods; 4. Analyzing the impact assessment results to identify areas with the most significant impact and opportunities for improving the product or process; 5. Making recommendations for improving the environmental performance of the product or process, such as through changes in materials, production methods, or end-of-life management; 6. Communicating the results of the LCA study to stakeholders, such as consumers, regulators, and industry partners, to inform decision-making and promote sustainable practices.

Damage assessment involves evaluating the extent of damage to buildings, infrastructure, and other property caused by natural disasters, accidents, or other events. Trained professionals such as engineers, architects, or insurance adjusters typically conduct this assessment by inspecting the affected area and documenting the damage. This process helps determine the cost of repairs, the safety of the structure, and the level of assistance needed for recovery efforts. It plays a crucial role in guiding decisions on rebuilding and resource allocation. Additionally, it incorporates human health, ecosystem quality, and resource scarcity as the three areas of protection and calculates characterization factors for endpoints linked to these areas of protection from midpoint characterization factors. Seventeen midpoint impact categories are taken into account in this process.

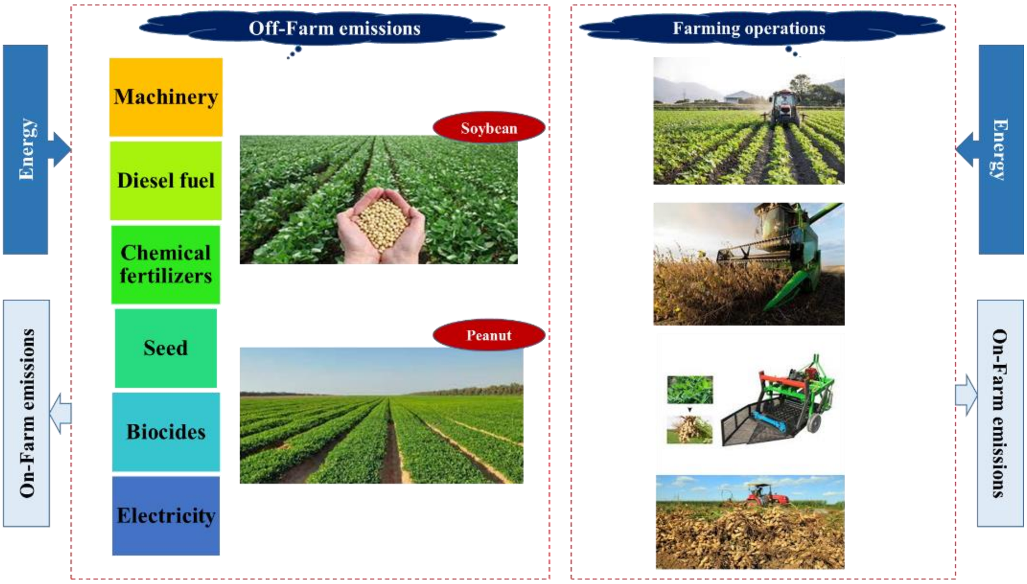


Fig. 2. The LCA stages delineate the boundaries of soybean and peanut production systems.

In LCA, inputs classified as Off-Farm emissions encompass human labor, electricity, water, seeds, biocides, chemical fertilizers, diesel fuel, and machinery. On the other hand, agricultural machinery such as tractors and trailers used for various farm tasks contribute to On-Farm emissions. To assess emissions related to machinery usage, diesel fuel combustion, and chemical fertilizers, data from Table 2, Table 3, and Table 4 is gathered. It is crucial to maintain uncontaminated fuel for optimal performance, as mishandling can lead to fuel pollution, resulting in contaminants like water, dust particles, and microbial growth, leading to black sludge. Therefore, ensuring fuel quality is essential for efficient operation, extended service life, and emission control in engines (Soam et al., 2017). Strategic crop production heavily relies on rice fertilizer, which is vital for boosting crop yields. However, excessive fertilizer use can have adverse effects, such as reducing yields and increasing environmental emissions. Chemical fertilizers negatively impact air and water quality and can lead to the emission of greenhouse gases and heavy metals into the soil. To determine the extent of these environmental emissions, the coefficients of the input consumption values are multiplied, as detailed in the findings of (Ghasemi-Mobtaker et al., 2022).

Table 2
Equivalent of direct emission of 1 MJ diesel fuel for 1 MJ burning in EcoInvent database.

Emission	Amount (g MJ^{-1} diesel)
CO_2	74.5
SO_2	2.41E-02
CH_4	3.08E-03
Benzene	1.74E-04
Cd	2.39E-07
Cr	1.19E-06
Cu	4.06E-05
N_2O	2.86E-03
Ni	1.67E-06
Zn	2.39E-05
Benzo (a) pyrene	7.16E-07
NH_3	4.77E-04
Se	2.39E-07
PAH	7.85E-05
HC, as NMVOC	6.80E-02
NO_x	1.06
CO	1.50E-01
Particulates (b2.5 μm)	1.07E-01

Table 3
Coefficients for calculating the On-Farm emissions related to application of inputs in paddy production (IPCC, 2006).

Characteristic		Coefficient (Emission result)
A. Emissions of fertilizers		
1	$\left[\frac{[\text{kg } N_2O - N]}{\text{kg } N_{\text{in fertilzers applied}}}\right]$	0.01 (to air)
2	$\left[\frac{\text{kg } NH_3 - N}{\text{kg } N_{\text{in fertilizers applied}}}\right]$	0.1 (to air)
3	$\left[\frac{\text{kg } N_2O - N}{\text{kg } N_{\text{in atmospheric deposition}}}\right]$	0.001 (to air)
4	$\left[\frac{[\text{kg } NO_3^- - N]}{\text{kg } N_{\text{in fertilzers applied}}}\right]$	0.1 (to water)
5	$\left[\frac{\text{kg P emission}}{\text{kg } P_{\text{in fertilizers applied}}}\right]$	0.02 (to water)
6	$\left[\frac{\text{kg } NO_x}{\text{kg } N_2O_{\text{from fertilizers and soil}}}\right]$	0.21 (to air)
B. Conversion of emissions		
1	Coversion from kg $CO_2 - C$ to kg CO_2	$\left(\frac{44}{12}\right)$
2	Coversion from kg $N_2O - N_2$ to kg N_2O	$\left(\frac{44}{28}\right)$
3	Conversion from kg NH_3 - N to kg NH_3	$\left(\frac{17}{14}\right)$
4	Conversion from kg NO_3 - N to kg NO_3	$\left(\frac{62}{14}\right)$
5	Conversion from kg P_2O_5 to kg P	$\left(\frac{62}{164}\right)$
C. Emissions from human labor		
1	$\left[\frac{\text{kg } CO_2}{\text{man - h Human labor}}\right]$	0.7 (to air)

Table 4
Coefficients for calculating the On-Farm emissions to soil of heavy metal related to application of chemical fertilizers in paddy production (IPCC, 2006).

Characteristic		Heavy metals						
		Cd	Cu	Zn	Pb	Ni	Cr	Hg
1	$\left[\frac{\text{mg Heavy metal}}{kg\ N_{in\ fertilzerapplied}}\right]$	6	26	203	5409	20.9	77.9	0.1
2	$\left[\frac{\text{mg Heavy metal}}{kg\ P_{in\ fertilzerapplied}}\right]$	90.5	207	1923	154	202	1245	0.7

3	$\left[\frac{\text{mg Heavy metal}}{kg\ K_{in\ fertilzerapplied}}\right]$	0.2	8.7	11.3	1.5	4.5	10.5	0.1

2.3.1. Damage assessment of LCA

Damage assessment is the process of evaluating the extent of damage to buildings, infrastructure, and other property caused by natural disasters, accidents, or other events. This assessment is typically conducted by trained professionals such as engineers, architects, or insurance adjusters, who inspect the affected area and document the damage (Kazemi et al., 2023). The assessment helps determine the cost of repairs, the safety of the structure, and the level of assistance needed for recovery efforts. It is an important step in the recovery process and can help guide decisions on rebuilding and resource allocation (Cheng et al., 2024). The incorporated human health, ecosystem quality, and resource scarcity as the three areas of protection. Characterization factors for endpoints, which are directly linked to these areas of protection, were calculated from midpoint characterization factors using a consistent mid-to-endpoint factor for each impact category. Have taken into account 17 midpoint impact categories (Fig 3).

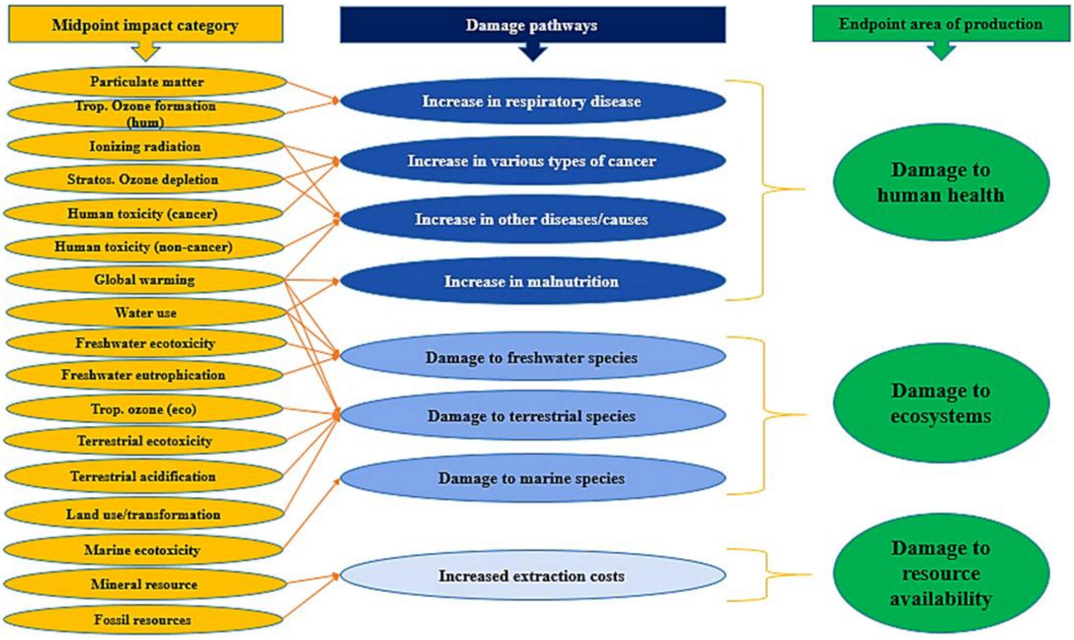


Fig. 3. The relationship between midpoints and endpoints is determined using the ReCiPe2016 method of LCA.

3. Results and discussion

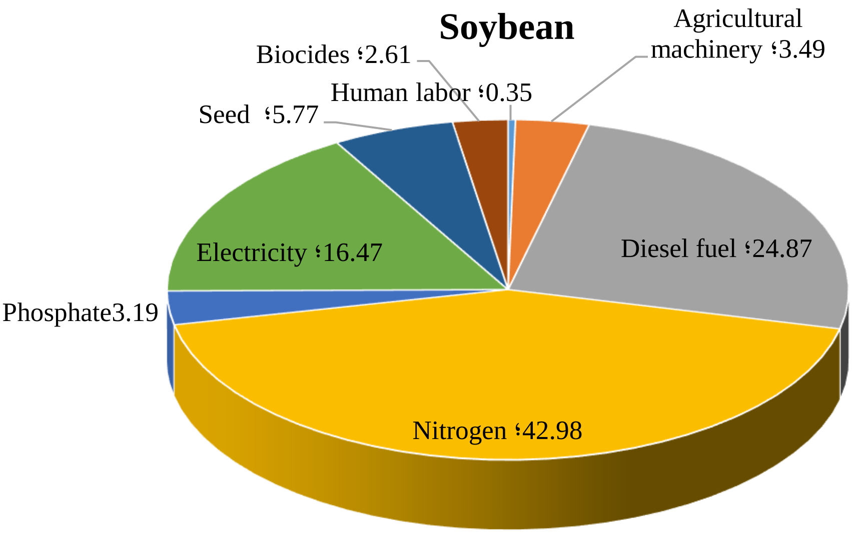
3.1. Energy use analysis

The energy consumption for soybean and peanut production was determined by calculating the average of collected samples. Table 5 presents the energy input and output for both crops, with each input evaluated based on its FU. A comparison of the energy consumption of different production systems was conducted. The total energy consumption of inputs for soybean production is 43674.05 MJ ha^{-1}, while the output energy is 63787.93 MJ ha^{-1}. Similarly, the total energy consumption of inputs for peanut production is 28677.36 MJ ha^{-1}, with the output energy also being 28677.36 MJ ha^{-1}. In a study by Shiv Kumar Lohan et al. (2023), the energy productivity of five major vegetable crops (potato, tomato, muskmelon, garden pea, and cauliflower) production systems was investigated. The study revealed that potato cultivation had the highest energy consumption at 53,412 ± 2,388 MJ.ha-1, followed by tomato at 47,489 ± 1,183 MJ ha^{-1}, cauliflower at 39,367 ± 1,127 MJ ha^{-1}, muskmelon at 37,827 ± 856 MJ ha^{-1}, and garden pea at 24,625 ± 497 MJ ha^{-1}. The study also identified irrigation as the primary energy-consuming farm operation, followed by the transportation of farmyard manure, fertilizers, and produce. Ahmadbeyki et al. (2023) discovered that enhancing ecological conditions and managing various factors in greenhouse crops is associated with increased energy usage. The study indicated that energy consumption ranged from 405405.75 to 412911.99 MJ ha-1, with diesel fuel accounting for over 60% of the total energy consumption. Furthermore, the energy output for cucumber and tomato was found to be 104982.94 and 228281.37 MJ ha^{-1}, respectively. In the study focuses on evaluating energy flow and greenhouse gas emissions in peanut production in Guilan province, Iran, due to increasing energy demand, limited fossil fuels, and environmental concerns. Data envelopment analysis is used to identify efficient energy usage patterns among 120 peanut farms. Results show that 18.33% and 75% of farms operate efficiently under constant and variable scales, respectively. Efficiency metrics are calculated at 0.79 for technical efficiency, 0.98 for pure technical efficiency, and 0.81 for scale efficiency. Improving inefficient farms could save 1760 MJ ha^{-1}, with chemical fertilizers playing a key role. Proper fertilizer use can enhance energy efficiency. Greenhouse gas emissions are estimated at 571.18 and 512.39 kg of CO_2 equivalent per hectare for current and optimized farms, respectively. Optimizing energy inputs could reduce emissions by 58.79 kg of CO_2 equivalent per hectare by managing diesel fuel, nitrogen, and machinery usage based on analysis results (Hosseinzadeh-Bandbafha et al., 2018).

Figure 4 depicts the contrast between input consumption percentages and irrigation techniques for the cultivation of soybeans and peanuts. Nitrogen fertilizers are essential for increasing crop yield, requiring a substantial energy input of more than 40%. The timing of nitrogen fertilizer application is a critical management strategy for enhancing nitrogen efficiency. It is crucial to understand the plants' requirements during the growing season to optimize nitrogen consumption. After nitrogen fertilizers, diesel fuel contributes to 24.87% and 24.85% of input consumption in soybean and peanut production, respectively.

Table 5
Amounts of inputs-outputs energy in soybean and peanut production systems.

Items	**Soybean**		**Peanut**	
	Unit per ha	Energy use (MJ ha^{-1})	Unit per ha	Energy use (MJ ha^{-1})
1. Human labor (h)	76.57	150.08	693.12	1358.52
2. Machinery (h)	24.00	1504.80	16.52	1036.11
3. Diesel fuel (L)	190.67	10736.90	126.55	7126.03
4. Chemical fertilizers (kg)				
(a) Nitrogen	280.52	18553.92	174.62	11549.69
(b) Phosphate (P_2O_5)	110.70	1377.10	40.95	509.41
(c) Potassium (K)	-	-	65.40	729.21
6. Biocides (kg)	9.40	1128.00	4.05	
7. Electricity (kwh)	605.95	7228.98	345.87	4149.86
8. Seed (kg)	140.70	3264.24	69.30	1732.50
Total energy use (MJ)	**-**	**43674.05**	**-**	**28677.36**
B. Output (kg)				
1. Soybean	2749.48	63787.93	-	-
2. Peanut	-	-	3601.5	43701.54



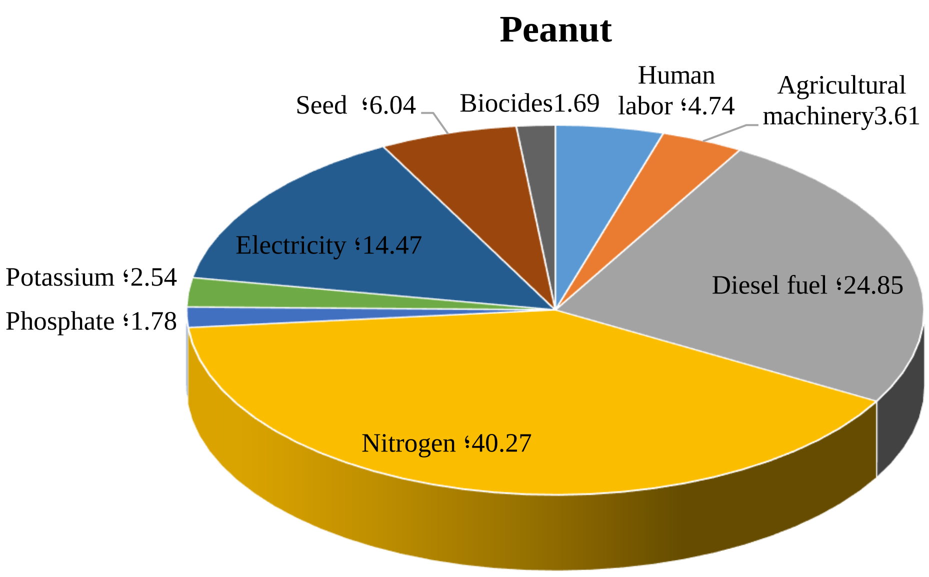


Fig. 4. The impacts of energy sources on soybean and peanut production.

Table 6 presents a comparison of energy indices between soybean and peanut production systems. The data indicates that peanut production demonstrates higher energy use efficiency than soybean production, suggesting that soybean provides more energy to consumers. Moreover, peanut production exhibits greater energy productivity, requiring less energy per kilogram of crop compared to soybean cultivation. However, specific energy results show the opposite trend in energy productivity. Additionally, peanut cultivation has achieved a net energy value of 15024.17 MJ ha^{-1}, signifying a high level of net energy. Ahmadbeyki et al. (2023) found that tomato had a higher energy use efficiency (0.55) compared to cucumber (0.26).

Table 6
Energy indices in soybean and peanut production systems.

Items	**Soybean**	**Peanut**
Energy use efficiency (ratio)	1.46	1.52
Energy productivity (kg MJ^{-1})	0.06	0.12
Specific energy (MJ kg^{-1})	16.66	7.96
Net energy gain (MJ ha^{-1})	20113.88	15024.17

3.2. LCA analysis

The collection and analysis of data play a crucial role in the LCA process, as they help identify the inputs and outputs of a product's life cycle. Accurate data collection is essential to avoid potential issues stemming from incomplete or inaccurate information. When obtaining data from public sources, it is important to maintain transparency and accuracy by clearly citing reference sources. The EcoInvent database is commonly utilized as a primary resource. The collected data should be relevant to the specific functional unit (FU) defined in the LCA objectives. Inventory flow can be categorized based on the scope of the system being analyzed. Environmental emissions from input production can be calculated using Off-Farm emissions. It is vital to consider all activities within the system boundary, including both upstream and downstream processes. Additionally, assessing data quality and addressing uncertainties are important for ensuring the reliability of the results. The results presented in Table 7 demonstrate that the production inputs for soybean and peanut production systems result in on-farm emissions, with diesel fuel and chemical fertilizers being the primary contributors. Soybeans exhibit higher levels of diesel fuel pollutants due to reduced usage, while peanuts have a higher prevalence of contaminants associated with diesel fuel.

Table 7
On-Farm emissions in soybean and peanut production systems based on 1 hectare.

	Soybean	**Peanut**
1. Emissions by diesel fuel to air (kg)		
(a). Carbon dioxide (CO_2)	799.89	530.88
(b). Sulfur dioxide (SO_2)	0.25	0.17
(c). Methane (CH_4)	0.03	0.021
(d). Benzene	0.001	0.001
(e). Cadmium (Cd)	0.000003	0.000001
(f). Chromium (Cr)	0.00001	0.000008
(g). Copper (Cu)	0.0004	0.0002
(h). Dinitrogen monoxide (N_2O)	0.03	0.02
(i). Nickel (Ni)	0.00001	0.00001
(j). Zink (Zn)	0.0002	0.0001
(k). Benzo (a) pyrene	0.000008	0.000005
(l). Ammonia (NH_3)	0.005	0.003
(m). Selenium (Se)	0.000003	0.000001
(n). PAH (polycyclic hydrocarbons)	0.0008	0.0005
(o). Hydro carbons (HC, as NMVOC)	0.73	0.48
(p). Nitrogen oxides (NOx)	11.38	7.55
(q). Carbon monoxide (CO)	1.61	1.06
(r). Particulates (b2.5 μm)	1.148	0.76
2. Emissions by fertilizers to air (kg)		
(a). Ammonia (NH3) by chemical fertilizers	34.06	21.20
3. Emissions by fertilizers to water (kg)		
(a). Nitrate	37.26	23.20
(b). Phosphate	2.41	0.89
4. Emission by N_2O of fertilizers and soil to air (kg)		
(a). Nitrogen oxides (NOx)	7.153	4.45
5. Emission by human labor to air (kg)		
(a). Carbon dioxide (CO_2)	53.60	485.18
6. Emission by heavy metals of fertilizers to soil (mg)		
(a). Cadmium (Cd)	11701.50	4766.80
(b). Copper (Cu)	30208.55	13585.88
(c). Zink (Zn)	269822.675	114934.74
(d). Lead (Pb)	1534407.525	950951.02
(e). Nickel (Ni)	28224.3725	12215.86
(f). Chromium (Cr)	159674.3975	65272.73
(g). Mercury (Hg)	105.5425	52.66

Table 8 displays the results of the damage assessment for soybean and peanut production, revealing that resources have the most significant environmental impact. Soybean production is associated with higher greenhouse gas emissions compared to peanut production. The level of ecosystem impact for soybean and peanut production is 8.49E-05 and 3.98E-05, respectively (Mostashari-Rad et al., 2021). A study utilizing the ReCiPe 2016 method to evaluate the environmental impact of horticultural products found that citrus, hazelnut, kiwifruit, tea, and watermelon had a greater impact on the environment and human health in terms of resource usage compared to other categories. Additionally, greenhouse gas emissions of 0.155 kg CO2eq, 0.15 to 0.3 kg CO_{2eq}, and 0.8 kg CO_{2eq} were reported by (Litskas et al., 2017), (Bosco et al., 2011), and (Point et al., 2012) respectively. Ahmadbeyki et al. (2023) emphasized in their LCA results that carbon dioxide emissions were the most prominent among 18 air pollutants, mainly due to diesel fuel usage. The assessment of harm using the ReCiPe 2016 method showed human health impacts of 0.012 and 0.004 DALY for cucumber and tomato, respectively. Importantly, on-site emissions had the greatest influence on human health, accounting for 82% and 78% for cucumber and tomato, respectively.

Table 8

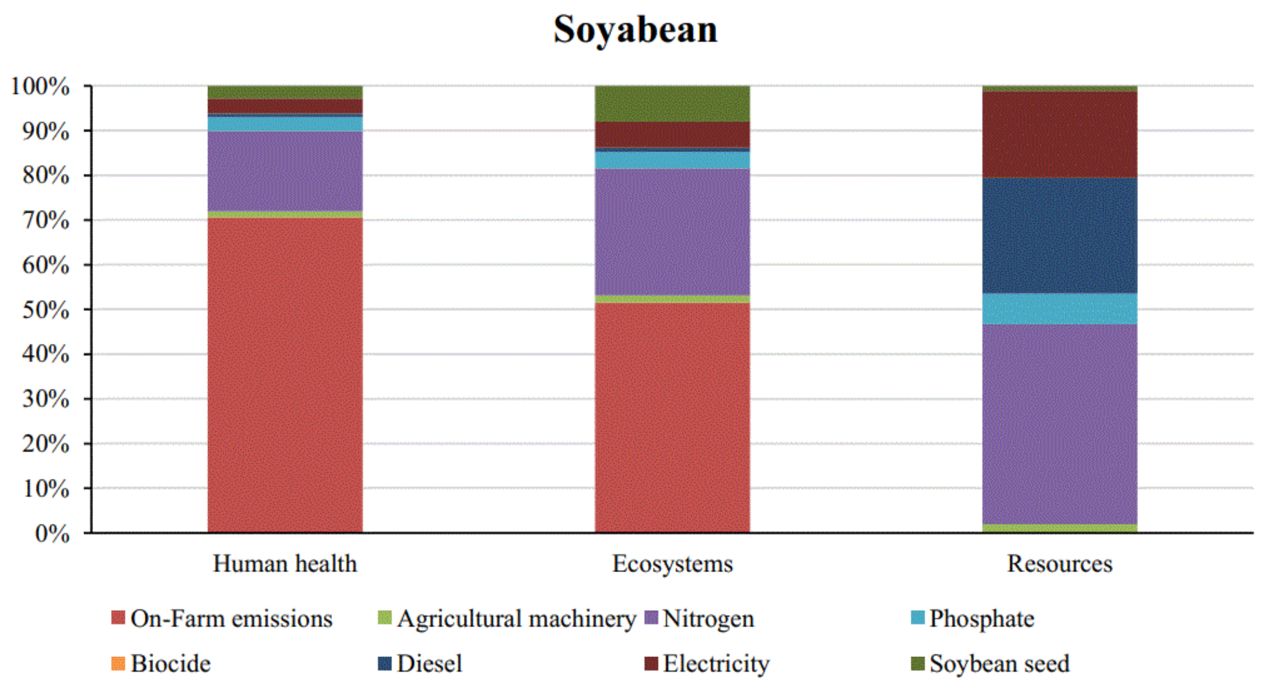
Values of the damage assessment per one in soybean and peanut production systems.

Items	Unit	Soybean	Peanut
Human health	DALY [a]	0.08	0.03
Ecosystems	species.yr [b]	8.49E-05	3.98E-05
Resources	USD2013	131.13	64.48

[a] DALY: disability adjusted life years. A damage of 1 is equal to: loss of 1 life year of 1 individual, or 1 person suffers 4 years from a disability with a weight of 0.25.

[b] species.yr: the unit for ecosystems is the local species loss integrated over time.

Figure 5 illustrates the distribution of emissions from various sources in soybean and peanut production. Both methods of production have a significant impact on human health, with soybean accounting for 70% of emissions and peanut contributing 65%. The use of diesel fuel and nitrogen fertilizer has the most substantial environmental impact, comprising over 50% of the overall impact. Effective management of nitrogen fertilizer is crucial for maximizing crop growth and yield, making it a top priority for researchers and farmers. Many regions worldwide have implemented strict regulations on chemical fertilizer usage in agriculture to prevent excessive pollution of the environment. This not only protects the environment and public health but also brings economic benefits such as lower costs, increased productivity, and resource conservation. Steenwerth et al. (2015) have proposed two sustainable agricultural production methods, mineral fertilizer and compost fertilizer, as effective techniques for fertilizer management. Thoughtful consideration of the appropriate application of fertilizers is essential to minimize environmental impacts and ensure efficient farming practices. In a study on peanut production in Guilan province, Iran, the environmental impacts were assessed using the LCA methodology. The study identified six key areas of impact: global warming, acidification, terrestrial eutrophication, depletion of fossil resources, depletion of phosphate, and depletion of potash resources. The analysis showed that per ton of peanut production, the calculated indices for these categories were 0.040, 0.216, 0.360, 3.98, 0.291, and 0.026, respectively, with fossil resource depletion having the most significant adverse impact. Farms ranging from 0.1 to 0.5 hectares exhibited high levels of global warming potential and fossil resource depletion. The environmental and resource depletion indices for one ton of peanut production were 0.62 and 4.30. Additionally, the final indices for generating 1000 MJ of energy were 0.0017 for global warming, 0.0091 for acidification, 0.0152 for terrestrial eutrophication, 0.168 for fossil resource depletion, 0.012 for phosphate resource depletion, and 0.001 for potash resource depletion (Nikkhah et al., 2015).



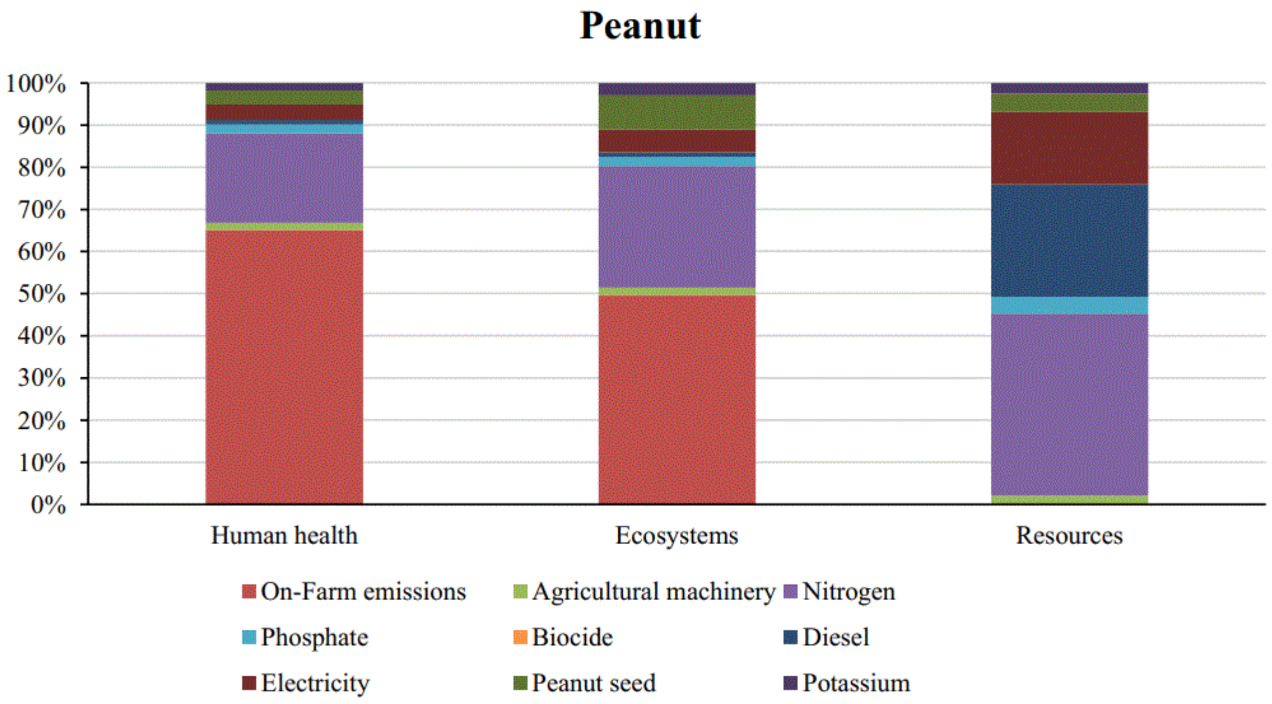


Fig. 5. Contribution of different inputs in the damages categories for soybean and peanut production systems.

The research suggests exploring the effects of different cultivation practices, technologies, and scenarios on the energy and environmental performance of crops. The results can be generalized by applying them to other contexts and regions to understand how different factors impact emissions in soybean and peanut production. Effective management of nitrogen fertilizer is highlighted as crucial for maximizing crop growth and yield, with regions implementing regulations to prevent environmental pollution. Sustainable agricultural production methods like mineral and compost fertilizers are proposed as effective techniques for managing fertilizers. Thoughtful consideration of fertilizer application is essential to minimize environmental impacts and ensure efficient farming practices.

Farmers can apply these results to improve the sustainability of their soybean and peanut crops by implementing the following practices:

1. Utilizing precision agriculture techniques to optimize inputs such as fertilizers, pesticides, and water. This can help reduce waste and minimize environmental impact.

2. Rotating crops to improve soil health and reduce the risk of pests and diseases. Crop rotation can also help improve nutrient cycling and reduce the need for synthetic inputs.

3. Implementing cover cropping to protect soil from erosion, improve soil structure, and increase organic matter content. Cover crops can also help suppress weeds and provide habitat for beneficial insects.

4. Adopting integrated pest management practices to reduce reliance on chemical pesticides. This can involve using biological control agents, crop rotation, and resistant crop varieties to manage pest populations.

5. Investing in sustainable irrigation practices such as drip irrigation or rainwater harvesting to reduce water usage and minimize water pollution.

By implementing these practices, farmers can improve the sustainability of their soybean and peanut crops, protect the environment, and ensure the long-term viability of their operations.

4. Conclusions

The study on energy usage and environmental impact assessment in soybean and peanut cultivation has provided valuable insights. It revealed that both crops require significant energy inputs, especially in terms of fuel for machinery and irrigation. The study also highlighted the risks of soil erosion and nutrient depletion, which can lead to long-term land damage. These findings are beneficial for farmers, policymakers, and researchers aiming for sustainable agricultural practices. Specifically, the study found that soybean production consumes 43170.20 MJ ha^{-1} of total energy, yielding 40417.28 MJ ha^{-1} of output energy, while peanut production requires 28677.36 MJ ha^{-1} of total energy and produces of output energy. The analysis showed that emissions on farms are closely tied to inputs used in soybean and peanut production, with diesel fuel and chemical fertilizers being the main sources of emissions in both systems. Soybean farming had higher levels of diesel fuel pollutants due to reduced usage compared to peanuts. The study also highlighted the distribution of emissions from different sources in soybean and peanut production, with soybean responsible for 70% of emissions and peanuts contributing 65% to human health impacts. Diesel fuel and nitrogen fertilizer were identified as the primary contributors to environmental impact, collectively accounting for over 50% of the overall impact. Overall, the research underscores the importance of sustainable farming practices and the necessity for more efficient energy use in crop cultivation. By adopting strategies to reduce energy consumption and mitigate environmental harm, farmers can progress towards more sustainable and resilient agricultural systems. This study offers valuable insights for policymakers, researchers, and farmers seeking to enhance the sustainability of soybean and peanut cultivation.

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