Frugal Solar Innovations and Rural Transformation: A Qualitative Inquiry into Livelihood and Educational Access in Telangana

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***Abstract*—This study explores the transformative impact of frugal solar innovations on rural livelihoods and education in Telangana, India. Based on interviews with 47 households representing over 200 individuals, the research highlights diverse rural experiences. The study focuses on Pagidipalli (Bibinagar Mandal), Gurrampode, Rajapet, and Peddagollapalli (Nalgonda District), where solar technologies are actively used. Findings reveal improved study time, school attendance, and income generation, especially among women and local enterprises. Adoption patterns align with Rogers' Diffusion of Innovations Theory. Key challenges include limited maintenance and awareness. In light of Telangana's pilot solar village initiative, the study advocates a scalable, community-led model to foster sustainable rural development.**

***Index Terms*—Frugal Innovation, Solar Energy, Rural Development, Telangana, Education Access, Livelihoods, Social Inclusion, Qualitative Research**

I. INTRODUCTION

In rural India, where 61% of the population resides (Census 2011), communities face persistent challenges of energy poverty, limited agricultural productivity, and insufficient educational opportunities. These obstacles significantly hinder socio-economic development and social mobility. Frugal solar innovations—such as affordable solar lanterns, rooftop panels, and irrigation pumps—have emerged as critical solutions in these underserved regions, providing decentralized, low-cost alternatives to conventional energy sources.In Telangana, these solar technologies are being integrated into rural livelihoods through various initiatives by government agencies like TSREDCO, alongside the efforts of NGOs such as the SELCO Foundation and Barefoot College, often supported by corporate social responsibility (CSR) contributions. These innovations are enabling improved income generation through more efficient agricultural practices and the support of micro-enterprises, while also enhancing education by providing reliable lighting and access to digital learning tools. As a result, households benefit from better study conditions, extended working hours, and reduced dependency on costly, unreliable power sources, allowing savings to be redirected to essential needs such as food, healthcare, and education.

A key recent development that strengthens the role of solar power in rural Telangana is the government's announcement to convert 25 villages into fully solar-powered communities. highlighted this initiative as a pilot project aimed at reducing electricity costs and dependency on conventional energy. The project will involve the installation of rooftop solar panels for both agricultural pump sets and household electricity, positioning these villages as models for broader, scalable solar adoption across the state. This pilot further emphasizes the urgency and policy relevance of this study, which examines how frugal solar innovations can contribute to sustainable rural development.

1.1 Review of Literature:

Frugal innovation has gained scholarly attention as a development strategy that emphasizes affordable, adaptable, and contextually relevant solutions, particularly in emerging economies. Radjou, Prabhu, and Ahuja (2012) popularized the concept of Jugaad Innovation, framing frugality not as a constraint, but as a design principle that fosters ingenuity in low-resource settings. These innovations are especially relevant in rural contexts where access to capital, infrastructure, and skilled labor is limited.

Solar-based frugal innovations, such as solar lanterns, rooftop systems, and low-cost irrigation pumps, have been widely adopted in India and Sub-Saharan Africa to address rural electrification gaps. According to Bhatti (2014), frugal technologies are most impactful when they are co-created with local communities, require low maintenance, and can scale with minimal technical dependence. In the Indian context, several studies have examined the role of solar technologies in enhancing rural livelihoods. Rathi and Vermaak (2018) found that access to solar lighting extended working hours for rural artisans and shopkeepers in Uttar Pradesh. Similarly, Rao et al. (2020) observed that solar irrigation systems in Maharashtra led to increased agricultural productivity and reduced dependence on diesel pumps.When it comes to education, solar technologies have shown measurable benefits. A study by Chakrabarti and Schweitzer (2011) noted that school attendance and evening study hours increased in villages with solar-powered lighting. More recent work by Selvaraj et al. (2021) highlights the role of solar-powered digital classrooms in reducing dropout rates in tribal schools across Tamil Nadu.However, the literature also identifies several barriers to adoption, including the lack of financing models, low technical awareness, and challenges in after-sales maintenance (Bhide & Monroy, 2011). In Telangana, despite policy support from agencies like TSREDCO and schemes like Mission Bhagiratha, academic literature on frugal solar innovation's qualitative impact—particularly on livelihood and education—is still limited. Most available studies are either techno-economic assessments or focused on broader state-level electrification without disaggregating community-level insights. This study seeks to fill this gap by exploring how grassroots-level adoption of solar technologies is driving socio-economic and educational transformation in rural households.

I.2 Theoretical Framework:

This study is grounded in two complementary theoretical frameworks. First, the Sustainable Livelihood Framework (SLF) is used to understand the impact of solar innovations on household assets, coping strategies, and livelihood outcomes. Second, Rogers' Diffusion of Innovations Theory helps explain the patterns of adoption and resistance within communities regarding solar technology. These frameworks help interpret both the socio-economic outcomes and the behavioral aspects of solar adoption.

Research Questions:

1. How do solar-based frugal innovations alter livelihood stability in rural Telangana?
2. In what ways do these innovations affect educational access and outcomes for school-going children?
3. What socio-economic and contextual factors influence the adoption and sustainability of solar technologies?

1.3 Need for the Study:

In rural Telangana, the lack of reliable energy access remains a significant barrier to socio-economic development. With over 61% of the population in rural areas, the need for affordable, sustainable solutions that address energy poverty, improve livelihoods, and enhance educational opportunities is urgent. Traditional methods of rural development have often overlooked the critical role that energy plays in shaping everyday life. In this context, solar-based frugal innovations—designed to be low-cost and contextually relevant—offer a powerful alternative. However, despite growing adoption, there is limited research examining the impact of these innovations on livelihood stability and educational access in Telangana. This study aims to fill this gap by exploring how grassroots-level adoption of solar technologies is driving change in rural communities.

1.4 Scope of the Study:

This study focuses on rural Telangana, examining the impact of solar-based frugal technologies on livelihoods and education. It will explore:

1. How solar technologies affect income generation and agricultural productivity.
2. How solar solutions improve school attendance and learning outcomes.
3. The factors influencing the adoption of solar technologies in rural communities.

1.5 Research Objectives:

1. To explore the impact of frugal solar innovations on rural livelihoods in Telangana,
2. To examine the role of solar-based technologies in improving educational access and performance in rural areas.
3. To assess the socio-economic factors influencing the adoption of solar technologies in rural Telangana.

II. RESEARCH METHODOLOGY

This study adopts a qualitative research design utilizing thematic analysis to explore the impact of solar-based frugal innovations on livelihoods and educational access in rural Telangana. Data were collected through semi-structured interviews with 47 households, selected through purposive sampling from villages in Telangana. The study focuses on villages such as Pagidipalli in Bibinagar Mandal, Gurrampode, Rajapet, and Peddagollapalli in Nalgonda District, all of which have actively adopted solar energy technologies. These locations provide a rich context for examining the effects of decentralized solar solutions on rural communities.

Data Collection: Semi-structured interviews focused on the changes in income, work conditions, and children's education after adopting solar solutions. In-depth discussions were held on themes such as income generation, agricultural productivity, and the influence of solar lighting on school attendance.

Data Analysis: Data from 47 semi-structured interviews were analyzed using thematic analysis as per Braun and Clarke (2006). Responses were coded and organized into core themes under two overarching categories: Livelihood Impact and Educational Access. Sub-themes such as affordability, safety, gender inclusion, and usage barriers provided further nuance.

III. DATA ANALYSIS AND INTERPRETATION

Thematic analysis of the semi-structured interviews with 47 rural households Telangana identified eight key themes that reflect the impact of solar-based frugal innovations on livelihoods and educational access.

1. Enhanced Agricultural Productivity (Found in: 30 out of 47 households)

Solar-powered irrigation pumps improved water scheduling and extended farming hours, leading to increased crop yields, especially for paddy and vegetables. These improvements in productivity are crucial for food security and sustainable livelihoods.

2. Rise in Micro-Enterprises and Small Businesses (Found in: 26 out of 47 households)

Solar lighting enabled small businesses like tailoring, grocery stores, and local workshops to operate during the evening, significantly enhancing entrepreneurial opportunities and income generation.

3. Reduced Energy Expenditure (Found in: 39 out of 47 households) Solar technologies helped households reduce their reliance on costly fuels like kerosene and diesel, leading to significant savings that were redirected toward food, healthcare, and education.

4. Improved Educational Environment and Digital Access Found in: 37 out of 47 households

Solar lighting extended study hours, improved academic performance, and enabled use of digital devices for learning, enhancing both school attendance and digital inclusion in rural areas.. Improved

5. Increased Safety and Well-Being (Found in: 32 out of 47 households)

The installation of solar streetlights and home lighting systems enhanced safety for rural families, reducing the risks of theft, accidents, and health hazards like snake bites, particularly for women and children.

6. Gender Empowerment through Access (Found in: 22 out of 47 households)

Women in rural areas reported feeling more empowered to engage in income-generating activities such as sewing and poultry care due to the extended working hours facilitated by solar energy.

7. Maintenance and Affordability Challenges (Found in: 18 out of 47 households)

Although solar technologies are frugal, some households faced challenges regarding maintenance and battery lifespan, necessitating the development of community-based maintenance models.

8. Aspirational Shift and Digital Access (Found in: 20 out of 47 households)

Solar-powered devices such as mobile phone chargers and televisions facilitated access to digital content, raising aspirations among rural children and expanding learning opportunities.

9. Socio-Economic Factors Influencing Adoption (Found in: 28 out of 47 households)

Adoption of solar technologies was shaped by factors such as community readiness, prior exposure to government schemes, awareness drives by NGOs, and support from self-help groups. Households with stronger local networks or leadership (e.g., proactive panchayats or school teachers) showed higher levels of adoption. However, affordability concerns and delayed subsidies emerged as common barriers. These findings reflect the importance of social capital,

institutional support, and perceived utility in driving adoption.

IV. FINDINGS AND DISCUSSION:

1. Economic Empowerment: Solar-powered irrigation, lighting, and tools have improved farming efficiency and supported rural enterprises, leading to increased income and reduced reliance on fossil fuels.
2. Educational Advancement: Solar lighting extends study hours, improves attendance, and allows access to digital learning, especially in households without grid electricity.
3. Digital Inclusion in Education: With solar-powered device charging and lighting, students can now access e-learning platforms and digital classrooms, narrowing the rural-urban educational divide.
4. Women's Empowerment: Access to solar energy has enabled women to engage in home-based income activities, participate in self-help groups, and benefit from enhanced safety and time management.
5. Improved Safety and Well-being: Solar lighting in homes and public spaces enhances mobility and reduces risks after dark, particularly for women and children.
6. Adoption Drivers and Barriers: Villages with active NGOs, local leadership, and awareness programs show higher adoption. However, issues like poor after-sales service, financing gaps, and limited training hinder wider uptake.

Implications for Policy and Practice:

- Establish community-based maintenance cooperatives for solar equipment.
- Promote awareness programs through schools, self-help groups, and panchayats.
- Integrate frugal solar solutions within Mission Kakatiya**,** MGNREGA, and NEP 2020 to align with state and national priorities.
- Develop micro-financing models and public-private partnerships for large-scale deployment.
- Introduce performance-based subsidies and **local** technician training programs.

V. LIMITATIONS OF THE STUDY

- The sample was limited to 47 households, which may restrict generalizability.
- The study focused only on rural Telangana, and findings may not be representative of other regions.
- Self-reported data may carry the risk of recall bias or social desirability bias.
- A cross-sectional design limits understanding of long-term impacts

VI. CONCLUSION

Frugal solar innovations in rural Telangana have gone beyond alleviating energy poverty to drive socio-economic and educational progress. These solutions have improved livelihoods, expanded educational access, and fostered social inclusion. Adoption was shaped by community engagement, institutional support, and financing, highlighting the importance of integrated socio-technical approaches. To scale impact, the study suggests strengthening community-based maintenance, fostering public-private partnerships, and implementing supportive policies. These findings align with Rogers' Diffusion of Innovations Theory, which identifies key adoption drivers—relative advantage, compatibility, simplicity, trialability, and observability. Households seeing clear economic or educational benefits adopted more readily, while barriers like lack of awareness or support led to delayed adoption, reflecting "early majority" and "late adopter" behavior. This underscores the need for peer-led trust-building and visible success stories.

Future Scope: Future studies could adopt a longitudinal design to assess long-term effects, or expand the research across other Indian states to identify regional variations in adoption and impact.

REFERENCES

[1] Ahlborg, H., & Hammar, L. (2014). Drivers and barriers to rural electrification in Tanzania and Mozambique–Grid-extension, off-grid, and renewable energy technologies. Renewable Energy, 61, 117–124. https://doi.org/10.1016/j.renene.2012.09.057

[2] Bhattacharyya, S. C. (2012). Energy access programmes and sustainable development: A critical review and analysis. Energy for Sustainable Development, 16(3), 260–271. https://doi.org/10.1016/j.esd.2012.05.002

[3] Bhatti, Y. A., & Ventresca, M. (2012). The emerging market for frugal innovation: Fad, fashion, or fit? Working Paper, University of Oxford.

[4] Breukers, S., & Wolsink, M. (2007). Wind power implementation: The nature of public attitudes: Equity and fairness instead of 'backyard motives'. Renewable and Sustainable Energy Reviews, 11(6), 1188–1207. https://doi.org/10.1016/j.rser.2005.10.005

[5] Government of India. (2020). Draft National Energy Policy. NITI Aayog.

[6] Gupta, A. (2016). Grassroots innovation. Penguin Random House India.

[7] Palit, D., & Bandyopadhyay, K. R. (2016). Rural electricity access in South Asia: Is grid extension the remedy? A critical review. Renewable and Sustainable Energy Reviews, 60, 1505–1515. https://doi.org/10.1016/j.rser.2016.03.012

[8] Pachauri, S., & Spreng, D. (2011). Measuring and monitoring energy poverty. Energy Policy, 39(12), 7497–7504. https://doi.org/10.1016/j.enpol.2011.06.038

[9] Prahalad, C. K. (2006). The fortune at the bottom of the pyramid. Wharton School Publishing.

[10] Prabhu, J., Radjou, N., & Ahuja, S. (2012). Jugaad innovation: Think frugal, be flexible, generate breakthrough growth. Harper Business.

[11] Radjou, N., Prabhu, J., & Ahuja, S. (2012). Jugaad innovation: Think frugal, be flexible, generate breakthrough growth. Harper Business.

[12] Rogers, E. M. (2003). Diffusion of innovations (5th ed.). Free Press.

[13] Sovacool, B. K., & D'Agostino, A. L. (2012). A comparative analysis of solar home system programs in China, Laos, Mongolia, and Papua New Guinea. Progress in Development Studies, 12(4), 315–335. https://doi.org/10.1177/146499341201200402

[14] TERI. (2019). Lighting a billion lives: A review of decentralized solar programs in India. The Energy and Resources Institute.

[15] World Bank. (2018). Tracking SDG 7: The Energy Progress Report 2018. Washington, DC: World Bank.