Resilient Innovation and the Pursuit of Universal Access to Clean Cooking in Subsistence Environments: A Review

T. Sreevaram[1], D. Suneetha[2], V. Neeraja[3]

[1]Principal, Government Degree College, Gummalakshmipuram, Affiliated to Andhra University, Andhra Pradesh, India

[2] Principal, Government Degree College, Yeleswaram, Affiliated to Adikavi Nannaya University, Andhra Pradesh, India

[3] Principal, SWR Government Degree College for Women, Affiliated to Krishna University, Andhra Pradesh India

*Corresponding Author mail id - varam.t@gmail.com

Abstract: Household Air Pollution (HAP) from solid cooking fuels still poses a critical global health and development challenge, especially in low- and middle-income countries (LMICs). This review synthesizes evidence from international agency reports and peer-reviewed literature to examine how resilient innovation can enable sustainable clean cooking transitions in subsistence environments. Using a narrative - scoping review approach, the paper evaluates modern energy cooking solutions (MECS), including LPG, electric cooking (eCooking), biofuels and advanced biomass technologies, focussing on health, affordability, emissions and adoption outcomes. Evidence indicates that while national LPG programs such as India's PMUY - deliver substantial short-term welfare gains, long-term resilience requires diversified, multi-fuel strategies adapted to local infrastructure, cultural practices, and market conditions. Emerging innovations, including bottled biogas systems, advanced combustion cookstoves, and IoT enabled indoor air quality monitoring, offer complementary pathways but show heterogeneous real-world performance. The review concludes that framing clean cooking as a resilience challenge rather than a single-technology intervention provides a more robust pathway toward universal access, economic development, and climate mitigation.

Keywords: Household Air Pollution (HAP), Modern Energy Cooking Solutions (MECS), Resilient Innovation, eCooking, Advanced Combustion Cookstoves (ACS), Indoor Air Quality.

G. Tejaswini and V. Sridhar (eds.), *Proceedings of the International Conference on Resilient Innovations for Subsistence Environment (IC-RISE 2025)*, Advances in Biological Sciences Research 53,
https://doi.org/10.2991/978-94-6239-606-7_9

1 Introduction

The global pursuit of universal access to clean cooking remains constrained by the socio-economic and infrastructural realities of low- and middle-income countries (LMICs). Despite decades of international commitments, nearly 3 billion people continue to rely on polluting solid fuels such as firewood, charcoal, and animal dung for daily cooking [1,2]. This persistent dependence has given rise to "cooking poverty," characterized by chronic exposure to household air pollution (HAP), heightened health risks, and substantial time and income losses [3].

The challenge is especially pronounced in Africa, where biomass accounts for over 51% of total primary energy consumption [4]. Continued reliance on traditional fuels exacerbates health burdens, reinforces gendered labor inequalities, accelerates environmental degradation, and constrains long-term economic growth [5,6]. These interlinked challenges underscore the limitations of isolated technological interventions and motivate the need for resilient, system-oriented approaches to clean cooking transitions.

2 Review Methodology and Scope

This paper adopts a narrative–scoping review approach [7], suitable for synthesizing interdisciplinary evidence across technology, policy, health, and socio-economic domains.

Literature was taken from:

1. Peer-reviewed databases (Scopus, Web of Science, Google Scholar)
2. Reports from international agencies (IEA, WHO, ESMAP, Clean Cooking Alliance, IRENA)
3. Programmatic and policy evaluations published between 2012 and 2023 [1,8,9,10]

Inclusion criteria focused on studies addressing:

1. Clean cooking technologies and fuels in LMICs
2. Adoption, affordability, health, emissions, or resilience outcomes
3. National or regional policy relevance

Exclusion criteria included:

1. Laboratory-only stove studies without field validation
2. High-income country–specific cooking transitions

The review does not claim to be a systematic meta-analysis; rather, it aims to identify patterns, trade-offs, and resilience implications across technologies and contexts [7,11].

3 The Imperative of Resilient Innovation

Resilient innovation emphasizes strengthening the entire clean cooking ecosystem so solutions can withstand external shocks, cultural resistance, fuel price volatility, and infrastructural fragility [12,13]. This perspective treats clean cooking as a dynamic socio-technical transition embedded within local markets, norms, and governance structures [12].

4 Structural Barriers in Subsistence Contexts

4.1 Economic Constraints

Evidence consistently shows that upfront appliance costs and cash-flow constraints dominate adoption decisions. Experimental studies in East Africa demonstrate that access to microfinance or installment-based payment schemes can more than double adoption rates, suggesting affordability—not awareness—is the binding constraint [14,15].

4.2 Infrastructural Gaps

Weak fuel supply chains and unreliable electricity services often lead to fuel stacking, where households continue using traditional fuels alongside modern ones [16,17]. While stacking may enhance short-term energy security, it significantly dilutes health and emissions benefits.

4.3 Socio-Cultural Barriers

Cultural preferences, taste perceptions, and safety concerns remain critical determinants of sustained use. Studies consistently find that modern fuels are sometimes perceived as risky or inappropriate for traditional dishes, reinforcing partial adoption patterns [18,19].

5 Comparative Performance of Clean Cooking Technologies

5.1 LPG versus eCooking: Affordability and Resilience

LPG offers rapid emissions reductions and ease of adoption but exposes households to global fuel price volatility and subsidy dependence [1]. In contrast, eCooking—particularly when paired with efficient appliances such as Electric Pressure Cookers (EPCs)—can be cost-competitive where electricity tariffs are moderate and grids are renewable-rich [20]. However, eCooking resilience remains contingent on grid reliability and appliance financing [12].

5.2 Improved and Advanced Biomass Cookstoves (ICS/ACS)

Field evaluations show highly variable outcomes. ICS transitions succeed where stoves are locally manufactured, culturally compatible, and supported by maintenance networks [21]. Failures often occur due to poor durability, insufficient emissions reductions, or lack of user training [22,23]. These findings reinforce the role of ICS as transitional not terminal solutions [19].

6 Evidence Synthesis Across Technologies

. Here, Table 1 provides comparative outcomes of Major clean cooking options.

Table 1. Comparative Outcomes of Major Clean Cooking Options

Technology	Health Impact	Affordability	Emissions	Adoption Stability
LPG	High short-term PM reduction	Medium (subsidy-dependent)	Moderate	Vulnerable to fuel price shocks
eCooking	High (near-zero indoor emissions)	High where EPCs used	Veryl ow (renewable grids)	Grid-dependent
Bio-CNG/ Biogas	High	Medium (local feedstock)	Low	Strong where agro-waste exists
ICS / ACS	Moderate, variable	High	Moderate	Often declined without support

Sources synthesized from [1,4,20–24].

7 Enabling Resilience Through Integrated Systems

7.1 Integrated Energy Planning

Tools such as the Integrated Clean Cooking Planning Tool (ICCPT) and on Stove enable governments to identify least-cost, multi-fuel pathways tailored to local conditions [25,26].

7.2 Digital and IoT-Enabled Systems

Recent advances in low-cost IoT sensors enable real-time indoor air quality monitoring, automated ventilation control, and digital monitoring, reporting, and verification (MRV). These systems enhance transparency, support carbon finance integrity, and improve user safety [27].

7.3 Innovative Finance and Local Ecosystems

PAYG models, carbon markets, and local manufacturing ecosystems are increasingly recognized as central pillars of resilience, enabling affordability while generating local employment [28–30].

8 Conclusions

This review reframes clean cooking as a resilience and systems challenge, rather than a purely technological one. Evidence indicates that no single fuel or technology can universally meet the diverse needs of subsistence environments [12,13].

Much like portfolio diversification in finance, reliance on a single cooking fuel exposes households and national energy systems to instability. A locally optimized mix-spanning eCooking, LPG, biofuels, and advanced biomass—offers the robustness needed to close the clean cooking access gap while advancing health, economic, and climate objectives [1,25].

References

1. International Energy Agency (IEA). Tracking SDG 7: The energy progress report. International Energy Agency, Paris (2023)
2. Clean Cooking Alliance. Clean cooking industry snapshot. Clean Cooking Alliance, Washington, DC (2022; 2023)
3. World Health Organization (WHO). Household air pollution and health. World Health Organization, Geneva (2021)
4. International Energy Agency (IEA). Africa energy outlook. International Energy Agency, Paris (2022)
5. Food and Agriculture Organization (FAO). Bioenergy in Africa. FAO, Rome (2017).
6. REN21. Renewables global status report. REN21 Secretariat, Paris (2021)
7. Troncoso, K., Castillo, A., Masera, O., Merino, L.: Adoption and sustained use of clean cooking technologies. Energy Policy **133**, 110922 (2019)
8. Rosenthal, J., Quinn, A., Grieshop, A.P., Pillarisetti, A.: Glass, R.I. Clean cooking and the Sustainable Development Goals. Energy Sustain. Dev. **42**, 152–159 (2018)
9. Mobarak, A.M., Dwivedi, P., Bailis, R., Hildemann, L., Miller, G.: Low demand for nontraditional cookstove technologies. Proc. Natl. Acad. Sci. U.S.A. **109**(27), 10815–10820 (2012)
10. Jeuland, M., Pattanayak, S.K.: Benefits and costs of clean cooking interventions. Energy Sustain. Dev. **16**(4), 460–468 (2012)
11. Levine, D.I., Beltramo, T., Blalock, G., Cotterman, C. Adoption barriers and financing of clean energy technologies. J. Dev. Econ. **136**, 102–118 (2018)
12. Lindgren, E., et al.: Clean cooking transitions and resilience pathways. Energy Policy **162**, 112806 (2022)
13. Grimm, M., Munyehirwe, A., Peters, J., Sievert, M.: Energy access, poverty and resilience. Energy Econ. **91**, 104880 (2020)
14. Bensch, G., Peters, J. The impact of improved cookstoves on household welfare. J. Health Econ. **36**, 1–13 (2015)

15. Batchelor, S., Brown, E., Scott, N., Leary, J.: The eCook concept paper. Modern Energy Cooking Services (MECS), Loughborough University (2018)
16. Kariuki, J., et al.: Electric cooking in Sub-Saharan Africa. Renew. Energy **154**, 910–920 (2020)
17. Kenya Power. Annual report. Kenya Power and Lighting Company, Nairobi (2022)
18. Leary, J., et al.: Modern energy cooking services (MECS) programme report. UK Aid/Loughborough University (2021)
19. Bailis, R., Drigo, R., Ghilardi, A., Masera, O.: The climate and health impacts of cookstoves. Nat. Clim. Change **5**, 512–518 (2015)
20. International Renewable Energy Agency (IRENA). Biogas for domestic cooking. IRENA, Abu Dhabi (2018)
21. United Nations Industrial Development Organization (UNIDO). Local manufacturing for clean energy transitions. UNIDO, Vienna (2021)
22. Jetter, J., Zhao, Y., Smith, K.R., Khan, B., Yelverton, T., DeCarlo, P.: Pollutant emissions from biomass cookstoves. Environ. Sci. Technol. **46**(19), 10827–10834 (2012)
23. Rosenthal, J., et al.: Field performance of improved cookstoves. Energy Sustain. Dev. **44**, 64–74 (2018)
24. Energy Sector Management Assistance Program (ESMAP). State of access to modern energy cooking services. World Bank, Washington, DC (2020)
25. Energy Sector Management Assistance Program (ESMAP). Integrated clean cooking planning tool (ICCPT). World Bank, Washington, DC (2023)
26. Lindgren, E., et al.: OnStove tool documentation. World Bank/MECS Programme (2022)
27. Gold Standard. Digital monitoring, reporting and verification (MRV) framework. Gold Standard Foundation, Geneva (2023)
28. GOGLA. Off-grid solar market report. Global Off-Grid Lighting Association, Utrecht (2023)
29. Kenya Power & Lighting Company. Electricity supply and reliability statistics. Kenya Power, Nairobi (2021)
30. International Energy Agency (IEA). Africa energy outlook: regional energy assessment. International Energy Agency, Paris (2022)