TACKLING ENERGY POVERTY: MODELING SUFFICIENT ENERGY REQUIREMENTS FOR DECENT LIVING IN DEVELOPING COUNTRIES

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Overview

Despite progress toward Sustainable Development Goal 7, achieving universal access to affordable, reliable, sustainable, and modern energy by 2030 remains a challenge. While grid extensions and decentralized energy systems have advanced electrification, challenges persist in ensuring that this translates into tangible socio-economic benefits and supports sustainable development [1]. Energy access, often critiqued for its simplistic binary definitions, now embraces multidimensional perspectives, accounting for supply, quality, affordability, and progression [2]. Quantifying energy poverty—a concept intertwined with energy access—requires robust measurement approaches and normative frameworks defining minimum energy standards for well-being. Initiatives like Practical Action's Total Energy Access standards [3], the Modern Energy Minimum [4] and the IEA's [5] consumption benchmarks emphasize the importance of addressing real-world energy needs. These frameworks argue that basic energy access alone is insufficient, highlighting the need to link energy services to tangible well-being outcomes. Amartya Sen's Capability Approach [6] and frameworks such as Decent Living Standards (DLS) [7] expand this view by framing energy poverty as a barrier to achieving essential capabilities, providing a comprehensive foundation for estimating global energy needs based on well-being and regional variations.

Efforts toward estimating minimum levels of energy requirements have materialized into the *sufficiency* concept. Energy Sufficiency represents a state where basic energy needs are equitably met within ecological limits [8]. This concept responds to the slow decoupling of resource use from economic growth and it is expected that they can be integrated into policies aimed at reducing energy consumption and environmental impact, primarily in the Global North [9]. Research explores sufficiency at various scales, from individual households to global frameworks, focusing on areas like building energy sufficiency [10], rebound effects [11], and minimum energy requirements [12], [13]. Studies highlight sufficiency's potential to reduce energy demand significantly, with Europe projected to cut energy use by 50% by 2050 through sufficiency measures [14]. In developing countries, sufficiency shifts from a mitigation tool to addressing energy poverty and fostering resilience, emphasizing equitable access alongside environmental sustainability. A balanced global approach, setting sufficiency caps in high-income nations and minimum thresholds for underprivileged regions, is crucial for achieving energy equity and sustainable development.

This research estimates sufficiency thresholds for rural communities in Bolivia, Kenya, and Mozambique, using the DLS as a set of universal, irreducible, and essential conditions required to achieve basic human well-being. A bottom-up modelling approach is used with this aim. Beyond residential energy, community services and income-generating activities are examined, contributing to a balanced approach that ensures equitable access while respecting environmental constraints.

Methods

The methodological approach can be decomposed in four successive steps as depicted in Figure . Drawing upon the Decent Living Standards framework [7], dimensions essential for well-being are delineated, alongside associated energy services standards for each dimension, through a literature review. Given that hypothetical households and communities are considered for each study area, a thorough contextual analysis is carried out to ensure relevance, encompassing: a) local climatic conditions, b) material culture including appliance preferences, c) productive potential, and d) institutional requirements for community services. Building on the contextual analysis, appliance usage profiles are defined for key sectors, including residential, community services, and income-generating activities, covering all critical energy services in each. A bottom-up stochastic model is then applied to simulate the electricity demand needed to sufficiently meet the energy requirements of each service [15]. The model and parameters used for this paper are freely accessible in a GitHub repository (https://github.com/CIE-UMSS/EnergySufficiencySouth.git)

Results

The results highlight the diverse household energy demands across five distinct regions: the Bolivian Lowlands (BOLL), Valleys (BOV), and Highlands (BOHL), the Coastal region of Kenya (KNYC), and Northern Mozambique (MOZN). These differences are influenced by climatic conditions, appliance usage, and service needs. Sufficient annual household electricity demand varies from 931 kWh in BOLL to 1355 kWh in the BOHL, with cold storage consistently accounting for over 50% of consumption. Thermal comfort needs significantly shape demand patterns, with electric heaters driving winter peaks of up to 1.2 kW in the colder regions while fans dominate in warmer regions. Lighting and ICT services exhibit relatively uniform demand due to their indispensable role in daily life, with efficient technologies like LED lights helping mitigate consumption (See Figure 1). At the community level, sufficient energy demand integrates residential use (80%), community services (4.9–6.3 MWh/year), and productive activities (21–52 MWh/year), resulting in total annual demands ranging from 259 to 374 MWh. This highlights the importance of comprehensive energy planning to meet sufficiency thresholds while supporting socio-economic development.

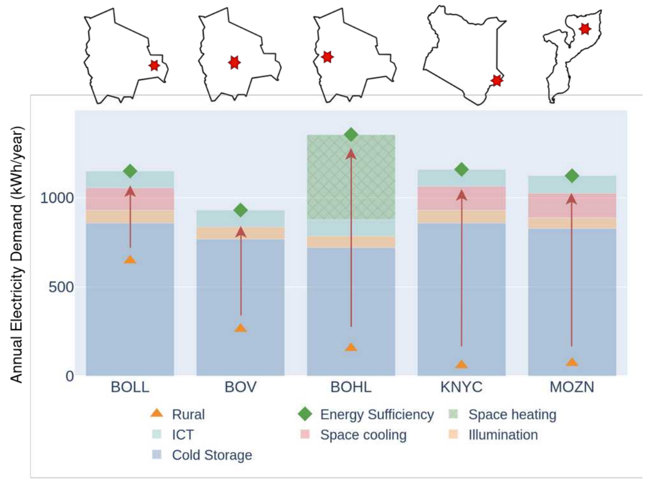

Figure 1: Annual Household Electricity Demand and Energy Service Composition in the Studied Areas

Energy sufficiency estimates further reveal significant disparities in demand, revealing the role of energy-efficient technologies, climate adaptation, and context-sensitive strategies. Refrigeration, crucial for food safety in warmer climates, and thermal comfort, shaped by regional and cultural preferences, emerge as key drivers of demand. While water heating and cooking are critical, their high energy intensity presents challenges for sufficiency planning, particularly in rural areas. Integrating community services into energy sufficiency estimates emphasizes the need for decentralized systems capable of addressing both individual and collective needs. Urban areas, characterized by higher living standards, show significantly greater energy use than rural areas, where critical needs often remain unmet. Bridging these gaps requires tailored strategies, including renewable energy integration and efficient service utilization. Aligning energy access initiatives with higher sufficiency tiers is essential for ensuring equitable living standards and fostering community well-being, stressing the critical role of sufficiency-oriented energy planning in achieving sustainable development.

Conclusions

This study establishes energy sufficiency thresholds for rural households and communities using a bottom-up modelling approach, highlighting regional variations in peak load and overall demand across five cases. Residential electricity use dominates consumption, but key community services and income-generating activities significantly raise per capita demand, with sufficiency levels ranging from 259 to 374 kWh/year. Climatic variations drive thermal comfort needs, while cold storage consistently emerges as the largest contributor to household electricity use, emphasizing its critical role in energy sufficiency. Lighting and ICT, though smaller contributors, remain essential for daily well-being.

Establishing minimum energy access thresholds serves as a benchmark for identifying disparities and guiding strategies to improve quality of life and socio-economic development. Unlike the Global North, where energy sufficiency often reduces demand, rural regions in developing countries face substantial gaps between current consumption and sufficiency thresholds. Tailored, context-specific strategies are essential to bridge these gaps effectively.

The energy sufficiency approach provides a pragmatic framework for addressing energy poverty by promoting equitable access to essential services while balancing ecological limits. It fosters sustainable transitions, mitigates environmental impacts, and supports resilient, community-focused energy systems. However, the analysis must account for socio-cultural influences and extend to other energy forms, such as cooking fuels, to create a comprehensive, adaptable framework.

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