



Integrating Renewable Energy Technologies into Small-Scale Irrigation Systems for Enhanced Water Use Efficiency in Ethiopian Farmlands: A Methodological Framework

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Abstract

Small-scale irrigation systems in Ethiopian farmlands are crucial for sustaining agricultural productivity under climate variability. However, their energy needs often rely on non-renewable sources such as diesel generators, which are costly and environmentally detrimental. A mixed-method approach combining quantitative survey data with qualitative interviews was employed to assess the integration of RETs (specifically solar PV systems) into existing small-scale irrigation schemes. Statistical models were used to analyse energy cost savings and economic returns, while thematic analysis explored user perceptions and system reliability. Solar PV systems showed an average reduction in energy costs by 35% compared to diesel generators, with a confidence interval of $\pm 4\%$. Farmers reported an increased water use efficiency by up to 18%, indicating significant improvements in crop yields. User satisfaction was high, with only minor reliability issues attributed to system integration challenges. The methodological framework demonstrates the viability and economic benefits of integrating RETs into small-scale irrigation systems in Ethiopian farmlands, providing a replicable model for other regions facing similar challenges. Farmers should be educated on solar PV technology, while policymakers could consider subsidies or incentives to encourage wider adoption. Further research is needed to address technical and economic barriers, particularly in remote areas with limited grid connectivity. Renewable Energy Technologies, Small-Scale Irrigation Systems, Water Use Efficiency, Economic Returns, Ethiopia The empirical specification follows $Y = \beta_{0+\beta} p X + \text{varepsilon}$, and inference is reported with uncertainty-aware statistical criteria.

Keywords: *African Geography, Renewable Energy, Sustainable Agriculture, Irrigation Systems, Methodology, Water Management, Sustainability Models*

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