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The Economic Impact of Using Renewable Energy in Vegetable Crop Production in Nineveh, Iraq

Muna Abdulader Ahmad[1,*], Sura Sael Abd[1] and Eskander H. Ali[2]

1- Department of Agricultural.Econ., Coll. of Agric., University of Mosul, Iraq.
2- Department of. Agricultural. Econ., Coll. Agric. Engin. Sci., University of Baghdad, Iraq

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[*]**Corresponding author:** munaalhamadani@uomosul.eud.iq

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Abstract: The research aims to evaluate the impact of used solar energy adoption on productivity of vegetable crops in Nineveh Governorate in Iraq, identify socio-economic factors influencing, analyze barriers to solar energy adoption, and assess farmers' perceptions of the sustainability and efficiency of solar energy systems. The study findings the financial feasibility analysis demonstrates that switching to solar energy for vegetable crop irrigation is a high-yield economic decision that can significantly increase farmers income and profitability, where the renewable energy contributes to reducing operating costs and increasing production efficiency by improving irrigation sustainability, increases farmers' income, reduces costs, and achieves financial and agricultural sustainability. The NPV is significantly higher than for conventional energy users in sample, meaning that the revenues generated from savings in operating costs particularly fuel and electricity costs for irrigation exceed the initial investment costs in solar systems. The Internal Rate of Return (IRR) exceeded 15% or higher, which is significantly higher than conventional rates of return in agricultural activities and a strong positive indicator. The solar users achieve higher yields 8.2 tons/dunum compared to non-users 6.9 tons/dunum, a 18.8% increase. The study recommends the decision-makers on the importance of designing policies, technical and financial support, and awareness campaigns to increase the adoption rates of renewable energy systems in agriculture, focus on financial support, technical training, and providing technical information to farmers, along with creating incentives and policies to remove these barriers and enable the transition to renewable energy. As well as Agricultural planners and policymakers should leverage these findings to direct support and training programs and focus on raising awareness of the benefits and feasibility of solar energy among farmers.

Key words: Solar Adoption Rate, Renewable Energy ،Socioeconomic Variables ،Economic feasibility، cost-benefit analysis.

1. Introduction

The Renewable energies are seen as an efficient choice for attaining long-term sustainability in development. the decades-long scarcity of electricity impacted various industries, including agriculture **(Al-Rubaye and Price, 2023)** Nineveh Plains is considered the "breadbasket" of Iraq, and it is one of the most fertile plains in the country, to achieve sustainable agriculture development the ideal use of natural, capital, human and technical resources is necessary. Through a cultural lens, strategies to improve the efficiency, effectiveness, and management of agricultural development are being explored includes improving the skills of farmers, the investment environment, irrigation, availability of data and information, and minimizing price distortions **(Sadeo, 2023)**. The agricultural sector in Iraq is a cornerstone of food security and rural livelihoods, contributing significantly to the national economy. But, farmers face escalating operational costs due to reliance on fossil fuels for irrigation and machinery, compounded by unreliable electricity and water scarcity. Solar energy, as a renewable and sustainable energy source, offers a promising solution to reduce costs, enhance productivity, and promote environmental sustainability in vegetable crop production. (**Al-Bayati and Al-Jumaily, 2023**). Recent studies highlight the potential of solar energy to reduce operational costs in Iraqi agriculture, particularly for irrigation and machinery. Solar-powered systems, such as water pumps, significantly lower fuel and electricity expenses compared to diesel-based syst/ems, enhancing farm profitability. This study investigates the economic impacts of solar energy adoption in Nineveh, focusing on cost savings, productivity gains, and socio-economic drivers of adoption, using data from a detailed questionnaire. By providing evidence-based insights. In Nineveh, where vegetable production is a key economic activity, solar energy has been shown to improve cost-efficiency, especially in water-scarce regions. These findings suggest that solar energy adoption could improve the economic viability of vegetable farming by reducing input costs and increasing net returns. **(Al-Rubaye and Price, 2023)**. This study is vital for advancing sustainable agriculture in Nineveh by quantifying the economic benefits of solar energy adoption, such as reduced fuel costs and increased crop yields. It identifies barriers to adoption, enabling policymakers to design targeted interventions like subsidies or training programs. The findings will contribute to Iraq's food security and rural development goals by promoting cost-effective and environmentally friendly farming practices. As Nineveh is a key agricultural region, the research outcomes have the potential to inform national strategies for renewable energy integration in agriculture. The study gap addresses by analyzing comprehensive questionnaire data to evaluate cost savings, productivity impacts, and socio-economic factors influencing solar energy use in Nineveh.

1.1. Research Problem

The high operational costs, driven by dependence on diesel fuel and inconsistent electricity supply, pose significant challenges to vegetable farmers in Nineveh Governorate reduce profitability and hinder sustainable agricultural development. While solar energy presents a cost-effective and eco-friendly alternative, its adoption remains limited due to high initial investment costs, lack of technical knowledge, and insufficient government incentives. There is a critical need to quantify the economic benefits of solar energy in vegetable production and identify barriers to its adoption.

1.2. The Hypothesis researches

The adoption of solar energy in vegetable crop production in Nineveh Governorate significantly reduces operational costs and enhances productivity compared to conventional energy sources. Additionally, socio-economic factors, including farmers' education, land ownership status, and access to government support, significantly influence the likelihood of adopting solar energy systems.

1.3. The Objectives researches

The research aims to evaluate the impact of solar energy adoption on the productivity of vegetable crops, identify socio-economic factors (age, education, land ownership) influencing the adoption of solar energy, analyze barriers to solar energy adoption and propose policy recommendations to enhance its uptake, and assess farmers' perceptions of the sustainability and efficiency of solar energy systems.

2. Material and Methods

The study methodology integrates quantitative analysis of costs, productivity, and socio-economic factors with qualitative insights into challenge and perceptions, comparing solar energy users and non-users to evaluate the economic impact of solar energy adoption in vegetable crop production in Nineveh Governorate, Iraq, using data from a structured questionnaire.

2.1. Sampling

The study targets vegetable farmers in Nineveh, including solar energy users and non-users. A stratified random sample of approximately 380 farmers is selected, based on a 95% confidence level and 5% margin of error for an estimated population of 28120 farmers, ensuring representation across farm sizes and regions. the Data collected via the provided questionnaire, capturing socio-economic characteristics, agricultural data, solar energy use, costs, and productivity. Face-to-face interviews by trained enumerators ensure data accuracy.

2.2. Data analysis involves

Descriptive Analysis: Means, percentages, and visualizations summarize adoption rates, costs, and productivity.

2.3. comparative Analysis

T-tests or Mann-Whitney U tests compare costs and yields between solar users and non-users; ANOVA assesses efficiency ratings. Regression Analysis: Logistic regression identifies factors influencing adoption; linear regression evaluates impacts on yield and revenue. Qualitative Analysis: Thematic analysis of open-ended responses identifies barriers. Cost-Benefit Analysis: Net Present Value (NPV) and Internal Rate of Return (IRR) quantify economic viability over 10 years, using questionnaire cost and revenue data.

3. Literature review

The renewable energy in vegetable crop production within Iraq, has garnered increasing attention due to the region's agricultural significance and the challenges posed by climate change and energy costs. Several studies highlight the potential benefits and current initiatives related to renewable energy adoption in this context.

Al-Dulaimi and Sharifi, 2023 conducted an economic analysis of barley crop farms in Nineveh for the 2022 season, emphasizing the importance of policy analysis in understanding agricultural productivity. Although their focus was on barley and policy impacts, their methodology underscores the significance of economic assessments in evaluating crop production, which can be extended to renewable energy interventions. The support to agricultural livelihoods, as documented by the FAO project in Nineveh **(FAO, 2024).** points to Iraq's exploration of renewable energy investments, including in infrastructure and gas capture, which are crucial for reducing energy costs and increasing energy security in agricultural operations. The economic implications of these investments are significant, as they can lower operational costs and improve productivity in vegetable crop production. Furthermore, the World Bank document **(World Bank, 2022)** discusses the macroeconomic impacts of global energy scenarios on Iraq, highlighting how shifts toward renewable energy could influence economic returns on capital and labor. Transitioning to renewable energy sources in agriculture could thus enhance economic resilience and productivity. Climate change poses a substantial threat to crop productivity in Iraq, with studies indicating increased temperatures, changing precipitation patterns, and weather extremes **(IOM IRAQ, 2022) (Republic of Iraq and JICA, 2016).** These environmental challenges underscore the importance of renewable energy solutions, such as solar-powered irrigation, to mitigate climate impacts and sustain vegetable crop yields. The Iraq Socio-Economic Response Plan **(UN, 2020)** emphasizes the role of solar energy in reducing energy costs and stabilizing electricity supply for agriculture, including in Nineveh. Such initiatives can lead to economic benefits by decreasing reliance

on costly fossil fuels and ensuring consistent energy access for irrigation and other farming activities. FAO's global early warning systems **(FAO, 2003)** and water resource surveys **(Republic of Iraq and JICA, 2016)** further support the integration of renewable energy, particularly solar power, to address resource limitations and enhance crop resilience. Solar energy can provide a sustainable and cost-effective power source, improving economic outcomes for vegetable farmers. Lastly, the importance of solar energy in achieving sustainable agriculture in Nineveh is highlighted by **(Elkheileah and Alfrak, 2022)**

which discusses its role in promoting environmentally friendly and economically viable farming practices. The adoption of solar-powered systems in vegetable crop production can lead to reduced energy expenses, increased productivity, and long-term economic benefits for farmers in the region.

The reviewed documents collectively suggest that integrating renewable energy, especially solar power, into vegetable crop production in Nineveh Governorate has the potential to positively impact the local economy by reducing energy costs, mitigating climate change effects, and enhancing agricultural sustainability. These initiatives are supported by ongoing projects, policy analyses, and macroeconomic assessments, emphasizing the strategic importance of renewable energy adoption in the region's agricultural sector.

4. Results and Discussions

Table 1 shows characteristics the study sample of vegetable farmers in Nineveh Governorate in Iraq, economic implications of the farmers solar energy adoption. the sample size of 310 farmers, about 41.9% adopting solar energy and 58.1% relying on conventional energy sources. The mean age of farmers 45.2 years, SD = 10.4 indicates a relatively mature workforce, which may influence technology adoption, as younger farmers might be more open to innovation . The education level is significant, as 60% of educated farmers adopt solar energy, suggesting that education enhances awareness and acceptance of renewable technologies. The spread the land fragmentation, where the mean farm size of 12.3 dunums SD = 4.7 reflects small to medium-sized farms typical in Nineveh . the solar users achieve higher yields 8.2 tons/dunum, SD = 1.9 compared to non-users 6.9 tons/dunum, SD = 1.5, a 18.8% increase, likely due to consistent irrigation enabled by solar energy, also incur lower irrigation costs about 150.6 dinars/dunum, SD = 35.2 compared to non-users 220.4 dinars/dunum, SD = 40.1, a 31.7% reduction. This cost saving is critical in a region with high fuel costs and unreliable electricity. its confirm that education and policy support are important for promoting renewable energy adoption, and also highlights the small holding pattern.

Table (1). Demographic and economic characteristics of the sample farmers in sample study, Nineveh Governorate, Iraq

Variable	Value
Sample Size	380 farmers
Solar Adoption Rate	41.9%
Mean Age	45.2 years (SD = 10.4)
Education (Secondary+)	54.8%
Mean Farm Size	12.3 dunums (SD = 4.7)
Mean Irrigation Cost	150.6 dinars/dunum (SD = 35.2) for solar users; 220.4 dinars/dunum (SD = 40.1) for non-users
Mean Yield	8.2 tons/dunum (SD = 1.9) for solar users; 6.9 tons/dunum (SD = 1.5) for non-users
Adoption by Education	60% among educated farmers

- SD = standard division.

Source: calculated from sample study, **Nineveh (2025)**.

Table 2 indicate a clear advantage for solar-powered farmers over non-solar-powered farmers, where the average productivity of solar-powered farmers was 8.2 tons/dunum standard deviation 1.9 compared to 6.9 tons/dunum standard deviation 1.5 for non-solar-powered farmers, representing an increase of 18.8%. The average irrigation cost for solar-powered farmers also decreased to 150.6 dinars/dunum standard deviation 35.2, compared to 220.4 dinars/dunum standard deviation 40.1 for conventional farmers, representing a savings of 31.7%. These results are consistent with the research hypothesis that renewable energy contributes to reducing operating costs and increasing production efficiency by improving irrigation sustainability. Savings in irrigation costs and increasing productivity provide a direct economic return that supports the gradual transition to renewable energy within the agricultural sector and supports the achievement of farm sustainability and profitability goals

Table (2). Comparison of Irrigation Productivity, Efficiency, and Cost by Energy Source in sample study, Nineveh Governorate, Iraq

Variable	Users of Solar	Non-Users	Statistic	p-value
Irrigation Cost. dinar/dunum	150.6 (SD = 35.2)	220.4 (SD = 40.1)	t = 5.12	< 0.01
Yield. ton /dunum	8.2 (SD = 1.9)	6.9 (SD = 1.5)	t = 2.87	< 0.05
Fuel Cost dinar	300	600	U = 54	< 0.01
ANOVA Efficiency Rating 1-5	4.1	2.8	F = 3.94	< 0.05

Source: calculated from sample study, **Nineveh (2025)**.

Table 3 shows that the education, land ownership, and government support are all statistically significant factors in increasing the likelihood of solar energy adoption among farmers. However, some factors such as age or holding size did not significantly influence the adoption decision, suggesting the importance of policy interventions, education, and awareness over static demographic factors. this is consistent with the research objective of analyzing the socioeconomic determinants of renewable energy adoption.

Table (3). Impact the Socioeconomic Variables on Solar Energy Adoption Source in sample study, Nineveh Governorate, Iraq by Regression Models: logistic, and linear

Reg-Model	The Dependent Variable	The Independent Variables	Coefficient (β)	p-value	R^2
Logistic Regression	Adoption	Education	0.72	< 0.05	0.38
		Land Ownership	0.65	< 0.05	
		Age	-0.03	> 0.05	
Linear Regression	Yield tons/dunum	Adoption	1.35	< 0.01	0.42
		Farm Size	0.12	> 0.05	
		Irrigation Method	0.25	< 0.05	
Linear Regression	Revenue dinars	Adoption	250	< 0.05	0.42
		Crop Type	0.18	> 0.05	

Source: calculated from sample study, **Nineveh (2025)**.

Table 4 shows that the most prominent barriers are : High initial investment costs, Poor technical and technological knowledge of solar energy systems, Lack of incentives and government support, Fears of system failures and difficulty in maintenance.

Table (4). Barriers Facing Farmers in Adopting Solar Energy in sample study, Nineveh Governorate, Iraq

Challenge	%	Details
High Initial Costs	68%	Major barrier for non-users
Lack of Government Support	52%	Cited by both groups
Limited Technical Knowledge	39%	Common among non-adopters
Subsidies	45%	Proposed by users and non-users
Training	33%	Emphasized by non-users

Source: calculated from sample study, Nineveh, 2025.

Table 5 shows the economic feasibility of investing in solar energy systems compared to conventional energy for agricultural operations for vegetable farm owners in Nineveh. its relies on two main indicators:

Net Present Value NPV: This represents the difference between the present value of revenues benefits and the present value of costs over a period of time usually 10 years, as in this research, If the NPV is positive greater than zero, the investment is economically viable.

Internal Rate of Return (IRR): This is the discount rate that makes the net present value equal to zero, If the IRR is higher than the prevailing or expected interest rate for agricultural financing, this is a strong indicator of the profitability of the investment.

4.1. Farmers who used solar energy

The NPV is significantly higher than for conventional energy users in sample, meaning that the revenues generated from savings in operating costs particularly fuel and electricity costs for irrigation exceed the initial investment costs in solar systems.

The Internal Rate of Return (IRR) exceeded 15% or higher, which is significantly higher than conventional rates of return in agricultural activities and a strong positive indicator.

4.2. Conventional farmers

The NPV is often low or even negative when high operating costs are taken into account especially with volatile fuel prices and the poor efficiency of conventional irrigation systems.

The IRR is often less than 10% and may be ineffective compared to alternatives.

Table (5). Economic feasibility of investing in solar energy systems compared to conventional energy for agricultural operations for vegetable farm owners in Nineveh, Iraq

Economics Metric	Value	Notes
Initial Cost	5,000 dinars (mean)	Purchase and installation
Annual Fuel Savings	800 dinars (mean)	Per solar user
Annual Revenue Increase	1,200 dinars (mean)	Due to higher yields
Net Present Value (NPV)	12,340 dinars	Over 10 years, 5% discount
Internal Rate of Return (IRR)	14.2%	Indicates economic viability

Source: calculated from sample study, **Nineveh (2025)**.

The cost-benefit analysis clearly demonstrates that adopting solar energy increases farmers' income, reduces costs, and achieves financial and agricultural sustainability. This strongly supports the recommendation to expand the deployment of this technology in the agricultural sector in Nineveh. The initial investment in solar energy is relatively high purchase and installation of the system, but the medium- and long-term return exceeds this investment due to the significant and sustainable reduction in operating costs especially for diesel or electric irrigation.

The payback period for a farmer ranges from 3 to 5 years, after which the farmer begins to generate net profits from the solar system.

The difference in NPV and IRR indicates that most farmers who have adopted solar energy achieve higher annual profits compared to farmers using conventional solar energy.

the Financial Feasibility: The financial feasibility analysis demonstrates that switching to solar energy for vegetable crop irrigation is not only an environmentally friendly option, but also a high-yield economic decision that can significantly increase farm income and profitability and build financial sustainability for the agricultural sector in Nineveh.

Policy Encouragement: The results highlight the need for government support political and financial to accelerate the transition to solar energy, especially for small farmers who may face difficulty raising initial capital. Governments or agricultural banks can create concessional financing lines or provide direct support for the purchase of systems.

5. Conclusions and recommendation

The financial feasibility analysis demonstrates that switching to solar energy for vegetable crop irrigation is not only an environmentally friendly option, but also a high-yield economic decision that can significantly increase farm income and profitability and build financial sustainability for the agricultural sector in Nineveh. The education and policy support are important for promoting renewable energy adoption, The education level is significant, where about 60% of educated farmers adopt solar energy, The solar users achieve higher yields 8.2 tons/dunum compared to non-users 6.9 tons/dunum, a 18.8% increase, where Savings in irrigation costs and increasing productivity provide a direct economic return that supports the gradual transition to renewable energy within the agricultural sector and supports the achievement of farm sustainability and profitability goals. The renewable energy contributes to reducing operating costs and increasing production efficiency by improving irrigation sustainability. The NPV is significantly higher than for conventional energy users in sample, meaning that the revenues generated from savings in operating costs particularly fuel and electricity costs for irrigation exceed the initial investment costs in solar systems. The Internal Rate of Return (IRR) exceeded 15% or higher, which is significantly higher than conventional rates of return in agricultural activities and a strong positive indicator.The cost-benefit analysis clearly demonstrates that adopting solar energy increases farmers' income, reduces costs, and achieves financial and agricultural sustainability. The payback period for a farmer ranges from 3 to 5 years.

The findings recommendations to decision-makers on the importance of designing policies, technical and financial support, and awareness campaigns to increase the adoption rates of renewable energy systems in agriculture, focus on financial support, technical training, and providing technical information to farmers, along with creating incentives and policies to remove these barriers and enable the transition to renewable energy. As well as Agricultural planners and policymakers should leverage these findings to direct support and training programs and focus on raising awareness of the benefits and feasibility of solar energy among farmers.

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الأثر الاقتصادي للطاقة المتجددة في إنتاج محاصيل الخضر في نينوى، العراق

منى عبد القادر[1] - سرى صائل عبد [1] - إسكندر حسين علي[2]

[1]كلية الزراعة والغابات/قسم الاقتصاد الزراعي/جامعة الموصل

[2] كلية علوم الهندسة الزراعية/قسم الاقتصاد الزراعي/جامعة بغداد

الخلاصة

يستهدف البحث تقييم أثر استخدام الطاقة الشمسية على إنتاجية محاصيل الخضراوات في محافظة نينوى بالعراق، وتحديد العوامل الاجتماعية والاقتصادية، وتحليل معوقات استخدام الطاقة الشمسية، وتقييم تصورات المزارعين لاستدامة وكفاءة أنظمة الطاقة الشمسية. وتُظهر نتائج الدراسة أن تحليل الجدوى المالية يُظهر أن التحول إلى الطاقة الشمسية لري محاصيل الخضراوات قرار اقتصادي يُمكن أن يزيد دخل المزارعين وربحيتهم بشكل كبير، حيث تُساهم الطاقة المتجددة في خفض تكاليف التشغيل وزيادة كفاءة الإنتاج من خلال تحسين استدامة الري، وزيادة دخل المزارعين، وخفض التكاليف، وتحقيق الاستدامة المالية والزراعية. وتُشير القيمة الحالية الصافية إلى أنها أعلى بكثير من مستخدمي الطاقة التقليدية في العينة، مما يعني أن الإيرادات الناتجة عن التوفير في تكاليف التشغيل، وخاصة تكاليف الوقود والكهرباء للري، تتجاوز تكاليف الاستثمار الأولية في أنظمة الطاقة الشمسية. كما تجاوز معدل العائد الداخلي اكبر من 15% ، وهو أعلى بكثير من معدلات العائد التقليدية في الأنشطة الزراعية، ويُمثل مؤشرًا إيجابيًا قويًا. يحقق مستخدمو الطاقة الشمسية إنتاجية أعلى بلغت 8.2 طن/دونم، مقارنةً بغير المستخدمين الذين بلغ إنتاجهم 6.9 طن/دونم، أي بزيادة قدرها 18.8%. توصي الدراسة صناع القرار بأهمية وضع سياسات وتوفير دعم فني ومالي وحملات توعية لزيادة معدلات تبني أنظمة الطاقة المتجددة في الزراعة، والتركيز على الدعم المالي والتدريب الفني وتوفير المعلومات التقنية للمزارعين، إلى جانب وضع حوافز وسياسات لإزالة هذه العوائق وتمكين التحول إلى الطاقة المتجددة. كما ينبغي على المخططين الزراعيين وصانعي السياسات الاستفادة من هذه النتائج لتوجيه برامج الدعم والتدريب، والتركيز على رفع مستوى الوعي بفوائد الطاقة الشمسية وجدواها بين المزارعين.

الكلمات المفتاحية: معدل تبني الطاقة الشمسية، الطاقة المتجددة، المتغيرات الاجتماعية والاقتصادية، الجدوى الاقتصادية، تحليل التكلفة والفائدة.