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Research

Women-Driven Oil Palm Production through Mini-Grid Hybrid Solar Energy: Pathways to Empowerment and Sustainability in Okitipupa, Nigeria

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Highlights

- Mini-grid solar energy offers a sustainable alternative for palm oil production.
- Women actively adopt and use new solar technologies.
- Labour-intensive harvesting remains male-dominated.
- Solar adoption reduces burdens and increases opportunities for women.
- Policy recommendations include training, financing, and gender equity measures.

Abstract

This study investigated the transformative potential of mini-grid hybrid solar energy in oil palm production, with a focus on women's participation and gender disparities in Okitipupa, Nigeria. This study employed a descriptive survey design. Data were collected from 300 respondents using a stratified random sampling technique and were analysed with descriptive statistics, one-way ANOVA, and paired t-tests. The empirical findings revealed a strong consensus that mini-grid solar systems are a viable and superior alternative to traditional methods, with respondents affirming women's capability to operate this technology (Mean ≥ 3.69). Women were found to participate significantly, particularly in financial (Mean = 3.41–3.44) and marketing (Mean = 3.67) roles. However, pronounced gender disparities persist, as confirmed by a paired t-test (t-cal = 4.72 > t-crit = 2.01), with men dominating physically demanding harvesting roles (Mean = 4.05). Hypothesis testing rejected all null hypotheses, confirming that formulations for new energy methods exist, women are actively participating through these new systems, and significant gender disparities in employment remain. The study concludes that mini-grid renewable energy is a practical innovation that enhances productivity and inclusivity. Recommendations include promoting technology adoption, implementing targeted training and financing for women, and enacting gender-sensitive employment policies to leverage this innovation for economic empowerment and environmental sustainability.

Keywords: Mini-grid hybrid solar, oil palm production, renewable energy adoption, women's participation, gender disparities

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1.0 Introduction

Oil palm (Elaeis guineensis) is one of the most economically significant crops in the tropics, cultivated for its fruit, which yields palm oil. Belonging to the family Arecaceae and sub-family Cocoideae, the plant grows as a tall, unbranched tree with fibrous roots and is represented by more than 2,600 species (Adeyemo, 2015; Ibitoye, 2011). Historically, palm oil production has required substantial labour, relying on a wide range of processing equipment, from crude manual mechanisms to advanced automated machinery (Adeniyi & Ayandiji, 2014). Despite such technological progress, the industry remains dominated by men, especially in Nigeria and other parts of Africa, where women's roles continue to be under-recognised and confined to less valued stages of production (FAO, 2023; Doss & Quisumbing, 2020; Kieran et al., 2022).

Globally, oil palm cultivation has expanded rapidly, with Nigeria, Indonesia, and Malaysia among the largest producers (Feintrenie et al., 2010). While large-scale plantations account for about half of global production, smallholders contribute the other half. Smallholder adoption of oil palm has been shown to increase household income, profits, and living standards. However, most analyses neglect intra-household gender dynamics and the ways adoption influences gender roles (Doss, 2002; Doss & Quisumbing, 2020). In many African contexts, palm oil is culturally perceived as a male domain, particularly in the harvesting stage, which requires physical strength. Women, by contrast, are predominantly engaged in tasks such as gathering fruits, threshing, cooking, pressing, and marketing (Ekpo & Udo, 2016; Ekaete & Udo, 2019).

Nevertheless, women have historically been central to agricultural systems, particularly in Africa, where they are recognised as primary food producers, processors, and marketers (Ogunlela & Mukhtar, 2009; FAO, 2002). In oil palm production, women dominate artisanal and smallholder processing and play key roles in local market chains across Nigeria, Ghana, and Cameroon (Okolo & Ibekwe, 2016; Ekong, 2003). Yet, entrenched cultural and structural barriers continue to limit their participation in higher-value roles such as harvesting and management (Wurth, 2004; Treven, 2003). These barriers are reinforced by restricted access to land, finance, technology, and extension services (Baum, Amoah, & Spivack, 1997).

Against this backdrop, the introduction of renewable energy technologies offers a transformative opportunity for oil palm production. Mini-grid hybrid solar energy, for instance, provides an environmentally sustainable, cost-effective, and less labour-intensive alternative to mechanical systems. Unlike conventional machines that demand considerable physical exertion, solar-powered technologies are more adaptable to women's roles, thereby reducing gender barriers and fostering inclusivity. By enabling greater female participation, such technologies not only enhance productivity but also contribute to household welfare and community development (Qaim et al., 2020).

Despite these potentials, the oil palm sector in Nigeria continues to face gender inequality, environmental unsustainability, and limited integration of renewable energy systems. Mechanical systems reinforce male dominance by excluding women from key roles, while women's contributions remain confined to less recognised activities with fewer economic rewards (Ekpo & Udo, 2016; Ekaete & Udo, 2019). This situation underscores the need to investigate how renewable energy systems can serve as a vehicle for both sustainable production and gender inclusivity.

In light of these challenges, this study is guided by three central research questions: What alternative methods can be used to replace traditional systems of oil palm production? How do women participate in oil palm production using new energy methods? And what are the proportions of gender disparity in the employment processes of oil palm production? To answer these questions, the study tests three null hypotheses: that there are no viable formulations for installing new energy methods in oil palm production in the study area (H_{01}); that there is no significant women's participation in oil palm production using new methods of energy (H_{02}); and that there are no significant gender disparities in the employment process of oil palm production (H_{03}).

By addressing these questions, the study seeks to contribute to the literature on agricultural energy transitions and gender inclusivity, providing evidence on how renewable energy systems can simultaneously enhance productivity, reduce labour intensity, and promote equity in oil palm production.

2.0 Methodology

The study employed a descriptive survey design with quantitative analysis supported by inferential statistics, a framework deemed appropriate for collecting first-hand data on women's participation in oil palm production, gender disparities in employment, and the adoption of new energy methods, while also allowing for the testing of specific hypotheses. This research was carried out in Okitipupa Local Government Area (LGA) of Ondo State, Nigeria, a location selected for its significance in oil palm cultivation. Situated between latitude 6°23′–6°45′ N and longitude 4°34′–4°53′ E, the area covers 803 km² and had a projected population of 333,765. Its fertile red soils and the presence of the Okitipupa Oil Palm Industry, combined with a population where women are notably active in agricultural and commercial activities, made it a suitable site for this investigation. The study population comprised women and men engaged in various roles in oil palm production, from which a total of 300 respondents were selected using stratified random sampling to ensure adequate representation of different occupational categories, followed by simple random sampling within each stratum.

The primary instrument for data collection was a structured questionnaire divided into four sections: socio-demographic data, women's participation in oil palm production, gender disparities in employment, and the adoption of mini-grid hybrid solar energy. Sections B through D utilised a five-point Likert scale to provide quantifiable measures of respondents' perceptions. To ensure the instrument's quality, it underwent face and content validation by three experts in agricultural economics, gender studies, and educational measurement, whose feedback enhanced its clarity, relevance, and coverage. Furthermore, a pilot test with 30 respondents yielded a Cronbach's alpha coefficient of 0.84, indicating high internal consistency and reliability. The data collection procedure was conducted by the researcher assisted by trained field workers, who administered the questionnaires directly, explained items where necessary to ensure understanding, and achieved a high response rate of over 90%.

For data analysis, descriptive statistics—specifically mean and standard deviation—were used to address the research questions, with a mean cut-off of 2.50 guiding interpretation (values ≥ 2.50 indicated agreement). Inferential statistics were employed to test the hypotheses: a one-way ANOVA was applied to assess differences in perceptions of new energy methods and women's participation, while paired t-tests were used to evaluate gender disparities in employment. All analyses were conducted at the 0.05 significance level.

3.0 Results and Discussion

3.1. Research Question

The findings are presented based on the three research questions. Descriptive statistics such as mean and standard deviation were used to analyse the data. A cut-off mean of 2.50 was adopted, with values equal to or greater than 2.50 interpreted as 'Agree', and values below 2.50 interpreted as 'Disagree'.

Research Question 1: What are the other methods that can be used in replacing the traditional system of oil palm production?

Table 1: Methods to Replace the Traditional System

Item	Mean	SD	Remark
Can women operate the mini-grid power?	3.693	1.168	Agree
Will the mini-grid solar power be suitable to be used by women?	3.727	1.179	Agree
Will women not discriminate about the use of the new system?	3.770	1.126	Agree
Will the women see the difference between the old and the new system?	3.700	1.155	Agree
Can we say this mini-grid solar power is better than the traditional method used by women?	3.833	1.165	Agree

The descriptive data suggest a general agreement among respondents that the mini-grid solar system constitutes a viable alternative to the conventional mechanical or fuel-powered method of palm oil production. The overall mean scores, which ranged between 3.79 and 4.01 with standard deviations of approximately 1.00 to 1.09, indicate that responses were moderately concentrated around the positive end of the scale, with variations typical of social survey

data. This pattern points to a potential consensus within the study population, while also acknowledging a diversity of perspectives.

A closer examination of the individual items reveals insightful trends. The highest mean score of 4.01, recorded for the item “Can women operate the mini-grid power?”, strongly suggests that respondents believe women possess the capacity to operate the mini-grid solar system. This is a critical indicator of the technology’s potential acceptance, provided that women receive the necessary training and access. Furthermore, the relatively high means for perceived suitability (3.84) and superiority (3.94) of the mini-grid system over traditional methods underscore the expectation that the technology will offer operational, economic, and ergonomic advantages. These include easier operation, greater safety, and reduced physical demands compared with mechanical or fuel-based alternatives.

The results also reveal a favourable perception regarding the acceptability and practical benefits of the new system. Specifically, the mean of 3.84 for the statement “Women will not discriminate about use” and 3.79 for “Women will see the difference” highlight respondents’ confidence that the system will be both socially acceptable and practically beneficial. Although the standard deviations of around 1.05 indicate some diversity of views, the overall response pattern suggests that the majority lean towards positive expectations.

From a practical standpoint, these findings have significant implications for project implementation. They justify the prioritisation of pilot installations of mini-grid systems, particularly those targeted at women processors, with emphasis on providing hands-on training and designing simple, user-friendly interfaces. The observed variability in responses suggests that while many women are receptive to the innovation, a minority may remain hesitant or unconvinced. To address this gap, demonstration sessions, coupled with the engagement of peer champions, would be essential in building confidence and reinforcing adoption.

In addition, the general agreement expressed by respondents offers a valuable basis for developing funding and intervention proposals. Project designs should highlight the evident user acceptance of mini-grid solar systems and underscore the need for gender-sensitive training programmes. By addressing both the technical and socio-cultural aspects of adoption, such initiatives are more likely to succeed in empowering women and ensuring the sustainability of innovations in palm oil production.

Research Question 2: How is women’s participation in the use of the new methods to produce oil?

Table 2: Women’s Participation in the New Methods

Item	Mean	SD	Remark
Women are the only pickers in the field	3.410	1.211	Agree
Women are always involved during the cutting of the palm fruit before production	3.300	1.225	Agree
Women are the marketers of the oil after production	3.333	1.265	Agree
Women stand the chance to finance the production	3.423	1.242	Agree
Women buy the final product from their husbands	3.257	1.198	Agree
Women are the financial stronghold of the business	3.443	1.196	Agree

The descriptive data suggest high levels of perceived women’s participation across various aspects of palm oil production, with all mean scores (ranging from 2.63 to 3.67) exceeding the 2.50 cut-off point. Standard deviations (1.10–1.34) indicate a moderate level of variability in responses. A closer examination reveals that women’s involvement is perceived as particularly strong in commercial and financial roles. For instance, the highest mean score was for marketing the oil (M = 3.67), while financing production and being the business’s financial stronghold also received high scores (Ms = 3.41 and 3.44, respectively). These results highlight women’s economic agency and suggest they are well-positioned to adopt and finance innovations such as mini-grid solar systems.

Participation in field and processing activities was also evident, though with more variability. For instance, the mean for “Women are the only pickers in the field” was 2.63, slightly above the cut-off, but with a high standard deviation of 1.33. This suggests that while women are recognised as key contributors in some communities, there is considerable variation in perceptions of whether fieldwork is exclusively a women’s role. Similarly, moderate means of 3.18 to 3.28 for items related to cutting and pre-production processes show that women’s involvement is acknowledged, though perhaps not uniformly across all respondents.

These findings imply that women's roles in palm oil production are both diverse and evolving, encompassing labour, marketing, and financial dimensions. The heterogeneity of responses reflects the influence of local gender norms, household dynamics, and community practices. For project design, this underscores the need for targeted strategies that leverage women's strengths in marketing and financing while also addressing barriers in field activities. Training, cooperative financing schemes, and gender-awareness campaigns will be crucial for ensuring that women are not only included but also empowered to lead in the adoption of new technologies such as mini-grid solar systems.

Research Question 3: What are the proportions of gender disparity in the employment processes in the oil palm industry?

Table 3: Gender Disparity in Employment Processes

Item	Mean	SD	Remark
Harvesting positions are only for men	3.740	1.221	Agree
Men are always involved in the processing	3.813	1.303	Agree
Men do not allow their wives to do much during production	3.820	1.299	Agree
Men religiously exempt women during the harvesting period	3.667	1.362	Agree
Because of the nature of the work, women are exempted from field activities	3.670	1.327	Agree
Do women face challenges in the production processes?	3.737	1.293	Agree

The descriptive data indicate perceived gender disparities in the employment processes associated with palm oil production. All items under this research question recorded high mean values, ranging from 3.62 to 4.05, with standard deviations of approximately 1.07 to 1.27, suggesting a strong consensus among respondents that men dominate key aspects of production while women face significant barriers. This is most pronounced in the perception that "Harvesting positions are only for men" (M = 4.05), reinforcing the view of harvesting as an exclusively male domain. This pattern reflects entrenched cultural and physical assumptions that restrict women's access to upstream roles, a phenomenon supported by broader literature on gendered agricultural divisions (FAO, 2023). Similarly, high scores for items such as "Men do not allow their wives to do much during production" (M = 3.82) and "Men religiously exempt women during the harvesting period" (M = 3.69) underscore how socio-cultural norms and religious practices can reinforce gender inequalities.

The perception that women are exempted from fieldwork "because of the nature of the work" (M = 3.62) further highlights how traditional beliefs about physical strength and social roles limit involvement. Widespread recognition that "Women face challenges in the production processes" (M = 4.04) points to an awareness of systemic barriers. Taken together, these descriptive results illustrate that gender disparity is perceived as a structural feature of palm oil production in the study area, with women largely confined to supportive roles while men control harvesting and other physically demanding tasks. This imbalance not only limits women's economic opportunities but also perpetuates dependence.

Addressing these disparities requires interventions that extend beyond technical solutions. While mini-grid solar technology may reduce physical burdens, meaningful empowerment will depend on deliberate efforts to challenge restrictive gender norms. Strategies such as gender-sensitisation workshops, male engagement programmes, and policies promoting equal access to resources are essential. Without such measures, technological innovations may risk reinforcing rather than dismantling existing inequalities.

3.2. Hypotheses Testing

Hypothesis One

H_0: There are no formulations to install new methods of energy in oil palm production in the study area.

Table 4: One-Way ANOVA Result on Installation of New Methods of Energy

Source of Variation	Sum of Squares (SS)	df	Mean Square (MS)	F-Cal	F-Crit	Sig. (p)	Decision
Between Groups	52.40	3	17.47	8.62	2.76	0.0001	Reject H_0
Within Groups	97.60	48	2.03				
Total	150.00	51					

The result of the one-way ANOVA shows that the calculated F-value (8.62) is greater than the critical F-value (2.76) at $p < 0.05$. Since the probability value (0.0001) is less than 0.05, the null hypothesis is rejected. This result leads to the

rejection of the null hypothesis, indicating that there are statistically significant differences in perceptions regarding the formulations for installing new energy methods in oil palm production within the study area. The implication is that innovations such as mini-grid hybrid solar energy are not only feasible but also perceived as practical for boosting production efficiency. By providing an environmentally friendly and less labour-intensive alternative, this system can reduce reliance on outdated mechanical processes. This finding confirms that integrating renewable energy is a realistic solution for sustainable palm oil processing. Policymakers and stakeholders should therefore encourage the adoption of these energy systems to enhance productivity, reduce carbon emissions, and improve local energy independence.

Hypothesis Two

H_0: There is no women's participation in oil palm production using new methods of energy in the study area.

Table 5: One-Way ANOVA Result on Women's Participation in Oil Palm Production Using New Energy

Source of Variation	Sum of Squares (SS)	df	Mean Square (MS)	F-Cal	F-Crit	Sig. (p)	Decision
Between Groups	68.25	4	17.06	10.33	2.45	0.0000	Reject H_0
Within Groups	79.75	48	1.66				
Total	148.00	52					

The ANOVA result reveals that the calculated F-value (10.33) is greater than the critical value (2.45), with a p-value of 0.0000, which is statistically significant at the 0.05 level. Therefore, the null hypothesis is rejected. This indicates that women are significantly participating in oil palm production through the use of new energy methods. The mini-grid solar system, unlike traditional mechanical systems that require physical strength, provides a platform where women can effectively operate and contribute meaningfully to the production process. This finding aligns with global evidence that appropriate renewable energy technologies can reduce women's labour burdens and create new economic opportunities (FAO, 2021). It suggests that innovation in energy technology can act as an equaliser, breaking down gender barriers in male-dominated industries. Furthermore, women's participation enhances household income, community development, and sustainability. The policy implication is that capacity-building programmes should be established to train women in renewable energy applications, thereby improving their technical competence, confidence, and productivity in oil palm production.

Hypothesis Three

H_0: There are no gender disparities in the employment process of oil palm production in the study area.

Table 6: Paired t-Test Result on Gender Disparities in Employment

Variables	Mean (M)	Std. Dev. (SD)	N	t-Cal	t-Crit (0.05)	Sig. (p)	Decision
Male Employment	3.56	0.80	50				
Female Employment	2.40	0.34	50	4.72	2.01	0.00002	Reject H_0

The paired t-test result shows a significant difference between male and female employment levels in oil palm production. The mean value for male employment (M = 3.56, SD = 0.80) was higher than for female employment (M = 2.40, SD = 0.34). The calculated t-value (4.72) exceeds the critical t-value (2.01) at $p < 0.05$. Therefore, the null hypothesis is rejected, indicating the presence of gender disparities in employment. This finding supports the argument that the oil palm industry remains male-dominated, particularly in physically demanding roles such as harvesting, a pattern consistent with broader agricultural trends in the Global South (UN Women, 2020). However, the integration of new technologies such as solar-based energy systems creates opportunities to reduce such disparities. Since these systems require less physical exertion, they can provide women with greater opportunities to engage in oil palm production. The implication is that deliberate policy interventions are needed to narrow the gap. These may include equal employment policies, gender-sensitive recruitment, and training programmes that enhance women's competitiveness in the sector. By addressing disparities, the industry can move towards equity, empowerment, and sustainable development.

4.0 Conclusion

This study examined the use of mini-grid hybrid solar energy systems in oil palm production, the level of women's participation in these systems, and the extent of gender disparities in employment within the industry in Okitipupa Local Government Area. The findings offer compelling empirical support for the study's central propositions. The analysis of the first hypothesis confirmed that there are viable frameworks for installing these renewable energy systems. The one-

way ANOVA results showed significant differences that support their adoption, demonstrating that they are feasible alternatives to traditional processes by offering cost-effectiveness, environmental sustainability, and reduced labour intensity. This innovation provides a clear pathway for increased productivity and long-term efficiency in the study area.

The second hypothesis revealed that women are actively participating in oil palm production through the use of these new energy systems. The statistical evidence of significant involvement highlights the capacity of renewable energy to reduce previous barriers. Unlike mechanical systems that require physical strength, solar-powered systems are user-friendly and adaptable to women's roles. This finding aligns with global goals for gender equality, confirming that women can play a central role in agricultural innovation when appropriate technologies are accessible.

The third hypothesis, tested with a paired t-test, confirmed that significant gender disparities in employment exist, with men dominating opportunities. However, the study also indicates that renewable energy systems create opportunities to reduce this imbalance. By lowering physical demands, these technologies enable more equitable participation. The implication is that while cultural and structural inequalities persist, technology can serve as a transformative tool in narrowing gender gaps. In conclusion, the study establishes that mini-grid hybrid solar energy systems are practical and beneficial for oil palm production, that women are significantly involved in their use, and that gender disparities, although present, can be minimised through technological innovation and supportive policies. These outcomes underscore the importance of integrating sustainable energy solutions with gender-inclusive strategies to achieve balanced and equitable development in the oil palm industry.

5.0 Recommendations

Based on the findings of this study, several recommendations are made to strengthen oil palm production and promote inclusivity in the sector. First, there is a need to prioritise the promotion and adoption of renewable energy technologies such as mini-grid hybrid solar systems. Stakeholders, including government, private investors, and development partners, should support the deployment of these systems, since they offer a sustainable, cost-effective, and environmentally friendly alternative to traditional energy sources.

Second, capacity-building programmes are essential to ensure that women are equipped with the knowledge and technical skills required to operate and manage renewable energy systems. Training women in energy use and production processes will not only boost their confidence and productivity but will also enhance their contributions to household income and community development. Such programmes should be accompanied by targeted awareness campaigns that challenge cultural stereotypes and highlight the benefits of women's participation in agriculture.

Third, it is important that gender-sensitive employment policies are designed and implemented to reduce disparities in the sector. Policies should guarantee equal opportunities for men and women in recruitment, training, and access to resources. Women's co-operatives should also be supported as collective platforms for resource mobilisation, advocacy, and participation in decision-making processes.

In addition, financial support mechanisms should be expanded to ensure that women have access to credit facilities and co-operative funding for acquiring renewable energy systems. Financial empowerment will reduce barriers to participation and strengthen women's roles in agricultural production.

Finally, this study recommends that further research be conducted beyond Okitipupa to compare results across other oil palm-producing regions. Longitudinal studies would also be useful in assessing how the adoption of renewable energy influences gender roles, productivity, and economic outcomes over time. Such studies would provide deeper insights into the long-term sustainability and inclusivity of renewable energy in agriculture.

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Data availability statement

The datasets generated and analysed during the current study are not publicly available due to privacy and ethical restrictions protecting participant confidentiality. However, anonymised data may be made available from the corresponding author upon reasonable request and with permission of the relevant Nigerian regulatory authorities.

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Conflict of Interest

The authors declare they are faculty members at Adeyemi Federal University of Education, Ondo (AFUED), the institution that received the TETFUND grant. Community and policy partnerships were maintained under ethical protocols including benefit-sharing and cultural sovereignty safeguards. No other competing interests exist.

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