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Life cycle of Energy-economic Analysis for Different Cultivation Scenarios of Paddy Production (Case of Khuzestan Province)

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ABSTRACT

In this study, energy and economic analyses of paddy production in Khuzestan province, Iran, were conducted. Paddy production was examined under three cultivation systems: Paddy-Transplanting System (PTS), Paddy Direct Seeding Flooding System (PDSFS), and Paddy-Upland Cultivation System (PUCS). PTS had the highest total input (87,993.14 MJ ha^{-1}) and output (105,400 MJ ha^{-1}) energies. Diesel fuel and nitrogen fertilizer had the largest shares of energy use. In PUCS, human labor accounted for a significant share of energy use. The energy ratio of the PUCS method (1.34) indicates that output energy greatly exceeds input energy. The productivity energy index showed no significant difference between the three methods in terms of paddy yield relative to input energy. The specific energy of the PTS method (14.19 MJ kg^{-1}) indicates high input energy relative to paddy yield. Despite this, the PTS method demonstrated a favorable benefit-to-cost ratio due to high revenue and low costs. The productivity of the PUCS method was reported at 212.65 kg \$$^{-1}$, reflecting high paddy production and the lowest costs among the methods.

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INTRODUCTION

Rice is one of the most important cereals globally, serving as a staple food for half of the world's population. Rice (*Oryza sativa L.*) belongs to the Poaceae family and thrives in tropical, water-abundant areas (Nabavi-Pelesaraei et al., 2019a). Iran is a major paddy producer in the Middle East, with its rice production meeting about two-thirds of the country's annual consumption. The total cultivated area and yield of paddy in Iran are approximately 422,746 hectares and 47,310 tons, respectively (FAO, 2020). In Khuzestan province, various rice cultivation methods are employed, including the Paddy-Transplanting System (PTS), Paddy Direct Seeding Flooding System (PDSFS), and Paddy-Upland Cultivation System (PUCS). Drought poses a problem in certain southern regions, while 200,000 to 300,000 hectares in Khuzestan are affected by water salinity (Ministry of Jihad-e-Agriculture of Iran, 2020). Local paddy cultivars typically yield 3 to 3.5 tons per hectare under standard soil conditions (pH 7.0-7.5), whereas modified cultivars can yield 5 to 7 tons per hectare. Despite the lower yield of local species (averaging 2.5 to 3.5 tons per hectare), their excellent quality characteristics have led to over 80 percent of Iran's total rice area being dedicated to these cultivars (Mahmuti et al., 2011).

The role of energy in the agricultural sector, especially in crop production, has garnered significant attention from researchers in recent years. Energy is a crucial driving force for human development, encompassing the capacity and ability to perform work. Historically, people have continuously sought to harness energy and convert it into useful forms (Saber et al., 2020). This process of energy conversion and consumption intensified during the transition from traditional to modern agricultural practices, where the import and use of energy inputs in agriculture coincided with increased production (Kaab et al., 2019). However, while modern agricultural systems have boosted production, they have also reduced energy efficiency compared to traditional systems, thereby challenging the sustainability of current agricultural practices (Gündoğmuş, 2006).

The use of fossil fuels has numerous negative environmental impacts, primarily through the release of carbon dioxide and other gases. Energy consumption in the agricultural sector depends on factors such as the number of people involved in agriculture, the amount of arable land, and the level of mechanization (Dalgaard et al., 2001). Efficient energy use in agriculture is crucial for achieving sustainable production, as it conserves financial resources, protects fossil fuel reserves, and reduces air pollution (Camargo et al., 2013).

The agricultural sector has inherent characteristics and potentials that enable it to significantly contribute to economic development in various ways (Tey et al., 2014). Focusing on regional capacities is fundamental to increasing the productivity of production factors, a necessary precondition for economic development. Given limited resources and the importance of preventing resource loss, especially in developing countries, evaluating investment projects from an economic perspective is essential (Erdal et al., 2007). This study examines the cost-benefit analysis of different rice cultivation systems in Khuzestan province's agricultural sector. Research has shown that improved farming methods can significantly reduce greenhouse gas emissions from the agricultural sector. However, increased energy consumption from diesel fuel, chemical fertilizers, and machinery has led to environmental issues such as greenhouse gas emissions. Under these conditions, quantifying input and output energy during production, along with assessing the environmental impacts related to the crop life cycle, has gained attention in agricultural management (Yadav and Mishra, 2013).

The study of energy and economic roles in agricultural products has received significant attention from researchers in recent years. Khan et al. (2010) demonstrated that in examining the energy needs of wheat, rice, and barley, rice had an energy efficiency of 1.6. They also noted that the highest input energy for rice fields was attributed to chemical fertilizers (43%). In a similar study, the ratio of water energy in canal irrigation systems for wheat, rice, and barley was estimated at 12.7, 93.37, and 86.12 percent, respectively, while the ratio for pump irrigation systems was 1.19, 50.47, and 40.35 percent, respectively (Khan et al., 2009a).

Iqbal (2007), in another study on rice in Bangladesh, showed that the input energy for a medium area (1-2 hectares) is 29,394 MJ, and the output energy is 1,154,444 MJ. The researchers calculated the average output and input energy for rice production on small, medium, and large farms in Nigeria, finding that input energy was about twice that of output energy. To reduce input energy, an increase in the level of mechanization is recommended. The net energy value for the fields was 82,733, 88,321, and 93,226 MJ ha^{-1}, respectively, highlighting the energy efficiency of large farms due to better resource management (Kosemani and Bamgboye, 2020). Additionally, a study in China comparing fully mechanized rice production (FM) and semi-mechanized rice production (SM) indicated that the input fuel for SM was 691.19 MJ ha^{-1} less than for FM. This estimate underscores the impact of mechanization level; alongside fuel, fertilizer and water were other significant inputs, accounting for 92.02 percent of the total input energy (Yang et al., 2022).

Khuzestan province of Iran has long been a center for rice cultivation. However, water shortage is one of the most pressing issues in this region, primarily due to mismanagement and inefficient use of resources. With rising rice prices, it is crucial to study the economic viability of rice cultivation to prevent the wastage of water resources. From an ecological perspective, energy analysis in agriculture is essential for understanding agricultural ecosystems and developing sustainable practices.

Energy analysis in agriculture enhances awareness of resource efficiency, energy production, and the optimization of energy input systems. Given the limited availability of energy resources, it is important to assess the agricultural system's dependency on various inputs. This understanding should inform future decisions aimed at designing sustainable agricultural ecosystems for long-term development. To this end, paddy production systems have been analyzed in terms of input and output energy to devise rational and sustainable solutions.

So far, no study has examined the energy consumption and economic viability of paddy cultivation in Khuzestan province. This study aims to evaluate the life cycle of paddy production systems and identify the best systems based on cultivation patterns. Considering the comparative advantage of different economic activities is a crucial aspect of economic planning. Given the significance of paddy in Iran's agricultural economy and the need to plan the development and export of paddy products based on comparative advantage, it is essential to understand and strengthen this advantage.

Three methods, including Paddy-Transplanting System (PTS), Paddy Direct Seeding Flooding System (PDSFS), and Paddy-Upland Cultivation System (PUCS), were studied and evaluated for their production efficiency in the agricultural sector. Since Khuzestan province is a key area for paddy crop production in Iran, a comprehensive investigation of energy and economic factors in different paddy systems is the primary purpose of this study. To achieve the research objectives, the following evaluation steps are necessary:

Calculation of energy indices for different paddy systems.

Evaluation of impact points in energy production to manage energy consumption.

Economic analysis of different paddy systems.

Determination of the best systems according to energy consumption and economic viability.

Methodology

Rice cultivation methods

The data for this study was collected from farmers in Shushtar County, Khuzestan province. Shushtar is located at latitudes from 48° 35′ to 49° 12′ East and longitudes from 56° 34′ to 56° 14′ North (Ministry of Jihad-e-Agriculture of Iran, 2020).

Initial data were gathered randomly from 200 paddy producers using a self-structured questionnaire. This data included various agricultural input parameters such as the quantities of seed, fertilizer, biocides, energy conduits, applied equipment and machinery, areas of land under cultivation, and yield of paddy farms. The required sample size for the study was calculated using the method of Cochran (1977).

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

Where, n is the required sample size, N is the number of farms per target population, z is the reliability coefficient (equals to 1.96, denoting 95% confidence level), p is the estimated proportion of an attribute that is present in the population (equals to 0.5), q is 1-p (equals to 0.5), and d is the permitted error ratio deviation from the average population (equals to 0.05).

An overview of energy-economic indices

Paddy production inputs include human labor, machinery, diesel fuel, chemical fertilizers, biocides, water, electricity, and seeds. Data related to these inputs and outputs of rice fields were collected through a questionnaire and interviews with farmers. In the next step, the amount of each input and output was calculated per hectare of arable land. Since different inputs and outputs have different units, comparisons can be challenging. Therefore, all inputs and outputs were converted into energy equivalents using specific coefficients. The energy equivalent of each of the inputs is reported in Table 1.

Table 1

Regression Analysis of Predictor Variables Versus Compliance with GAPs.

Items	Unit	Energy equivalent(MJ unit^{-1})	References
A. Inputs			
1. Human labor	h	1.96	(Banaeian et al., 2011)
2. Machinery	kg yr[1]	62.70	(Ghasemi-Mobtaker et al., 2020)
3. Diesel fuel	L	56.31	(Ghasemi-Mobtaker et al., 2020)
4. Chemical fertilizers	kg		
(a) Nitrogen		78.10	(Canakci et al., 2005)
(b) Phosphate (P2O5)		17.40	(Canakci et al., 2005)
5. Biocides	kg	250	(Kaab et al., 2019)
6. Electricity	kWh	12	(Mohseni et al., 2018)
7. Seed	kg	14.7	(Šarauskis et al., 2018)
B. Output	kg		
1. Paddy		17	(Šarauskis et al., 2018)

1 The economic life of machine (year).

By estimating the total input and output energies, energy evaluation indicators such as energy ratio or efficiency, energy productivity, specific energy, and net energy efficiency were calculated for each planting system (Mohseni et al., 2018). These indices were determined to evaluate the relationship between input and output energy per hectare, which varies according to crop type, soil type, tillage operations for seedbed preparation, type and amount of chemical and livestock fertilizers, storage, maintenance, and harvesting operations (Mohammadi et al., 2010).

The energy indicators are as follows: Energy efficiency (Equation 2) is the ratio of energy input to the system to energy output from the system. In economic terms, energy efficiency is the amount of product (output) obtained per unit of energy consumed by the energy-consuming sectors. Energy efficiency involves processes that reduce the amount of energy consumed in the production of goods and services in an economic unit and prevent unnecessary consumption (Brentrup et al., 2001).Energy productivity (Equation 3) is the amount of production of goods and services per unit of energy consumption. This index shows how much added value is produced for a specific energy consumption; the larger the index, the lower the energy consumption and the higher the energy productivity (Yang et al., 2022).Energy intensity (Equation 4) indicates the amount of energy consumption per unit of production of goods and services. This index expresses the amount of energy productivity, showing how much energy is consumed to produce each unit of goods and services. Since the reverse energy intensity index is the energy productivity index, a larger energy intensity index indicates lower energy productivity and higher energy consumption per unit of goods and services, and vice versa (Hosseinzadeh-Bandbafha et al., 2018).Net energy gain (Equation 5) is the difference between the total amount of energy output and the input energy. This index is defined in units of area.

$$\text{Energy use efficiency} = \frac{\text{Output energy (MJ)}}{\text{Input energy (MJ)}}$$

$$\text{Energy productivity} = \frac{\text{Production (kg)}}{\text{Input energy (MJ)}}$$

$$\text{Specific energy} = \frac{\text{Input energy (MJ)}}{\text{Production (kg)}}$$

$$\text{Net energy} = \text{Output energy (MJ)} - \text{Input energy (MJ)}$$

In agricultural production, especially for crops grown for energy production, the goal is usually to achieve the maximum net energy gain.

The goal in all activities, including agricultural activities, is maximum profit. The profitability of a system is examined by economic indicators (Demircan et al., 2006). To calculate the cost of each production unit, the price of the inputs used in its production must be obtained. Expenses for purchasing seeds, fertilizers, fuel, renting machines, human labor, etc., are variable costs, while the cost of renting land, farmer premiums, and taxes are considered fixed costs (Rajaeifar et al., 2014). The most prominent economic indicators were obtained using the following equations (Mohammadi-Barsari et al., 2016): Net profit (Equation 6) is obtained by subtracting the total cost of production from the gross income per hectare.Benefit-cost ratio (Equation 7) is the ratio of total revenue to total cost. It is the most important economic indicator used in agricultural activities. Productivity (Equation 8) is another economic indicator used in economic analysis. Productivity is the weight of the product relative to the total cost, showing the amount of product per unit cost.In economic matters, the effect of inflation must be taken into account.

$$\text{Net return} = \text{Gross production value} \left(\frac{\$}{\text{ha}}\right) - \text{Production costs} \left(\frac{\$}{\text{ha}}\right)$$

$$\text{Benefit to cost ratio} = \frac{\text{Gross production value } (\$\ \text{ha}^{-1})}{\text{Production costs } (\$\ \text{ha}^{-1})}$$

$$\text{Productivity} = \frac{\text{Yeild (kg)}}{\text{Production cost (\$)}}$$

Results and discussion

Energy and economic analysis

The paddy production in the study region was analyzed under three multiple cropping system scenarios based on life cycle energy and economic assessments, including (a) PTS, (b) PDSFS, and (c) PUCS.

The PTS nursery is a small piece of agricultural land where germinated seeds are planted to become seedlings. Since rice planting in Iran is generally done by transplanting, farmers prepare the plot of agricultural land, called the treasury, about six months before seed germination. In autumn, the land is plowed, and in late winter, the soil is covered with fertilizer. They plow the land again and remove all rocks and lumps from the soil surface. Finally, the area around the treasury is flooded with water to be stored inside the treasury.

PDSFS is divided into two types: stagnant flooding and current flooding. In the stagnant flooding method, water consumption and nutrient transfer are lower than in current flooding. In the current flooding method, irrigation efficiency is low, and nutrient transfer is higher, but in lands where soil permeability is high, this method can prevent the accumulation of toxic substances and regulate soil temperature. The advantages of permanent flooding include lower costs in weed control and less irrigation supervision.

Recently, using the PUCS method, dry seeds are planted in a dry bed by various seeders or manually at a depth of 3-4 cm, and irrigation is immediately applied until the soil moisture reaches saturation. This process can continue depending on the soil texture, area conditions, and soil preparation status until the end of the seedling period, 25-31 days after planting, and the beginning of tillering. In this method, over-irrigation and creating flooding conditions for more than 15-18 hours after planting can cause seed suffocation. If there is a suitable device for sowing swollen rice seeds, it is possible to soak the seeds in water at a temperature of 25 to 30°C for 24 to 36 hours and then place them in the open air for 2-3 hours. Seeds cultivated under these conditions germinate and emerge from the soil earlier than dry seeds, even before the second irrigation. The utilization of this planting method in the field, under farmers' conditions, has shown relatively good growth (Ministry of Jihad-e-Agriculture of Iran, 2020).

The amount of input energy was calculated based on the amount of input consumed and agricultural operations. According to Table 2, the mean value of the total input energy for paddy production was reported by PTS (87993.14 MJ ha^{-1}), PDSFS (67351.57 MJ ha^{-1}) and PUCS (69493.40 MJ ha^{-1}) methods. In PTS method, the most energy is consumed, for transplanting operations, the seedlings are removed from the treasury and transferred to the main land. Before planting the seedlings, the nursery should be thoroughly irrigated so that the seedlings can be harvested easily and the roots will not be damaged. Due to more operations in the PTS method, its energy consumption is the highest. PTS (105400 MJ ha^{-1}), PUCS (93500 MJ ha^{-1}) and PDSFS (90100 MJ ha^{-1}) methods had the output energy from highest to lowest. In another experiment, intensive planting systems, improved and common (traditional) area in the rice field were evaluated. All energy consumption for fertilizers, seeds, plant protection, tools and machinery, transportation and crop operations in planting systems were calculated, the results showed that the average input energy in the studied systems including direct, indirect, renewable and non-renewable energies was 2424.229 MJ ha^{-1}, The total output energy in production systems was estimated at 191341 MJ ha^{-1} (Habibi et al., 2019). Another study reported that rice production consumes an average of 12906.8 MJ of energy per hectare (Ibrahim et al., 2012). The results of studies in Myanmar showed that alternative rice planting methods require significantly less input energy than conventional methods. Energy efficiency in the modified intensive planting systems method was significantly higher compared to the transplanting method and the direct planting method (Htwe et al., 2021). According to the results of rice producers in Golestan province, Iran, the types of energy inputs and outputs were calculated as 34423.28 and 120088.4 MJ ha^{-1}, respectively (Mardani et al., 2022).

Figure 1 shows the share of each input as a percentage. Diesel fuel consumption, with 33 percent, has the highest share of energy inputs in the PTS method. In addition, nitrogen fertilizer accounts for a significant share of 31percent. As shown in Fig. 1, chemical fertilizers and diesel fuel are the highest energy inputs for rice production, consistent with the findings of Pishgar-Komleh et al. (2011) in Iran. Due to the preparation of the treasury for rice planting and the length of the work process, human labor has the largest share of input energy in the PTS method. In the PDSFS method, nitrogen fertilizer (33%) and diesel fuel (26%) are the primary energy inputs. This method consumes the most water, which is a critical issue given the water shortage in Khuzestan province. The use of electric pumps to extract water from underground sources has increased the energy associated with these sources, making electricity a significant share at 12 percent. In the PUCS method, diesel fuel (10%) and nitrogen fertilizer (27%) are significant energy inputs. This method requires extensive plowing and machinery due to the cultivation of rice on dry land. Water consumption and the use of human labor are minimized, but more fertilizer is needed due to the dryness of the soil. A comparison of the three methods is also shown in Fig. 2. Consumption of inputs such as electricity, nitrogen, and human labor in the PUCS method is less than in the PTS and PDSFS methods. The use of diesel fuel and machinery has the least energy consumption in the PDSFS method. In a similar report, the chemical energy input from herbicides had the largest share (53.55%), while human labor had the lowest share (0.74%) of total energy consumption (Ibrahim et al., 2012). Fertilizer, fuel, and water were the three major inputs for fully mechanized rice (FM) and semi-mechanized rice (SM) in China, accounting for 92.02 percent of total input energy (Yang et al., 2022). Energy consumption in different parts of Thailand for the production of irrigated and rain-fed rice showed that the energy of chemical fertilizers, pesticides, and herbicides has the highest input energy. This finding differs from the results of this study (Chamsing et al., 2006). Studies show that 25 percent of all energy used to produce corn in the United States comes from machinery and fuel, and 45 percent from the use of chemical fertilizers. The costs of the methods discussed are also compared in Figure 3. The PUCS method is less expensive for agriculture. Due to the increase in labor costs and its shortage in agricultural areas, the PUCS method is more practical.

Table 3 shows the calculations of the most im-

Table 2
Mean Values of Inputs-outputs Energy Equivalents in Different Paddy Production Systems in Khuzestan Province.

Items	**PTS[1]**		**PDSFS[2]**		**PUCS [3]**	
	Unit per ha	Energy use (MJ ha^{-1})	Unit per ha	Energy use (MJ ha^{-1})	Unit per ha	Energy use (MJha^{-1})
1. Human labor (h)	780.36	1529.51	360.65	706.87	180.32	353.43
2. Machinery (kg)	320.36	20086.57	290.63	2615.67	340.89	3068.01
3. Diesel fuel (L)	520.32	29299.22	380.59	21431.07	620.31	34929.66
4. Chemical fertilizers (kg)						
(a) Nitrogen	350.00	27335.00	350.00	27335.00	300.00	23430.00
(b) Phosphate (P2O5)	50.00	870.00	50.00	870.00	100.00	1740.00
5. Biocides (kg)	2.56	640.00	8.56	2140.00	6.32	1580.00
6. Electricity (kwh)	600.32	7203.84	800.56	9606.96	200.65	2407.80
7. Seed (kg)	70.00	1029.00	180.00	2646.00	135.00	1984.50
Total energy use (MJ)	**-**	**87993.14**	**-**	**67351.57**	**-**	**69493.40**
B. Output (kg)	-	-	-	-	-	-
1. PTS	6200.00	105400.00	-	-	-	-
2. PDSFS	-	-	5300.00	90100.00	-	-
3. PUCS	-	-	-	-	5500.00	93500.00

1 Paddy-Transplanting System
2 Paddy Direct Seeding Flooding System
3 Paddy-Upland Cultivation System

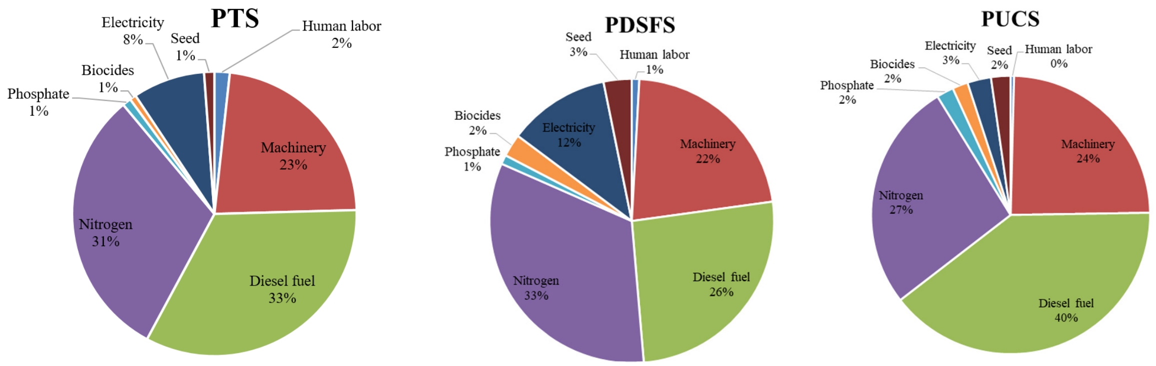

Figure 1. Shares of Energy Sources in Different Paddy Production Systems in Khuzestan Province, Iran (Paddy-Transplanting System (Pts), Paddy Direct Seeding Flooding System (Pdsfs) and Paddy-Upland Cultivation System (Pucs)).

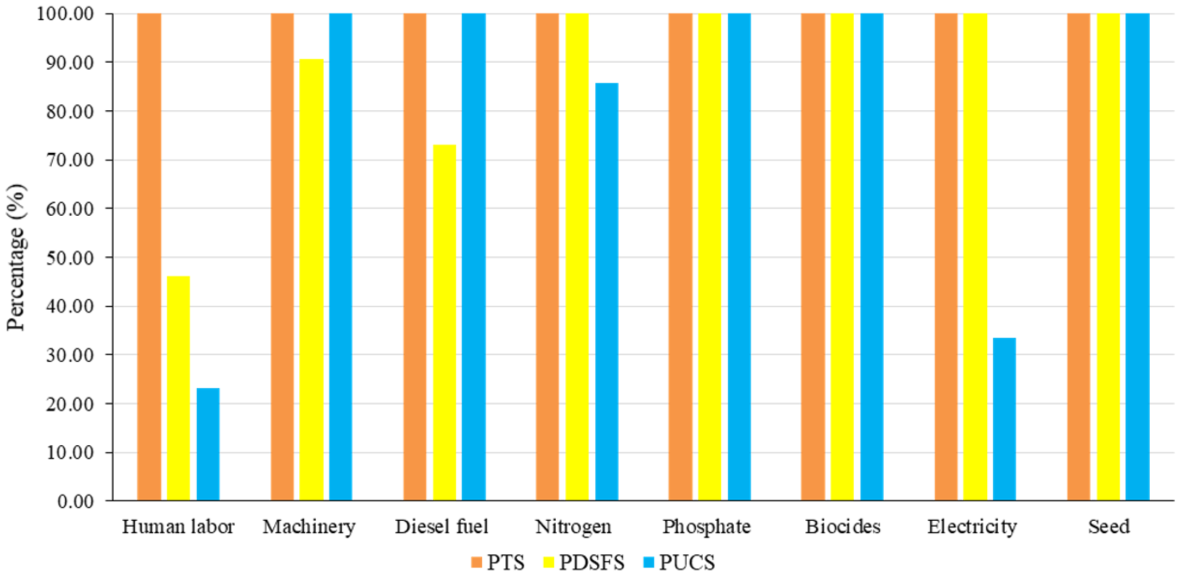

Figure 2. Comparison between Energy Inputs in Different Paddy Cultivation Systems in Khuzestan Province, Iran (Paddy-Transplanting System (Pts), Paddy Direct Seeding Flooding System (Pdsfs) and Paddy-Upland Cultivation System (Pucs)).

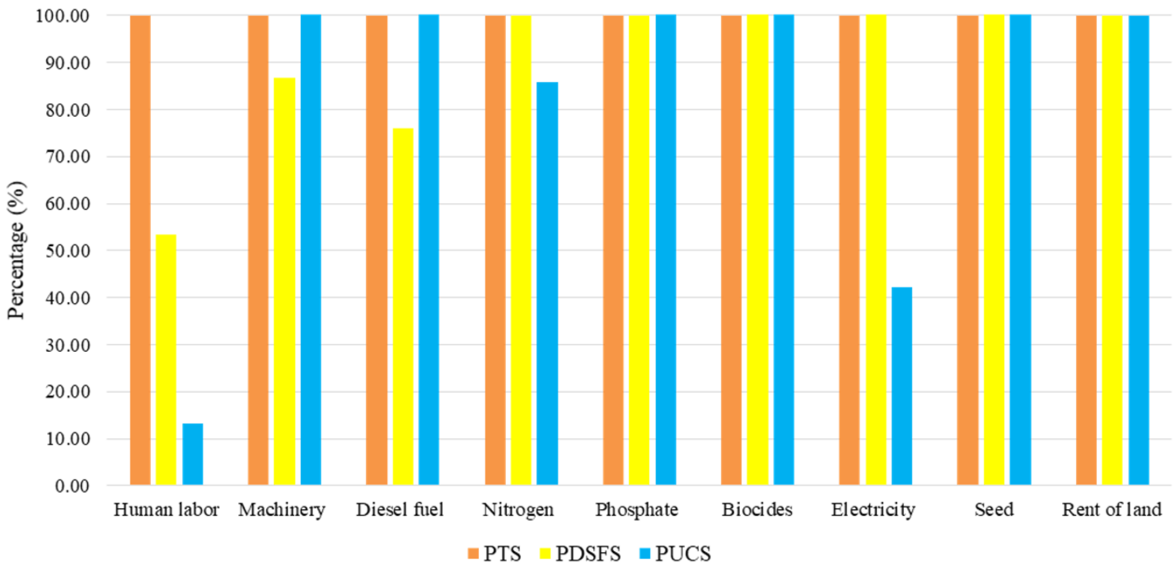

Figure 3. Comparison between| Cost Inputs in Different Paddy Cultivation Systems in Khuzestan Province, Iran (Paddy-Transplanting System (PTS), Paddy Direct Seeding Flooding System (PDSFS) and Paddy-Upland Cultivation System (PUCS)).

portant energy and economic indicators, the estimation of the energy ratio for the PUCS method (1.34) indicates that the amount of output energy is much higher than the input energy. The productivity energy index showed that there is no significant difference between the three methods in terms of the amount of paddy relative to input energy. The specific energy of the PTS method (14.19 MJ kg-1) indicates large amounts of input energy relative to the amount of paddy produced. The net energy gain was reported to be positive for the three methods discussed. As a result, the output energies were higher than the input energies for the PUCS (24006.6 MJ ha^{-1}), PDSFS (22748.43 MJ ha^{-1}) and PTS (17406.86 MJ ha^{-1} methods, respectively. Energy ratio and energy productivity values vary from 1.39 to 1.67 and 0.064 to 0.070 kg MJ^{-1} for rice production in different geographical areas of Iran (Kazemi et al., 2015). Reports of energy indicators of rice production indicated that the ratio of energy and energy productivity were 4.1 and 0.3 kg MJ^{-1}, respectively (Ibrahim et al., 2012). Energy productivity for rice production in Australia was estimated at 0.41 kg MJ−1, but the energy intensity was reported to be 2.44 MJ kg^{-1} (Khan et al., 2009b). The product value (3472 $ ha^{-1}) and cost (529.60 $ ha^{-1}) in PTS method are the highest and lowest, respectively. As a result, the net return of PTS method is 2942.40 $ ha^{-1}. Based on the high revenue and low cost, the benefit to cost ratio at the expense of PTS method is significant. The productivity of the PUCS method was reported to be 212.65 kg $$^{-1}$ due to the high production of paddy compared to the lowest costs. Analysis of economic benefits of rice production shows that alternative rice cultivation methods have significantly higher cost-benefit ratio than conventional methods (Htwe et al., 2021).

Table 3
Energy and Economic Indices and Water Use Efficiency in Different Paddy Cultivation Systems in Khuzestan Province, Iran.

A. Energy indices *(unit)*	**PTS**[1]	**PDSFS**[2]	**PUCS**[3]
Energy use efficiency (ratio)	1.19	1.33	1.34
Energy productivity (kg MJ^{-1})	0.07	0.07	0.08
Specific energy (MJ kg^{-1})	14.19	12.70	12.63
Net energy gain (MJ ha^{-1})	17406.86	22748.43	24006.6
Water use efficiency (kg m^{3})	0.89	0.64	2.20
B. Economic indices (unit)			
Total value from production ($ ha^{-1})	3472.00	2968.00	3080.00
Total cost from production ($ ha^{-1})	529.60	628.70	526.70
Net return ($ ha^{-1})	2942.40	2339.30	2553.30
Benefit to cost ratio (ratio)	6.60	4.72	5.84
Productivity (kg $$^{-1}$)	194.50	184.50	212.65

1 Paddy-Transplanting System
2 Paddy Direct Seeding Flooding System
3 Paddy-Upland Cultivation System

Conclusions

This study analyzes energy and economic aspects of different paddy systems in Khuzestan province. The mean value of total input energy for paddy production was reported as 87,993.14 MJ ha^{-1} for the PTS method, 67,351.57 MJ ha^{-1} for the PDSFS method, and 69,493.40 MJ ha^{-1} for the PUCS method. Input and output energies for these methods indicate high energy consumption in the PTS method, with an energy intensity of 14.19 MJ kg^{-1}, showing the highest energy consumption per paddy production. The significant use of electricity to pump water is an important reason for this difference. Leveling paddy lands can help reduce water and energy consumption.

Economically, the net return of the PTS method is \$2942.40 ha^{-1}. Based on high revenue and low cost, the benefit-to-cost ratio for the PTS method is significant. The productivity of the PUCS method was reported to be 212.65 kg $\$^{-1}$ due to high paddy production compared to the lowest costs. High labor costs in rice cultivation and the challenges of working in rice fields highlight the importance of agricultural mechanization.

To achieve a sustainable production system, energy efficiency and the share of renewable energy in ecosystems must be increased. The disadvantages and problems of the rice system include high labor costs, high energy costs for pumping groundwater, water shortages due to insufficient supply, and high input costs. Optimizing energy consumption in crop systems will help reduce crop operation costs, improve air quality, reduce greenhouse gas emissions, and promote sustainable development. Therefore, managing different paddy systems indicates a desirable method for optimizing required inputs, performance, and net energy supply. Appropriate solutions should be used to reduce the environmental impact of agricultural production systems, improve productivity, and achieve high yields per unit of land by increasing resource efficiency.

Conflict of Interest

Declaration of No Conflict of Interest.

Authors' Contributions

Heidar Molaee Jafrodi: Data curation, Methodology, Writing-Original draft preparation, Writing-Reviewing and Editing.

Mohammad Gholami Parashkoohi: Conceptualization, Formal analysis, Supervision, Validation.

Hamed Afshari: Investigation, Writing-Reviewing and Editing.

Davood Mohammad Zamani: Resources, Software analysis.

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