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Energy Poverty and Access Metrics

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CERTIFICATION PAGE

This report is certified as an original research work conducted by African Energy Research (AER) in accordance with approved research standards, methodologies, and ethical guidelines.

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DECLARATION

This research report has not been submitted to any other institution for any purpose and all sources of data and references have been duly acknowledged.

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TABLE OF CONTENTS

Contents

LIST OF ACRONYMS

Acronym	Full Form
AC	Air Conditioning
AF	Alkire-Foster
CDM	Clean Development Mechanism
CDD	Cooling Degree Days
CO_2	Carbon Dioxide
DDG	Decentralized Distributed Generation
DDUGJY	Deen Dayal Upadhyaya Gram Jyoti Yojana (India)
DEval	German Institute for Development Evaluation
DHS	Demographic and Health Survey
DisCos	Distribution Companies (Nigeria)
DME	Dimethyl Ether
ECPR	European Consortium for Political Research
EDI	Energy Development Index
EED	Energy Efficiency Directive (EU)
EPOV	Energy Poverty Observatory (EU)
EPBD	Energy Performance of Buildings Directive (EU)
EPRA	Energy and Petroleum Regulatory Authority (Kenya)
ESMAP	Energy Sector Management Assistance Program (World Bank)
ETS2	Emissions Trading System 2 (EU)
EU	European Union
EU-SILC	European Union Statistics on Income and Living Conditions
FARC	Revolutionary Armed Forces of Colombia
FRA	European Union Agency for Fundamental Rights
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GOGLA	Global Off-Grid Lighting Association
GW	Gigawatt
H	Headcount Ratio (in MEPI calculation)
HBS	Household Budget Survey
HDD	Heating Degree Days
HDI	Human Development Index
IAEA	International Atomic Energy Agency
IDCOL	Infrastructure Development Company Limited (Bangladesh)
IEA	International Energy Agency
IISD	International Institute for Sustainable Development

IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
K	Poverty Cutoff (in MEPI calculation, typically 0.30)
kWh	Kilowatt-hour
KNES	Kenya National Electrification Strategy
LIHC	Low Income High Cost (indicator)
LPG	Liquefied Petroleum Gas
LSMS	Living Standards Measurement Study
M	Million
MDGs	Millennium Development Goals
MEPI	Multidimensional Energy Poverty Index
MFIs	Microfinance Institutions
MICS	Multiple Indicator Cluster Survey
MKr	Million Kroner
MP	Member of Parliament
MSMEs	Micro, Small and Medium Enterprises
MTF	Multi-Tier Framework
MW	Megawatt
N/A	Not Applicable
NEP	National Electrification Project (Nigeria)
NECPs	National Energy and Climate Plans (EU)
NERC	Nigerian Electricity Regulatory Commission
NGOs	Non-Governmental Organizations
ODI	Overseas Development Institute
OnSSET	Open Source Spatial Electrification Toolkit
PAYG	Pay-as-you-go
PHCN	Power Holding Company of Nigeria
PLN	Perusahaan Listrik Negara (Indonesia state utility)
PMUY	Pradhan Mantri Ujjwala Yojana (India)
REA	Rural Electrification Agency (Nigeria)
RWI	Rhine-Westphalia Institute for Economic Research
SCF	Social Climate Fund (EU)
SDG 7	Sustainable Development Goal 7
SEI	Stockholm Environment Institute
SHAP	SHapley Additive exPlanations
SHS	Solar Home System
SMEs	Small and Medium Enterprises
SPN	Solar Power Naija (Nigeria)
SUSENAS	Survei Sosial Ekonomi Nasional (Indonesia)

TV	Television
UCLA	University of California, Los Angeles
UCSD	University of California, San Diego
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNICEF	United Nations International Children's Emergency Fund
UPME	Unidad de Planeación Minero Energética (Colombia)
USAID	United States Agency for International Development
W	Watt
WHO	World Health Organization
ZNI	Zonas No Interconectadas (Non-Interconnected Zones, Colombia)

EXECUTIVE SUMMARY

This study examines the evolving concept of energy poverty and the effectiveness of various energy access metrics used to measure deprivation across different regions and socioeconomic contexts. It explores the transition from traditional binary electrification measures to multidimensional frameworks such as the Multi-Tier Framework (MTF) and the Multidimensional Energy Poverty Index (MEPI), which provide deeper insight into energy quality, affordability, reliability, clean cooking access, digital connectivity, and productive energy use.

The report highlights that despite global progress in electrification, approximately 685 million people still lack access to electricity, with Sub-Saharan Africa remaining the most affected region. Clean cooking access continues to lag significantly, exposing billions of people to health risks, environmental degradation, and economic limitations. The study also identifies persistent urban-rural disparities, affordability challenges, and growing concerns surrounding digital and thermal energy poverty.

Through comparative case studies across Africa, Asia, Latin America, and Europe, the report demonstrates that traditional access metrics often underestimate the true scale of energy deprivation. Multidimensional metrics such as MTF and updated MEPI provide more accurate and policy-relevant assessments by capturing service quality, reliability, and socioeconomic impacts beyond simple grid connectivity.

The study concludes that effective energy poverty reduction requires integrated policy approaches combining electrification, clean cooking solutions, affordability measures, digital inclusion, and reliable energy infrastructure. It further emphasizes the need for improved data systems, context-specific metrics, and stronger policy implementation to support the achievement of Sustainable Development Goal 7 and ensure universal access to affordable, reliable, and sustainable energy.

CHAPTER ONE

INTRODUCTION AND THEORETICAL FRAMEWORK

1.1 Background and Context

Energy poverty represents one of the most persistent and complex challenges facing global development in the 21st century. As of 2024, approximately 685.2 million people worldwide lack access to electricity, a reversal from previous trends where access rates had been steadily improving (World Bank, 2024). This increase of 10 million people without access since 2021 marks the first time in over a decade that the absolute number of energy-poor individuals has grown, attributed primarily to the compounding effects of the COVID-19 pandemic, the war in Ukraine, and subsequent global economic shocks that have disproportionately affected the poorest nations (International Energy Agency, 2024).

The geographic concentration of energy poverty has intensified, with Sub-Saharan Africa now hosting nearly 80% of the global population without electricity access. The region's rural electrification crisis is particularly acute: while urban access rates have reached approximately 78%, rural areas languish at roughly 25%, creating a stark urban-rural divide that perpetuates inequality (World Bank, 2024). The situation is exacerbated by demographic trends, rural populations in Sub-Saharan Africa continue growing at 24.5 million annually, while electrification efforts only reach 11.2 million people yearly, effectively widening the access gap despite absolute progress (World Bank, 2024).

Simultaneously, 2.3 billion people continue to rely on traditional biomass for cooking, exposing primarily women and children to severe indoor air pollution that causes approximately 3.8 million premature deaths annually (World Health Organization, 2024).

The health burden of energy poverty extends beyond mortality to encompass chronic respiratory diseases, cardiovascular conditions, and developmental impacts on children, creating intergenerational cycles of disadvantage.

The Sustainable Development Goal 7 (SDG 7) targets universal access to affordable, reliable, and modern energy services by 2030, are increasingly viewed as unattainable under current trajectories. The required annual increase in electrification access must accelerate from the current 0.43 percentage points (2020-2022) to 1.08 percentage points through 2030, necessitating more than a doubling of current efforts (World Bank, 2024). At present trends, approximately 660 million people will remain without electricity access in 2030, with the access gap stalling at 8% globally (IEA, 2024).

This crisis occurs against a backdrop of accelerating climate change, which introduces new dimensions to energy poverty. Rising temperatures increase cooling needs, yet cooling access remains severely limited in tropical developing regions. The cooling poverty dimension previously absent from energy poverty discourse now affects over 1.1 billion people at risk from extreme heat exposure, requiring urgent integration into energy access frameworks (Guevara et al., 2025).

1.2 Problem Statement

Despite decades of international attention and investment, energy poverty persists due to fundamental limitations in how the problem is conceptualized, measured, and addressed. The core problem is threefold:

First, traditional binary metrics (connected/not connected to electricity) mask the reality that many "connected" households experience suppressed demand, unreliable supply, and unaffordable tariffs (Nussbaumer et al., 2012). A household connected to a grid that provides 4 hours of daily electricity with frequent voltage fluctuations cannot be considered energy-secure, yet conventional statistics count such households as "electrified."

Second, energy poverty is inherently multidimensional, encompassing cooking energy, heating/cooling, lighting quality, appliance access, and digital connectivity. However, policy interventions often focus narrowly on electricity grid extension while neglecting clean cooking transitions, productive use of energy, and gender-differentiated impacts (Alkire & Foster, 2011).

Third, the metrics used to track progress influence policy priorities. When governments are evaluated solely on electrification rates, they prioritize grid connections over service quality, urban areas over rural regions, and household consumption over productive applications. This creates metric-induced distortions that perpetuate energy injustice.

The research problem, therefore, centers on developing and applying comprehensive, multidimensional metrics that accurately capture the depth and complexity of energy poverty, enabling more effective policy interventions and resource allocation.

1.3 Research Objectives and Questions

To develop a comprehensive analytical framework for understanding energy poverty through multidimensional access metrics, examining their theoretical foundations, practical applications, and policy implications across diverse geographic and economic contexts.

To critically evaluate the evolution of energy poverty measurement from uni-dimensional indicators to sophisticated multidimensional indices

To analyze the methodological strengths and limitations of current metrics including the Multi-Tier Framework (MTF) and Multidimensional Energy Poverty Index (MEPI)

To examine the 2024-2025 updates to MEPI methodology incorporating digital access, cooling/heating, and indoor pollution location factors

To conduct detailed case studies demonstrating metric applications across developing and developed economies

To formulate evidence-based policy recommendations for metric selection and energy poverty reduction strategies

Research Questions

RQ1: How have energy poverty metrics evolved from simple electrification rates to multidimensional frameworks, and what theoretical developments drove this evolution?

RQ2: What are the methodological advantages and limitations of the Multi-Tier Framework (MTF) compared to the Multidimensional Energy Poverty Index (MEPI) in different contexts?

RQ3: How do the 2024-2025 updates to MEPI methodology—including digital access, cooling/heating indicators, and refined indoor pollution measurement—alter energy poverty assessments?

RQ4: What do comparative case studies reveal about the relationship between metric selection and policy effectiveness across diverse economies?

RQ5: How can energy access metrics be optimized to guide SDG 7 achievement and ensure no one is left behind?

1.4 Theoretical Framework

This report employs an integrated theoretical framework combining Capability Approach, Energy Justice Theory, and Multidimensional Poverty Theory.

1.4.1 Capability Approach

Developed by Amartya Sen and operationalized by Martha Nussbaum, the Capability Approach posits that development should be evaluated not by resources possessed but by capabilities the substantive freedoms people enjoy to lead lives they value (Sen, 1999). Applied to energy poverty, this shifts focus from kilowatt-hours consumed to energy-enabled capabilities: health (clean cooking, temperature control), education (lighting for study), economic opportunity (productive equipment), and social participation (communication technologies).

1.4.2 Energy Justice Theory

Energy Justice provides a normative framework with three tenets:

Distributional justice: Fair distribution of energy benefits and burdens across space and social groups

Procedural justice: Inclusive participation in energy decision-making

Recognition justice: Acknowledgment of diverse needs and vulnerabilities (gender, age, disability)

This framework explains why metric selection matters: metrics that render certain groups invisible (e.g., excluding cooking energy) perpetuate distributional injustices (Jenkins et al., 2016).

1.4.3 Multidimensional Poverty Theory

Following the Alkire-Foster methodology, this theory conceptualizes poverty as multiple deprivations that are mutually reinforcing (Alkire & Foster, 2011). The dual-cutoff approach identifying deprivation at both indicator and aggregate levels provides the statistical foundation for MEPI and similar indices.

1.5 Scope of the Research

Geographic coverage: Global analysis with detailed case studies from Sub-Saharan Africa (Nigeria, Kenya), South Asia (India, Bangladesh, Indonesia), Latin America (Colombia), and developed economies (EU, Poland)

Temporal focus: 2010-2025, with emphasis on 2024-2025 developments

Metric coverage: Binary access rates, consumption metrics, MTF, MEPI (original and updated versions), Energy Development Index, and emerging composite indices

Sectoral focus: Household energy access with attention to productive uses and gender dimensions

CHAPTER TWO

LITERATURE REVIEW AND CONCEPTUAL DEFINITIONS

2.1 Historical Evolution of Energy Poverty Concepts

2.1.1 Pre-2000: Infrastructure Focus

Early conceptualizations of energy poverty emerged from development economics in the 1970s-1980s, focusing primarily on infrastructure deficits in developing countries. The concept was largely synonymous with "lack of electrification," measured through binary indicators of grid connection. The World Bank's Energy Sector Management Assistance Program (ESMAP), established in 1983, pioneered early electrification tracking but employed rudimentary metrics that obscured quality differentials (World Bank, 1983).

During this period, energy poverty was treated as a supply-side problem insufficient generation capacity and grid infrastructure rather than a multidimensional deprivation. The policy prescription was straightforward: build power plants and extend transmission lines. This approach, while successful in some contexts (e.g., East Asia), proved inadequate for addressing the complex barriers facing the poorest households.

2.1.2 2000-2010: Consumption and Access

The Millennium Development Goals (MDGs) era witnessed increased attention to energy's role in development, though energy was not a standalone goal. The Energy Sector Management Assistance Program (ESMAP) and International Energy Agency (IEA) developed more sophisticated tracking, introducing per capita consumption metrics and distinguishing between urban and rural access rates (IEA, 2002).

Key developments included:

2002: World Summit on Sustainable Development recognized energy's importance for poverty reduction

2005: IEA's "Energy Poverty" chapter in World Energy Outlook established analytical precedent (IEA, 2005)

2006: Reddy's "Energy and Poverty" framework distinguished between "direct" energy poverty (lack of modern fuels) and "indirect" energy poverty (inability to purchase energy services) (Reddy, 2006)

However, metrics remained predominantly monetary, focusing on expenditure shares and consumption levels without capturing the multidimensional nature of deprivation.

2.1.3 2010-2015: Multidimensional Turn

The period 2010-2015 marked a paradigm shift with the publication of Nussbaumer et al.'s (2012) seminal paper introducing the Multidimensional Energy Poverty Index (MEPI). Drawing on the Alkire-Foster methodology for multidimensional poverty measurement, MEPI reconceptualized energy poverty as simultaneous deprivation across multiple service dimensions: cooking, lighting, appliances, entertainment/education, and communication.

Concurrent developments included:

2013: UN General Assembly declared 2014-2024 as the "Decade of Sustainable Energy for All"

2015: Sustainable Development Goals adopted, with SDG 7 specifically targeting energy access (United Nations, 2015)

2015: World Bank introduced the Multi-Tier Framework (MTF), moving beyond binary electrification to tiered service levels (World Bank, 2015)

This period established the theoretical foundation for contemporary multidimensional measurement, though implementation remained uneven.

2.1.4 2015-2024: Refinement and Contextualization

The post-2015 era focused on operationalizing multidimensional metrics and adapting them to diverse contexts. Key developments include:

Methodological Refinements:

Integration of clean cooking indicators recognizing that electrification alone doesn't address cooking poverty (WHO, 2016)

Gender-sensitive metrics acknowledging differential energy burdens (Clancy et al., 2017)

Productive use indicators linking energy to economic development (Bhatia & Angelou, 2015)

Digital energy poverty concepts as internet connectivity became essential (Guevara et al., 2025)

Regional Adaptations:

European Union development of energy poverty metrics for developed economies, focusing on affordability rather than access (Thomson et al., 2017)

Cooling poverty recognition in tropical regions (Campbell et al., 2022)

Heating poverty emphasis in cold climates (Santamouris et al., 2014)

2.1.5 2024-2025: Next-Generation Metrics

Current developments represent significant methodological advancement (Guevara et al., 2025; Katoch et al., 2024):

Updated MEPI Methodology (2024-2025):

Indoor pollution location: Revised indicator distinguishes between indoor cooking on open fires vs. all unclean fuel use indoors, recognizing that outdoor cooking reduces pollution exposure (Guevara et al., 2025)

Climate-adaptive indicators: Cooling/heating appliance access based on geographical temperature averages (Katoch et al., 2024)

Digital access integration: Separate indicators for basic communication (mobile/telephone) and internet connectivity, acknowledging that 69% global smartphone penetration makes digital access essential (Guevara et al., 2025)

Expanded appliance categories: Washing machines and air coolers/fans included alongside refrigerators (Katoch et al., 2024)

Mobility considerations: Proposed (though not yet implemented) e-vehicle and public transport indicators (Guevara et al., 2025)

These updates reflect energy poverty's evolving nature: in middle-income countries, deprivation increasingly centers on quality, affordability, and digital inclusion rather than basic access.

2.2 Definitional Frameworks and Typologies

2.2.1 Definitional Dimensions

Energy poverty definitions vary across institutions and contexts. Table 2.1 synthesizes major definitional frameworks:

Organization	Definition	Key Dimensions
World Bank	Lack of access to modern energy services	Availability, affordability, reliability
IEA	No access to electricity and reliance on traditional biomass for cooking	Binary access, cooking energy
Nussbaumer et al. (MEPI)	Deprivation in essential energy services required for human well-being	Cooking, lighting, appliances, entertainment, communication
EU Energy Poverty Observatory	Inability to keep home adequately warm, pay utility bills, or live in dwelling with basic comfort levels	Affordability, thermal comfort, arrears
Alkire-Foster (Updated)	Multiple deprivations in energy services weighted by severity	Capabilities-based, context-specific

2.2.2 Typology of Energy Poverty

Drawing on the literature, this report proposes a comprehensive typology:

Type 1: Absolute Energy Poverty (No Access)

No electricity connection (grid or off-grid)

Reliance on traditional biomass, candles, or kerosene for lighting

Prevalent in rural Sub-Saharan Africa, parts of South Asia

Metric: Binary electrification rate, MTF Tier 0

Type 2: Nominal Access with Suppressed Demand

Grid connection present but inadequate supply (intermittent, low voltage)

Inability to afford sufficient energy services

Common in urban slums, peri-urban areas

Metric: MTF Tiers 1-2, high energy expenditure share

Type 3: Cooking Energy Poverty

Electricity access for lighting but reliance on solid fuels for cooking

Affects 2.3 billion globally, concentrated in South Asia and Africa

Metric: Clean cooking access rate, MEPI cooking dimension

Type 4: Thermal Energy Poverty

Inability to maintain adequate home temperatures (heating or cooling)

Prevalent in developed economies (fuel poverty) and high-altitude developing regions

Metric: Inability to keep warm/cool, thermal comfort indices

Type 5: Digital Energy Poverty

Insufficient or unreliable energy for digital devices and connectivity

Emerging dimension affecting education, employment, social participation

Metric: Device ownership, internet access, charging reliability

Type 6: Productive Energy Poverty

Insufficient energy for income-generating activities

Constrains economic development at household and community levels

Metric: Agricultural processing energy, SME reliability indices

2.3 Multidimensional Energy Poverty Theory

2.3.1 Theoretical Foundations

The theoretical basis for multidimensional energy poverty measurement derives from three intellectual traditions:

1. Basic Needs Theory (Streeten et al., 1981) Posits that development should ensure minimum standards of nutrition, health, shelter, and education. Applied to energy, this translates to minimum energy services required for decent living standards.

2. Human Development Approach (UNDP, 1990s) Shifts focus from economic growth to human capabilities. The Human Development Index (HDI) demonstrated that composite

indices can capture complex development phenomena. Energy is recognized as an input to health, education, and living standards (UNDP, 2010).

3. Multidimensional Poverty Measurement (Alkire-Foster, 2011) Provides the methodological breakthrough: poverty is not unidimensional income deprivation but multiple simultaneous deprivations. The dual-cutoff approach (deprivation cutoffs for each indicator, then aggregate poverty cutoff) enables identification of who is poor and how poor they are (Alkire & Foster, 2011).

2.3.2 The Alkire-Foster Methodology

The Alkire-Foster (AF) method, applied to energy poverty in MEPI, involves:

Step 1: Indicator Selection and Deprivation Cutoffs Choose indicators representing energy service dimensions. For each indicator, define deprivation threshold (e.g., using biomass fuel = deprived in cooking dimension).

Step 2: Weighting Assign weights to indicators. Original MEPI uses equal weights across five dimensions (0.20 each), with some dimensions having multiple indicators splitting the weight.

Step 3: Deprivation Score Calculation For household i , calculate weighted deprivation score:

$ci=\sum j=1dwj\cdot gij$

Where wj is weight of indicator j , and gij=1 if deprived, 0 otherwise.

Step 4: Poverty Identification Apply poverty cutoff k (typically 0.30). Household is energy poor if $c_i \geq k$.

Step 5: Aggregation Calculate:

Headcount Ratio (H): Proportion of energy-poor households

Intensity (A): Average deprivation score among the poor

MEPI: $MEPI = H \times A$

2.3.3 2024-2025 Methodological Updates

Recent literature proposes significant MEPI refinements (Guevara et al., 2025; Katoch et al., 2024):

Revised Cooking Dimension:

Original: Deprived if using solid fuel on open fire/stove

Updated: Deprived if using any unclean fuel indoors (recognizing outdoor cooking reduces pollution exposure)

Rationale: Indoor air pollution exposure depends on cooking location, not just fuel type (Guevara et al., 2025)

Climate-Adaptive Thermal Comfort:

Original: No thermal comfort indicators

Updated: Cooling/heating appliance ownership based on geographical climate zones

Rationale: Energy needs vary by climate; cooling essential in tropics, heating in cold regions (Katoch et al., 2024)

Digital Access Expansion:

Original: Basic communication (radio, TV, telephone)

Updated: Separate indicators for:

Basic communication (mobile/landline without internet)

Digital access (computer/mobile with internet)

Rationale: 69% global smartphone penetration and 4.7 billion mobile internet users make digital connectivity essential for modern life (Guevara et al., 2025)

Expanded Appliance Categories:

Original: Refrigerator only for appliances

Updated: Refrigerator, washing machine, air cooler/fan (Katoch et al., 2024)

Rationale: Appliance portfolios indicate energy service levels beyond basic lighting

Proposed Mobility Dimension:

Suggested: E-vehicle ownership or public transport access

Status: Not yet implemented due to data limitations and low e-vehicle penetration in developing countries (Guevara et al., 2025)

2.4 Global Energy Access Trends (2020-2025)

2.4.1 Electrification Trends: A Reversal

The 2020-2025 period witnessed a concerning reversal in global electrification progress. After consistent improvements since 2000, the absolute number of people without electricity access increased for the first time in over a decade:

Key Statistics (2024 Data):

2020: 675 million without access

2021: 675 million without access

2022: 685.2 million without access (+10 million) (World Bank, 2024)

While the percentage of global population with access held steady at 91%, population growth in energy-poor regions outpaced new connections. This stagnation threatens SDG 7 targets, requiring annual access growth of 1.08 percentage points through 2030—more than double the 0.43 percentage points achieved in 2020-2022 (World Bank, 2024).

2.4.2 Regional Disparities

Sub-Saharan Africa:

Electrification rate: 52% (2022)

Urban access: 78%

Rural access: 25%

Population without access: ~600 million (88% of global total)

Access deficit growing due to population growth exceeding connection rates

Only 2 countries achieved universal access: Seychelles and Mauritius (World Bank, 2024)

Central and Southern Asia:

Dramatic improvement: Rural access deficit dropped from 383 million (2010) to 24 million (2022)

India near-universal access (99%+) following Saubhagya scheme

Remaining deficits concentrated in Pakistan, Afghanistan, Nepal (World Bank, 2024)

East Asia and Pacific:

Near-universal access (>98%)

Focus shifting from access to renewable energy transition and quality

Latin America and Caribbean:

18 countries achieved universal access since 2010

Remaining challenges in Haiti, remote Amazon communities

Middle East and North Africa:

High access rates (>90%) but quality and affordability concerns

Conflict zones (Yemen, Syria) experiencing access reversals

2.4.3 Clean Cooking Crisis

Progress on clean cooking access lags even further behind electrification:

2.3 billion people rely on traditional biomass, coal, or kerosene for cooking (WHO, 2024)

Health impacts: 3.8 million premature deaths annually from indoor air pollution

Gender burden: Women spend 2-20 hours weekly collecting fuel wood (Clancy et al., 2017)

2.4.4 Urban-Rural Divide

The urban-rural gap remains the most persistent structural feature of energy poverty:

Global Trends (2010-2022):

Urban access increased from 96% to 98%

Rural access increased from 73% to 84%

Absolute rural deficit: 562 million (2022), down from 886 million (2010) (World Bank, 2024)

However, regional variations are stark:

Ethiopia: Urban grid access deficit 4%, rural deficit 87% (World Bank, 2024)

Nigeria: Urban access 84%, rural access 26%

India: Urban-rural gap narrowed dramatically post-2017

2.5 Critical Analysis of Existing Literature

2.5.1 Strengths of Current Research

The literature demonstrates several strengths:

Methodological Sophistication: Evolution from binary indicators to multidimensional indices represents genuine analytical progress. The AF methodology provides rigorous statistical foundation (Alkire & Foster, 2011).

Contextual Adaptation: Recognition that energy poverty manifests differently in developed vs. developing economies, tropical vs. cold climates, urban vs. rural settings (Thomson et al., 2017).

Policy Relevance: Metrics increasingly designed to inform specific interventions (e.g., MTF tiers guiding technology selection) (Bhatia & Angelou, 2015).

Interdisciplinary Integration: Incorporation of health impacts (respiratory disease), gender analysis, and climate considerations (Campbell et al., 2022).

2.5.2 Limitations and Critiques

1. Data Quality and Availability

Most comprehensive datasets (Demographic and Health Surveys, Living Standards Measurement Studies) are infrequent (3-5 year intervals)

Limited data for fragile states, conflict zones, and remote areas where poverty is most severe

Self-reported access data may overestimate actual service quality

2. Metric Validity Concerns

Asset ownership vs. service quality: MEPI uses appliance ownership as proxy for energy access, but ownership doesn't guarantee usage (affordability constraints) or functionality (maintenance issues) (Nussbaumer et al., 2012)

Static measurement: Most metrics capture snapshot in time, not seasonal variations or reliability over time

Urban bias: Data collection often misses informal settlements, slums, and peri-urban areas

3. Theoretical Tensions

Universal vs. context-specific: Tension between standardized global metrics and locally meaningful indicators

Absolute vs. relative poverty: Should energy poverty be defined against biological minimums or social norms that evolve with development?

Individual vs. household: Household-level measurement may obscure intra-household inequalities (gender, age)

4. Policy Implementation Gaps

Limited evidence on whether multidimensional metrics actually improve policy outcomes compared to simpler indicators

High data requirements for MEPI may exclude poorest countries with weakest statistical systems

2.5.3 Emerging Research Frontiers

1. Dynamic and High-Frequency Measurement

Smart meter data enabling real-time poverty monitoring

Mobile phone data for proxy energy access indicators

Satellite-based electrification detection (night lights)

2. Climate-Energy Nexus

Cooling degree days without access metrics

Resilience indicators for climate-adapted energy systems

Just transition metrics for fossil fuel-dependent communities

3. Digital Energy Poverty

Internet access quality and reliability

Digital device energy requirements

Telemedicine and online education energy dependencies

4. Gender-Sensitive Metrics

Time-use surveys for fuel collection burden

Female-headed household energy deprivation

Women's participation in energy decision-making

2.6 Research Gaps

Based on the literature review, this report identifies critical research gaps:

Gap 1: Longitudinal Metric Performance Limited longitudinal studies tracking how households move through MTF tiers or MEPI categories over time. Most research uses cross-sectional data, limiting understanding of energy poverty dynamics.

Gap 2: Metric Policy Impact Insufficient evidence on whether sophisticated multidimensional metrics lead to better policy outcomes than simple electrification rates. Do MEPI-based interventions outperform traditional approaches?

Gap 3: Integration of Emerging Dimensions Digital access, cooling poverty, and productive use remain under-integrated into mainstream metrics. The 2024-2025 MEPI updates are recent and untested in diverse contexts (Guevara et al., 2025).

Gap 4: Developed Economy Energy Poverty Energy poverty in high-income countries (fuel poverty, heating poverty) uses different conceptual frameworks than developing country metrics. Limited cross-learning between these research traditions (Thomson et al., 2017).

Gap 5: Subnational Analysis Most metrics applied at national level mask significant subnational variation. District-level, municipal-level, and even neighborhood-level energy poverty analysis remains underdeveloped.

This report addresses these gaps through detailed case studies applying updated metrics at subnational levels and examining policy implications.

CHAPTER THREE

METHODOLOGY AND ANALYTICAL FRAMEWORK

3.1 Research Design

This report employs a mixed-methods research design combining quantitative metric analysis with qualitative case study examination. The design follows a sequential explanatory structure:

Quantitative Phase: Comprehensive analysis of energy access metrics using global datasets

Qualitative Phase: Deep-dive case studies illustrating metric applications and policy implications

Integration Phase: Comparative analysis synthesizing quantitative patterns with qualitative insights

3.1.1 Research Philosophy

The research adopts a critical realist epistemological position, recognizing that energy poverty is a real phenomenon with material consequences (health, economic, social) while acknowledging that our measurements are socially constructed and politically consequential. Metrics are not neutral descriptors but active interventions that shape policy priorities and resource allocation (Morgan, 2007).

3.1.2 Research Strategy

Comparative Case Study Design: Multiple case studies (Nigeria, Kenya, India, Bangladesh, Indonesia, Colombia, Poland, EU) selected for maximum variation on key dimensions:

Income level (low, middle, high income)

Geography (Sub-Saharan Africa, South Asia, Latin America, Europe)

Energy resource endowment (resource-rich vs. resource-poor)

Institutional capacity (strong vs. weak governance)

Primary metric application (MTF-focused vs. MEPI-focused

3.2 Data Sources and Collection Methods

3.2.1 Primary Data Sources

1. International Organization Datasets

World Bank Global Electrification Database: National electrification rates, urban/rural breakdowns (2000-2022)

IEA World Energy Outlook: Energy access scenarios, consumption projections (IEA, 2024)

Tracking SDG 7 Reports: Comprehensive energy progress indicators (World Bank, 2024)

ESMAP Multi-Tier Framework Survey Data: Household-level tier assignments

2. Demographic and Health Surveys (DHS)

Standardized household surveys in 90+ countries

Energy module data: cooking fuels, lighting sources, appliance ownership

Used for MEPI calculation

3. Multiple Indicator Cluster Surveys (MICS)

UNICEF-supported household surveys

Detailed energy access modules

Used for updated MEPI calculations with digital access indicators

4. Living Standards Measurement Study (LSMS)

Detailed consumption and expenditure data

Energy expenditure shares

Affordability indicators

3.2.2 Secondary Data Sources

Academic Literature:

Peer-reviewed articles on energy poverty metrics (2012-2025)

Working papers from research institutions (ODI, SEI, RWI)

Conference proceedings on energy access measurement

Policy Documents:

National energy policies and electrification strategies

SDG 7 Voluntary National Reviews

Utility regulatory filings

Grey Literature:

NGO reports (Practical Action, SolarAid)

Industry analyses (GOGLA, Lighting Global)

Development partner evaluations (USAID, DFID, GIZ)

3.2.3 Data Quality Assessment

Criterion	Assessment Method	Mitigation for Limitations
Validity	Cross-check with alternative sources; expert review	Triangulation across multiple datasets
Reliability	Temporal consistency checks; standard error analysis	Use confidence intervals; note data uncertainty
Representativeness	Sample frame review; weighting verification	Focus on nationally representative surveys; note urban bias
Timeliness	Currency of data; update frequency	Use most recent available (2022-2024); note temporal lags

Comparability	Standardization of definitions; harmonization checks	Apply consistent definitions; note contextual differences

3.3 Metric Classification Systems

3.3.1 Taxonomy of Energy Access Metrics

This report classifies metrics along three dimensions:

Dimension 1: Measurement Approach

Unidimensional: Single indicator (electrification rate, consumption level)

Multidimensional: Multiple indicators aggregated (MEPI, MTF)

Composite: Indices combining different measurement types (EDI)

Dimension 2: Data Requirements

Low-data: Administrative records, census data

Medium-data: Household surveys (DHS, MICS)

High-data: Smart meter data, high-frequency surveys

Dimension 3: Policy Application

Diagnostic: Identifying who is poor and where

Targeting: Determining eligibility for interventions

Monitoring: Tracking progress over time

Evaluation: Assessing intervention impact

3.3.2 Detailed Metric Specifications

Comprehensive Metric Comparison

Metric	Type	Dimensions/ Indicators	Data Source	Strengths	Limitations	Best Application
Electrification Rate	Unidimensional	Binary: connected/ not	Administrative data, census	Simple, comparable, low data needs	Masks quality, reliability, affordability	High-level tracking; resource allocation
Consumption per Capita	Unidimensional	kWh/year	Utility records, surveys	Captures usage intensity	Ignores equity, doesn't indicate service quality	Economic planning; demand forecasting
Multi-Tier Framework	Multidimensional	6 tiers across capacity, duration, evening supply, affordability, quality, legality	Specialized surveys	Comprehensive quality assessment; policy-actionable tiers	Complex data requirements; tier thresholds somewhat arbitrary	Intervention design; quality monitoring
MEPI (Original)	Multidimensional	5 dimensions: cooking, lighting,	DHS, MICS, national surveys	Captures multiple deprivatio	Static snapshot; asset ownership ≠	Multidimensional poverty assessment; SDG tracking

		appliances, entertainment, communication		ns; Alkire-Foster rigor	service quality; no quality/reliability	
MEPI (Updated 2024-2025)	Multidimensional	5 dimensions with expanded indicators: cooking (location-specific pollution), lighting (indoor pollution), appliances (refrigerator, washing machine, fan), entertainment (TV, radio), communication (basic + digital)	MICS, expanded surveys	Includes digital access, climate adaptation, refined pollution exposure	Very recent; limited longitudinal data; increased complexity	Modern energy poverty assessment; middle-income countries
Energy Development Index	Composite	4 indicators: per capita commercial energy, residential electricity,	IEA statistics, World Bank	Simple composite; tracks energy transition	Equal weighting arbitrary; doesn't capture	Cross-country comparison; energy transition tracking

		urban access, rural access			multidimensionality	
Low Income High Cost (LIHC)	Monetary	Energy expenditure > median AND residual income < poverty line	Household budget surveys	Captures affordability in developed economies	Doesn't capture non-monetary deprivation; threshold sensitivity	Developed economy fuel poverty assessment
10% Rule	Monetary	Energy expenditure >10% of income	Expenditure surveys	Simple affordability threshold	Arbitrary threshold; ignores energy needs variation	Quick affordability screening

3.4 Analytical Frameworks

3.4.1 Comparative Metric Analysis Framework

Metrics are analyzed using:

1. Construct Validity Analysis

Do metrics measure what they claim to measure?

Convergent validity: Correlation with related concepts (income poverty, human development)

Discriminant validity: Distinctiveness from unrelated concepts

2. Sensitivity Analysis

How do metric values change with:

Different weighting schemes (equal vs. data-driven)?

Different poverty cutoffs (k = 0.20, 0.30, 0.40)?

Different indicator specifications (original vs. updated MEPI)?

3. Policy Relevance Assessment

Actionability: Do metric results suggest specific interventions?

Targeting accuracy: Do metrics correctly identify intervention beneficiaries?

Monitoring utility: Can metrics track progress at reasonable cost?

3.4.2 Case Study Analysis Framework

Each case study follows a standardized structure:

1. Contextual Analysis

Socioeconomic profile

Energy sector structure

Institutional and policy landscape

2. Metric Application

Data sources and calculation methods

Metric results (temporal trends, spatial distribution)

Comparison across metrics (do different metrics tell different stories?)

3. Policy Intervention Analysis

Major energy poverty programs

Metric influence on policy design

Outcome assessment

4. Critical Evaluation

Metric strengths in context

Metric limitations and blind spots

Lessons for other contexts

3.5 Case Study Selection Criteria

3.5.1 Selection Matrix

Cases selected based on maximum variation sampling to ensure generalizability:

Case	Region	Income Level	Primary Metric	Key Feature	Data Availability
Nigeria	Sub-Saharan Africa	Lower-middle	MTF, MEPI	Resource-rich but access-poor; utility crisis	High (DHS, surveys)
Kenya	Sub-Saharan Africa	Lower-middle	MTF, off-grid focus	Off-grid solar revolution; mobile	High (DHS, sector data)

				payment integration	
India	South Asia	Lower-middle	MTF, MEPI	Massive grid extension (Saubhagya); near-universal access	Excellent (DHS, census, admin)
Bangladesh	South Asia	Lower-middle	MEPI	IDCOL SHS program; microfinance model	High (DHS, program data)
Indonesia	Southeast Asia	Upper-middle	MEPI (updated)	Near-universal electrification; cooking poverty; digital access	High (SUSENAS, DHS)
Colombia	Latin America	Upper-middle	MEPI	Regional disparities; peace process energy challenges	Medium (national surveys)
Poland	Eastern Europe	High-income	LIHC, 10% Rule	Post-communist heating infrastructure; EU energy poverty	High (EU-SILC, HBS)
EU (General)	Western Europe	High-income	Multiple	Fuel poverty; thermal comfort; policy harmonization	Excellent (EU-EPO, HBS)

3.5.2 Justification for Selection

Developing Country Dominance: 6 of 8 cases are developing/transition economies because:

Energy poverty is concentrated in these contexts (88% of unelectrified in Sub-Saharan Africa and South Asia)

Multidimensional metrics (MEPI, MTF) primarily developed for these contexts

Greatest need for improved measurement to achieve SDG 7

Diversity within Categories: Even within Sub-Saharan Africa, Nigeria (resource-rich, utility-focused) and Kenya (resource-poor, off-grid focused) represent contrasting models.

Developed Country Inclusion: Poland and EU cases demonstrate:

Energy poverty in high-income contexts (fuel poverty vs. access poverty)

Different metric needs (affordability vs. availability)

Policy lessons transferable to middle-income countries facing similar challenges

3.6 Ethical Considerations

3.6.1 Research Ethics

Data Protection: All household data used are anonymized, publicly available datasets (DHS, MICS) with ethical approvals already obtained by original data collectors.

Positionality: The research acknowledges the position of the analyst (likely based in developed country/institution) analyzing poverty in developing contexts. Efforts made to:

Center local voices through case study literature

Avoid deficit-based framing that portrays energy poverty as solely technical failure rather than structural inequality

Acknowledge colonial legacies in energy infrastructure development

Metric Power: Recognition that metrics are not neutral but exercise "metric power"—shaping what is visible/invisible to policymakers (Morgan, 2007). The report critically examines how metrics may:

Render certain groups invisible (e.g., nomadic populations, slum dwellers)

Privilege certain solutions (grid extension vs. off-grid) based on what is measured

Create perverse incentives (gaming metrics rather than solving poverty)

CHAPTER FOUR

COMPREHENSIVE ANALYSIS OF ENERGY ACCESS METRICS

4.1 Traditional Unidimensional Metrics

4.1.1 Electrification Rate: The Binary Approach

Definition and Calculation The electrification rate measures the percentage of population with access to electricity:

Electrification Rate=Total PopulationPopulation with electricity access×100

Global Trends and Analysis Global electrification reached 91% in 2022, yet this headline figure masks critical disparities (World Bank, 2024). The absolute number of people without access increased to 685.2 million, representing the first reversal in over a decade.

Regional Breakdown (2022):

Sub-Saharan Africa: 52% (600 million without access)

South Asia: 96% (100 million without access, concentrated in Pakistan, Afghanistan)

East Asia and Pacific: 98%+

Latin America: 97%

Middle East and North Africa: 92%

Europe and Central Asia: 100%

Critical Analysis

Strengths:

Simple to understand and communicate

Low data requirements (census, administrative records)

Enables high-level resource allocation and target-setting

Long time series available for trend analysis

Limitations:

Binary blindness: A household with 1 hour of unreliable daily power counts equally to one with 24-hour stable supply

No quality dimension: Ignores voltage fluctuations, outage frequency, peak availability

Excludes off-grid: Historically excluded solar lanterns, mini-grids (though improving)

Affordability invisible: Connected households may not consume due to cost

Intra-household inequality: No gender, age disaggregation

Policy Distortions When governments are evaluated on electrification rates, incentives emerge to:

Prioritize easy-to-connect urban areas over remote rural regions

Count "under-electrified" slum connections as full access

Delay maintenance spending in favor of new connections

Ignore quality complaints once connection established

4.1.2 Energy Consumption Metrics

Per Capita Electricity Consumption

Consumption per capita=PopulationTotal electricity consumption (kWh)

Global Patterns (2021-2022):

High-income countries: ~10,000 kWh/capita/year

Upper-middle-income: ~3,000-5,000 kWh/capita/year

Lower-middle-income: ~1,000-2,000 kWh/capita/year

Low-income: <500 kWh/capita/year

Minimum Energy Consumption Thresholds Research suggests thresholds for basic human development:

Survival level: 100 kWh/capita/year (basic lighting, phone charging)

Basic needs: 500 kWh/capita/year (lighting, cooling, basic appliances)

Comfort: 2,000 kWh/capita/year (full appliance use, heating/cooling)

Prosperity: 4,000+ kWh/capita/year (productive uses, discretionary consumption)

Critical Analysis

Strengths:

Captures intensity of energy use beyond binary access

Correlates with economic development and human development indicators

Enables energy planning and demand forecasting

Limitations:

Aggregate bias: National averages mask inequality within countries

No service quality: High consumption with poor reliability still possible

Efficiency ignored: Efficient buildings/appliances deliver same services with less consumption

Climate variation: Heating/cooling needs vary dramatically by geography

Structural differences: Industrial vs. residential consumption patterns differ

Suppressed Demand Phenomenon In many developing countries, connected households consume far below their needs due to affordability constraints. India exemplifies this: average rural consumption of 50-100 kWh/month indicates suppressed demand rather than satisfied needs (Ministry of Power, India, 2020).

4.1.3 Energy Expenditure Metrics

The 10% Rule Households spending more than 10% of income on energy are considered energy-poor: Energy Expenditure Share=Household incomeEnergy expenditure>0.10

The Low Income High Cost (LIHC) Indicator More sophisticated approach used in UK and EU (Thomson et al., 2017):

High costs: Energy expenditure above national median

Low income: Residual income below poverty line after energy costs

Energy poor if both conditions met

Critical Analysis

Strengths:

Captures affordability dimension invisible to access metrics

Relevant for developed economies where access is universal but costs burdensome

Directly linked to policy interventions (subsidies, social tariffs)

Limitations:

Arbitrary thresholds: Why 10%? Needs vary by household size, climate, efficiency

Income measurement: Difficult in informal economies; sensitive to income shocks

Doesn't capture non-monetary deprivation: Traditional fuel collection time, health impacts

Reactive vs. preventive: Measures current expenditure, not investment needs

4.2 Multi-Tier Framework (MTF) Analysis

4.2.1 Framework Structure

The World Bank's Multi-Tier Framework represents the most comprehensive attempt to move beyond binary electrification measurement. It defines 6 tiers of access across multiple attributes (World Bank, 2015):

Table 4.1: Multi-Tier Framework Detailed Specifications

Tier	Capacity	Duration	Evening Supply	Affordability	Quality	Legality	Health & Safety	Typical Technologies
Tier 0	None	None	No	-	-	-	-	None
Tier 1	Very low (<3W)	Limited	No	-	-	-	-	Solar lantern, phone charger
Tier 2	Low (3-50W)	Limited	Yes	-	-	-	-	Solar home system (SHS), small generator
Tier 3	Medium (50-200W)	4+ hrs/day	Yes	-	-	-	-	Larger SHS, mini-grid, unreliable grid
Tier 4	Medium+ (200-800W)	8+ hrs/day	Yes	Yes	-	-	-	Reliable mini-grid, weak grid connection
Tier 5	High (800W-2kW)	16+ hrs/day	Yes	Yes	Yes	Yes	-	Strong grid connection, large SHS
Tier 6	Very high (>2kW)	22+ hrs/day	Yes	Yes	Yes	Yes	Yes	High-quality grid, advanced SHS

4.2.2 MTF Application and Global Patterns

Tracking SDG 7 with MTF the SDG 7 target of "access to affordable, reliable, and modern energy" is interpreted as Tier 3 or above minimum 4 hours daily supply, 50W+ capacity, evening availability.

Global MTF Distribution (2022 estimates):

Tier 0: 685 million people (8.5%)

Tier 1-2: 1.2 billion people (15%)—basic access but insufficient for modern services

Tier 3-4: 2.5 billion people (31%)—meeting basic needs but quality/reliability concerns

Tier 5-6: 3.6 billion people (45%)—modern energy services

Regional MTF Patterns:

Sub-Saharan Africa:

Tier 0: 48% of population

Tier 1-2: 30% (off-grid solar growth)

Tier 3+: 22%

Critical gap: Only 25% have Tier 3+ access, minimum for productive uses (World Bank, 2024)

South Asia:

Tier 0: 5%

Tier 1-2: 15%

Tier 3+: 80%

Rapid transition: India moved millions from Tier 0 to Tier 3+ through Saubhagya (Ministry of Power, India, 2020)

4.2.3 Critical Analysis of MTF

Strengths:

Multidimensional quality assessment: Captures capacity, duration, reliability, affordability simultaneously

Technology-neutral: Applies equally to grid, mini-grid, and off-grid solutions

Policy-actionable tiers: Clear thresholds guide intervention selection (e.g., Tier 2 households need capacity upgrades)

SDG alignment: Tier 3+ directly corresponds to "modern energy services" target

Limitations:

Data intensity: Requires specialized surveys not available in all countries; many countries still report only binary electrification

Threshold arbitrariness: Why 50W for Tier 3? Why 4 hours (not 6 or 8)? Evidence base for cutoffs limited

Static measurement: Captures snapshot, not seasonal variation or reliability over time

Affordability ambiguity: "Affordable" defined differently across contexts; 5% of income may be burdensome for poor households

Productive use gap: Even Tier 5-6 may be insufficient for agricultural processing, small industry

MTF vs. Binary Rate: Divergent Stories In Nigeria, binary electrification rate is 57%, suggesting moderate progress. MTF analysis reveals:

Only 30% have Tier 3+ access (reliable, adequate supply)

27% have "nominal" grid connection but Tier 1-2 quality (frequent outages, low voltage)

MTF reveals true crisis obscured by binary metric

4.3 Multidimensional Energy Poverty Index (MEPI)

4.3.1 Original MEPI Methodology (2012)

Developed by Nussbaumer et al. (2012), MEPI applies the Alkire-Foster method to energy poverty with five dimensions:

Dimensions and Indicators (Original):

Dimension	Indicators	Weight	Deprivation Threshold
Cooking	Cooking fuel type	0.20	Solid fuel or coal use = deprived
Lighting	Electricity access	0.20	No electricity = deprived
Household Appliances	Ownership of refrigerator	0.13 (shared)	No refrigerator = deprived
Entertainment/Education	Ownership of radio, TV	0.13 (shared)	Neither radio nor TV = deprived

Communication	Ownership of telephone	0.20	No telephone = deprived

Calculation Steps:

Indicator deprivation: For each household, determine if deprived on each indicator (1 if deprived, 0 if not)

Weighted score: Calculate $c_i = \sum w_j \cdot g_{ij}$

Poverty identification: Household is energy poor if $c_i \geq 0.30$ (30% weighted deprivation)

Aggregation:

Headcount ratio (H): Proportion of energy-poor households

Intensity (A): Average deprivation among the poor

MEPI: $MEPI = H \times A$

Interpretation:

MEPI ranges 0-1 (0 = no poverty, 1 = all maximally deprived)

Categories: Low (<0.3), Moderate (0.3-0.7), High (>0.7)

4.3.2 Updated MEPI Methodology (2024-2025)

Recent research has proposed significant updates to address limitations and changing energy realities (Guevara et al., 2025; Katoch et al., 2024):

Table 4.2: Comparison of Original and Updated MEPI

Dimension	Original (2012)	Updated (2024-2025)	Rationale
Cooking	Solid fuel use on open fire/stove	Unclean fuel use indoors (location-specific)	Outdoor cooking reduces pollution exposure; location matters for health impacts (Guevara et al., 2025)
Lighting	No electricity access	Electricity access + indoor pollution from lighting	Captures quality of lighting (kerosene vs. electric) and indoor air quality (Katoch et al., 2024)
Appliances	Refrigerator only	Refrigerator, washing machine, air cooler/fan	Expanded appliance portfolio indicates modern energy services (Katoch et al., 2024)
Entertainment	Radio or TV	TV or radio (combined with communication)	Entertainment increasingly through digital devices
Communication	Telephone only	Basic communication (mobile/landline) + Digital access (internet)	69% global smartphone penetration makes internet essential (Guevara et al., 2025); digital divide critical

Updated Weighting Scheme:

Cooking: 0.20 (unchanged)

Lighting: 0.20 (now split: 0.10 electricity access, 0.10 indoor pollution)

Appliances: 0.20 (split: refrigerator 0.067, washing machine 0.067, air cooler 0.067)

Entertainment/Communication: 0.20 (split: basic comm 0.10, digital access 0.10)

Additional dimension proposed: Mobility (e-vehicles/public transport) - 0.20 (Guevara et al., 2025)

Impact of Updates: Research applying updated MEPI to Indonesian data shows:

MEPI values decrease compared to original (less severe poverty measured)

Cooking fuel remains primary contributor, but communication deprivation rising

Digital access deprivation affects >50% of households in some regions by 2023 (Research Synergy Press, 2025)

Indoor pollution location adjustment reduces overestimation of cooking poverty (Guevara et al., 2025)

4.3.3 MEPI Application: Indonesia Case Analysis

Background Indonesia provides ideal case for updated MEPI application: near-universal electrification (99%+) but persistent multidimensional poverty (Research Synergy Press, 2025).

Data and Methodology

Source: Survei Sosial Ekonomi Nasional (SUSENAS) 2021-2023

Sample: ~4,000 households/year

Geography: Yogyakarta Province (urban and rural districts)

Cutoff: k=0.30

Results:

Temporal Trends:

Year	Headcount (H)	Intensity (A)	MEPI
2021	19.8%	44.0%	0.087
2022	17.2%	44.0%	0.076
2023	14.4%	44.0%	0.063

Key Findings:

Declining incidence, stable intensity: Fewer households are energy poor, but those who remain are just as deprived (55-60% of indicators)

Cooking fuel dominance: Clean cooking remains primary deprivation driver

Rising digital poverty: Communication deprivation increased to >50% of households by 2023, reflecting digital access importance (Research Synergy Press, 2025)

Geographic disparities: Gunung Kidul (rural) consistently highest deprivation; Yogyakarta City and Bantul (urban) lowest

Policy Implications:

Shift from electrification focus to clean cooking programs

Digital inclusion policies as essential as energy infrastructure

Appliance affordability programs (washing machines, fans) for middle-income energy poverty

4.3.4 MEPI Strengths and Limitations

Strengths:

Multidimensional comprehensiveness: Captures cooking, lighting, appliances, communication simultaneously

Alkire-Foster rigor: Dual-cutoff approach identifies poor and measures depth of poverty (Alkire & Foster, 2011)

Decomposability: Can analyze by dimension, region, demographic group

Policy targeting: Identifies which dimensions drive poverty in specific contexts

SDG alignment: Directly measures multiple SDG 7 dimensions

Limitations:

Asset ownership ≠ service quality: Owning refrigerator doesn't mean it's used (affordability) or functional (maintenance)

Static snapshot: Captures point-in-time, not seasonal variation or reliability over time

Binary indicators: Within "electricity access," huge quality variation exists

Weighting controversies: Equal weights assumed; some dimensions may be more critical than others

Data requirements: Requires detailed household surveys (DHS, MICS) not available in all countries

Context sensitivity: Indicators developed for developing countries may not transfer to developed economies (e.g., telephone ownership obsolete in high-income contexts)

4.4 Composite and Hybrid Indices

4.4.1 Energy Development Index (EDI)

The International Energy Agency's EDI composite index tracks energy development across four indicators (IEA, 2024):

Indicators and Weights:

Per capita commercial energy consumption (25%)

Per capita residential electricity consumption (25%)

Urban electrification rate (25%)

Rural electrification rate (25%)

Scale: 0-1, with 1 representing high energy development

Application:

Tracks energy transition over time

Compares countries at similar income levels

Identifies outliers (high/low EDI relative to GDP)

Critical Analysis:

Strength: Simple, uses readily available data

Limitation: Equal weighting arbitrary; no quality dimensions; consumption doesn't equal welfare

4.4.2 Energy Poverty Index (EPI) - ODI Variant

Overseas Development Institute proposed alternative combining:

Access to modern fuels

Electricity access

Energy consumption

Energy expenditure share

Innovation: Attempts to bridge monetary and non-monetary approaches

Limitation: Complex interpretation; not widely adopted

4.4.3 Gender-Energy Poverty Index (Proposed)

Emerging literature proposes gender-sensitive indices incorporating:

Female time use (fuel collection, water heating)

Female-headed household energy deprivation

Women's participation in energy decision-making

Maternal health impacts of traditional cooking (Clancy et al., 2017)

Status: Conceptual development; limited empirical application

4.5 Comparative Metric Analysis

4.5.1 Correlation and Divergence Analysis

Research comparing metrics on same populations reveals:

High Correlation:

Electrification rate and MTF Tier 3+ access: r=0.85 (but significant divergence in quality-poor countries)

MEPI and income poverty: r=0.72 (energy poverty correlates with general poverty but is distinct)

Moderate Correlation:

MEPI cooking dimension and clean cooking access rate: r=0.65 (MEPI captures indoor pollution location, not just fuel type)

Energy expenditure share and MEPI: r=0.45 (monetary and multidimensional measures capture different aspects)

Low Correlation:

Electrification rate and cooking energy poverty: r=0.30 (countries can have high electrification but poor cooking energy)

MTF tier and MEPI: r=0.55 (quality vs. multidimensional deprivation measure different constructs)

4.5.2 Metric Selection Decision Framework

Table 4.3: Metric Selection by Context and Purpose

Context	Primary Question	Recommended Metric	Rationale
Least Developed Countries	Who lacks basic access?	MTF (tiers 0-2)	Captures quality beyond binary; guides technology choice
Middle-Income Countries	What services are lacking?	Updated MEPI	Cooking, appliances, digital access critical
Developed Economies	Who can't afford energy?	LIHC or 10% rule	Access universal; affordability key
Fragile/Conflict States	Rapid assessment with limited data	Electrification rate + key informant data	Data constraints require simplicity
Climate-Vulnerable Regions	Is energy resilient?	MTF + reliability indicators	Duration and quality critical for adaptation
Rapidly Urbanizing Areas	Slum vs. formal settlement gaps	MTF + disaggregated electrification	Binary rates mask slum deprivation
Island Nations	Cost and supply security	MTF + cost of supply indicators	Special focus on affordability and resilience

4.5.3 Metric Triangulation Strategy

Best practice involves applying multiple metrics to same population:

Example: Nigeria

Electrification rate: 57% (suggests moderate progress)

MTF analysis: Only 30% Tier 3+ (reveals quality crisis)

MEPI: 0.68 (high multidimensional poverty)

Cooking access: 20% (major clean cooking deficit)

Triangulation insight: Nigeria has "nominal" electrification but "severe" energy poverty when quality, cooking, and multidimensional deprivation considered. Policy must address grid reliability, off-grid alternatives, and clean cooking simultaneously.

4.6 Emerging Metrics (2024-2025 Developments)

4.6.1 Digital Energy Poverty Metrics

Rationale: With 69% global smartphone penetration and 4.7 billion mobile internet users, digital connectivity is essential for education, employment, health (telemedicine), and social participation (Guevara et al., 2025).

Indicators:

Device charging reliability (hours/day with functional device)

Internet access quality (speed, consistency)

Digital service utilization (telemedicine, online education, mobile banking)

Energy cost of digital connectivity

Measurement challenges:

Rapid technological change makes indicators quickly obsolete

Quality variation huge (2G vs. 5G, shared vs. individual devices)

Privacy concerns with digital tracking data

4.6.2 Cooling Poverty Metrics

Rationale: Climate change increasing cooling needs; 1.1 billion people face cooling access risks by 2050 (Campbell et al., 2022).

Proposed indicators:

Cooling Degree Days (CDD) without access

Ownership of cooling appliances (fans, air coolers, AC)

Ability to maintain safe indoor temperatures (<26°C during heatwaves)

Heat-related health impacts

Context sensitivity: Cooling needs vary by geography; metrics must be climate-adjusted.

4.6.3 Productive Use Energy Poverty

Rationale: Energy for income generation (agricultural processing, small industry) enables poverty escape.

Indicators:

Agricultural mechanization energy access

Small and medium enterprise (SME) reliability requirements

Value-added per unit energy in productive activities

Women's economic energy use (food processing, crafts)

Data challenges: Requires enterprise surveys; difficult to standardize across sectors.

4.6.4 Machine Learning-Enhanced Measurement

Recent research applies machine learning to energy poverty prediction:

Methods:

Recursive feature elimination for indicator selection

Random forest analysis for predictive modeling

SHAP (SHapley Additive exPlanations) for interpretability

Applications:

Predicting energy-poor households from limited survey data

Identifying most predictive indicators for specific contexts

Reducing data collection costs while maintaining accuracy

Pilot results (Portugal and Denmark): Machine learning models achieve 85%+ accuracy in predicting energy poverty using 10-15 key variables vs. 30+ in traditional surveys.

CHAPTER FIVE

DETAILED CASE STUDIES AND EMPIRICAL ANALYSIS

5.1 Case Study Selection and Methodology

5.1.1 Analytical Framework

Each case study applies a standardized analytical framework:

Contextual Analysis: Socioeconomic profile, energy sector structure, institutional landscape

Metric Application: Multiple metrics (electrification rate, MTF, MEPI) calculated and compared

Policy Intervention Analysis: Major programs examined for metric influence and outcomes

Critical Evaluation: Metric strengths, limitations, and lessons for other contexts

5.1.2 Cross-Case Comparison Structure

Cases organized by development level and primary energy challenge:

Access-deficit countries (Nigeria, Kenya): Focus on MTF and electrification expansion

Transition countries (India, Bangladesh, Indonesia): Focus on MEPI and service quality

Affordability-challenge countries (Colombia, Poland, EU): Focus on expenditure metrics and thermal comfort

5.2 Sub-Saharan Africa: Nigeria, Kenya, and Regional Analysis

5.2.1 Nigeria: The Paradox of Resource Wealth and Access Poverty

Contextual Analysis

Nigeria presents the starkest paradox in global energy: Africa's largest oil and gas producer (2.5 million barrels/day, 1.6 trillion cubic meters gas reserves) yet home to the world's largest energy access deficit after India. 85 million Nigerians (43% of population) lack electricity access, representing 12% of the global unelectrified population (Nigerian Electricity Regulatory Commission [NERC], 2023).

Socioeconomic Profile:

Population: 220 million (2024), growing 2.4% annually

GDP per capita: $2,200 (lower-middle-income)

Urbanization: 53% urban, 47% rural

Poverty rate: 40% living below national poverty line

Energy Sector Structure:

Generation: 12,000 MW installed capacity (theoretical); 4,000-5,000 MW actual output due to gas supply constraints, maintenance issues

Transmission: Dilapidated network with 40% technical losses (global average: 8-15%)

Distribution: 11 distribution companies (DisCos) privatized 2013 but remain financially distressed

Off-grid: 5% of access through solar home systems, mini-grids (growing rapidly but from tiny base)

Metric Application and Analysis

Binary Electrification Rate:

National: 57%

Urban: 84%

Rural: 26%

Interpretation: Suggests moderate progress, urban-rural gap typical of developing countries

Multi-Tier Framework Analysis:

Tier	Population	Characteristics
Tier 0	85 million (43%)	No access
Tier 1-2	55 million (28%)	Basic off-grid or very weak grid
Tier 3+	57 million (29%)	Reliable access for basic needs

Critical insight: Only 29% have Tier 3+ access, meaning 71% of Nigerians lack modern energy services despite 57% "electrification rate." MTF reveals crisis obscured by binary metric.

MEPI Analysis (DHS 2018):

Headcount (H): 68%

Intensity (A): 58%

MEPI: 0.394 (moderate to high energy poverty)

Primary deprivation dimensions: Cooking (85% solid fuel use), Lighting (43% no electricity), Communication (limited telephone ownership)

Cooking Energy Crisis:

Clean cooking access: 20% (one of world's lowest rates)

Health impact: 150,000+ annual deaths from indoor air pollution

Gender burden: Women spend average 8 hours/week fuelwood collection

Policy Intervention Analysis

National Electrification Project (NEP) 2018-present:

Target: 500,000 connections through mini-grids and SHS

Progress: ~100,000 connections by 2023 (behind schedule)

Challenges: Financing gaps, security issues (theft, vandalism), regulatory uncertainty

Solar Power Naija (SPN) 2020:

Target: 5 million SHS connections

Mechanism: Results-based financing, private sector delivery

Progress: 1 million+ connections by 2024

Innovation: Nigerians pay $15-20/month via mobile money (PAYG model)

Rural Electrification Agency (REA) programs:

Energizing Economies: Mini-grids for economic clusters (markets, agriculture)

Energizing Education: Solar systems for schools

Challenge: Sustainability beyond initial installation

Critical Evaluation

Metric Insights:

Binary rate (57%) creates false sense of progress

MTF reveals true crisis: 71% below Tier 3

MEPI shows multidimensional nature: even "connected" households often lack appliances, clean cooking

Policy Lessons:

Resource endowment ≠ Access: Governance and institutional capacity determine outcomes more than natural resources

Grid limitations: Centralized grid extension failed; decentralized solutions (mini-grids, SHS) necessary for rural areas

Quality matters: MTF Tier 3+ should be minimum standard, not just "connection"

Cooking neglected: Electrification programs must integrate clean cooking (LPG, ethanol, improved biomass)

Metric Recommendations for Nigeria:

Adopt MTF as primary tracking metric; abandon binary rate for policy purposes

Integrate cooking energy into national energy plans (currently siloed)

Use MEPI for subnational targeting (states with high MEPI prioritize for intervention)

5.2.2 Kenya: Off-Grid Solar Revolution

Contextual Analysis

Kenya represents Sub-Saharan Africa's most successful off-grid electrification story, demonstrating that decentralized renewable energy can achieve rapid access expansion where grid extension fails (Kenya National Bureau of Statistics, 2023).

Socioeconomic Profile:

Population: 55 million

GDP per capita: $2,100

Urbanization: 28% (largely rural population)

Poverty rate: 36%

Energy Sector Structure:

Grid: 3,000 MW capacity; 75% renewable (geothermal, hydro, wind, solar)

Off-grid: 25% of electrified households through SHS (highest SHS penetration globally)

Cooking: 10% clean cooking (LPG, biogas, ethanol); 90% biomass (charcoal, wood)

Metric Application and Analysis

Electrification Progress:

Year	Electrification Rate	Grid	Off-grid
2009	23%	18%	5%
2015	56%	38%	18%
2020	71%	50%	21%
2022	75%	52%	23%

MTF Analysis (2022):

Tier 0: 25% (14 million people)

Tier 1-2: 30% (off-grid solar, basic access)

Tier 3+: 45% (grid and high-quality off-grid)

MEPI Trends:

Year	H (%)	A (%)	MEPI
2010	68%	52%	0.354
2015	48%	48%	0.230
2020	35%	45%	0.158

Key finding: Kenya reduced energy poverty faster than income poverty, demonstrating energy-specific interventions can outpace general development.

Policy Intervention Analysis

Kenya National Electrification Strategy (KNES) 2018:

Target: Universal access by 2026

Strategy: Grid extension for dense areas; mini-grids for peri-urban; SHS for remote rural

Innovative feature: Geospatial planning tool (OnSSET) optimizes technology selection by settlement density

Off-Grid Solar Ecosystem:

M-KOPA: 1 million+ SHS customers; $35/month PAYG; mobile money integration

Azuri Technologies: 200,000+ systems; AI-powered optimization

Sun King (Greenlight Planet): 300,000+ systems;

Focus on productive use (solar TVs, radios)

Critical Evaluation

Metric Insights:

Off-grid solutions can rapidly improve electrification rates but may plateau at Tier 2 (basic lighting, phone charging)

MEPI captures cooking deprivation missed by electrification focus

MTF Tier 3+ remains challenge even with high "access" rates

Policy Lessons:

Decentralized delivery works: Private sector + PAYG + mobile money = rapid scale

Quality standards essential: Prevent market spoilage from low-quality products

Integrated planning needed: Grid expansion plans must account for existing off-grid assets

Cooking requires separate strategy: Electrification doesn't automatically solve cooking poverty; integrated LPG/biogas programs needed

5.2.3 Regional Analysis: Sub-Saharan Africa Synthesis

Comparative Regional Assessment

Sub-Saharan Africa remains the global epicenter of energy poverty, with 600 million people lacking electricity access and 900 million without clean cooking solutions (WHO, 2024). The region's energy crisis is characterized by four structural features:

1. Demographic-Access Gap Divergence While electrification rates have improved from 33% (2010) to 52% (2022), absolute numbers without access have grown due to rapid population growth (2.5% annually). Rural areas face particular crisis: only 25% electrification vs. 78% urban, with rural populations growing 24.5 million annually while electrification reaches only 11.2 million yearly (World Bank, 2024).

2. Health System Energy Crisis In 2023, only 50% of hospitals and health centers in Sub-Saharan Africa had reliable electricity access (WHO, 2024). This creates catastrophic consequences:

Maternity wards where midwives work by mobile phone light

Vaccine refrigeration failures

Inability to operate medical equipment or store medicines safely

Emergency surgery conducted without adequate lighting

3. Gendered Energy Burden Women and girls bear disproportionate energy poverty impacts:

Time poverty: 2-20 hours weekly collecting fuelwood and water

Health burden: Primary exposure to indoor air pollution from cooking

Economic constraint: Limited time for education or income-generating activities

Educational impact: Girls' school attendance reduced due to domestic energy duties

4. Productive Use Deficit Energy poverty constrains economic development:

Micro, small and medium enterprises (MSMEs) cannot expand due to unreliable power

Agricultural processing limited by lack of mechanical energy

Business start-ups inhibited by high generator costs (where available)

Regional Metric Application

Country	Electrification Rate	MTF Tier 3+	MEPI	Primary Challenge
Nigeria	57%	29%	0.68	Grid reliability, cooking
Kenya	75%	45%	0.35	Cooking, Tier 3+ expansion
Ethiopia	45%	20%	0.72	Access expansion, cooking
Uganda	42%	18%	0.75	Access, reliability
Ghana	85%	60%	0.45	Quality, cooking transition
Senegal	70%	55%	0.40	Cooking, rural access

Policy Synthesis for Sub-Saharan Africa

Abandon binary electrification targets: Adopt MTF Tier 3+ as minimum standard

Integrate clean cooking: Electrification programs must include cooking energy (LPG, ethanol, improved biomass, induction where grid reliable)

Decentralized prioritization: Mini-grids and SHS for remote rural areas where grid extension uneconomical

Productive use integration: Energy programs must explicitly address agricultural processing, small industry

Gender mainstreaming: Target women in program design, address time poverty and health burdens

5.3 South Asia: India, Bangladesh, and Indonesia

5.3.1 India: The Saubhagya Scheme and Universal Electrification

Contextual Analysis

India represents the world's largest energy poverty reduction success story, achieving near-universal electrification through massive state-led intervention. However, the transition from access to service quality and clean cooking remains incomplete.

Socioeconomic Profile:

Population: 1.4 billion

GDP per capita: $2,400 (lower-middle-income)

Rural population: 65% (down from 75% in 2000)

Poverty rate: 10% (extreme poverty, World Bank)

Energy Sector Structure:

Generation: 400+ GW capacity; 40% renewable (solar, wind, hydro)

Grid: World's largest integrated grid; 99%+ household connectivity

Access: 99%+ electrification (urban and rural)

Cooking: 60% LPG penetration (PMUY scheme); 40% still using biomass

Metric Application and Analysis

Electrification Achievement:

Year	Electrification Rate	Rural	Urban
2010	76%	55%	94%
2015	88%	75%	97%
2017	82%	70%	96%
2020	99%+	99%	99%+

Saubhagya Scheme Impact Assessment (2017-2023):

A comprehensive 2024-2025 impact assessment by UCLA, UCSD, and RTI International surveyed 33,037 households to evaluate Saubhagya's socio-economic impacts (UCLA Institute of the Environment and Sustainability, 2025):

Key Findings:

Asset ownership surge: Significant increases in tube lights, bulbs, cellphones, fans, and aspirational appliances (TVs, refrigerators)

Service quality: 85% of households rated electricity supply as good, very good, or excellent; average outages <4 hours

Health improvements: Majority of households with pre-existing health problems reported improvement post-electrification (though attribution complicated by concurrent PMUY LPG cooking program)

Time reallocation: Households shifted time from domestic work/sustenance activities to employment, leisure, self-care, and education

Economic impact: Increased consumption spending on modern fuels, phones, groceries, education, health

MTF Analysis Post-Saubhagya:

Tier 3+: 80% of households (minimum modern energy services)

Tier 4+: 45% (reliable supply for appliances)

Tier 5+: 25% (high-quality supply for productive uses)

Challenge: 20% remain Tier 1-2 (suppressed demand, unreliable supply, or off-grid solar)

MEPI Trends:

Year	H (%)	A (%)	MEPI	Notes
2005	65%	55%	0.358	High deprivation
2012	45%	50%	0.225	Rapid improvement
2020	25%	45%	0.113	Saubhagya impact
2023	18%	42%	0.076	Quality challenges remain

Clean Cooking Crisis: Despite electrification success, cooking energy poverty persists:

2.3 billion people globally lack clean cooking; India hosts ~400 million

PMUY (Ujjwala) scheme distributed 90 million LPG connections (2016-2020)

Challenge: Refill rates low (many use LPG only for emergencies, biomass for daily cooking)

Updated MEPI cooking dimension: Still 35% deprivation due to indoor biomass use

Policy Intervention Analysis

Saubhagya Scheme (2017-2019):

Target: Universal household electrification

Mechanism: Free grid connections to poor households; metered connections for others

Innovation: Prepaid smart meters for remote monitoring; geospatial tracking

Cost: $2.5 billion

Achievement: 28 million households electrified; universal village electrification

Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY):

Focus: Rural feeder separation (agricultural vs. household supply)

Result: Reduced load shedding; 24-hour power to 95% rural households (theoretically)

UJALA Programme:

Focus: Energy-efficient appliances (LED bulbs, tube lights, fans)

Achievement: 47.8 billion kWh energy saved; 38.78 million tons CO_2 reduction annually (Bureau of Energy Efficiency, India, 2025)

PMUY (Ujjwala) for Cooking:

Target: Clean cooking for 80 million poor women

Achievement: 90 million LPG connections distributed

Challenge: Sustained LPG use requires behavioral change and affordable refills

Critical Evaluation

Metric Insights:

Binary rate success: 99%+ electrification demonstrates massive infrastructure achievement

MTF reveals quality gaps: Only 45% Tier 4+ indicates reliability and capacity constraints

MEPI shows multidimensional progress: Declining from 0.358 to 0.076, but cooking deprivation persists

Suppressed demand phenomenon: Many "connected" households consume <50 kWh/month due to affordability constraints

Policy Lessons:

State capacity matters: India's administrative capacity enabled massive, rapid roll-out

Grid extension works at scale: For dense rural populations, grid more cost-effective than off-grid

Connection ≠ consumption: Affordability constraints require targeted subsidies (lifeline tariffs)

Cooking requires separate strategy: Electrification doesn't automatically solve cooking poverty; integrated LPG/biogas programs needed

Quality maintenance critical: Grid expansion must be matched by generation capacity and distribution investment

Limitations and Ongoing Challenges:

Agricultural supply: Farmers still receive subsidized/free power leading to utility financial distress

Coal dependence: 55% of generation from coal creates environmental tension

Storage deficit: Renewable integration hampered by limited battery storage

Regional disparities: Northeastern states, tribal areas lag behind national averages

5.3.2 Bangladesh: IDCOL Solar Home Systems Program

Contextual Analysis

Bangladesh demonstrates that microfinance-based decentralized energy can achieve massive scale, with the Infrastructure Development Company Limited (IDCOL) implementing the world's largest off-grid solar program.

Socioeconomic Profile:

Population: 170 million (high density: 1,200 people/km^2)

GDP per capita: $2,700

Rural population: 60%

Poverty rate: 20% (declining from 40% in 2005)

Energy Sector Structure:

Generation: 25 GW capacity; 95% domestic natural gas (declining reserves)

Grid: Limited coverage; load shedding common

Off-grid: 6 million+ Solar Home Systems (SHS) installed; 20% of rural electrification

Renewable target: 10% by 2025 (solar, wind, biogas)

Metric Application and Analysis

IDCOL SHS Program (2003-2018):

Period	SHS Installed	Cumulative	Average System Size	Cost
2003-2010	1 million	1 million	20-50W	$200-400
2010-2015	3 million	4 million	50-100W	$300-600
2015-2018	2 million	6 million	100W+	$400-800

MTF Impact:

Pre-program (2000): Rural electrification 25%; most households Tier 0

Post-program (2018): Rural electrification 75%; SHS contributed 20 percentage points

SHS households typically achieve Tier 2 (lighting, phone charging, radio/TV)

Grid-connected households: Tier 3-4 (but reliability issues)

MEPI Analysis:

Period	H (%)	A (%)	MEPI	Primary Deprivation
2000	85%	60%	0.510	Cooking, lighting, appliances
2010	65%	55%	0.358	Cooking, appliances
2018	45%	50%	0.225	Cooking, digital access

Economic Impact:

Kerosene displacement: 400 million liters/year kerosene replaced

Cost savings: $2-5/month per household on fuel costs

Carbon finance: 1.5 million tons CO_2 reduced annually; sold via CDM and voluntary markets

Employment: 100,000+ jobs in solar supply chain (sales, installation, maintenance)

Policy Intervention Analysis

IDCOL Program Design:

Financing: Microfinance loans (3-year terms, 6% interest)

Quality standards: Technical specifications for panels, batteries, lights

Private sector: 50+ partner organizations (NGOs, MFIs) for last-mile delivery

Subsidy: $25-50 per system from carbon credits and government

Grid Expansion Threat:

As grid reaches rural areas, SHS face stranded asset risk

IDCOL pivoting to solar irrigation pumps (1 million target) and mini-grids

Policy challenge: How to integrate existing SHS into expanding grid?

Solar Irrigation Pump Program:

150,000+ pumps installed (world's largest solar pumping program)

Replaces diesel pumps; reduces irrigation costs by 50%

Enables dry-season cropping; increases farmer incomes 20-30%

Critical Evaluation

Metric Insights:

SHS excel at rapid access expansion (Tier 1-2) but limited in achieving Tier 3+

MEPI shows cooking remains primary deprivation despite lighting improvements

Economic impacts (kerosene savings, employment) significant even with modest MTF tiers

Policy Lessons:

Microfinance + standards = scale: Quality control prevents market spoilage; microfinance enables affordability

Carbon finance viability: CDM and voluntary markets provided critical subsidy bridge

Grid integration planning needed: Off-grid programs must anticipate grid arrival

Productive use pivot: Transition from household lighting to agricultural/industrial applications sustains sector

Bangladesh-India Comparison:

Dimension	Bangladesh	India
Primary Strategy	Off-grid SHS	Grid extension
Rural Electrification Rate	75%	99%
MTF Tier 3+ (Rural)	40%	65%
Cooking Poverty	85%	40%
Cost per Connection	$300 (SHS)	$150 (grid)
Reliability	Moderate (SHS)	Improving (grid)

Insight: Different strategies appropriate for different contexts. Bangladesh's density and grid limitations made SHS optimal; India's scale and state capacity enabled grid extension. Both face cooking poverty challenge.

5.3.3 Indonesia: Transition to Service Quality and Digital Inclusion

Contextual Analysis

Indonesia exemplifies middle-income country energy poverty: near-universal electrification but persistent multidimensional deprivation in cooking, appliances, and digital access. The 2024-2025 MEPI updates were partly developed and tested using Indonesian data (Guevara et al., 2025; Research Synergy Press, 2025).

Socioeconomic Profile:

Population: 275 million (world's 4th largest)

GDP per capita: $4,800 (upper-middle-income)

Urbanization: 57%

Poverty rate: 9.5% (national line); energy poverty persists beyond income poverty

Energy Sector Structure:

Generation: 80 GW capacity; 85% coal (energy security priority)

Electrification: 99%+ (PLN state utility achieved universal access 2020)

Cooking: 84% LPG (subsidized), 10% biomass, 6% other

Renewable: 12% (geothermal, hydro, solar target 23% by 2025)

Metric Application and Analysis

Updated MEPI Application (SUSENAS 2021-2023):

Research applying updated MEPI to Yogyakarta Province (representative of Java's development level) reveals Indonesia's energy poverty evolution (Research Synergy Press, 2025):

Year	H (%)	A (%)	MEPI	Primary Contributors
2021	19.8%	44.0%	0.087	Cooking (40%), Communication (25%), Appliances (20%)
2022	17.2%	44.0%	0.076	Cooking (35%), Communication (30%), Appliances (20%)
2023	14.4%	44.0%	0.063	Communication (50%+), Cooking (30%), Appliances (15%)

Key Findings:

Declining incidence, stable intensity: Fewer households energy poor, but those remaining face 55-60% of possible deprivations

Digital deprivation rising: Communication deprivation increased to >50% by 2023, becoming single largest contributor

Cooking persistence: Clean cooking deprivation remains 30% contributor despite 84% LPG penetration (indicating sustained biomass use alongside LPG)

Electricity universal: Lighting deprivation near zero; "access" no longer the issue

Geographic Disparities:

Region (Yogyakarta)	MEPI 2023	Primary Deprivation
Gunung Kidul (rural)	0.125	Cooking (60%), Communication (30%)
Kulon Progo (rural)	0.095	Cooking (50%), Appliances (25%)
Bantul (peri-urban)	0.045	Communication (60%), Appliances (20%)
Yogyakarta City (urban)	0.025	Communication (40%), Appliances (30%)

Policy Intervention Analysis

LPG Subsidy Program:

Scale: IDR 80.2 trillion ($5.14 billion) in 2024—largest energy subsidy (IISD, 2025)

Coverage: Universal (3kg cylinder subsidy intended for poor but used by all income deciles)

Challenge: Regressive (wealthy households capture more subsidy due to higher consumption); import dependency (6 million tonnes imported vs. 2 million domestic production)

Clean Cooking Transition Options (2024-2025 Analysis): Research by IISD evaluated alternatives to LPG (IISD, 2025):

Induction stoves: Most viable for on-grid households; cheaper than unsubsidized LPG; enables renewable integration

DME (Dimethyl Ether): Drop-in LPG replacement from coal/biomass; limited infrastructure

City gas (piped natural gas): Urban areas only; high infrastructure cost

Recommendation: Targeted induction subsidies for wealthy households (swapping LPG subsidy), maintaining LPG support for poor; potential government savings IDR 7.6-11.9 trillion annually (IISD, 2025)

Critical Evaluation

Metric Insights:

Updated MEPI reveals digital energy poverty as emerging crisis: smartphone penetration 69% global, but energy for charging, data costs, and internet access create new deprivation dimension

Indoor pollution location: Refined cooking indicator shows outdoor biomass cooking reduces pollution exposure, suggesting behavior matters as much as fuel type

Appliance expansion: Washing machines and fans included in updated MEPI reflect middle-income service expectations

Policy Lessons:

Beyond connections: Universal electrification achieved; policy must shift to service quality, affordability, and productive use

Subsidy reform urgency: Universal LPG subsidies fiscally unsustainable and regressive; targeted support needed

Digital inclusion: Energy policy must address digital divide (charging infrastructure, affordable data, device access)

Just transition: Cooking transition from LPG to electric/induction requires careful management to avoid burdening poor households

Indonesia's Regional Significance: As Southeast Asia's largest economy, Indonesia's energy poverty transition path influences regional policy. The shift from "access" to "quality and digital inclusion" foreshadows challenges for other middle-income countries (Vietnam, Philippines, Thailand).

5.4 Latin America: Colombia and Regional Trends

5.4.1 Colombia: Persistent Disparities in Upper-Middle-Income Context

Contextual Analysis

Colombia demonstrates that energy poverty persists even in upper-middle-income countries with high electrification rates, manifesting as quality deficits, affordability challenges, and regional disparities linked to conflict history.

Socioeconomic Profile:

Population: 52 million

GDP per capita: $6,600 (upper-middle-income)

Urbanization: 77%

Poverty rate: 39% (multidimensional poverty); 12% income poverty

Energy Sector Structure:

Generation: 18 GW capacity; 70% hydro (vulnerable to drought); 20% thermal; 10% renewable

Electrification: 98% national; 100% urban, 93% rural

Cooking: 85% LPG/natural gas; 15% biomass (rural, indigenous areas)

Regional disparity: Post-conflict regions (former FARC territories) lag in infrastructure

Metric Application and Analysis

Multi-Tier Framework:

Tier 5-6: 60% (urban centers)

Tier 3-4: 30% (small cities, stable rural areas)

Tier 1-2: 8% (remote rural, indigenous territories, former conflict zones)

Tier 0: 2% (isolated settlements)

MEPI Analysis:

Region	MEPI	Primary Deprivation
Bogotá (capital)	0.05	None significant
Medellín	0.08	Minor affordability
Coffee Region	0.15	Appliance access
Pacific Coast (Afro-Colombian)	0.35	Cooking, reliability
Amazon (indigenous)	0.45	Access, cooking, appliances
Former FARC territories	0.40	Access, quality, affordability

Affordability Crisis: Despite high electrification, energy expenditure share reveals affordability stress:

National average: 4% of income

Poor households: 12-15% of income

Pacific Coast: 15-20% due to diesel generation dependence

Policy Intervention Analysis

Peace Process Energy Component (2016-):

Investment: $500 million for energy infrastructure in post-conflict territories

Approach: Mini-grids and solar systems for remote areas

Challenge: Security risks, land tenure disputes, limited state presence

Non-Conventional Renewable Energy (ZNI) Program:

Target: 100% renewable mini-grids for isolated zones (Zonas No Interconectadas)

Progress: 15% of isolated systems renewable (solar, wind, biomass)

Innovation: Hybrid systems reducing diesel dependence

Critical Evaluation

Metric Insights:

Binary rate misleading: 98% electrification obscures 35% MEPI in marginalized regions

Conflict-energy nexus: Energy poverty concentrated in former conflict zones, perpetuating underdevelopment

Affordability invisible to access metrics: High electrification + high costs = suppressed consumption

Policy Lessons:

Peace-building through energy: Electrification as component of territorial consolidation

Renewable mini-grids: Cost-effective for isolated regions; reduce fossil fuel import dependence

Social tariffs: Targeted subsidies for poor households (existing but implementation gaps)

Ethnic disparities: Indigenous and Afro-Colombian communities require culturally appropriate energy solutions

5.4.2 Latin American Regional Synthesis

Regional Energy Poverty Profile:

Electrification: 97% average (highest of developing regions)

Quality: Significant reliability issues in Central America, Caribbean

Cooking: 85% clean cooking (LPG dominant); biomass persists in rural Guatemala, Honduras, Bolivia

Affordability: Energy poverty manifests as expenditure burden rather than access deficit

Key Distinctions from Other Regions:

Urban bias less severe: Higher urbanization reduces rural access gaps

LPG transition success: Most countries achieved clean cooking through LPG subsidies

Renewable potential: Abundant hydro, solar, wind resources

Inequality driver: Energy poverty correlates with income inequality (Gini coefficients 0.45-0.55)

5.5 Developed Economies: European Union and Poland

5.5.1 European Union: Fuel Poverty and the Just Transition

Contextual Analysis

The EU presents a fundamentally different energy poverty profile: universal electrification but significant affordability and thermal comfort challenges affecting 35-72 million people (8-16% of population) (Noel, 2025; EAPN, 2023).

Socioeconomic Profile:

Population: 450 million

GDP per capita: $38,000 (high-income)

Electrification: 100%

Energy poverty: 10.6% unable to keep home warm (2023, up from 6.9% in 2021) (Noel, 2025)

Energy Poverty Definition (EU 2024): "Lack of access to affordable, reliable, and sustainable energy services, which affects households' ability to meet their basic energy needs, exacerbating existing inequalities and disproportionately affecting vulnerable groups such as low-income households, the elderly, and those in rural or disadvantaged areas" (Climate Alliance, 2025).

Metric Application and Analysis

Traditional Metrics (Binary): 100% electrification—useless for policy

Affordability Metrics:

Indicator	2021	2022	2023	Trend
Unable to keep warm	6.9%	9.3%	10.6%	↑ Worsening
Arrears on bills	6.0%	7.0%	6.9%	→ Stable
Poor housing conditions	14.0%	15.0%	15.0%	→ Stable

Country Variation (2024):

Country	Energy Poverty Rate	Primary Issue
Bulgaria	30%	Heating, building efficiency
Lithuania	30%	Heating, income
Greece	30%	Cooling/heating, arrears
Portugal	30%	Arrears, building stock
Netherlands	10%	Moderate issue
Sweden	20%	High costs, efficiency
Germany	15%	Moderate, rising

LIHC Application:

Low Income: Below 60% median income after housing costs

High Costs: Energy expenditure above national median

EU average: 8-10% of households meet both criteria

Policy Intervention Analysis (2024-2025 Framework)

The EU has implemented comprehensive energy poverty legislation through four interconnected directives (Climate Alliance, 2025; BUILD UP, 2025):

1. Energy Efficiency Directive (EED) Recast:

Article 8(3): Minimum share of energy savings among low-income/energy-poor households

Article 22(3a): One-stop shops for renovation support

Article 24: Prioritization of vulnerable groups in efficiency policies

2. Energy Performance of Buildings Directive (EPBD) Recast:

Article 3: Mandatory quantification of energy poverty in National Building Renovation Plans

Article 9(4a): Prioritization of worst-performing buildings (often occupied by poor)

Article 17(18): Financial incentives targeted at vulnerable households

Article 17(17)-(19): Protection from eviction due to renovation-related rent increases

3. Social Climate Fund (SCF):

Funding: €65 billion (2025-2032), potentially €144 billion with Member State matching (European Commission, 2024)

Target: Vulnerable households affected by ETS2 (Emissions Trading System for buildings/transport)

Measures: Direct income support, building renovation, zero-emission mobility

4. Electricity Market Design Reform:

Article 27a: Supplier of last resort guarantee

Article 28a: Disconnection bans for vulnerable customers during extreme weather

Article 28a: Early intervention mechanisms (debt management, payment plans)

Critical Evaluation

Metric Insights:

Binary rate useless: 100% electrification requires entirely different metric framework

Affordability central: Energy expenditure share and thermal comfort primary indicators

Building efficiency crucial: Poor housing stock (worst-performing buildings) drives energy poverty

Dynamic measurement needed: Energy poverty worsened 2021-2023 due to price crisis; metrics must capture volatility

Policy Lessons:

Renovation wave: Building efficiency improvements reduce energy needs and costs

Social safeguards essential: Renovation must not displace poor tenants through rent increases

Targeted subsidies: Universal subsidies regressive; need means-tested support

One-stop shops: Integrated advice, financing, and technical assistance improve uptake

Disconnection bans: Protect vulnerable households during crises

Challenge: Scale of Investment

€65 billion SCF vs. estimated €300+ billion needed for comprehensive renovation

Member State implementation varies; some lack capacity to deploy funds effectively

5.5.2 Poland: Post-Communist Heating Poverty

Contextual Analysis

Poland represents Central and Eastern Europe's energy poverty challenges: inefficient post-communist building stock, coal dependence, and heating poverty in cold climate (Energy Poverty Observatory, 2025; FRA, 2024).

Socioeconomic Profile:

Population: 38 million

GDP per capita: $18,000 (high-income, but regional disparities)

Energy poverty: 12-15% (various definitions)

Energy Sector Structure:

Generation: 40 GW; 70% coal (highest EU coal dependence)

Heating: District heating (legacy systems, inefficient); individual coal stoves (rural)

Building stock: 4 million multi-family buildings (70% pre-1990, poor efficiency)

Renovation rate: 1% annually (insufficient for 2050 targets)

Metric Application and Analysis

Thermal Comfort Indicators:

Inability to keep warm: 15% of households (vs. 10.6% EU average)

Heating expenditure share: 15-20% for poor households (vs. 5-8% EU Western average)

Indoor temperature: <18°C in 20% of poor households during winter

CEESEN-BENDER Project Analysis: EU-funded project examining Soviet-era multi-apartment buildings in Poland, Croatia, Slovenia, Estonia, Romania (BUILD UP, 2025):

Energy intensity: 200-300 kWh/m²/year (vs. 50-100 in new buildings)

Renovation barriers: Split incentives (landlords/tenants), financing gaps, governance challenges

Social impact: Respiratory diseases, excess winter mortality, energy arrears

Policy Intervention Analysis

Clean Air Programme:

Target: Eliminate coal stoves in households

Mechanism: Subsidies for heat pumps, gas connections, building efficiency

Progress: 1 million+ coal stoves replaced (2020-2024)

Social Tariff:

Mechanism: Reduced electricity rates for vulnerable households

Eligibility: Means-tested; ~2 million households

Challenge: Fiscal cost; targeting accuracy

Renovation Support:

Thermo-modernization: 30% grants for building efficiency improvements

One-stop shops: 16 regional energy agencies providing advice and financing access

Challenge: Limited uptake among poorest (upfront costs, complexity)

Energy Voucher (2024):

New instrument: Mid-2024 introduction under Act of 23 May 2024

Purpose: Mitigate rising electricity prices for households at risk of energy poverty

Expansion: Higher income thresholds than previous protective allowance (FRA, 2024)

Critical Evaluation

Metric Insights:

Heating poverty distinct: Cold climate creates unique energy poverty profile (heating vs. cooling)

Building efficiency central: Poor building stock drives high energy needs regardless of income

Air quality co-benefits: Coal heating elimination reduces outdoor air pollution (health, climate)

Policy Lessons:

Coal transition management: Just transition required for coal-dependent regions and households

Heat pump deployment: Efficient heating technology but high upfront costs; subsidies essential

District heating modernization: Legacy systems need efficiency upgrades, renewable integration

Split incentive solutions: Policies must align landlord/tenant interests for rental housing renovation

5.6 Cross-Case Comparative Analysis

5.6.1 Metric Performance Comparison

Dimension	Nigeria	Kenya	India	Bangladesh	Indonesia	Colombia	Poland	EU Average
Primary Metric	MTF	MTF/MEPI	MTF/MEPI	MEPI	Updated MEPI	MEPI	LIHC/10%	LIHC
Electrification	57%	75%	99%	85%	99%	98%	100%	100%
MTF Tier 3+	29%	45%	80%	40%	85%	90%	100%	100%
MEPI	0.68	0.35	0.076	0.225	0.063	0.15	N/A	N/A
Cooking Poverty	80%	90%	40%	85%	16%	15%	0%	0%
Key Challenge	Access/Quality	Quality/Cooking	Cooking/Quality	Cooking	Digital/Affordability	Affordability/Regional	Heating/Buildings	Affordability/Buildings

5.6.2 Pattern Analysis

Pattern 1: Metric Sophistication Increases with Development Level

Low-income countries: Binary rate + MTF tiers

Lower-middle-income: MTF + original MEPI

Upper-middle-income: Updated MEPI (digital, appliances)

High-income: Affordability metrics + building efficiency

Pattern 2: Cooking Poverty Persistence Despite electrification progress, clean cooking access lags:

Sub-Saharan Africa: 80-90% cooking poverty

South Asia: 40-85% cooking poverty

Latin America: 15% cooking poverty (LPG success)

Developed economies: Near-zero cooking poverty

Pattern 3: Quality vs. Access Divergence Countries with >90% electrification show wide variation in MTF Tier 3+:

India: 99% electrification, 80% Tier 3+ (20% quality deficit)

Indonesia: 99% electrification, 85% Tier 3+ (15% quality deficit)

Colombia: 98% electrification, 90% Tier 3+ (8% quality deficit)

Pattern 4: Digital Divide Emergence Updated MEPI reveals digital energy poverty as significant in middle-income countries:

Indonesia: 50%+ communication deprivation by 2023

India: 30% digital deprivation (estimated)

Bangladesh: 40% digital deprivation (estimated)

5.6.3 Metric-Policy Alignment Assessment

Metric	Best Aligned Policies	Misalignment Risks
Binary Electrification Rate	Grid extension, connection subsidies	Quality neglect, off-grid exclusion, cooking omission
MTF	Technology selection, quality standards, subsidy targeting	Data intensity, complexity for policymakers
Original MEPI	Multidimensional poverty reduction, SDG tracking	Asset ownership focus, no reliability/quality
Updated MEPI	Digital inclusion, appliance programs, clean cooking	Very recent, limited validation, data requirements
LIHC/10% Rule	Social tariffs, bill assistance, efficiency programs	Ignores non-monetary deprivation, threshold arbitrariness

5.7 Policy Implications and Recommendations

5.7.1 Metric Selection Guidelines by Country Type

Type A: Low-Access Countries (Sub-Saharan Africa, Afghanistan, Haiti)

Primary Metric: MTF Tier 3+ (minimum modern energy services)

Secondary Metrics: Electrification rate (tracking), cooking access rate

Rationale: Binary rate insufficient; MTF guides technology choice (grid vs. off-grid)

Implementation: Invest in MTF survey capacity; integrate into national statistics

Type B: Transition Countries (India, Bangladesh, Indonesia, Philippines)

Primary Metric: Updated MEPI (cooking, appliances, digital)

Secondary Metrics: MTF for quality monitoring, affordability indicators

Rationale: Access largely solved; multidimensional deprivation in cooking, digital, productive use

Implementation: Adapt MEPI indicators to local appliance/digital contexts; subnational disaggregation

Type C: Affordability-Challenge Countries (Latin America, Eastern Europe)

Primary Metric: Energy expenditure share + thermal comfort

Secondary Metrics: MEPI for regional disparities, building efficiency ratings

Rationale: Universal access but affordability and quality constraints

Implementation: Targeted subsidies, social tariffs, building renovation programs

Type D: Developed Economies (EU, North America, East Asia)

Primary Metric: LIHC or equivalent + building efficiency

Secondary Metrics: Thermal comfort, arrears, health outcomes

Rationale: Energy poverty = affordability + building quality, not access

Implementation: Integrated housing/energy policies; just transition frameworks

5.7.2 Universal Recommendations

1. Abandon Binary Electrification as Primary Metric Binary rates obscure quality deficits and cooking poverty. All countries should transition to MTF or multidimensional metrics for policy purposes (World Bank, 2024).

2. Integrate Cooking Energy into All Energy Poverty Frameworks Electrification programs must explicitly address cooking energy (LPG, biogas, ethanol, induction). Separate "electricity" and "cooking" silos perpetuate multidimensional poverty (WHO, 2024).

3. Prioritize Tier 3+ as Minimum Standard MTF Tier 3 (50W+, 4+ hours, evening supply, affordable) should replace "electrification" as SDG 7 operational target. Tier 1-2 insufficient for modern human development (World Bank, 2015).

4. Adopt Updated MEPI for Middle-Income Countries Digital access, appliance ownership, and refined cooking indicators capture evolving energy poverty. Original MEPI underestimates deprivation in contexts with near-universal electrification (Guevara et al., 2025).

5. Implement Dynamic Measurement Annual or biennial high-frequency surveys (vs. 5-year DHS cycles) enable responsive policy. Mobile phone surveys, smart meter data, and satellite imagery complement traditional surveys (Kleinman Center for Energy Policy, 2026).

6. Gender-Mainstream All Metrics All energy poverty metrics should be sex-disaggregated and include gender-specific indicators (female time use, female-headed household deprivation, women's decision-making participation) (Clancy et al., 2017).

7. Subnational Disaggregation National averages mask extreme disparities. Metrics must be calculable at subnational (district, municipal) levels for targeted intervention.

8. Metric-Policy Integration Metrics should directly inform policy design:

MTF tiers → Technology selection (grid extension, mini-grid, SHS)

MEPI dimensions → Program targeting (cooking program, appliance subsidies, digital infrastructure)

Affordability metrics → Social protection design

5.7.3 Research and Data Priorities

Immediate (2025-2026):

Validate updated MEPI in diverse contexts (Africa, Asia, Latin America)

Develop cooling poverty metrics for tropical regions

Standardize digital energy poverty measurement

Medium-term (2026-2030):

Integrate machine learning for predictive energy poverty mapping

Develop productive use energy poverty metrics

Create integrated climate-energy poverty indices

Long-term (2030+):

Real-time energy poverty monitoring via smart infrastructure

Global standardized energy poverty database (analogous to World Bank poverty data)

Causal impact evaluation of metric-informed interventions

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APPENDICES

Appendix A: Detailed MEPI Calculation Methodology

A.1 Original MEPI (2012)

Dimensions and Weights:

Cooking (0.20): Cooking fuel type

Lighting (0.20): Electricity access

Household appliances (0.20): Refrigerator ownership (0.20)

Entertainment/education (0.20): Radio (0.10) + TV (0.10)

Communication (0.20): Telephone ownership

Deprivation Cutoffs:

Cooking: Solid fuel (wood, charcoal, dung, coal) = deprived

Lighting: No electricity = deprived

Appliances: No refrigerator = deprived

Entertainment: Neither radio nor TV = deprived

Communication: No telephone (mobile or fixed) = deprived

Calculation Example: Household using solid fuel (0.20), no electricity (0.20), no refrigerator (0.20), has radio but no TV (0.10), has mobile phone (0): $c_i=0.20+0.20+0.20+0.10+0=0.70$ With $k=0.30$, this household is energy poor ($0.70 > 0.30$).

A.2 Updated MEPI (2024-2025)

Revised Dimensions and Weights:

Cooking (0.20): Unclean fuel used indoors = deprived

Lighting (0.20):

Electricity access (0.10): No electricity = deprived

Indoor pollution from lighting (0.10): Kerosene/candles used indoors = deprived

Appliances (0.20):

Refrigerator (0.067): No refrigerator = deprived

Washing machine (0.067): No washing machine = deprived

Air cooler/fan (0.067): No cooling appliance = deprived

Entertainment/Communication (0.20):

Basic communication (0.10): No mobile/landline = deprived

Digital access (0.10): No internet access (via any device) = deprived

Entertainment (0.20): No TV or radio = deprived

Climate Adaptation:

Cooling/heating appliance indicators adjusted based on geographical climate zones (Cooling Degree Days/Heating Degree Days)

Appendix B: Multi-Tier Framework Technical Specifications

B.1 Attribute Definitions

Capacity: Maximum power that can be drawn by household (Watts) Duration: Hours of electricity supply per day Evening Supply: Availability during 6pm-12am (critical for lighting, study, social activities) Affordability: Cost of 365 kWh/year < 5% of household income (or context-specific threshold) Quality: Voltage stability, frequency stability, waveform quality Legality: Formal connection with utility/operator (vs. illegal connections) Health & Safety: No accidents, proper wiring, safe installation

B.2 Technology Mapping

Technology	Typical Tier	Capacity Range	Duration	Evening	Key Limitations
Solar lantern	1	1-3W	Limited	No	Minimal services
SHS (20W)	2	20W	4-6 hrs	Yes	Limited appliances
SHS (50W)	3	50W	4-8 hrs	Yes	No refrigeration
Mini-grid diesel	3-4	200W	4-12 hrs	Yes	Fuel cost, pollution

Mini-grid solar	4-5	200W-1kW	8-16 hrs	Yes	Weather dependent
Weak grid	2-3	Variable	4-8 hrs	Intermittent	Unreliable
Strong grid	5-6	>2kW	22+ hrs	Yes	Connection cost

Appendix C: Case Study Data Sources

C.1 Nigeria

DHS 2018 (primary MEPI source)

MTF survey 2020 (World Bank/ESMAP)

NERC annual reports (2018-2024)

REA project databases

C.2 Kenya

DHS 2014, 2022

Kenya National Bureau of Statistics Economic Surveys

GOGLA market data (off-grid solar)

KNES implementation reports

C.3 India

DHS 2015-16, 2019-21

Saubhagya impact assessment (UCLA/RTI 2024-2025)

National Sample Survey (NSS) 2017-18, 2022-23

Ministry of Power administrative data

C.4 Bangladesh

DHS 2011, 2014, 2017-18

IDCOL annual reports (2003-2024)

World Bank survey data

MICS 2019

C.5 Indonesia

SUSENAS (National Socioeconomic Survey) 2021, 2022, 2023

DHS 2017, 2022

PLN (state utility) annual reports

IISD cooking transition study (2024-2025)

C.6 Colombia

DHS 2015, 2020

National Energy Planning Unit (UPME) reports

Ministry of Energy databases

Peace process energy component evaluations

C.7 Poland

EU-SILC (European Union Statistics on Income and Living Conditions) 2015-2024

Household Budget Survey (HBS)

CEESEN-BENDER project data (2023-2025)

National Energy Conservation Agency (KAPE) reports

C.8 European Union

EU Energy Poverty Observatory (EPOV) database

EU-SILC 2015-2024

Eurostat energy statistics

EPAH (Energy Poverty Advisory Hub) reports

National Energy and Climate Plans (NECPs) 2021-2025

Appendix D: Glossary of Terms

Capability Approach: Development theory focusing on substantive freedoms people enjoy to lead lives they value; applied to energy as "energy-enabled capabilities."

Clean Cooking: Use of non-solid fuels (LPG, natural gas, biogas, ethanol, electricity) or advanced biomass stoves meeting ISO standards for emissions and efficiency.

Cooling Poverty: Inability to maintain safe indoor temperatures during heat periods due to lack of cooling equipment or energy access.

Digital Energy Poverty: Deprivation in digital connectivity due to insufficient energy for device charging, internet access, or related services.

Energy Development Index (EDI): IEA composite index tracking commercial energy consumption, residential electricity consumption, and electrification rates.

Energy Justice: Framework with three tenets: distributional justice (fair distribution), procedural justice (inclusive participation), recognition justice (acknowledgment of diverse needs).

Energy Poverty: Inability to access affordable, reliable, and modern energy services necessary for human development and well-being.

Fuel Poverty: Term used primarily in developed economies for inability to afford adequate heating/cooling due to high energy costs, low income, and/or poor building efficiency.

Headcount Ratio (H): Proportion of population identified as energy poor.

Intensity (A): Average deprivation score among energy-poor population.

Low Income High Cost (LIHC): Energy poverty indicator identifying households with energy costs above median and residual income below poverty line.

MEPI (Multidimensional Energy Poverty Index): Composite index measuring deprivation across cooking, lighting, appliances, entertainment, and communication dimensions.

Mini-grid: Localized electricity generation and distribution system serving multiple customers (typically 10-10,000), isolated from national grid.

MTF (Multi-Tier Framework): World Bank framework measuring electricity access across 6 tiers based on capacity, duration, reliability, affordability, quality, legality.

Multi-Tier Framework (MTF): See MTF.

Off-grid Solar: Standalone photovoltaic systems (solar home systems, lanterns) not connected to central grid.

PAYG (Pay-as-you-go): Financing model enabling poor households to purchase solar systems through small mobile money payments over time.

Productive Use of Energy: Energy for income-generating activities including agricultural processing, small industry, commercial services.

SDG 7: Sustainable Development Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all by 2030.

SHS (Solar Home System): Standalone photovoltaic system providing electricity to individual households, typically 20-200W capacity.

Suppressed Demand: Energy consumption below actual needs due to affordability constraints, even with physical access.

Thermal Comfort: Ability to maintain indoor temperatures within healthy, comfortable range (typically 18-26°C depending on climate).

Tier 3+: MTF Tier 3 or higher, considered minimum for "modern energy services" (50W+, 4+ hours daily, evening availability, affordable).