International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 14s,2025
https://theaspd.com/index.php

Economic and Environmental Analysis of the Use of Solar-Powered Irrigation Systems Compared to Conventional Irrigation in Wheat Production: A Field Study in Al-Hawija District, Iraq

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Abstract
This study aims to evaluate the economic viability and environmental efficiency of two irrigation systems—traditional (diesel/electricity-based) and solar-powered—used in wheat production in Hawija District, Kirkuk Governorate, Iraq, during the 2024 growing season. A field survey was conducted on a sample of 100 wheat farms, evenly divided between the two systems. Data were collected through structured questionnaires and in-depth interviews, and analyzed using various statistical tools including T-tests and sensitivity analysis.
The findings reveal that the solar irrigation system significantly outperforms the traditional system in terms of net income, benefit-cost ratio (BCR), and return on investment (ROI). Additionally, the solar system offers lower operating costs and greater environmental sustainability by substantially reducing carbon emissions. The study recommends expanding the adoption of solar-powered irrigation systems and providing both financial and technical support to facilitate their uptake by local farmers.
Keywords: *Solar Energy, Traditional Irrigation, Wheat Production, Economic Feasibility, Environmental Sustainability, Iraq.*

Introduction

Agriculture is a vital sector of the Iraqi economy. However, it faces mounting challenges due to severe climate change, shrinking water resources, and rising input costs, particularly fuel. Irrigation is one of the most costly components of the production process, especially given that most farmers rely on traditional energy sources (diesel or electricity), which increases the financial burden and negatively impacts the sustainability of rural agriculture.

In light of these challenges, solar energy has emerged as a promising alternative technology option that can contribute to reducing irrigation operating costs by up to 60–80%, improve the efficiency of natural resource use, and reduce harmful carbon emissions(IRENA, 2022: p. 19). This technology has become an important input into sustainable agricultural transformation strategies, especially in countries with high solar radiation, such as Iraq.

Data from the Iraqi Ministry of Planning (2024: p. 47) indicate that the average area planted with wheat during the period (2019–2024) amounted to approximately 2.3 million dunums, distributed among the governorates, including approximately 165,000 dunums in Kirkuk Governorate alone. The season also recorded a production of approximately 4.9 million tons of wheat, according to a 2023 report by the Food and Agriculture Organization(FAO, 2024: 23) ,which reflects the importance of this crop to national food security.

Based on this, this study aims to analyze the economic and environmental performance of traditional and solar irrigation systems in wheat production in Al-Hawija district, Kirkuk Governorate, by

evaluating costs, returns, and environmental and financial feasibility indicators, in an attempt to determine the optimal option for farmers under local production conditions. According to a report by the International Renewable Energy Agency(IRENA, 2022: 19) relying on solar energy in agriculture , can reduce operating costs by 60–80% and contribute to reducing carbon emissions, making it a sustainable and effective option for agriculture in rural areas .

Research problem and objectives

Research problem

Wheat farmers in rural areas suffer from the high operating costs of fuel- or electricity-based irrigation systems, which undermines the economic viability of production. Meanwhile, the feasibility of using solar energy in these systems remains insufficiently documented.

Research hypotheses

We launch this The research is based on scientific hypotheses based on the reality of using irrigation systems in Al-Hawija District, which are as follows:

The first hypothesis

Wheat farmers in Al-Hawija district suffer from the high cost of operating traditional irrigation systems (diesel/electricity), which leads to a decrease in the profitability of agriculture.

The second hypothesis

Using a solar-powered irrigation system reduces operating costs and increases net incomecompare to a traditional system .

The third hypothesis

Solar-powered irrigation systems contribute to improved environmental efficiency by reducing greenhouse gas emissions.

The fourth hypothesis

Solar farmers enjoy higher satisfaction due to stable performance and fewer breakdowns compared to their counterparts using conventional systems.

The fifth hypothesis

In the face of fluctuating fuel prices or declining production, the solar system remains more resilient .and profitable in the medium and long term

The importance of research from a scientific point of view

This research contributes to providing field evidence based on real data from Kirkuk Governorate, on the impact of irrigation pattern on economic and environmental performance.

It combines financial and environmental analysis, while most previous studies focused on one aspect rather than the other.

It highlights agriculture as an important area for renewable energy applications in Iraq, an area that remains under-exploited.

The importance of research from a practical perspective

This research is of direct benefit to farmers, helping them make investment decisions based on accurate data, especially in light of difficult economic conditions and rising fuel prices.

Provides digital tools based on clear indicators (such as= BCR ,ROI net income), which can be , used by agricultural departments to evaluate the feasibility of supporting solar energy projects.

The research findings help direct government and international organization support for financing solar energy projects in rural areas, especially in light of weak infrastructure and the absence of stable electrical networks.

Research objectives

Comparison of economic performance between conventional and solar systems .

Evaluation of the environmental efficiency of each system .

Measuring farmers' satisfaction with each system .

To come up with recommendations to expand the use of renewable energy inirrigation .

Research methodology

The comparative quantitative analytical approach was used, relying on primary data collected .through questionnaires and interviews, along with secondary data from the Directorate of Agriculture

The sample included 100 farms distributed as follows:

A farm using traditionalirrigation diesel or electricity)(50))

Farms using solar-powered irrigation (50) .

The data were analyzed using statistical analysis software SPSS

The data were analyzed using the program Analytical tools such as T-Test sensitivity analysis, and , calculation of feasibility indicators were applied(FAO, 2023) .

Results and Analysis-4

Total cost comparison

Table (1) illustrates the fundamental differences in the cost structure between the traditional and solar irrigation systems for each dunum of wheat crop in Al-Hawija District. It is evident that the operating costs of the traditional irrigation system (330,000 dinars/dunum) are much higher than those of the solar system (45,000 dinars/dunum). This is primarily due to the traditional system's reliance on diesel fuel or paid electricity, as well as the frequency of breakdowns and high maintenance costs.

In contrast, despite the higher fixed costs of the solar system (250,000 dinars/dunum) compared to the traditional system (150,000 dinars/dunum) due to the cost of equipping the solar panel system and its pumps, this difference is clearly compensated by the lower operating expenses, which leads to a decrease in the total cost of the solar system to (295,000 dinars/dunum) compared to (480,000 dinars/dunum) in the traditional system, i.e. a difference of approximately 38.5% in favor of the solar system . This difference represents a strong indicator of the efficiency of solar energy in reducing the ongoing financial burden on the farmer, allowing him to expand agriculture or improve net income without the need to increase production . This result also reflects the high economic flexibility of the solar system in the face of fluctuations in traditional energy prices, which is a crucial factor in achieving agricultural sustainability, especially in isolated rural environments that lack stable and low-cost energy services.

Table (1): Comparison between the total cost structure of traditional and solar irrigation systems in wheat production (dinar/dunum) - Al-Hawija District, 2024

Irrigation type	Total costs Dinar / dunum	Operating costs (dinar/dunum)	Fixed costs (dinar/dunum)
traditional irrigation	480,000	330,000	150,000
Solar-powered irrigation	295,000	45,000	250,000

own work based on the questionnaire.

Site analysis in the context of Al-Hawija district and wheat crop

Hawija District is a strategic agricultural area in Kirkuk Governorate, boasting fertile soil and a climate relatively favorable for the production of grain crops, particularly wheat. However, the district suffers from limited, stable access to traditional energy sources, coupled with high fuel prices, making the operating costs of traditional irrigation systems a real burden on local farmers.

Table (2) reflects this field reality, as the cost of fuel and maintenance represents the largest proportion of the operating expenses of the traditional system . Field interviews indicate that some farmers in Al-Hawija are forced to operate their pumps via generators that operate for long hours daily during the irrigation season, which doubles the operating cost and increases breakdowns due to intensive use.

In contrast, the solar-powered irrigation system clearly demonstrates superiority in this context , as the reduction in operating costs to a quarter of those of the traditional system is due to the abundance of solar radiation in Hawija, which exceeds 5.8 kilowatts/square meter per day on an annual average which provides an ideal environment for investing solar energy with high efficiency ,.

Also, the reduced failures of the solar system compared to the conventional one gives farmers in Hawija stability in irrigation operations without interruption, which is crucial for the wheat crop, which requires precise regularity in irrigation schedules to achieve high productivity.

When calculating the differences between the total costs of the two systems, it becomes clear that the solar energy system not only reduces expenses, but also increases the opportunities for expanding cultivated areas in the future, as a result of reducing the financial pressure on farmers, thus enhancing local food security in a region that relies largely on agricultural production as a primary source of income. 5% compared to its counterpart in the traditional system (480,000 dinars), which is a positive indicator in favor of solar energy in the context of reducing expenses and increasing economic efficiency, especially in the medium and long term.

Table (2): Detailed cost structure of traditional and solar irrigation systems for wheat production in Al-Hawija District - 2024

Irrigation type	Total cost (dinar/dunum)	Operating costs (dinar/dunum)	Fixed costs (dinar/dunum)	Cost reduction ratio in favor of the solar system

traditional irrigation	480,000	330,000	150,000	–
Solar–powered irrigation	295,000	45,000	250,000	38.5%

own work based on the questionnaire.

Revenue and net income

Table (3): Comparison of total revenues and net income between traditional irrigation systems and solar energy in wheat production (dinar/dunum) – Al–Hawija District, 2024

Irrigation type	Net income (dinar/dunum)	Total revenues (dinar/dunum)	Price per ton (dinar)	Productivity /tons)acre
traditional irrigation	415,000	895,000	500,000	1.79
Solar–powered irrigation	625,000	920,000	500,000	1.84

own work based on the questionnair.

The results of Table (3) show the subtle differences in production performance and financial returns between the two systems . At the productivity level, a slight superiority is observed for the solar–powered irrigation system (1.84 tons/dunum) compared to the traditional system (1.79 tons/dunum) . This difference is significant in the context of a sensitive crop such as wheat, where the regular irrigation schedules provided by the solar system improve the plant's absorption of nutrients and reduce water stress in the critical stages of growth.

In terms of total revenues, the solar system generates 920,000 dinars per dunum, compared to dinars in the conventional system. Although the price difference is the same in both systems 895,000 the higher productivity in the solar system directly translates into higher ,(dinars per ton 500,000) returns.

Net income is the most important indicator in assessing feasibility, and the difference is clear 625,000 dinars/dunum for the solar system compared to 415,000 dinars/dunum for the traditional system, an increase of more than 50% . This is attributed to the lower operating costs of the solar system, which enables farmers to achieve higher profits without the need for large increases in production.

These results demonstrate that using solar energy for irrigation not only improves productivity, but also increases overall economic efficiency, enhancing farmers' ability to achieve sustainability and profitability in the face of rising input costs.

Economic feasibility indicators

The economic feasibility indicators in Table (4) show the superiority of the solar–powered irrigation system over the traditional system in many aspects.

This indicator indicates the return for every dinar spent : Benefit–to–Cost Ratio(BCR).

In the traditional system, every 1 dinar spent yields 1.72 dinars in return, while in the solar system it yields 2.11 dinars, which reflects the higher efficiency of the solar system in using resources.

Payback period : The results show that farms relying on solar systems recoup their investment costs in just 3.8 years, compared to 6.2 years for conventional systems. This means that solar systems recover their capital more quickly, an important factor in investment decisions.

) Return on InvestmentROI)

These results indicate that adopting a solar system not only achieves cost savings, but also provides a profitable investment feasibility that encourages farmers to switch to it.

Table (4): Comparison of economic feasibility indicators between traditional irrigation and solar energy systems in wheat production – Al-Hawija District, 2024

Indicator	solar irrigation	traditional irrigation
Benefit-Cost Ratio(BCR)	2.11	1.72
Payback period (year)	3.8	6.2
Return on Investment(ROI) (%)	47.8%	29.6%

own work based on the questionnaire.

Environmental efficiency

Table (5) indicates that the traditional irrigation system results in an average emission of 1.6 tons of carbon dioxide equivalent per farm per year, due to the use of fossil fuels (such as diesel or electricity from unclean sources). In contrast, this figure decreases significantly in the solar-powered irrigation system to only 0.4 tons, which means a 75% reduction in carbon emissions.

This significant difference is due to the fact that the solar system does not require fuel to operate the pumps. Instead, it relies on clean, renewable energy, which directly contributes to reducing the environmental footprint of agricultural activities. Reducing these emissions not only achieves local environmental benefits (such as improved air quality), but also aligns with national and international trends toward low-carbon agriculture and achieving the goals of the Paris Climate Agreement.

Table (5): Comparison Carbon dioxide emissions between traditional irrigation and solar energy systems in Al-Hawija District – 2024

System type	Estimated emissions (tonnes (equivalent CO_2/ /farm$_{year}$	Reduction rate compared to traditional
traditional irrigation	1.6	–
Solar-powered irrigation	0.4	75%

Source: IRENA (2022: p.25)

Sensitivity analysis

Table (6) shows the results of the sensitivity analysis, which is an important tool for evaluating the flexibility of economic feasibility indicators when potential changes occur in input prices or agricultural production.

If fuel prices increase by 20% traditional irrigation systems are significantly affected, with net income , ,declining by 18% due to heavy reliance on fossil fuels. Solar-powered irrigation systems, however are virtually unaffected, as they rely on a free and stable energy source, enhancing their economic resilience.

If the production decreases by 10 % , the benefit-cost ratio(BCR) decreases in both systems, but remains higher in the solar system (1.92 vs. 1.54 in the conventional system) , This demonstrates This , that the solar system is more resilient to production shocks due to its lower operating costs analysis reflects the importance of solar energy not only in ideal conditions, but also in cases of economic fluctuations, making it a safer and more profitable option in the long ter.

Table (6): The impact of changes in fuel prices and production on the economic feasibility indicators of the two irrigation systems - Al-Hawija District, 2024

Solar system	traditional system	Scenario
No significant effect	Net income decreased by 18%	Fuel prices increase by 20%
BCR = 1.92	BCR = 1.54	Production decreased by 10%

own work based on the questionnair.

Farmer satisfaction

It shows farmers' satisfaction and explains the economic and social dimensions behind the (7) Table 'differences between conventional and solar irrigation systems. The table reflects the level of farmers satisfaction with three basic dimensions of the two irrigation systems.

operational stability, and the intent to expand :These indicators can be analyzed as follows.

Satisfaction with lower costs.

The satisfaction rate in the solar system reached% compared to38%. In the traditional system, the impact of lower operating costs is reflected in improved profitability.

This huge difference is due to the fact that the traditional system relies on high-cost fuel (diesel or electricity) in addition to frequent breakdowns, which burdens the small farmer.

In contrast, solar energy provides a nearly free source of energy once established, which enhances economic efficiency and reduces dependence on the local energy market.

Rate Operational stability

He pointed out79% Solar system users report operational stability, compared to only42% in the traditional system.

This reflects the technical and economic impact of using systems that are less prone to failure, which ensures regular irrigation and thus improves wheat productivity and quality.

,System stability directly translates into reduced downtime and costs associated with maintenance which means increased marginal efficiency of labor and capital.

Intention to expand using the system :

88% of solar farmers expressed a desire to expand, compared to25% Only in the traditional system This indicator is considered one of the strongest indicators of economic feasibility, as the decision to expand is only made when the system is profitable and stable in the medium and long term.

The intention to expand also reflects farmers' confidence in the new system, and is evidence that the expected return exceeds the marginal cost of any future expansion.

These results demonstrate that the solar system not only achieves financial savings, but also generates a positive psychological and social impact on farmers, represented by their feeling of economic security and desire to invest and expand.

These indicators are necessary in assessing the social sustainability of the agricultural system, as producer satisfaction is a basic condition for the widespread adoption of any technology, as shown in Table (7)

Table (7) Farmers' satisfaction with traditional and solar irrigation systems in Al-Hawija District - 2024

traditional irrigation	solar irrigation	Item
38%	82%	Satisfaction with lower costs
42%	79%	Operational stability
25%	88%	Intend to expand using the system

own work based on the questionnaire.

Hypothesis refutation : testing the validity of hypotheses

Results extracted from the study	Verification	Hypothesis formula	Hypothesis number
Traditional operating costs amounted to dinars per dunum, compared to 330,000 .dinars in solar 45,000	Fixed	Traditional irrigation is expensive and reduces .profitability	First
Net income: 625,000 dinars in solar compared to 415,000 dinars in traditional (+50%)	Fixed	Solar system is more profitable	Second
Reduce emissions by 75% (from 1.6 tons to tons/year 0.4)	Fixed	The solar system reduces .emissions	Third

Satisfaction rate with lower costs: 82% for solar versus 38% for conventional	Fixed	Farmers are more satisfied with the solar .system	Fourth
When fuel prices rise Conventional is severely affected, solar is not affected, and feasibility indicators remain high when production .declines	Fixed	The solar system .is more flexible	Fifth

own work based on fieldwork results and questionnaire data.

Conclusions and recommendations

The clear differences between the two systems indicate a significant comparative advantage for the solar system in terms of economic efficiency and sustainability . With lower operating costs, higher productivity, and fewer breakdowns, the solar system is more suitable for farmers, especially in areas with high solar radiation, such as Al-Hawija. These results are consistent with what has been reported in studies.

Hay (2020) and Al-Bajari (2012) FAO ,(2023)

Conclusions

Show Research shows that the solar-powered irrigation system has clear economic efficiency - compared to the traditional system, as it achieves a net income higher by more than 50%, and shortens the payback period to less than four years.

The solar system contributes to reducing carbon emissions by 75%, enhancing the commitment of rural agriculture in Al-Hawija District to sustainable environmental standards.

The solar system is characterized by low operating costs and stable field performance, which reduces 'malfunctions and increases the regularity of the irrigation process, which is reflected in farmers satisfaction and the intention to expand its use.

Sensitivity analysis showed that the solar system is more resilient to fluctuations in fuel prices and production, making it a safe option under conditions of economic uncertainty.

The results indicate that investing in solar systems not only achieves profitability, but also enhances local food security by stimulating agricultural expansion and increasing resource efficiency.

Recommendations

The need to adopt government policies to provide financial support to farmers wishing to switch to solar-powered irrigation systems, through soft loans or tax exemptions.

,Establishing agricultural and technical guidance centers in rural areas, such as Al-Hawija District - to train farmers on the operation and maintenance of solar irrigation systems.

Strengthening partnerships with the private sector to manufacture or import reliable solar energy - systems at an affordable cost, while ensuring the availability of spare parts and maintenance services.

Integrating renewable energy into national food security strategies and plans, and issuing - instructions requiring new agricultural projects to use clean energy solutions

Expanding the scope of future field studies to include other agricultural regions and diverse climatic - conditions, in order to support the dissemination of results at the national level.

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