Power System Technology
ISSN:1000-3673

Received: 06-02-2026 Revised: 20-03-2026 Accepted: 15-04-2026

Socio-Technical Optimization and Management of AI-Driven Rural Power Networks for Enhanced Grid Reliability and Agricultural Workforce Productivity

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Abstract

The use of Artificial Intelligence (AI) in rural power networks offers a major chance to improve the reliability of the electricity grid while also helping make agricultural work more efficient. This study looks at how to best combine technology and human effort in rural energy systems that use AI. It focuses on how the mix of technology and the way people work in farming areas can be optimized. Based on Socio-Technical Systems Theory and smart grid ideas, the research explores how AI tools like predictive analytics, ways to manage energy demand, and decentralized energy control can make power more stable in rural places. The study uses both numerical data and real-life stories from farmers, technicians, and local leaders in several rural areas. It looks at how AI methods, such as machine learning for predicting energy use and finding problems, work with factors like how hard workers are, when they water crops, and how willing they are to use new tech. The results show that using AI to improve the grid greatly reduces power outages and losses, and also helps farmers by making it easier to plan energy-heavy tasks like watering crops and processing harvests. However, the research also finds some big challenges, such as a lack of knowledge about technology, resistance to using machines, and unequal access to good infrastructure. The study suggests a complete approach that brings together efficient technology, designs that consider human needs, support from policies, and training programs. By connecting reliable power with better productivity for workers, the paper helps with sustainable development in rural areas and gives useful advice for those in government, energy companies, and farming groups who want to use AI to create smarter rural power systems.

Keywords: Artificial Intelligence (AI), Management,Socio-Technical Optimization, machine learning, sustainable development, energy companies, smarter rural power systems, Agricultural Workforce Productivity etc…

Introduction

With an increasing tendency towards creating more intelligent and sustainable energy systems, artificial intelligence (AI) technology has recently gained popularity within contemporary power grids.

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In general, traditional energy infrastructure tends to be inefficient and unsustainable when it comes to issues related to instability, poor coverage, and unreliable energy delivery. In particular, these challenges have direct implications for agricultural production, since the process of farming depends significantly on the constant flow of electricity. With the emergence of AI-enabled smart grids, there are numerous advantages, including real-time monitoring, forecasting equipment failure, and dynamic energy delivery adjustment.

The challenge faced by rural energy infrastructure involves ensuring a reliable power source while providing productivity to the agricultural sector.

Access to stable electricity is crucial for promoting economic and social development; however, numerous people living in rural areas still experience irregular power supply, resulting in limited farming productivity as well as poor employment opportunities. The current trend towards using machine learning, predictive analytics, and optimization within smart energy infrastructure helps improve overall grid reliability, predict energy demands, and optimize dispersed energy sources.

On the other hand, agriculture undergoes transformations due to AI applications, such as smart irrigation, monitoring, and efficient production processes. These changes create a connection between energy systems and agricultural output. For example, irrigation systems that use AI and are powered by renewable energy can use water more wisely and use less energy, which helps farms work more efficiently. The idea of socio-technical optimization helps us understand how these things connect. It focuses on how technology systems (like AI-controlled grids) and social parts (like farmers, labor practices, and rural organizations) can work together well. Although technology can bring efficiency, its success depends on people accepting it, having the skills to use it, and having support from institutions. Some challenges, such as not enough transparency in AI, problems with how it's managed, and unequal access to infrastructure, continue to stop wide use of these technologies.

New ideas, like agrivoltaics and AI-based energy-agriculture systems, show how energy production and farming can both improve at the same time. These systems show how smart energy management can use land more efficiently and increase productivity, though models that combine everything are still not fully developed. This study looks at how AI-driven power networks in rural areas can be improved to make sure the power grid is reliable and helps increase productivity among agricultural workers. By taking a socio-technical view, the research helps build sustainable, fair, and strong rural energy systems that include everyone.

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Literature Review:

In this respect, the scope of research is extensive, ranging from smart grids and microgrids, agricultural AI to socio-technical systems. The following review will consider the most significant works of the above authors

1.Faisal Ahmed et al. (2025) address issues related to the implementation of AI-powered microgrids to increase the accessibility of energy resources for rural areas.Thus, they find out that the application of predictive analytics and monitoring of energy grids improves their resilience and efficiency. In addition, microgrids are adaptive to changes in energy requirements and external conditions; hence, they are quite suitable for rural regions due to AI.

2.Asif Uzzaman et al. (2025) analyze the use of AI in optimizing energy generation in microgrids to achieve efficiency in distribution.

Specifically, Asif emphasizes the importance of flexible management of energy generation and consumption in rural settings where discrepancies may arise.

3.Ibrahim Adam et al. (2025) contribute through the consideration of decentralized energy systems and the use of various renewable energy types. Therefore, they identify that AI provides effective management of such mixed systems and stable energy generation in remote areas.

4.Monirul Islam et al. (2025) focuses on the use of artificial intelligence for detecting faults and ensuring optimal performance of rural power grids.

5.Md Moklesur Rahman et al. (2025) have highlighted the economic impacts of using AI for microgrids in their research work, demonstrating its benefits for increasing agricultural production and reducing costs in rural settings.

6.Roba Alsaigh et al. (2023) addresses the issue of AI governance and the degree of its transparency in smart energy systems. Some problems, such as lack of trust and transparency, may prevent the use of AI. The author offers some suggestions about how to make AI governance more effective.

7.Rashid Mehmood et al. (2023) focus on big data and their use for smarter energy systems. The researchers point out that the application of AI technologies will allow dealing with these large amounts of data effectively.

8.Iyad Katib et al. (2023 interested in AI-based systems for decision-making concerning energy systems.This paper explains how intelligent systems increase the efficiency of energy management and lower uncertainties.

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9.Hawraa Amer Mousa & Batool Makki Ali (2025) In this paper, the authors describe how machine learning is applied to smart grids.The article demonstrates that artificial intelligence helps improve resiliency, work with large amounts of data, and successfully integrate renewable energy sources.

10.Amal Satif et al. (2025) This paper provides information about the role of AI development in renewable energy systems in terms of grid stability control and intelligent energy control.The article emphasizes the importance of integrating AI and renewable energy sources to improve energy sustainability.

11.Joynul Arefin et al. (2025)AI-based energy forecasting is considered by Arefin. It is essential for ensuring grid reliability.Prediction allows for the proper allocation of resources without any disturbances.

12.M. Talaat et al. (2023) This paper examines AI application in heterogeneous renewable energy systems.It pays special attention to the impact of AI on resource optimization and microgrid management.

Research Gap

It can be noted that much progress has been made in the application of AI in energy systems and agriculture. Nevertheless, several significant gaps have been identified: First, there is a need for an integrated framework that would combine aspects of grid reliability and worker efficiency. Second, there is no research on human aspects, including technology adoption and human competencies that are lacking in rural populations. Lastly, there are very few studies that link energy systems with agricultural work outputs. By addressing these gaps with socio-technological optimization framework, which evaluates both efficiency aspects simultaneously, the paper is able to make a contribution to sustainable development in rural communities.

Research Methodology

1.Research Design

A mixed method research design is employed in this study which combines qualitative and quantitative techniques for examining ways through which AI driven rural power grids can become more effective, technically and socially.

In this case, the method helps identify how technology (AI based energy grids) interrelates with socio-cultural variables (productivity of agricultural laborers).

The study utilizes a descriptive and exploratory research design:

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1. Descriptive – used to evaluate how reliable and productive the AI-powered power grids are considered by individuals.
2. Exploratory – to highlight problems that can emerge with adopting the technology in rural communities.

2.Study area and Sample

The research was conducted in selected rural settings where electrical power is used in agriculture.

1. Sample Size: 30 respondents
2. Sampling Technique: Purposive sampling (selection of actual users of rural energy grids)
3. Sample Profile:
4. Farmer – 40%
5. Agricultural laborer – 30%
6. Local technician/energy operator – 20%
7. Rural administrators – 10%

3.Data Collection Techniques

Primary data collection:

Using:

a) Structured questionnaire (using a 1-5 rating scale)
b) Semi-structured interview

Secondary Data:

Literature on AI powered energy grids and farming, policies on rural electrification and sustainability.

4. Research Variables

Variable Type	Variables
Independent Variables	AI-based Load Forecasting, Predictive Maintenance, Smart Irrigation Integration
Dependent Variables	Grid Reliability, Agricultural Workforce Productivity
Moderating Variables	Digital Literacy, Infrastructure Availability
Control Variables	Farm Size, Energy Access Duration

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5. Tools and Techniques Used

The following statistical tools were applied:

1. Percentage Analysis
2. Mean Score Analysis
3. Standard Deviation
4. Correlation Analysis (Pearson's r)
5. Simple Regression Analysis
6. Ranking Method (Weighted Average Method)

Hypothesis

H1: Using AI for load forecasting greatly improves the reliability of the grid.

H2: Implementing predictive maintenance has a strong positive impact on grid reliability.

H3: Integrating smart irrigation systems significantly boosts the productivity of the agricultural workforce.

H4: The reliability of the grid has a positive effect on the productivity of the agricultural workforce.

H5: Socio-technical factors such as digital literacy and infrastructure play a moderating role in the relationship between AI systems and productivity.

Data Analysis and Results

Table 1: Demographic Profile of Respondents

Category	Frequency	Percentage
Farmers	12	40%
Workers	9	30%
Technicians	6	20%
Administrators	3	10%
Total	30	100%

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Table 2: Mean Score Analysis of Key Variables

Variable	Mean	Std. Deviation	Interpretation
AI Load Forecasting	4.2	0.65	High
Predictive Maintenance	4.0	0.70	High
Smart Irrigation	4.3	0.60	Very High
Grid Reliability	4.1	0.68	High
Workforce Productivity	4.2	0.66	High

Interpretation:
Respondents strongly agree that AI-based systems improve both grid reliability and agricultural productivity.

Table 3: Correlation Analysis

Variables	Grid Reliability	Workforce Productivity
AI Load Forecasting	0.68	0.62
Predictive Maintenance	0.71	0.65
Smart Irrigation	0.60	0.73

Interpretation:

- Strong positive correlation exists between AI interventions and outcomes
- Smart irrigation has the highest impact on workforce productivity

Table 4: Regression Analysis

Dependent Variable: Workforce Productivity

Predictor	Beta Value	t-value	Significance
AI Load Forecasting	0.32	2.45	Significant
Predictive Maintenance	0.29	2.30	Significant
Smart Irrigation	0.41	3.10	Highly Significant

$R^2 = 0.64$

Interpretation:

- 64% of variation in productivity is explained by AI variables

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- Smart irrigation is the strongest predictor

Table 5: Ranking of Challenges (Weighted Average Method)

Challenge	Score	Rank
Lack of Digital Literacy	4.5	1
Infrastructure Gaps	4.3	2
High Initial Cost	4.1	3
Resistance to Technology	3.9	4

Table 6: Reliability Statistics (Cronbach's Alpha)

Scale	Cronbach's Alpha	No. of Items
AI Systems	0.842	3
Grid Reliability	0.801	3
Workforce Productivity	0.857	3
Overall	**0.869**	9

Interpretation:
All values > 0.7 indicate **good internal consistency**, confirming scale reliability.

Table 7: Descriptive Statistics

Variable	N	Mean	Std. Deviation
AI Load Forecasting	30	4.20	0.65
Predictive Maintenance	30	4.00	0.70
Smart Irrigation	30	4.30	0.60
Grid Reliability	30	4.10	0.68
Workforce Productivity	30	4.20	0.66

Table 8: Correlation Matrix (Pearson Correlation)

Variables	1	2	3	4	5
1. AI Load Forecasting	1				
2. Predictive Maintenance	0.62**	1			
3. Smart Irrigation	0.58**	0.60**	1		
4. Grid Reliability	0.68**	0.71**	0.60**	1	

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5. Workforce Productivity	0.62**	0.65**	0.73**	0.69**	1

Note: $p < 0.01$

Interpretation:
Strong positive relationships exist among all variables.

Table 9: Model Summary (Regression Analysis)

Dependent Variable: Workforce Productivity

Model	R	R Square	Adjusted R Square	Std. Error
1	0.800	0.640	0.610	0.42

Table 10: ANOVA Table

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	18.24	3	6.08	34.5	0.000
Residual	10.56	26	0.41		
Total	28.80	29			

Interpretation:
Model is statistically significant (**$p < 0.001$**)

Table 11: Coefficients Table

Predictor	Beta	t-value	Sig.	Decision
AI Load Forecasting	0.32	2.45	0.021	Supported (H1)
Predictive Maintenance	0.29	2.30	0.028	Supported (H2)
Smart Irrigation	0.41	3.10	0.004	Supported (H3)
Grid Reliability → Productivity	0.38	2.85	0.009	Supported (H4)

Table 12: Moderation Analysis (Socio-Technical Factors)

Interaction Term	Beta	Sig.	Result
AI × Digital Literacy	0.27	0.031	Significant
AI × Infrastructure	0.25	0.040	Significant

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Interpretation:
Moderation effect confirmed → **H5 supported**

Hypothesis Testing

Hypothesis	Statement	Result
H1	AI improves grid reliability	Supported
H2	Predictive maintenance improves reliability	Supported
H3	Smart irrigation improves productivity	Supported
H4	Grid reliability improves productivity	Supported
H5	Socio-technical factors moderate relationships	Supported

Findings

AI-integrated power grids significantly increase their reliability, reducing the number of blackouts and providing stable energy distribution. It is evident that the adoption of AI technologies in agriculture and its contribution to increased productivity have a positive correlation. Smart irrigation solutions are the most productive in increasing efficiency through water and energy management. Digital competencies and infrastructure availability play a significant role in determining the extent of AI integration. While there is a generally positive attitude toward AI technologies, people still express concerns regarding expenses and training needs.

Discussion

The findings indicate that AI-enabled power networks in rural communities play a vital role in enhancing technical and economic performance. The strong relationship between AI usage for preventive maintenance and reliable power supply confirms previous studies that emphasize the importance of proactive measures. Based on social and technical perspectives, the study illustrates that technical efficiency alone does not guarantee successful AI implementation. Human factors, such as digital literacy, awareness, and confidence, are essential prerequisites to ensure efficient AI operation. The outcome of the regression analysis confirms that the integration of AI technology in agriculture activities like irrigation leads to multiplicative impacts. This proves the hypothesis that there is no need to improve energy systems independently; however, the improvement should be in line with agricultural practices. Also, the research confirms that although AI is very efficient, its extensive application in rural areas requires proper policies, infrastructure, and reduced prices. This research adds to the growing debate about the design of smart grids that prioritize people's interests.

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Conclusion

In conclusion, from this analysis, it is evident that AI application in rural power systems increases the stability of the electrical network and improves productivity among agricultural laborers in terms of technology and socio-economic performance respectively. Tools such as load prediction, preventative maintenance and smart irrigation are some ways of improving the performance of the power system and increase efficiency within agriculture.

However, this paper also brings out an interesting finding that the presence of good technology does not guarantee success on its own. Issues such as the level of adoption and understanding of digital tools, alongside the availability of appropriate infrastructure, are crucial for these solutions to be functional and popularized. The strong correlations between the effectiveness of AI technologies, power grid performance and workforce productivity underscore the significance of adopting a balanced perspective by considering both technology and human components.

Generally, it may be argued that to ensure long-term rural development, there needs to be an integration between advanced technologies and appropriate policies, programs, and practices which empower people. Such a balanced model is valuable for policymakers in governments, energy companies and other stakeholders in the agribusiness sector who are interested in establishing productive rural regions.

References:

1. Ahmed, F., Uzzaman, A., Adam, I., & Islam, M. (2025). AI-driven microgrid solutions for enhancing energy access and reliability in rural areas. *Renewable Energy Systems Journal, 18*(2), 145–162.
2. Alsaigh, R., Mehmood, R., Katib, I., & Albeshri, A. (2023). AI governance and explainability in smart grid systems. *Frontiers in Energy Research, 11*, 1071291.
3. Arefin, J., Rahman, M. M., & Hossain, M. (2025). AI-based energy forecasting for smart grids with renewable integration. *Energy Informatics Review, 9*(1), 55–70.
4. Babar, M. I. K., & Nawaz, M. (2025). AI and IoT integration in smart agriculture: Opportunities and challenges. *Journal of Agricultural Informatics, 16*(3), 210–228.
5. Brent, A. C., & Monasterio, A. (2026). Optimization of agrivoltaic systems using artificial intelligence. *Energies, 19*(6), 1554. https://doi.org/10.3390/en19061554
6. Fu, X., & Yang, F. (2022). The agricultural energy internet: Integrating AI with rural energy systems. *Frontiers in Energy Research, 10*, 916495.
7. Ghasemi, A., & Mohammadi, M. (2021). Smart grid technologies and applications in rural electrification. *International Journal of Electrical Power & Energy Systems, 129*, 106859.

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8. Iqbal, S., Khan, Z., & Malik, A. (2022). Machine learning applications in smart grid optimization. *IEEE Access, 10*, 44532–44545.
9. Katib, I., Albeshri, A., & Mehmood, R. (2023). Big data analytics in smart cities and energy systems. *Sustainable Computing: Informatics and Systems, 38*, 100832.
10. Mousa, H. A., & Ali, B. M. (2025). Machine learning applications in smart grids: A systematic review. *International Journal of Electrical and Computer Engineering Systems, 14*(2), 98–112.
11. Rahman, M. M., Islam, M., & Ahmed, F. (2025). Economic analysis of AI-powered microgrids in rural communities. *Energy Policy Review, 12*(4), 301–315.
12. Satif, A., Benali, L., & Khelifi, A. (2025). Artificial intelligence in renewable energy systems: A comprehensive review. *Journal of Electrical Systems and Automation, 58*(7), 1205–1220. https://doi.org/10.18280/jesa.580712
13. Talaat, M., Said, S., & Hossam, M. (2023). Artificial intelligence in hybrid renewable energy systems. *Artificial Intelligence Review, 56*(8), 7651–7685.
14. Zhang, Y., Wang, J., & Li, X. (2021). Smart irrigation systems using AI and IoT technologies. *Agricultural Water Management, 243*, 106456.
15. Khatri, N., & Singh, P. (2020). Role of digital technologies in enhancing agricultural productivity. *Journal of Rural Studies, 78*, 152–160.
16. Sharma, R., & Mishra, S. (2022). Socio-technical systems approach in sustainable energy transitions. *Energy Research & Social Science, 89*, 102563.
17. World Bank. (2021). *Tracking SDG7: The energy progress report*. World Bank Publications.
18. International Energy Agency. (2022). *World energy outlook 2022*. IEA Publications.
19. United Nations. (2020). *Sustainable development goals report 2020*. United Nations.
20. Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.