

Equitable Energy Access in Grid Modernization: Frameworks for Justice-Centered Utility Transformation

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Abstract

The global shift to clean energy systems through grid modernization offers opportunities for sustainability but risks deepening inequities if not guided by energy justice principles. This enhanced report explores frameworks for justice-centered utility transformation, emphasizing recognition (acknowledging vulnerabilities), procedural (inclusive decision-making), distributive (fair benefit allocation), and restorative (remedying harms) justice. Drawing on an expanded literature review and diverse case studies including deepened African examples like South Africa's coal phase-out challenges and integrated models it addresses gaps in affordability, reliability, and participation. By incorporating feasibility constraints from recent studies on South Africa's just energy transition, the analysis proposes equity-weighted tools for resilience planning. Findings advocate for community-engaged policies to advance UN SDGs 7 and 13, with implications for policymakers navigating techno-economic and socio-political barriers in the Global South.

Purpose of the Study and Research Questions

The purpose of this study is to bridge theoretical energy justice with practical utility transformation, evaluating how feasibility constraints (techno-economic, socio-political, and socio-technical) influence equitable outcomes (Mirzania et al., 2023). It addresses literature gaps, such as limited restorative justice applications in African contexts and under-explored SDG intersections (Sovacool et al., 2019). Research questions include:

- How do procedural injustices manifest in renewable procurement programs like South Africa's REIPPPP, and what interventions promote inclusivity?
- What common distributive challenges across case studies hinder low-income adoption of energy-efficient technologies?
- How can restorative metrics, such as vulnerability mapping, align grid investments with historical equity remediation in coal-dependent regions?

Introduction

Grid modernization, integrating renewables, smart technologies, and decentralized generation, drives the development of resilient energy systems but often overlooks equity, perpetuating disparities in access and affordability (Jenkins et al., 2016). Energy justice frameworks ensure fair distribution of benefits and burdens, particularly for marginalized communities facing energy poverty and climate vulnerability (Sovacool & Dworkin, 2015). This report builds on foundational work by examining how utilities can embed these principles amid global pressures like the COVID-19 pandemic's amplification of grid unreliability (Amir & Khan, 2022). By synthesizing global and African insights, this analysis proposes actionable models, emphasizing South Africa's unique position as a coal-reliant economy pursuing a Just Energy Transition Partnership (JETP). As of September 2025, South Africa's renewable capacity stands at 15 GW, projected to reach 32 GW by 2030, yet coal dominates 80% of generation, with energy poverty affecting 45% of households (GreenCape, 2025). This context underscores the urgency of justice-centered approaches to avoid locking in fossil dependencies (Heffron & McCauley, 2017).

Literature Review

The literature on energy justice and grid modernization has expanded significantly since the mid-2010s, evolving from foundational conceptualizations to interdisciplinary applications that integrate social sciences, engineering, economics, and policy analysis. This review synthesizes key developments, drawing on over 50 seminal and recent works (2016-2025), with a focus on global trends and African contexts, particularly South Africa's coal-to-renewable shift. It is structured into conceptual foundations, persistent challenges, policy and regulatory frameworks, recent advances in developing regions, and identified gaps, incorporating bibliometric insights and emerging themes like feminist and decolonial justice.

Sovacool and Dworkin (2015) in *Energy Policy* advocate for energy justice as a decision-making tool, emphasizing affordability, reliability, and sustainability. They argue that grid modernization through renewables and smart grids must integrate these principles to avoid perpetuating disparities, such as energy poverty where households spend over 10% of income on energy (Boardman, 2010). Recent extensions link energy justice to climate action, aligning with SDGs 7 and 13 by promoting equitable access to clean energy (Sovacool et al., 2019).

Challenges in Affordability, Reliability, and Participation

Literature highlights persistent challenges in operationalizing justice in grid modernization. Affordability is a core issue, with low-income households facing high energy burdens due to inefficient housing and limited access to subsidies (Brown et al., 2020). In *Progress in Energy*, Brown et al. (2020) review U.S. evidence showing low-income groups spend 6-10% of income on energy, compared to 3% for higher-income households, exacerbated by geographic factors like rural isolation and climate vulnerability. Similarly, Schleich (2019) in *Energy Policy* analyzes EU data, finding low-income homeowners adopt energy-efficient technologies (EETs) at lower rates due to upfront costs and credit constraints, despite potential savings.

Reliability disparities are evident in outage impacts on marginalized communities. Farabi-Asl et al. (2019) in the ADBI Working Paper Series discuss Asia's clean cooking challenges, where unreliable grids hinder equitable access, leading to health inequities from biomass reliance. In Africa, Amir and Khan (2022) in *Energy and Built Environment* note COVID-19's amplification of reliability issues, with remote areas facing prolonged blackouts amid supply chain disruptions. Expanded African literature reveals similar patterns in countries like Malawi (13.4% access) and Nigeria (low per capita consumption), where grid fragility limits modernization (Zalengera et al., 2020; Ibrahim et al., 2021).

Participation barriers include exclusion from decision-making and technology adoption. Jenkins et al. (2016) emphasize procedural justice gaps, where low-income and minority groups are underrepresented in utility planning. Brown et al. (2020) highlight how programs like rooftop solar and electric vehicles bypass low-income households due to affordability, calling for community engagement metrics. In African contexts, studies on renewable communities in South Africa and Cameroon underscore low ownership and policy inadequacies (Mourik et al., 2023).

Frameworks for Justice-Centered Utility Transformation

To operationalize energy justice, utilities must embed the four principles into grid planning and policy. This section outlines integrated frameworks, drawing on literature.

Recognition and Procedural Justice: Inclusive Policymaking

Recognition involves identifying vulnerable groups (e.g., low-income, rural, minority communities). Procedural justice ensures their voices in planning. Frameworks should mandate community impact assessments in regulatory filings, using metrics like participation rates in public hearings (Jenkins et al., 2016). In African contexts, this includes addressing gender disparities in energy access (Muhoza & Johnson, 2023).

Distributive and Restorative Justice: Equitable Outcomes

Distributive justice focuses on fair benefit allocation, e.g., subsidizing EETs for low-income adopters (Schleich, 2019). Restorative justice remedies past harms, such as targeted investments in historically underserved areas. Metrics include energy burden reduction (target <6% of income) and equitable renewable benefits (e.g., community solar shares) (Brown et al., 2020). For African grids, this means prioritizing rural mini-grids to counter colonial-era urban biases.

Integrated Models for Grid Resilience

Proposed models integrate equity into resilience planning: (1) Equity-weighted investment prioritization, scoring projects on justice metrics; (2) Data-driven tools for vulnerability mapping; (3) Community partnerships for co-designing programs. These advance SDGs 7 and 13 by linking affordable energy to climate resilience (Sovacool et al., 2019). Challenges include regulatory alignment e.g., cost-benefit analyses often undervalue social equity and data gaps on marginalized groups (Amir & Khan, 2022). In Africa, models emphasize hybrid systems and policy de-risking (Ibrahim et al., 2021).

Case Studies

a) Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) in South Africa

South Africa's REIPPPP integrates wind/solar into the grid (26,000 GWh/year), but low community ownership hinders equity (Mourik et al., 2023; Ibrahim et al., 2021). Challenges include policy contradictions and urban focus. Outcomes include job creation, yet procedural gaps persist. This demonstrates potential for restorative justice through community trusts, though sustainability issues remain.

b) Renewable Energy Supply in Nigeria

Nigeria's grid (13,435 MW) is fossil-dominant, with renewables at 17.7% despite high potential (Ibrahim et al., 2021). Low access (151 kWh/capita) exacerbates poverty, especially rural. Modernization efforts like hybrid PV-hydro models face policy lopsidedness. Equity focuses on green jobs and socio-economic growth; recommendations urge integrated planning for distributive justice.

c) Grand Ethiopian Renaissance Dam (GERD) in Ethiopia

The GERD aims to triple Ethiopia's electricity (45% access), enhancing grid modernization via hydropower (Grünhaupt, 2023). However, it raises distributive justice issues with downstream Egypt and Sudan over water allocation, risking 25% flow reduction. Regional implications include export potential (\$800M) but tensions from historical treaties. Recommendations emphasize cooperative frameworks for equitable benefits, supporting SDG 7 amid climate vulnerability.

Discussion

The frameworks and case studies demonstrate that justice-centered transformations require holistic approaches. Utilities must prioritize metrics like energy poverty reduction and community engagement to align with SDGs (Sovacool et al., 2019). Limitations include regional biases in literature (e.g., less on restorative justice in developing contexts). Future research should explore scalable models using AI for equity analytics (Amir & Khan, 2022). In Africa, incremental transitions balancing fossils and renewables are key, addressing mining rights and gender equity (Muhoza & Johnson, 2023).

Country	Grid Access (%)	Key Challenge	Justice Focus	Policy Example
Malawi	13.4	Rural underservice	Distributive/Gender	Decentralized mini-grids
Ethiopia	45	Water disputes	Regional equity	Cooperative treaties
Ghana	80	Outages	Rural access	Renewable incentives
Nigeria	Low (151 kWh/capita)	Policy gaps	Socio-economic	Hybrid systems
South Africa	High but uneven	Ownership low	Procedural	REIPPPP trusts
Kenya (Kipeto)	Varies	Land consultation	Procedural	Community committees

Namibia (Tsumkwe/Gam)	Low rural	Maintenance/degradation	Affordability	Hybrid optimization
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Findings

Key findings from the literature and case studies underscore persistent inequities in grid modernization. In the EU, low-income households adopt EETs at lower rates due to financial barriers, with subsidies mitigating gaps in some countries like the UK (Schleich, 2019). U.S. evidence shows rural and Southern households bear higher energy burdens (10%+ of income), exacerbated by gentrification and limited solar access (Brown et al., 2020). In Africa, COVID-19 amplified reliability issues, with outages disproportionately affecting marginalized groups (Amir & Khan, 2022). Asian clean cooking challenges highlight health inequities from biomass reliance, affecting women (Farabi-Asl et al., 2019).

Expanded African cases reveal distributive injustices dominate (58%), from resource dispossession and job disparities, while procedural injustices stem from limited participation (Ndi, 2024). In Ethiopia's GERD, hydropower boosts access but raises transboundary water equity issues (Grünhaupt, 2023). Namibia's mini grids show performance declines due to degradation, limiting affordability (Tjirare et al., 2025). Overall, inclusive processes enhance acceptance, but cultural and gender biases persist.

Limitations

The synthesis reveals several limitations. Literature biases toward developed regions, with fewer studies on restorative justice in Africa (Jenkins et al., 2016). Short-term data in cases like Kipeto (operational since 2021) limits long-term impact assessment (Ndi, 2024). Gender and intergenerational inequalities are underexplored, as cultural norms may silence women (Muhoza & Johnson, 2023). Regional disparities in funding favor East/Southern Africa over West/Central (Tjirare et al., 2025). Single-case focus reduces generalizability, and data gaps on vulnerable groups hinder comprehensive equity analyses (Amir & Khan, 2022).

Possible Interventions or Solutions

Interventions should prioritize inclusive policies. For procedural justice, mandate community committees and transparent consultations, as in Kipeto (Ndi, 2024). Distributive solutions include subsidies for EETs and equitable benefit-sharing in RE projects (Schleich, 2019). Restorative measures: compensate for historical harms, e.g., land rights for rural women in biofuel expansions (Muhoza & Johnson, 2023). Gender-inclusive policies: enhance women's

roles in mining and decision-making (Grünhaupt, 2023). Hybrid mini-grids with AI forecasting for reliability (Amir & Khan, 2022). Basin-wide cooperation for transboundary projects like GERD (Grünhaupt, 2023). Scale mini-grids with subsidies and capacity building to address affordability (Tjirare et al., 2025).

Conclusion

Equitable energy access in grid modernization demands frameworks operationalizing recognition, procedural, distributive, and restorative justice. By addressing challenges in affordability, reliability, and participation through inclusive policies and metrics, utilities can mitigate disparities and advance SDGs 7 and 13. Expanded case studies from the EU, U.S., Asia, and Africa (including Malawi, Ethiopia, Ghana, Nigeria, South Africa, Kenya, Namibia) underscore the need for targeted investments and community involvement. Policymakers should mandate equity assessments in regulations to ensure a just transition.

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