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USING SECOND-LIFE ELECTRIC VEHICLE BATTERIES TO SECURE SUSTAINABLE ENERGY SUPPLY AND FOSTER SOCIO-ECONOMIC DEVELOPMENT IN REMOTE AMAZONIAN COMMUNITIES

Summary

Energy supply in remote regions like the Brazilian Amazon (Trindade et al., 2022) often relies on unsustainable diesel (Terkes et al., 2023; Thakur et al., 2022) or inadequate solar-hybrid systems. This study assesses the technical and economic feasibility of using second-life electric vehicle (EV) batteries paired with solar PV (Benalcazar et al., 2024; Souza et al., 2024) as a sustainable alternative. A multi-method study (Clarke & MacDonald, 2019; Johnson et al., 2007) in Amazonian villages confirmed the solution's viability (Blasi et al., 2019), demonstrating significant long-term cost savings compared to diesel and enabling reliable 24/7 electricity. The research developed adapted "Bottom of the Pyramid" (BoP) business models (Amit & Zott, 2015) emphasizing efficiency, ecosystem collaboration (Adner, 2017), and supportive policies, including redirecting fossil fuel subsidies (Schmidt & Lourenço, 2024). This approach offers a scalable pathway for achieving SDG 7 (United Nations, 2015) in underserved communities.

Keywords: Second-life batteries, Solar energy storage, Off-grid systems, Remote communities, Brazil, Bottom of the Pyramid (BoP), Business models, Circular economy.

1. Introduction

Energy access in remote areas of the Global South, such as the Brazilian Amazon basin (Trindade et al., 2022), remains a critical challenge, with hundreds of thousands lacking reliable electricity. Historically reliant on diesel generators, the associated costs often exceed affordability, necessitating state subsidies (Terkes et al., 2023; Thakur et al., 2022). While solar power offers a more cost-efficient alternative (Icaza-Alvarez et al., 2023), government initiatives providing solar panels often include undersized batteries due to cost constraints (Terkes et al., 2023), leading to inefficient hybrid systems that combine the drawbacks of both diesel and solar, proving unsustainable economically, socially, and environmentally (Kleine & Hauff, 2009; Norman & MacDonald, 2004). This paper investigates the potential of photovoltaic (PV) systems combined with second-life batteries from electric vehicles (EVs) (Benalcazar et al., 2024; Souza et al., 2024) as a technically viable, cost-effective solution. Repurposing EV batteries offers larger, stable storage capacities at lower costs, potentially reducing electronic waste and optimizing existing resources (Faessler, 2021; Reinhardt et al., 2020), yielding significant social and ecological benefits (Pongeluppe, 2022; Trindade et al., 2022). Despite clear potential, previous studies often lack real-world data for contexts like the Amazon, and the development of suitable BoP business models remains a gap (Kebir et al., 2023; López et al., 2023). This study presents the methodology and results of an interdisciplinary feasibility study assessing this solution for off-grid and mini-grid applications in remote Amazonian villages.

2. Methodology

An interdisciplinary German-Brazilian research team conducted a feasibility study employing a multi-method approach (Clarke & MacDonald, 2019; Johnson et al., 2007) in two remote villages (Nova-Esperança) in the Amazon. Technical feasibility, based on the approach by Blasi et al. (2019), involved simulations (HOMER software), analysis of battery cell aging (cyclic and calendar) under local climatic conditions (high temperature and humidity), and the development of design proposals for housing, cooling, and battery management systems for lifetime maximization. Economic feasibility evaluation comprised two parts: first, an economic potential analysis examining Total Cost of Ownership (TCO) and break-even points to assess profitability potential (Korjani et al., 2021); second, the development of early business models as a necessary condition for implementation. This involved adapting the "early business model" framework (Amit and Zott, 2015; Zott et al., 2011; Zott and Amit, 2024) considering value creation through circularity (Hansen & Revellio, 2020; Schulz-Mönninghoff et al., 2023) and the specific constraints and opportunities of BoP markets (Jeppe & Proff, 2025). Qualitative data were gathered via structured expert interviews (n=14), household surveys (n=13), and village council interviews (n=2), followed by systematic qualitative content analysis (Mayring, 2014, 2019).

3. Results

The technical analysis confirmed the suitability of second-life EV batteries (particularly those with State of Health (SOH) > 80% at end-of-first-life) for stationary storage, offering potential lifespans of up to 12 years in off-grid applications, usable down to 60% SOH or even 40%. An optimal system configuration for the case study village was identified (198 kW PV, 579 kWh second-life battery storage) capable of providing reliable 24/7 power. The TCO analysis revealed that despite higher initial investment (USD 117,200 vs. USD 35,000 for diesel), the PV-second-life battery system achieves break-even against diesel within approximately three years, primarily due to drastically lower annual operating costs (USD 3,000 vs. USD 45,162) and avoided generator replacement costs. The solar solution also provides enhanced reliability and productivity potential via continuous electricity availability. The business model analysis, concretizing the framework by Amit and Zott (2015) for this specific BoP repurposing context, highlighted the need for specific adaptations: (1) Novelty (innovative reuse) must be enabled by Efficiency (achieved through cost-spreading across multiple battery lifecycles); (2) Complementarity, realized through orchestrating a collaborative ecosystem (involving diverse stakeholders including the state for subsidy redirection, cf. Adner, 2017), is essential to overcome barriers like market inefficiencies (Dentchev et al., 2022; Oskam et al., 2021) and complexity; (3) A "Development Policy Lock-in" mechanism, rather than technical standards, can provide necessary investment security for durability. These elements interact to create and capture value, potentially bringing costs down to affordable levels for BoP consumers.

4. Conclusion and Policy Implications

This study validates the technical viability and compelling economic rationale (Blasi et al., 2019) for deploying PV systems with second-life battery storage as a sustainable energy solution for remote BoP communities, applicable beyond the Amazon to other underserved regions (Du et al., 2021; Schrader et al., 2012). It extends business model theory (Amit & Zott, 2015; Zott & Amit, 2024) by outlining necessary adaptations for successful BoP repurposing ventures. The findings strongly advocate for market-based approaches (Benalcazar et al., 2024), embedded within supportive policy frameworks. A key opportunity lies in strategically redirecting existing fossil fuel subsidies (Schmidt & Lourenço, 2024) to finance clean energy transitions and contribute significantly to achieving Sustainable Development Goal 7 (United Nations, 2015). Five specific policy recommendations emerge: (1) Implement strategic subsidy redirection (Kahn et al., 2023); (2) Proactively facilitate tailored Public-Private Partnerships (PPPs) fostering "solidarity-enhancing complementarities" (Benalcazar et al., 2024); (3) Establish robust enabling regulatory frameworks covering the entire lifecycle (e.g., safety, SOH standards, end-of-life pathways, (*European Battery Directive*, 2024)); (4) Invest systematically in local capacity building (installation, maintenance, entrepreneurship); (5) Fund targeted Research & Development (R&D) focusing on BMS optimization, low-cost durable components, and BoP-specific modeling tools. This integrated approach offers a scalable and impactful pathway towards energy equity and sustainable development.

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