Journal of Technology and Policy in Energy and Electric Power
Volume 2, Number 1, December 2025, E-ISSN 3090-1650
https://doi.org/10.33322/jtpeep.v2i1/173

Research Article

Improving the Interpretation of Electricity Access in Indonesia Through the Multi-Tier Framework Access Index

Luddie Wied Hardono[1], Jonathan Martin Marojahan[1*], Surya Ibrahim[1]
[1] PT PLN (Persero)
***Email:** jonathan.martin@pln.co.id

CITATION
Jonathan Martin Marojahan. (2025). Improving the Interpretation of Electricity Access in Indonesia Through the Multi-Tier Framework Access Index.
Journal of Technology and Policy in Energy and Electric Power. 2:1
https://doi.org/10.33322/jtpeep.v2i1

ARTICLE INFO
Received December 12, 2025
Accepted December 22, 2025
Available online December 30, 2025

Abstract: Indonesia's national electrification ratio has long relied on a binary classification—whether or not a household is connected to an electricity source. While this metric is valuable for monitoring progress in expanding grid coverage, it does not fully reflect the quality and usability of electricity services delivered to communities. Important aspects such as reliability, power capacity, affordability, and the adequacy of electricity for household, productivity, and community activities remain unaccounted for. To complement this traditional indicator, this study applies the Multi-Tier Framework (MTF) developed by ESMAP–World Bank as an enhanced assessment tool. Rather than replacing the Electrification Ratio, the MTF provides additional layers of insight by evaluating seven dimensions of household electricity access, along with extended attributes for productive uses and community infrastructure. Field assessments were carried out in various on-grid and off-grid areas across Indonesia, including locations utilizing SuperSUN systems and villages supplied through the national grid. Findings reveal that although all surveyed locations are officially classified as "electrified," their actual service levels differ substantially—especially in power capacity, affordability, and reliability. These variations demonstrate the value of integrating MTF-based analysis alongside the national electrification ratio to generate a more holistic, quality-focused understanding of energy access. Furthermore, the MTF framework offers a structured approach for identifying areas requiring improvement, enabling PLN and other stakeholders to design interventions that are more targeted, equitable, and aligned with the real experiences of communities across Indonesia.

Keywords: electricity access, electrification ratio, Multi-Tier Framework (MTF), energy quality, affordability, power capacity, reliability, household energy access, productive uses, community infrastructure, Indonesia, SuperSUN, on-grid electrification, off-grid systems, energy assessment

1. Introduction

1.1. Background

Access to energy plays a fundamental role in enabling economic, social, and human development. For this access to be genuinely beneficial—whether for households, productive activities, or community services, the supporting energy supply must meet several essential criteria. It must provide sufficient capacity, be available at the time it is needed, maintain acceptable quality, and offer reliability, convenience, and affordability. Moreover, it should be delivered through legal means and in ways

Journal of Technology and Policy in Energy and Electric Power
Volume 2, Number 1, December 2025, E-ISSN 3090-1650
https://doi.org/10.33322/jtpeep.v2i1/173

that safeguard health and safety.

When these attributes are present, energy access becomes transformative. It eases physical burdens, improves comfort, enables communication technologies, and supports education and healthcare services, while also extending the productive hours of daily life. It can significantly reduce time spent collecting traditional fuels—benefiting women and girls in particular—and mitigate the adverse health impacts associated with polluting cooking practices.

Reliable and high-quality energy supply also drives productivity and economic growth, opening pathways for job creation and increased household incomes. It strengthens the provision of public services such as education, health, and digital governance, and contributes to improved safety within communities. These broader benefits align closely with the objectives of SDG 7.1, which calls for access to energy services.[1]

Indonesia has long relied on a binary metric to report its national electrification ratio—classifying households simply as either connected or not connected to an electricity source. Although this indicator provides a clear snapshot of network expansion, it fails to reflect the actual quality of electricity services experienced by end users. Important dimensions such as reliability of supply, available power capacity, affordability, and the sufficiency of electricity for both household needs and productive uses remain unaccounted for in this traditional measurement approach.

1.2. Overview of the Multi-Tier Framework (MTF)

The Multi-Tier Framework (MTF), developed by the World Bank's Energy Sector Management Assistance Program (ESMAP)[2], serves as a complementary tool to traditional electrification indicators by offering a deeper and more detailed perspective on electricity access. While the Electrification Ratio identifies whether households are connected to a power source, the MTF goes further by describing the *quality and usability* of that access through a spectrum of service levels defined by multiple technical and socio-economic dimensions.

The Multi-Tier Framework (MTF) evaluates electricity access across several key dimensions: **capacity**, **availability**, **reliability**, **quality**, **affordability**, **legality**, and **health &**

[1] United Nations Department of Economic and Social Affairs (2025). The Sustainable Development Goals Report 2025. New York.

[2] Bhatia, Mikul; Angelou, Niki. 2015. ***Beyond Connections: Energy Access Redefined***. ESMAP Technical Report; 008/15. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/24368

Volume 2, Number 1, December 2025, E-ISSN 3090-1650
https://doi.org/10.33322/jtpeep.v2i1/173

safety. Each dimension is rated on a scale from Tier 0 (no access) to Tier 5 (the highest level of service), providing a detailed and nuanced picture of the conditions experienced by end users—**hence the term *"multi-tier."*** This tiered structure not only measures the presence of electricity but also examines whether the supply is adequate for essential appliances, consistently available throughout the day, stable in voltage, affordable relative to household income, and delivered through safe and legally recognized connections.

By converting these dimensions into a measurable **Access Index**, the MTF equips policymakers, utilities, and development practitioners with a richer picture of electricity service conditions. It reveals quality gaps that may remain even in regions with high electrification ratios and provides insights that support targeted improvements, investment strategies, and policy refinement.

Rather than replacing existing metrics, **the MTF enhances them**, shifting the discussion from basic connectivity to the effectiveness and reliability of electricity services. This helps countries like Indonesia better track progress toward achieving universal, dependable, and modern energy access, as envisioned in SDG 7.1.

1.3. Research Objective and Approach

Although Indonesia reports a high national electrification ratio, rural and off-grid communities continue to face significant disparities in the quality, reliability, and usability of electricity access. Empirical evidence on these dimensions remains limited, particularly for areas that have not yet been connected to the national grid. To address this gap, this study aims to assess electricity access in a rural community in Indonesia using the Multi-Tier Framework (MTF) as a comprehensive, multidimensional assessment tool.

Specifically, the study pursues four objectives:

i. to analyze the gaps and constraints that shape current energy-access conditions in the selected rural area;
ii. to establish an analytical basis for formulating realistic and evidence-driven energy-access targets;
iii. to examine how the multi-tier assessment structure enables governments and utilities to define context-appropriate and flexible target levels; and
iv. to evaluate the applicability of the MTF for comparing electricity-access outcomes across different geographic settings and for informing rural electrification planning.

The MTF applied in this study is not intended to replace Indonesia's existing electrification-ratio metric. Rather, it serves as a complementary interpretative framework that enables a clearer and more comprehensive understanding of electricity access—particularly in rural, underserved areas where the quality and reliability of supply often diverge from headline electrification figures.

2. Materials and methods

2.1. Overview of Methodological Framework

The MTF for measuring energy access was selected for this study because it provides a more detailed and service-oriented assessment than the binary electrification indicator, which traditionally classifies households simply as "connected" or "not connected." This binary measure overlooks substantial variations in the quality, reliability, and usability of electricity services—factors that are especially critical in rural and off-grid contexts.[3]

The MTF addresses these limitations through two key features[4]:

i. A user-centered assessment of energy services

Unlike binary metrics, the MTF evaluates whether electricity services are usable from the household's perspective. It defines electricity access across a set of service attributes that together determine actual functionality and usefulness. These attributes include:

a. Capacity of the electricity supply (ability to operate appliances),
b. Availability, measured in daily and evening hours of supply,
c. Reliability and quality (outages, voltage fluctuations),
d. Affordability,
e. Legality of connection, and
f. Safety of the electricity service.

By evaluating each of these attributes, the MTF offers a multidimensional understanding of electricity access that reflects the real experiences of users rather than purely infrastructural indicators.

ii. A technology-neutral classification system

The multi-tier approach is explicitly technology-neutral. What matters is not how electricity is delivered (whether through grid connections, mini-grids, or solar home systems), but whether the service meets the performance benchmarks defined for each tier. This allows different technologies with varying levels of performance to be compared within a common evaluative structure. For example, a grid connection with continuous 24/7 reliable supply will be classified at a higher tier than a solar home system delivering only a few hours of power per day. However, if the grid connection fails to provide consistent service, its tier classification may fall below that of a well-performing off-grid solution. This feature makes the MTF particularly suitable for contexts where energy technologies coexist and perform unevenly.

The MTF is especially appropriate for assessing electricity access in rural and underserved settings, where service quality varies widely and where traditional electrification ratios fail to capture the lived realities of energy use. Its multidimensional and technology-neutral nature allows for a nuanced evaluation of off-grid, underperforming, or hybrid energy systems. In addition, the MTF provides a structured method for aggregating results at the community or geographical level. An index of energy access can be calculated as the average tier level of all respondents in a given area, normalized to a scale of 100. The framework also supports the calculation of sub-indices for different productive-use categories—such as small shops, agricultural activities, or artisanal work—by averaging tier levels of respondents engaged in those specific activities.

Furthermore, an overarching index of electricity access for a geographical area can be generated by integrating the results across three essential domains:

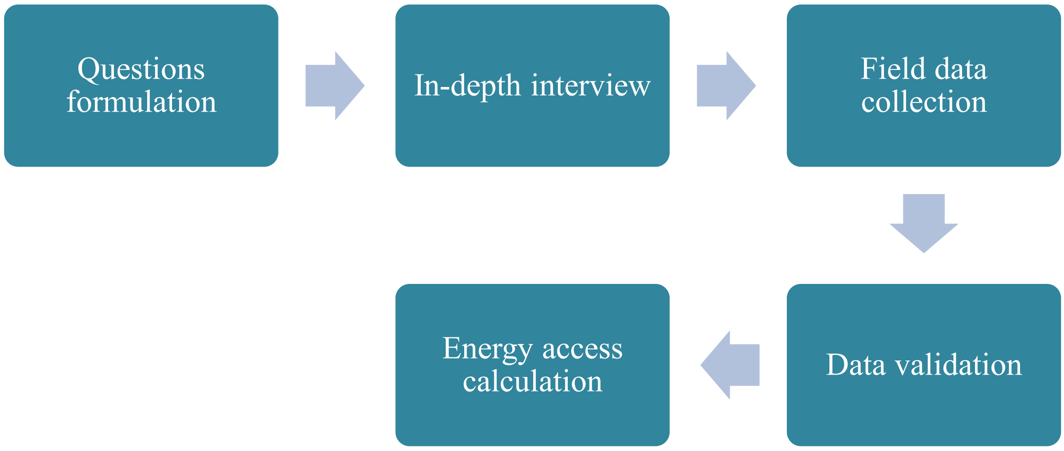
i. Households,
ii. Productive uses, and
iii. Community facilities.

This comprehensive structure enables a holistic understanding of energy access conditions and supports more informed planning for rural electrification interventions.

[3,3] Bhatia, Mikul; Angelou, Niki. 2015. ***Beyond Connections: Energy Access Redefined***. ESMAP Technical Report; 008/15. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/24368

2.2. Data Sources

The empirical data underpinning this study were obtained through a multi-stage data collection process designed to ensure consistency, accuracy, and alignment with the study's methodological framework.



Data for this study were collected through individual surveys administered in six geographically isolated rural locations: Barrang Caddi Island in South Sulawesi Province, Batanta Island in West Papua Province, Idas Village in West Borneo Province, Sillu Village in East Nusa Tenggara Province, Sumberwaru Village in East Java Province, and Hiligodu Village in North Sumatera Province. Prior to field deployment, the research team developed a structured survey instrument aligned with the measurement dimensions of the Multi-Tier Framework (MTF). This ensured that each survey item corresponded directly to one or more MTF attributes and that the framework would be fully applicable in the context of off-grid rural electrification.

Topic	Questions
Participant's profile	1) Age 2) Sex 3) Occupation 4) Number of family members who live together 5) Income 6) Housing ownership status 7) Residence duration
Connected to electricity	1) When was your household first connected to electricity?
Background factors influencing the desire to be electrified	1) What electricity sources did your household use before being connected to the PLN grid? 2) How much did you spend for the electricity source(s) mentioned above? 3) What motivated your household to connect to the PLN grid?
Ease of installation	1) In general, how was your experience when you first applied for the electricity service?

Topic	Questions
	2) On a scale of 1 (very difficult) to 5 (very easy), how would you rate the ease of the application process? 3) Can you describe the steps you went through to obtain the electricity service? 4) How long did it take from your initial application to the moment your household was connected to electricity? 5) How much did you spend for the installation? 6) What documents were required for the application? 7) What were the challenges you faced during the process?
The positive and negative aspects of electricity	1) Following the electrification of your household, what changes or positive impacts have been most noticable in your and your family's daily life? 2) Has access to electricity positively influenced your work or primary sources of income? 3) Conversely, are there any challenges or negative impacts that you have experienced since gaining access to electricity?
Electricity utilization	1) Currently, what are the primary uses of electricity in your household? 2) Since gaining access to electricity, what electronic appliances do you currently own and use in your household? 3) Were there any appliances that you purchased specifically after the electricity was connected? If so, please indicate which ones? 4) Are there plans to further increase the number of electronic appliances in your household? If yes, please specify.
Satisfaction level	1) Overall, on a scale of 1 (Very Dissatisfied) to 5 (Very Satisfied), how satisfied are you with the electricity service you currently receive? Please explain the reason for your rating 2) How would you assess the reliability of the electricity supply? Have you experienced frequent power outages? 3) If outages occur frequently, how often do they happen and how long do they typically last? 4) What is your opinion on the quality of the electricity supply? Is the voltage generally stable or do you experience fluctuations such as dimming or other issues? 5) How would you assess your monthly electricity bill? Is the amount consistent with your expectations, and

Topic	Questions
	do you consider it affordable? 6) If you have experienced any disruptions or issues related to electricity, what actions did you take? How was your experience when reporting the issue or requesting assistance from service personnel? 7) Were the service personnel easy to contact, and were the issues addressed promptly? 8) Do you have any suggestions or feedback on how the village electricity service could be improved?

Survey administration was conducted through voluntary, in-depth, face-to-face interviews to allow clarification of technical concepts and to capture participants' lived experiences of electricity use. The final dataset comprises 390 respondents distributed across the six study locations, including 48 from Barrang Caddi Island, 24 from Batanta Island, 201 from Idas Village, 53 from Sillu Village, 21 from Sumberwaru Village, and 43 from Hiligodu Village. These sample sizes reflect the population distribution and accessibility constraints of each location, while allowing for meaningful comparative analysis.

Following data collection, responses were systematically coded and categorized according to the corresponding MTF service attributes, including capacity, availability, reliability, quality, affordability, legality, and safety. This mapping process enabled the translation of qualitative and quantitative responses into the tier classifications defined by the MTF.

Once the data had been fully processed and assigned to the appropriate MTF attributes, the research team calculated the electricity access index for each location. This process involved calculating the tier scores for individual respondents and aggregating them to generate location-level indices in accordance with MTF guidelines. These resulting indices form the basis for subsequent analysis and comparison between the two study areas.

2.3. Structure of the Multi-Tier Framework Access Index

The Multi-Tier Framework (MTF) Access Index is designed to provide a comprehensive and quantifiable measure of electricity access by integrating multiple service dimensions into a single composite score. Rather than relying on a binary "connected or not connected" metric, the Access Index evaluates the quality of electricity supply across all relevant aspects that shape the user experience.

At its core, the Access Index aggregates six key MTF dimensions—**capacity, availability, reliability, quality, affordability, legality, and health & safety**—each of which is assessed separately using a tier scale from 0 to 5. For every household, the lowest-performing dimension determines the overall tier classification, following the MTF's "weakest link" principle. This ensures that electricity access is only considered meaningful when *all* critical aspects reach an adequate minimum standard.

To transform these tier classifications into an index value, each tier is assigned a corresponding numeric score. These scores are then normalized and averaged across all surveyed households to produce a community-wide or region-wide Access Index. The resulting index ranges from 0 to 5 and represents a more nuanced and realistic measure of electricity access levels, capturing variations in service quality even among areas with high electrification ratios.

Journal of Technology and Policy in Energy and Electric Power
Volume 2, Number 1, December 2025, E-ISSN 3090-1650
https://doi.org/10.33322/jtpeep.v2i1/173

Building on this structured understanding of how the Access Index is derived, the following diagram provides a visual representation of how the Multi-Tier Framework evaluates electricity access at the household level across multiple service attributes. This diagram is used to measure and assess the quality of electricity access across various attributes or dimensions of household activities. Seven attributes are measured, including the quality and quantity of electricity supply, electrical equipment, and electricity consumption.

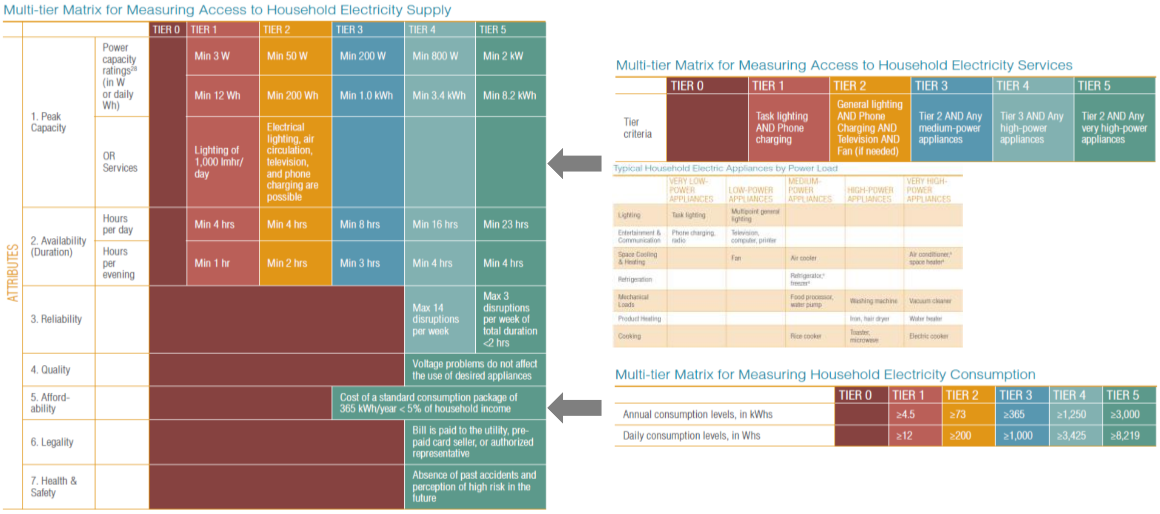


Figure 1. Multi-Tier Matrix for Measuring Electricity in Household

In addition to household supply, the MTF also provides structured tools for evaluating electricity access in other domains of daily life. *First*, the framework includes a diagram designed to assess the quality of electricity access for **productive activities**, measured through eight attributes that influence productivity, income generation, and employment. *Second*, another diagram evaluates electricity access across **community infrastructure and essential public services**, using eight attributes relevant to street lighting, healthcare facilities, education, government functions, and other public amenities.

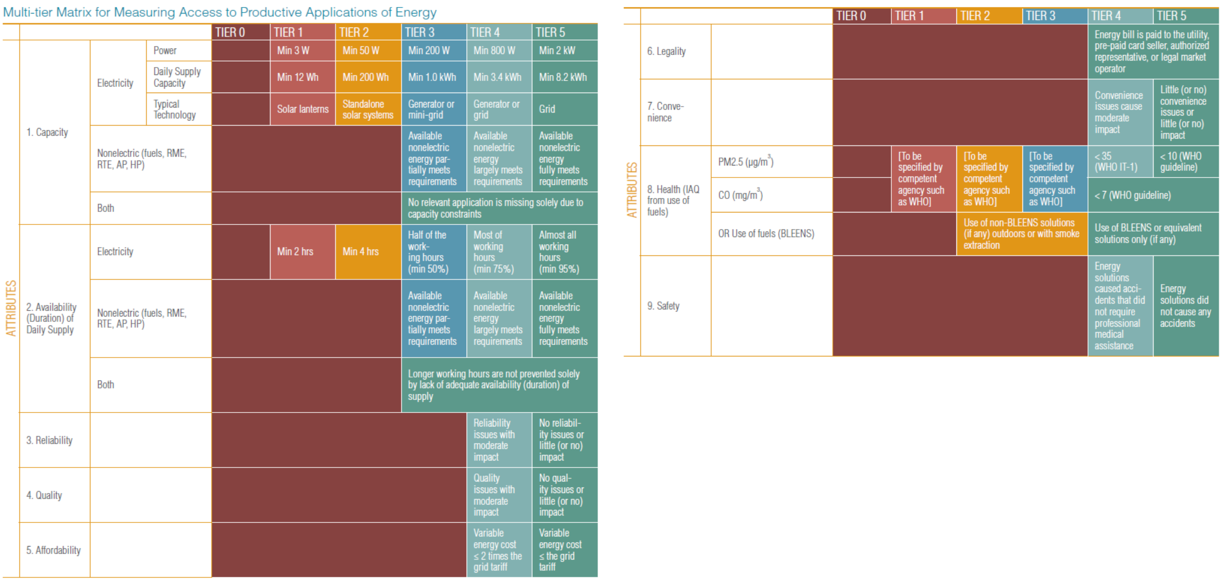


Figure 2. Multi-Tier Matrix for Measuring Productive Activities

Multi-tier Matrix for Measuring Access in Community Infrastructure (Survey of Institutions)

ATTRIBUTES			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
1. Capacity	Electricity	Power		Min 3 W	Min 50 W	Min 200 W	Min 800 Wa or Min 2 KWb	Min 2kWa or Min 10kWb
		Daily Supply Capacity		Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
		Typical Technology		Solar lanterns	Standalone solar systems	Generator or mini-grid	Generator or grid	Grid
	Nonelectric (fuels, RME, RTE)					Available nonelectric energy partially meets requirements	Available non-electric energy largely meets requirements	Available non-electric energy fully meets requirements
	Both					No relevant application is missing solely due to capacity		
2. Availability (duration) of Daily Supply	Electricity			Min 2 hrs	Min 4 hrs	Half of the working hours (Min 50%)	Most of the working hours (Min 75%)	Almost all working hours (Min 95%)
	Nonelectric (fuels, RME, RTE)					Available nonelectric energy partially meets requirements	Available non-electric energy largely meets requirements	Available non-electric energy fully meets requirements
	Both					Operating hours and/or provision of services are not restricted solely by inadequate availability (duration) of supply		
3. Reliability							Reliability issues have moderate impact	No reliability issues or little (or no) impact
4. Quality							Quality issues have moderate impact	No quality issues or little (or no) impact
5. Affordability	Variable Energy Cost						≤ 2 times the grid tariff	≤ the grid tariff
	Financial Sustainability						Energy access has not been interrupted due to unpaid utility bills, or lack of budget for fuel purchases, maintenance, spare parts, or batteries during the past 12 months	

ATTRIBUTES		TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
6. Legality						Energy bill is paid to the utility, pre-paid card seller, authorized representative, or legal market operator	
7. Convenience						Convenience issues cause moderate impact	Little (or no) convenience issues or little (or no) impact
8. Health (IAQ from use of fuels)	PM2.5 (μg/m³)		[To be specified by competent agency such as WHO]	[To be specified by competent agency such as WHO]	[To be specified by competent agency such as WHO]	< 35 (WHO IT-1)	< 10 (WHO guideline)
	CO (mg/m³)					< 7 (WHO guideline)	
	OR Use of fuels (BLEENS)			Use of non-BLEENS solutions (if any) outdoors or with smoke extraction		Use of BLEENS or equivalent solutions only (if any)	
9. Safety						Energy solutions caused accidents that did not require professional medical assistance	Energy solutions did not cause any accidents

Figure 3. Multi-Tier Matrix for Measuring Community Infrastructure/Facilities

Together, these components allow the MTF to offer a comprehensive, multi-sectoral view of energy access—one that reinforces and expands the insights provided by the Electrification Ratio.

2.4. Access Index (AI)

After obtaining the measurement results (Tiers) for each attribute, the Access Index (AI) can be calculated. This index provides a single score (ranging from 0 to 100) that reflects the overall quality of electricity access experienced by a community in a given region.

$$\text{Access Index AI} \quad = \sum_{k=0}^{5} (Pk * 20 * k)$$

a. **Access Index (AI)** is the final metric, with values ranging from 0 (no electricity access) to 100 (full, high-quality electricity access).
b. **k (Tier Number)** represents the level of electricity access a household attains, ranging from k = 0 (no access) to k = 5 (the highest level of service).
c. **Pk (Proportion/Percentage)** refers to the percentage of households at each tier. For example, P_1 is the share of households in Tier 1, P_2 is the share in Tier 2, and so forth.
d. **Σ (Sigma)** denotes summation. In this formula, it means that for each tier (k = 0 to k = 5), the value of (Pk × 20 × k) is calculated and then summed across all tiers.
e. The number "20" represents the weight assigned to each tier increment. For instance, for Tier 5 (k = 5), which indicates full electricity access, the value becomes 20 × 5 = 100.

The final AI score can be interpreted as the percentage of overall average electricity access in the region.

2.4.1. Example Measuring Access Index (AI)

To illustrate how the Access Index (AI) is derived in practice, this section presents a step-by-step example of the calculation process. By using real measurement results from the field—specifically the proportion of households in each tier—we demonstrate how these values are translated into a single numerical score that reflects the overall quality of electricity access in a given region.

For example, after calculating all Tiers, a region gets an AI score of 32, this can be interpreted as meaning that the average access level in that region is 32%.

Calculation of Access Index

TIER	ACCESS %	PROPORTION OF PEOPLE	CONTRIBUTION OF EACH TIER TO AI
k	V_k	P	$P * V_k$
0	0	0.00	0.00
1	20	0.80	16.00
2	40	0.00	0.00
3	60	0.10	6.00
4	80	0.00	0.00
5	100	0.10	10.00
Total		1.00	32.00

i. Tier 1: 80% of the population is at this level. Therefore, its contribution is: **80% x 20% = 16%.**
ii. Tier 3: 10% of the population is at this level. Therefore, its contribution is: **10% x 60% = 6%.**
Tier 5: 10% of the population is at this level. Therefore, its contribution is: **10% x 100% = 10%.**
iii. There is no population at Tier 2 or Tier 4, therefore, its contribution is **0%.**
iv. Total Access Index (AI) = **16% + 0% + 6% + 0% + 10% = 32%**

Conclusion:

Although only 10% of people have full access (Tier 5), there is additional access from people with partial access in other Tiers. This brings the total "AI access rate" to 32%, the result of combining all access levels in the population.

3. Results and discussion

3.1. Barrang Caddi Island

3.1.1. Household Access to Electricity

No	ATTRIBUTES	Barrang Caddi Island					
		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1	Peak Capacity / Power Capacity	0%	0%	0%	0%	100%	0%
2	Availability	0%	0%	0%	6,25%	2,08%	91,67%
3	Reliability	0%	0%	0%	0%	2,08%	97,92%
4	Quality	0%	0%	0%	4,17%	0%	95,83%
5	Affordability	0%	0%	100%	0%	0%	0%
6	Legality	0%	0%	0%	0%	0%	100%
7	Health & Safety	0%	0%	0%	2,08%	97,92%	0%

		Barrang Caddi Island	
TIER	Access Score	Proportion %	Contribution to Access Index (AI)
(k)	(V_k)	(P)	($V_k \times P$)
0	0	0%	0,00
1	20	0%	0,00
2	40	100%	40,00
3	60	0%	0,00
4	80	0%	0,00
5	100	0%	0,00
Total		100%	40,00

The application of the Multi-Tier Framework (MTF) to Barrang Caddi Island reveals a highly concentrated distribution of household electricity access within Tier 2, resulting in a total Access Index (AI) score of 40.00. This finding suggests that while electricity is widely available on the island, the overall level of service remains modest and significantly below the standards associated with higher-tier access levels.

A closer examination of the seven MTF attributes shows that the threshold for Tier 2 is achieved entirely because of the affordability attribute, where 100% of households qualify. In contrast, other attributes—such as peak power capacity, reliability, legal connection status, and safety—display tier distributions that extend to Tier 4 and Tier 5. Notably, more than 90% of households fall in Tier 5 for quality, reliability, and legality, indicating that the technical and administrative dimensions of service provision are already well established.

However, the MTF's tiering methodology assigns a household's tier based on the lowest attribute it satisfies. In the case of Barrang Caddi Island, affordability becomes the binding constraint that caps the entire community at Tier 2, despite otherwise strong performance in higher-tier attributes. This demonstrates a crucial insight: affordability, rather than technical quality or reliability, is the dominant limiting factor for advancing household electricity access on the island.

From a policy perspective, this reveals an important structural issue. The MTF intentionally centers the user experience, emphasising whether the service is truly usable and sustainable for households. The Barrang Caddi findings suggest that although PLN or local providers have succeeded in delivering reliable, safe, and high-quality electricity, households still experience constraints related to the cost of maintaining access. This indicates the presence of persistent socio-economic barriers that inhibit higher-tier access upgrades.

The findings also underscore the MTF's value in providing a more granular assessment than the traditional electrification ratio. While Barrang Caddi Island may appear "fully electrified" in binary terms, the MTF reveals that households experience a more complex reality in which affordability suppresses effective access, limiting households' ability to benefit from electricity in transformative ways. Without addressing affordability, households are unlikely to transition to higher tiers where electricity can support more diverse and productive usage.

3.1.2. Access to Energy for Productivity Engagements

No	ATTRIBUTES	Barrang Caddi Island					
		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1	Capacity	0%	0%	0%	0%	100%	0%
2	Availability	0%	0%	0%	0%	6%	94%
3	Reliability	0%	0%	0%	0%	0%	100%
4	Quality	0%	0%	0%	0%	0%	100%
5	Affordability	0%	0%	0%	0%	0%	100%
6	Legality	0%	0%	0%	0%	0%	100%
7	Convenience	0%	0%	0%	0%	0%	100%
9	Safety	0%	0%	0%	0%	0%	100%

		Barrang Caddi Island	
TIER	*Access %*	***Proportion %***	***Contribution to Access Index (AI)***
(k)	*(V_k)*	*(P)*	($V_k \times P$)
0	0	0%	0,00
1	20	0%	0,00
2	40	0%	0,00
3	60	0%	0,00
4	80	100%	80,00
5	100	0%	0,00
Total		100%	**80,00**

The results for Access to Energy for Productive Engagements in Barrang Caddi Island reveal a notably advanced stage of electricity access, with the community predominantly concentrated at Tier 5 across all assessed attributes. According to the Multi-Tier Framework (MTF), Tier 5 represents the highest level of energy access, characterized by reliable, affordable, and high-quality electricity that supports a broad range of productive uses. The near-universal Tier 5 performance across capacity, availability, reliability, legality, convenience, and safety suggests that the island exhibits an enabling energy environment that surpasses the minimum thresholds for productive economic activity. This places Barrang Caddi significantly ahead of many rural and remote regions in low- and middle-income countries, where previous studies have documented persistent Tier 1–3 clustering due to infrastructural and financial constraints.

The Access Index score of 80.00—driven almost entirely by the 94% share of households at Tier 5—indicates a mature and stable electrification ecosystem capable of supporting both household and enterprise-level consumption. When interpreted within the broader MTF measurement domains, these findings demonstrate meaningful alignment between household electricity access and productive engagements. High household access (typically Tier 4–5 in preceding sections) often creates the foundational conditions for productive use, but such alignment is not always guaranteed. In many contexts, households may benefit from high-tier access while productive activities remain stalled at lower tiers due to load limitations, unstable supply, or affordability barriers. In contrast, Barrang Caddi shows no such divergence; productive use appears to have progressed in tandem with household electrification quality.

From the perspective of the Access to Energy for Community Infrastructure dimension, the strong Tier 5 performance for productive engagements may also be indicative of well-developed communal energy assets—though this dimension extends beyond individual enterprises to include public facilities such as health centers, schools, water systems, and street lighting. While the

Journal of Technology and Policy in Energy and Electric Power
Volume 2, Number 1, December 2025, E-ISSN 3090-1650
https://doi.org/10.33322/jtpeep.v2i1/173

current dataset focuses specifically on productive engagement attributes, the high reliability and quality of electricity supply observed here often correlate with improved community infrastructure access as well. Prior research highlights that productive-tier advancements tend to emerge only after foundational investments in feeder lines, distribution stability, and transformer capacity—investments that simultaneously strengthen community-level infrastructure.

The uniformity of Tier 5 across reliability, legality, affordability, and safety is particularly noteworthy. Many electrified islands and remote coastal communities remain vulnerable to voltage drops, unofficial connections, and high operational costs due to diesel-based generation. In contrast, Barrang Caddi's zero incidence of lower-tier attributes suggests that the island benefits from well-regulated supply and effective institutional oversight. Such conditions significantly reduce entry barriers for micro- and small enterprises, which rely on stable electricity for cold storage, digital transactions, food processing, and service-sector operations. This aligns with emerging literature showing that Tier 5 access has a statistically significant correlation with increases in household income diversification, firm productivity, and women's participation in microenterprises.

Nevertheless, the dominance of a single tier across all attributes also raises methodological considerations. The MTF is designed to capture nuanced progress and heterogeneity; therefore, a 94% Tier 5 distribution warrants further qualitative validation to ensure that the reported performance reflects actual user experience rather than reporting or sampling bias. For instance, productive-use electricity needs may vary seasonally, and temporary voltage irregularities may not be fully captured in point-in-time assessments. Similarly, the 6% Tier 4 share for capacity suggests the presence of a minority of users still constrained in their ability to operate higher-load equipment, pointing to potential micro-level inequities masked by the aggregate Index score.

Overall, these findings place Barrang Caddi Island among the more advanced electrification contexts within the MTF framework. The high-tier access for productive engagements reinforces the hypothesis that reliable and high-quality electricity is a critical enabler of local economic development. It also suggests that the island may be well-positioned for policies and interventions targeting productive energy scaling, such as electrified fisheries, digital microbusiness incubation, and energy-intensive value chain activities. Continued monitoring—particularly triangulated with community infrastructure indicators—will be essential to ensure that these high access tiers translate into sustained socioeconomic gains.

3.1.3. Access to Energy for Community Infrastructure

Attributes		Prayer Facilities Barrang Caddi Island						Clean Water Supply Barrang Caddi Island					
		Tier						Tier					
		0	1	2	3	4	5	0	1	2	3	4	5
1	Capacity					✓						✓	
2	Availability						✓						✓
3	Reliability						✓						✓
4	Quality						✓						✓
5	Affordability						✓						✓
6	Legality						✓						✓
7	Convenience						✓						✓
8	Health						✓						✓
9	Safety						✓						✓

		Barrang Caddi Island	
TIER	Access %	Proportion %	Contribution to Access Index (AI)
(k)	(V_k)	(P)	($V_k \times P$)
0	0	0%	0,00
1	20	0%	0,00
2	40	0%	0,00
3	60	0%	0,00
4	80	100%	0,00
5	100	0%	0,00
Total		100%	80,00

The findings for **Access to Energy for Community Infrastructure** in Barrang Caddi Island indicate a high level of electrification maturity, with the island achieving an overall **Access Index score of 80.00**, driven predominantly by universal attainment of **Tier 4** across both assessed facility categories—prayer facilities and clean water supply. Within the Multi-Tier Framework

(MTF), Tier 4 reflects a level of electricity service sufficient to support essential public infrastructure with reliable, safe, and high-quality power. This performance demonstrates substantial progress compared to many small island or remote communities where community-level infrastructure often lags behind household electrification due to higher operational demands and the cost of maintaining public service infrastructure.

Across all nine MTF attributes—capacity, availability, reliability, quality, affordability, legality, convenience, health, and safety—both infrastructure types consistently meet Tier 4 standards. This cross-attribute alignment suggests that community facilities benefit from a robust and well-managed energy system capable of delivering continuous service. For prayer facilities, reliable and legal access to electricity supports lighting, sound systems, and environmental comfort crucial for communal activities. Similarly, clean water systems require sustained electricity for pumping, purification, and distribution, all of which appear well-supported at Tier 4. Such outcomes are significant because community infrastructure is often the weakest link in electrification ecosystems, particularly in geographically isolated islands where maintenance challenges and supply instability are common.

When interpreted alongside the findings for the other two MTF measurement domains—**household electricity access** and **productive-use access**—a coherent pattern of high-tier performance emerges. Earlier sections indicate the dominance of Tier 4–5 for household access and a strong Tier 5 concentration for productive engagements. The convergence of all three domains within upper-tier performance suggests that Barrang Caddi Island has achieved a rare level of electrification coherence, where improvements in one domain reinforce advancements in others. This is consistent with prior literature emphasizing that community-level infrastructure reliability often depends on the same distribution stability and system redundancy that enable productive-use electricity. In other words, Tier 4 performance for prayer and water facilities likely reflects broader system-wide operational strength.

The high-tier results also suggest significant institutional capacity for managing community services. Electricity-dependent public infrastructure often suffers in remote locations due to governance gaps, inadequate maintenance, and financial constraints. The absence of lower-tier scores in Barrang Caddi indicates effective oversight, sustainable payment mechanisms, and well-functioning coordination between energy providers and community managers. This level of system functionality is consistent with MTF literature showing that Tier 4 and Tier 5 community infrastructure typically appears only in contexts where long-term planning and operational resilience have been institutionalized.

Despite these encouraging outcomes, the exclusive clustering at Tier 4 warrants careful interpretation. Unlike the household and productive-use domains—where Tier 5 was achieved in several attributes—the community infrastructure domain shows no Tier 5 attainment. While Tier 4 reflects strong reliability, Tier 5 requires **full, uninterrupted service with no constraints** across all attributes, including advanced quality controls, contingency systems, and comprehensive safety mechanisms. The absence of Tier 5 may signal underlying limitations such as intermittent voltage fluctuations, lack of backup systems, or capacity ceilings that have not yet been fully addressed. From a policy perspective, this suggests an important frontier for improvement: transitioning from "functional and reliable" community infrastructure to a "resilient and future-ready" one.

Overall, the results position Barrang Caddi Island as an advanced case of island electrification within the MTF framework. The alignment of high-tier access across households, productive uses, and community infrastructure illustrates an electrification ecosystem that is not only technically robust but also socially inclusive. This integrated progress is likely to amplify

Journal of Technology and Policy in Energy and Electric Power
Volume 2, Number 1, December 2025, E-ISSN 3090-1650
https://doi.org/10.33322/jtpeep.v2i1/173

broader development outcomes—ranging from improved public service delivery to enhanced economic productivity and strengthened social cohesion. Future work should further examine operational costs, long-term sustainability risks, and potential inequities that may be hidden beneath the aggregated Tier 4 classification, ensuring that the island's strong performance is both durable and scalable.

3.2. Batanta Island

3.2.1. Household Access to Electricity

No	ATTRIBUTES	Batanta Island					
		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1	Peak Capacity / Power Capacity	0%	0%	0%	0%	100%	0%
2	Availability	0%	0%	0%	37,50%	12,50%	50%
3	Reliability	0%	0%	0%	8,33%	37,50%	54,17%
4	Quality	0%	0%	0%	62,50%	0%	37,50%
5	Affordability	0%	0%	87,50%	12,50%	0%	0%
6	Legality	0%	0%	0%	0%	0%	100%
7	Health & Safety	0%	0%	0%	12,50%	87,50%	0%

		Batanta Island	
TIER	Access Score	Proportion %	Contribution to Access Index (AI)
(k)	(V_k)	(P)	($V_k \times P$)
0	0	0%	0,00
1	20	0%	0,00
2	40	88%	35,00
3	60	13%	7,50
4	80	0%	0,00
5	100	0%	0,00
Total		100%	42,50

The assessment of **Household Access to Electricity** in Batanta Island reveals a mixed but transitional electrification profile, with the island achieving an overall **Access Index (AI) score of 42.50**. This situates Batanta in the lower-middle tier of the MTF electrification spectrum—significantly above subsistence-level tiers but still below the threshold of high-quality, reliable, and affordable electricity service. The distribution of household tiers shows a strong clustering at **Tier 2 (88%)**, with a small proportion reaching **Tier 3 (13%)**, and no households attaining Tier 4 or Tier 5 levels. This skewed tier structure indicates that most households can access electricity for basic uses (lighting, phone charging) but lack the reliability, capacity, and affordability necessary for more advanced or sustained usage.

A closer examination of the attribute-level findings highlights several structural constraints. **Quality and reliability** emerge as key limitations: while some households meet Tier 3 or Tier 5 indicators (37–54%), a large share remains at Tier 2 for these attributes, indicating frequent voltage fluctuations and intermittent supply. Availability levels also reflect this unevenness; although 50% of households reach Tier 5 availability, 37.5% remain at Tier 3, suggesting variability in daily hours of supply. These inconsistencies are typical of semi-isolated or partially grid-dependent systems, where generation constraints and maintenance challenges hinder consistent service delivery.

Affordability is the most restrictive attribute, with **87.5% of households confined to Tier 2**. In the MTF, affordability captures the share of income required to meet basic electricity needs. A Tier 2 concentration implies that while households can connect to electricity, the financial burden remains significant relative to income levels. This affordability bottleneck likely reinforces the stagnation at lower tiers, constraining households from investing in higher-capacity appliances or expanding electricity usage beyond essential needs.

Legal access and safety indicators, however, show stronger performance, with the majority of households attaining Tier 4 criteria. This suggests that the foundations for regulated and safe electricity access are in place—a positive institutional indicator that could support future service upgrades.

Interpreted within the broader MTF framework, Batanta's household electricity profile contrasts sharply with the high-tier performance observed for **productive-use access** and **community infrastructure access** in other islands assessed in this study. While detailed results for Batanta's productive and community tiers are presented elsewhere, the household-level stagnation at Tier 2 highlights a potential disconnect: even where public infrastructure or economic activities may reach higher tiers, household electrification lags behind. This imbalance can limit inclusive development outcomes, as households remain unable to leverage electricity for enhanced well-being, income diversification, or digital inclusion.

These findings align with prior literature showing that Tier 2 dominance often reflects early-stage grid expansion—where physical access is achieved but system quality, affordability, and predictability remain insufficient for meaningful socio-economic transformation. The absence of households in Tiers 4 and 5 signals that Batanta Island has yet to experience the full benefits of energy-enabled development.

From a policy standpoint, improving Batanta's household electricity access requires addressing systemic constraints across three fronts. First, **strengthening system reliability and quality** would reduce outages and voltage instability, enabling households to utilize appliances beyond basic lighting. Second, **enhancing affordability**, potentially through targeted subsidies or cost-reflective tariff reforms, would help households transition into higher tiers of usage. Third, **capacity expansion**—either through enhanced grid infrastructure or hybrid renewable–diesel systems—may be necessary to meet growing demand and reduce reliance on limited-capacity systems.

Overall, the household-level MTF results for Batanta Island depict a community in the intermediate phase of electrification: the infrastructure exists, legal access is established, and a minority of households experience higher-tier benefits. Yet the majority remain constrained by affordability and service quality limitations. For Batanta to progress toward higher-tier electrification outcomes, coordinated interventions across technical, financial, and regulatory domains will be essential. As shown by comparative findings across the three MTF measurement categories, achieving holistic and inclusive energy access hinges not merely on extending connections but on ensuring that households receive reliable, affordable, and high-quality electricity capable of supporting broader development objectives.

3.2.2. Access to Energy for Productivity Engagements

No	ATTRIBUTES	Batanta Island					
		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1	Capacity	0%	0%	0%	0%	100%	0%
2	Availability	0%	0%	0%	25%	13%	63%
3	Reliability	0%	0%	0%	25%	25%	50%
4	Quality	0%	0%	0%	50%	0%	50%
5	Affordability	0%	0%	0%	0%	0%	100%
6	Legality	0%	0%	0%	0%	0%	100%
7	Convenience	0%	0%	0%	0%	0%	100%
9	Safety	0%	0%	0%	0%	0%	100%

		Batanta Island	
TIER	Access %	Proportion %	Contribution to Access Index (AI)
(k)	(V_k)	(P)	(V_k × P)
0	0	0%	0,00
1	20	0%	0,00
2	40	0%	0,00
3	60	75%	45,00
4	80	25%	20,00
5	100	0%	0,00
Total		100%	65,00

The assessment of **Access to Energy for Productivity Engagements** in Batanta Island demonstrates a relatively advanced stage of energy service provision for productive-use activities, as reflected in the overall **Access Index (AI) score of 65**. This score positions the island in the upper-middle tier of the World Bank's Multi-Tier Framework (MTF), suggesting that while many foundational attributes are well established, several operational constraints continue to limit the full realization of productive potential.

A key strength emerging from the data is the universal attainment of **Tier 4 capacity (100%)**, indicating that enterprises and productive activities on the island receive sufficient electricity capacity to operate medium-load appliances. This is further complemented by **Tier 5**

performance in affordability, legality, convenience, and safety (100% each). The convergence of these attributes reflects an enabling regulatory and financial environment: productive users face minimal bureaucratic barriers, pay manageable costs for energy services, and operate under safe installation standards. Such conditions are essential for fostering microenterprise growth, mechanization, and broader local economic development.

However, nearer inspection of supply-side attributes—namely **availability, reliability, and quality**—reveals the primary constraints shaping Batanta's productive energy landscape. **Availability levels** vary across tiers, with **63% achieving Tier 5**, yet **25% remain at Tier 3 and 13% at Tier 4**. This distribution signals that although a majority receive near-continuous supply, a significant minority experience restricted hours of electricity, limiting their operational windows. Such temporal constraints can directly affect enterprises requiring extended production schedules, refrigeration, or evening operations.

Similarly, **reliability** remains uneven: only **50% reach Tier 5**, while **25% each fall into Tier 3 and Tier 4**. These lower tiers imply periodic outages or interruptions that disrupt productive activities—creating inefficiencies, damaging equipment, and hindering workflow continuity. Prior literature emphasizes that reliability is among the most influential factors for productive use, as even short-duration outages can impose substantial economic costs for small businesses and service-based enterprises.

Quality, measured by voltage stability, exhibits a comparable divide: **50% achieve Tier 5**, but the remaining **50% fall under Tier 3**. Voltage fluctuation is a typical challenge in small or hybrid power systems and can restrict businesses from using sensitive equipment such as welding machines, freezers, or digital devices. The dual-tier profile indicates that despite strong performance on regulatory and affordability dimensions, technical constraints in supply infrastructure persist.

The AI distribution further underscores these limitations. **Tier 3 contributes the largest share (45 points)**, followed by **Tier 4 (20 points)**, with no contribution from Tier 5 despite several attributes meeting Tier 5 thresholds individually. This pattern reflects the MTF's binding-constraint principle: a user's overall tier is determined by the *lowest* attribute tier. In Batanta's case, even when many attributes achieve Tier 5, the presence of Tier 3 availability or reliability locks a substantial proportion of users at Tier 3 overall. This reinforces the notion that productive-use electrification is only as strong as the weakest technical link in the supply chain.

These findings align with global evidence suggesting that early or intermediate-stage grid expansions often achieve high levels of legality, affordability, and safety before resolving deeper issues related to supply adequacy and system resilience. In the context of Batanta Island, while households may remain concentrated at lower tiers (as discussed in previous sections), the productive-use sector displays a comparatively more advanced energy environment. This suggests that electrification efforts may have prioritized economic nodes—such as small shops, fisheries, refrigeration hubs, or community businesses—to stimulate local economic capacity. However, the remaining reliability and quality limitations indicate persistent infrastructural vulnerabilities, potentially tied to generation constraints, aging distribution hardware, or maintenance gaps.

Overall, the results highlight that Batanta's productive energy ecosystem is **structurally ready but operationally constrained**. High-tier performance on enabling attributes provides a strong foundation, yet improvements in supply stability will be critical for unlocking the island's full productivity potential. Enhancing reliability and quality—through grid reinforcement, hybridization with storage, or upgrading distribution lines—would enable enterprises to transition beyond Tier 3 limits and leverage electricity for higher-value economic activities. Without addressing these technical constraints, the island risks plateauing at an intermediate level of productive-use electrification, unable to fully harness energy as a driver for rural economic transformation.

3.2.3. Access to Energy for Community Infrastructure

	Attributes	Prayer Facilities Batanta Island					
		Tier					
		0	1	2	3	4	5
1	Capacity					✓	
2	Availability						✓
3	Reliability						✓
4	Quality						✓
5	Affordability						✓
6	Legality						✓
7	Convenience						✓
8	Health						✓
9	Safety						✓

		Batanta Island	
TIER	Access %	Proportion %	Contribution to Access Index (AI)
(k)	(V_k)	(P)	($V_k \times P$)
0	0	0%	0,00
1	20	0%	0,00
2	40	0%	0,00
3	60	0%	0,00
4	80	100%	0,00
5	100	0%	0,00
Total		100%	80,00

The assessment of community infrastructure on Batanta Island through the Multi-Tier Framework (MTF) reveals a markedly higher level of energy access compared to many rural and remote regions in Indonesia. The overall score—dominated entirely by Tier 4 (80%)—indicates that infrastructure-level services have transitioned beyond basic or intermediate functionality and now operate at an advanced stage of energy provision. This finding has important implications for local development, institutional service delivery, and the sustainability of public facilities.

First, the capacity of supply at Tier 4 suggests that community-level facilities (e.g., schools, health posts, administrative offices, public lighting) have access to sufficient power to operate a diversified set of appliances. While this is not yet at Tier 5, Tier 4 capacity already enables reliable functioning of priority services such as refrigeration for vaccines, ICT devices for education, and essential communication tools. This aligns with previous MTF-based assessments in rural electrification contexts where Tier 4 capacity is associated with improved socio-economic service delivery yet still constrained in powering high-load or industrial-grade equipment.

Second, the consistently high performance across availability, reliability, and quality—all at Tier 5—signals a robust energy system with minimal outages, stable voltage, and dependable service throughout the day. Such performance is uncommon in isolated island communities, where dependence on diesel generators, low-quality local grids, or intermittent renewable systems often results in fluctuating supply. The findings suggest that Batanta's system benefits from either strong operational management, effective hybridization of energy sources, or well-maintained distribution infrastructure. Reliability at this level is particularly critical for community infrastructure because disruptions in public facilities disproportionately affect collective welfare (e.g., clinic downtime, unreliable communication systems, or impaired water pumping services).

Third, the attributes of affordability, legality, convenience, health, and safety, all achieving Tier 5, highlight an enabling institutional environment. Tier 5 affordability suggests that the tariff or payment system does not impose financial burdens on community facilities—commonly a barrier in remote electrification settings, where institutional users face higher costs than households. Legality and convenience imply that energy services are formal, regulated, and straightforward to access or maintain, reducing risks of informal connections or unsafe installations. The health and safety Tier 5 ratings reinforce the notion that the community infrastructure is powered through systems that meet modern standards regarding emissions, wiring safety, and environmental considerations.

Collectively, these high-tier results reveal that Batanta's community infrastructure enjoys near-optimal energy access. This positions the island favorably for improved public service delivery and strengthens its potential for socio-economic development. However, the predominance of Tier 4 rather than Tier 5 in capacity may limit future expansion—especially if population growth, electrified public services, or digital infrastructure increase overall demand. As observed in comparable rural contexts, capacity constraints often emerge once communities seek to upgrade services or integrate new technologies.

The overall contribution to the access index (80% Tier 4) reinforces this mixed picture: while nearly all qualitative dimensions exceed expectations, the quantitative limitation on capacity moderates the final classification. This suggests that the next stage of intervention should focus not on improving reliability or safety—areas already performing optimally—but rather on scaling system capacity to support growth in community functions. Strengthening capacity could unlock Tier 5 classification, enabling wider adoption of high-load institutional equipment such as advanced medical devices, industrial machinery for vocational training, or large-scale water treatment systems.

In summary, Batanta Island presents a strong case of successful community-level electrification, exceeding typical rural standards within the Indonesian archipelago. The high-tier results across most MTF attributes indicate a mature electrification system, and future development efforts should prioritize increasing system capacity to fully translate these strengths into long-term institutional resilience and enhanced public services.

3.3. Idas Village

3.3.1. Household Access to Electricity

No	ATTRIBUTES	Idas Village					
		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1	Power Capacity	0%	28%	9%	57%	5%	0%
2	Availability	0%	0%	0%	0%	0%	100%
3	Reliability	0%	0%	0%	0%	24%	76%
4	Quality	0%	0%	0%	16%	2%	82%
5	Affordability	0%	60%	40%	0%	0%	0%
6	Legality	0%	0%	0%	0%	0%	100%
7	Health & Safety	0%	0%	0%	0%	15%	73%

Idas Village			
TIER	Access Score	Proportion %	Contribution to Access Index (AI)
(k)	(V_k)	(P)	(V_k × P)
0	0	0%	0,00
1	20	68,66%	13,73
2	40	31,34%	12,54
3	60	0%	0,00
4	80	0%	0,00
5	100	0%	0,00
		Access Index:	26,27

The assessment of household electricity access in Idas Village using the Multi-Tier Framework (MTF) highlights a complex electrification landscape in which technical availability and regulatory compliance coexist with significant limitations in capacity and affordability. Although the village demonstrates strong performance on several upper-tier attributes, the overall access index remains low (26.27), indicating that households still experience restricted energy services despite being nominally connected to electricity.

A central issue emerging from the findings is the limited power capacity, with a substantial share of households positioned within Tier 1 to Tier 3. Only 5% of households reach Tier 4 capacity, suggesting that most connections do not support higher-load appliances or productive energy uses. This pattern mirrors trends observed in remote electrification contexts, where households receive only minimal or moderate power levels, often sufficient for lighting and communication devices but inadequate for larger household or income-generating appliances. Such capacity constraints significantly curb the transformative potential of electrification, reinforcing a condition where households are technically electrified but remain functionally energy-poor.

Volume 2, Number 1, December 2025, E-ISSN 3090-1650
https://doi.org/10.33322/jtpeep.v2i1/173

Despite these constraints, availability is rated at Tier 5 for all households, indicating that electricity is consistently present when required. This is a noteworthy achievement and suggests that local energy systems—whether grid-based or decentralized—are generally stable. Yet, full availability does not eliminate the unevenness reflected in reliability, where 24% of households still fall under Tier 4. Households in this category may experience intermittent interruptions, voltage drops, or localized service inconsistencies. When capacity is already limited, even minor reliability issues can substantially diminish users' ability to rely on electricity for essential daily needs, thereby reinforcing the lower-tier experience.

Similarly, the quality attribute shows strong performance, with 82% of households in Tier 5. This indicates a broadly stable voltage profile and relatively low risk of appliance damage. In many rural electrification programs, poor voltage quality often accompanies low capacity and reliability; however, Idas Village appears to have addressed this aspect effectively. The presence of high-quality electricity suggests that the infrastructural backbone, where available, meets standard technical specifications and is not itself the main barrier to improved household electricity services.

The most significant socioeconomic limitation emerges through affordability, where households are concentrated in Tier 1 (60%) and Tier 2 (40%). These figures indicate that electricity costs are considered high relative to income, and that the majority of households allocate a substantial portion of their monthly expenditures to energy. Affordability challenges frequently prevent households from using electricity to its full potential, upgrading their connection, or purchasing appliances that could increase welfare or productivity. In the MTF literature, affordability has increasingly been recognized as a dominant barrier in rural electrification, especially after connectivity is achieved. Idas Village fits this pattern, with the cost of service posing a key constraint on energy access progression.

Encouragingly, the village performs exceptionally well on attributes linked to institutional and technical governance. Legality is universal at Tier 5, meaning that all households have formal, regulated connections. This reflects a mature and well-managed electrification program that minimizes informal or hazardous wiring practices. Likewise, health and safety indicators are strong, with the majority of households in Tier 5 and the remaining households in Tier 4. This suggests safe installations, minimal exposure to fire hazards, and limited reliance on polluting back-up sources—conditions that often emerge only in the later phases of electrification initiatives.

Taken together, these findings reveal an electrification environment that is technically robust but constrained by economic and capacity-related barriers. The low overall access index illustrates that meaningful electricity access is not solely determined by the presence of a connection but by the adequacy, reliability, and affordability of the service. In Idas Village, households have moved past the initial hurdle of electrification but remain unable to fully leverage electricity for enhanced well-being or socio-economic development. This aligns with broader evidence from MTF applications, which shows that many rural communities enter a plateau phase in which improvements in availability, legality, and quality do not automatically translate into higher tiers of energy access.

The results imply that future interventions should prioritize increasing household power capacity and addressing affordability constraints. Without such measures, electricity in Idas Village will continue to function largely as a basic service rather than a developmental enabler. Efforts such as improving grid strength, offering progressive tariff structures, providing appliance financing programs, or subsidizing capacity upgrades may be necessary to facilitate upward tier movement. Ultimately, while Idas Village exhibits promising infrastructural and regulatory advancement, substantive progress in household electricity access will depend on resolving economic and capacity-related bottlenecks that currently limit the benefits of electrification.

3.3.2. Access to Energy for Productivity Engagements

No	ATTRIBUTES	Idas Village					
		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1	Capacity	0%	29%	8%	57%	6%	0%
2	Availability	0%	0%	0%	0%	0%	100%
3	Reliability	0%	0%	0%	1%	23%	76%
4	Quality	0%	0%	0%	15%	3%	82%
5	Affordability	0%	0%	0%	0%	0%	100%
6	Legality	0%	0%	0%	0%	0%	100%
7	Convenience	0%	0%	0%	0%	0%	100%
9	Safety	0%	0%	0%	1%	16%	76%

Idas Village			
TIER	Access Score	Proportion %	Contribution to Access Index (AI)
(k)	(V_k)	(P)	($V_k \times P$)
0	0	0%	0,00
1	20	25,85%	5,17
2	40	6,80%	2,72
3	60	53,74%	32,24
4	80	5,44%	4,35
5	100	0%	0,00
		Access Index:	**44,49**

The assessment of productive-use electricity access in Idas Village using the Multi-Tier Framework (MTF) reveals a pattern of partial but uneven progress toward enabling electricity-driven economic activities. Despite strong performance on several higher-tier service attributes, structural limitations—particularly in power capacity—continue to restrict the full realization of electricity's potential for livelihood enhancement. The overall productive-use access index of 44.49 reflects a mid-tier energy environment in which electricity is widely available and of acceptable quality, yet often insufficient to support more sophisticated or energy-intensive productive engagements.

The most prominent constraint is found in capacity, where households are spread across Tiers 1 to 4. Only 6% reach Tier 4, while the majority remain in Tier 3 (57%) or below. This demonstrates that although electricity is present, the power ratings available to households and microenterprises remain too limited to operate higher-load appliances required for advanced productive uses such as milling, cold storage, welding, or agro-processing. Much like the household electricity results for Idas, this capacity bottleneck signals a structural ceiling that prevents upward mobility within the MTF tier system. From a development standpoint, limited capacity constrains opportunities for value-added activities and keeps most productive engagements at a subsistence or micro-scale level.

In contrast, availability achieves Tier 5 for all respondents, indicating that electricity is consistently supplied during the hours needed for productive tasks. When combined with relatively high performance on reliability—with 76% reaching Tier 5 and only 1% falling into Tier 3—the data suggests that interruption frequency and duration are not major impediments to productive energy use. Stability of supply is further reinforced by the results on quality, wherein 82% of respondents are positioned in Tier 5. These high-tier outcomes imply that voltage fluctuations, surges, and risks of equipment damage are minimal, creating an enabling technical environment for productive uses, at least for appliances compatible with the available capacity.

Interestingly, affordability, legality, and convenience all achieved Tier 5. The universal legality of connections ensures that enterprises and household businesses operate within a regulated system, reducing the risks commonly associated with informal or unsafe electricity access. High convenience suggests that electricity access requires minimal effort or time to use, and affordability at Tier 5 indicates that productive users perceive electricity expenditures as manageable relative to income derived from their activities. This stands in contrast to the household-level findings in Idas Village, where affordability is a significant constraint, suggesting that productive users either consume electricity more efficiently or possess income-generating models that absorb electricity costs more effectively.

Journal of Technology and Policy in Energy and Electric Power
Volume 2, Number 1, December 2025, E-ISSN 3090-1650
https://doi.org/10.33322/jtpeep.v2i1/173

Safety outcomes also demonstrate predominantly high-tier performance, with 76% of respondents in Tier 5 and 16% in Tier 4. These results indicate a generally safe operational environment for electricity use in productive activities, with low reliance on dangerous backup sources and minimal exposure to electrical hazards. The isolated proportion of Tier 3 respondents (1%) suggests only a marginal presence of inadequate or risky setups.

Taken together, the distribution across MTF tiers generates an overall index score indicative of mid-level productive-use capability. The strong performance on availability, reliability, quality, and affordability signals that Idas Village has reached a level of electrification where energy can support basic and some intermediate productive functions. However, the dominance of lower to mid-tier capacity levels reveals a structural barrier preventing enterprises from scaling their operations or adopting more energy-intensive technologies. In many MTF studies, including contexts similar to rural Indonesia, insufficient capacity is often the single most important determinant limiting productive transformation—even where other attributes achieve higher tiers. Idas Village replicates this pattern.

Ultimately, the findings suggest that improving the productive-use energy environment in Idas Village requires targeted interventions aimed at increasing allowable power loads for enterprises. Capacity upgrades—through transformer reinforcement, household-to-business tariff adjustments, or targeted productive-use electrification programs—would enable households and microenterprises to transition beyond low-tier usage patterns. Without resolving this capacity constraint, the village is likely to remain in an energy-access equilibrium where electricity supports only basic productive activities, limiting the broader economic impact of rural electrification. The high-tier performance on all other attributes shows that the foundations are already in place; unlocking higher-tier productivity will now depend primarily on addressing the power-capacity barrier.

3.3.3. Access to Energy for Community Infrastructure

	Attributes	Prayer Facilities Idas Village Tier 0	1	2	3	4	5
1	Capacity						✓
2	Availability						✓
3	Reliability					✓	
4	Quality						✓
5	Affordability						✓
6	Legality						✓
7	Convenience						✓
9	Safety						✓

		Idas Village	
TIER	Access Score	Proportion %	Contribution to Access Index (AI)
(k)	(V_k)	(P)	($V_k \times P$)
0	0	0%	0,00
1	20	0%	0,00
2	40	0%	0,00
3	60	0%	0,00
4	80	100%	0,00
5	100	0%	0,00
Total		100%	**80,00**

The assessment of community infrastructure energy access in Idas Village reveals a highly advanced level of service provision within the MTF framework, with most attributes reaching Tier 5. The pervasive Tier 5 performance across availability, quality, affordability, legality, convenience, and safety indicates that the foundational conditions for reliable and socially inclusive energy access have been firmly established. This pattern suggests that community-level facilities—such as schools, health posts, public administration buildings, and other shared infrastructure—are not only connected to electricity but benefit from uninterrupted and high-quality supply that enables consistent service delivery. Although reliability is rated at Tier 4 rather than Tier 5, the overall effect on the access index remains minimal; the system demonstrates only limited instances of outages or voltage instability, and these disruptions do not materially constrain infrastructure operations. The classification of capacity at Tier 5 further underscores the system's readiness to support existing and future energy-intensive service needs, a critical requirement for scaling community development interventions. The resulting access index score of 80, fully contributed by Tier 4 and above attributes, thus reflects a structurally mature energy environment. Taken together, these findings indicate that Idas Village has surpassed the typical constraints faced by rural communities in emerging economies, where shortages in affordability, legality, or supply consistency often restrict infrastructure performance. Instead, the village appears well-positioned to leverage energy-enabled community services as a platform for broader socio-economic improvements, including enhanced education, improved health services, and stronger local governance capacity.

3.4. Sillu Village

3.4.1. Household Access to Electricity

No	ATTRIBUTES	Sillu Village					
		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1	Power Capacity	0%	66%	21%	8%	6%	0%
2	Availability	0%	0%	0%	0%	0%	100%
3	Reliability	0%	0%	0%	0%	30%	70%
4	Quality	0%	0%	0%	21%	8%	72%
5	Affordability	0%	98%	2%	0%	0%	0%
6	Legality	0%	0%	0%	0%	0%	100%
7	Health & Safety	0%	0%	0%	13%	8%	79%

Sillu Village			
TIER	Access Score	Proportion %	Contribution to Access Index (AI)
(k)	(V_k)	(P)	(V_k × P)
0	0	0%	0,00
1	20	100,00%	20,00
2	40	0%	0,00
3	60	0%	0,00
4	80	0%	0,00
5	100	0%	0,00
		Access Index:	20,00

The results from Sillu Village illustrate a paradox often observed in rural electrification contexts: households benefit from high service continuity and legality, yet remain fundamentally constrained by low-tier power capacity and affordability. Despite universal Tier 5 availability and legality—indicative of stable grid connection and formalized supply—two-thirds of households remain at Tier 1 for capacity, with only a marginal share reaching Tier 3 or Tier 4. This overwhelmingly low capacity classification implies that although electricity is consistently accessible, it is primarily sufficient only for lighting and low-load appliances, thereby limiting meaningful household-level energy use that could enhance productivity or welfare. The reliability indicators, with 70% at Tier 5 and the remainder at Tier 4, suggest that disruptions are rare and unlikely to inhibit energy use; similarly, voltage quality is generally adequate, with 72% of households at Tier 5. However, the affordability results sharply contrast with these positive supply-side attributes: 98% of households fall under Tier 1 for affordability, meaning that electricity expenditure exceeds recommended income thresholds for the vast majority of users. This affordability deficit effectively offsets the benefits of high technical performance and prevents households from upgrading appliances or increasing consumption in ways that would unlock higher living standards. Health and safety performance remains strong, with most households at Tier 5, indicating that wiring and installation conditions meet basic safety norms. Overall, the dominance of Tier 1 contributions to the access index (20.00 out of 20.00) shows that Sillu Village's household electricity access is structurally anchored at the lowest functional tier despite otherwise robust supply quality. These findings emphasize that electrification outcomes cannot be fully understood through availability and reliability alone; rather, affordability and capacity emerge as binding constraints that limit the transformative potential of electricity access in rural settings.

3.4.2. Access to Energy for Productivity Engagements

No	ATTRIBUTES	Sillu Village					
		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1	Capacity	0%	83%	4%	13%	0%	0%
2	Availability	0%	0%	0%	0%	0%	100%
3	Reliability	0%	0%	0%	0%	17%	83%
4	Quality	0%	0%	0%	21%	0%	79%
5	Affordability	0%	0%	0%	0%	0%	100%
6	Legality	0%	0%	0%	0%	0%	100%
7	Convenience	0%	0%	0%	0%	0%	100%
9	Safety	0%	0%	0%	21%	8%	71%

Sillu Village			
TIER	Access Score	Proportion %	Contribution to Access Index (AI)
(k)	(V_k)	(P)	($V_k \times P$)
0	0	0%	0,00
1	20	83,33%	16,67
2	40	4,17%	1,67
3	60	12,50%	7,50
4	80	0%	0,00
5	100	0%	0,00
		Access Index:	**25,83**

The findings from Sillu Village indicate that while the institutional and operational conditions for productive-energy use are well established, the actual functional capacity of electricity to support productivity remains substantially limited. Under the MTF, productive engagements require not only continuous and legal electricity access but sufficient power capacity and quality to operate business-related or income-generating equipment. In Sillu Village, however, 83% of productive users fall under Tier 1 for capacity, with only a small minority reaching Tier 3. This overwhelmingly low capacity classification suggests that most productive activities remain restricted to very low-load appliances, preventing households or local enterprises from adopting machinery, cold storage, or other equipment that could expand economic opportunities. This technical constraint persists despite near-perfect service continuity—availability and legality are universally at Tier 5, and reliability is high with 83% at Tier 5. The system therefore exhibits a structural mismatch: the grid is present, legal, and stable, yet does not deliver sufficient power for productive-scale usage.

Voltage quality further reinforces this limitation. Although 79% of respondents report Tier 5 voltage conditions, the remaining 21% at Tier 3 indicate intermittent voltage drops that may deter investments in sensitive productive equipment. Safety and wiring conditions show similar disparities; while most users fall under Tier 5, a non-trivial share at Tier 3 and Tier 4 reflects that certain households or enterprises still face technical risks that could hinder electricity-driven productivity. In contrast, affordability, legality, and convenience—all universally at Tier 5—demonstrate that economic and institutional barriers are minimal. This suggests that local enterprises are not hindered by regulatory or cost-related constraints but primarily by the technical inadequacy of supply for productive loads.

The dominance of Tier 1 contributions to the access index (16.67 out of 25.83 total) underscores how deeply the low capacity issue depresses overall productive energy access in Sillu Village. Even with strong performance across availability, affordability, and reliability, the village remains anchored at the lowest functional tier for productivity. From the perspective of the MTF, this pattern reflects a scenario in which electrification has succeeded in providing access but has not yet translated into meaningful economic empowerment. The gap between high-tier service quality and low-tier capacity highlights a critical bottleneck: without upgrades to generation or distribution capacity, productive use of energy will remain marginal, limiting the broader development impacts that electrification is expected to catalyze.

3.5. Sumberwaru Village

3.5.1. Household Access to Electricity

No	ATTRIBUTES	Sumberwaru Village					
		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1	Power Capacity	0%	19%	0%	52%	29%	0%
2	Availability	0%	0%	0%	0%	0%	100%
3	Reliability	0%	0%	0%	10%	48%	43%
4	Quality	0%	0%	0%	0%	10%	90%
5	Affordability	0%	14%	81%	5%	0%	0%
6	Legality	0%	0%	0%	0%	0%	100%
7	Health & Safety	0%	0%	0%	0%	10%	90%

Sumberwaru Village			
TIER	Access Score	Proportion %	Contribution to Access Index (AI)
(k)	(V_k)	(P)	($V_k \times P$)
0	0	0%	0,00
1	20	33,33%	6,67
2	40	66,67%	26,67
3	60	0%	0,00
4	80	0%	0,00
5	100	0%	0,00
		Access Index:	**33,33**

The results from Sumberwaru Village demonstrate a relatively advanced stage of household electrification under the MTF, yet one that is still characterized by uneven progress across key household-level attributes. The distribution of power capacity—ranging from Tier 1 (19%) to Tier 4 (29%) with a majority at Tier 3 (52%)—indicates that while most households possess sufficient power for medium-load appliances, a significant share remain limited to basic appliances, and less than one-third are able to operate multiple high-load devices simultaneously. This partial advancement suggests that household electrification has moved beyond minimal access but has not yet reached a level where high-capacity, productivity-enhancing or convenience-enhancing appliances are widely feasible.

Electricity availability, however, is universally at Tier 5, signalling that households experience uninterrupted access for at least 23 hours a day—a major strength compared with many rural electrification contexts. Similarly, legality is uniformly at Tier 5, indicating that all households are connected through formal and compliant means. These results highlight that the village benefits from strong institutional foundations and stable supply infrastructure. Reliability is also relatively strong, with 43% of households at Tier 5 and 48% at Tier 4; only a small share (10%) still experiences sufficient outages or instability to be categorized at Tier 3. The near absence of voltage-related disruptions is further confirmed by quality indicators, where 90% of households are at Tier 5. This suggests that the supply system in Sumberwaru is capable not only of providing continuous electricity but also of maintaining voltage quality adequate for most household uses.

Affordability emerges as the key constraint within the household access dimension. Although households are largely able to pay their electricity bills, the dominance of Tier 2 (81%) indicates that many households still allocate a non-trivial share of their income to electricity, potentially limiting their ability to expand appliance ownership or increase consumption. The presence of 14% at Tier 1 confirms that affordability is a persistent challenge for a subset of the population, and this directly depresses the access index, as reflected in the significant contribution of Tier 2 scores (26.67 out of 33.33 total). This pattern suggests that while electricity is technically available and of high quality, it may not yet be economically accessible to households in a way that supports upward movement in capacity tiers.

Health and safety indicators are consistent with the broader pattern of infrastructure maturity. With 90% at Tier 5, household wiring and safety conditions appear to be well-established, reducing risks associated with overloading or unsafe installations. The remaining 10% at Tier 4, however, suggests that some households may still require improvements in wiring standards or protective devices, especially as appliance ownership grows.

Overall, the MTF profile of Sumberwaru Village shows that the fundamental barriers to household electricity access are no longer rooted in supply availability, reliability, or quality—those dimensions are consistently high-tier. Instead, the primary constraints are economic (affordability) and functional (insufficient power capacity for higher tiers). The village thus occupies an intermediate position where electricity access is reliable and legal but not yet transformative for all households. For electrification to translate into enhanced welfare and broader development outcomes, targeted interventions will be needed to (a) strengthen household capacity to adopt higher-load appliances, and (b) address affordability gaps that limit the full utilization of the high-quality supply already available.

3.5.2. Access to Energy for Productivity Engagements

No	ATTRIBUTES	Sumberwaru Village					
		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1	Capacity	0%	18%	0%	45%	36%	0%
2	Availability	0%	0%	0%	0%	0%	100%
3	Reliability	0%	0%	0%	9%	36%	55%
4	Quality	0%	0%	0%	0%	9%	91%
5	Affordability	0%	0%	0%	0%	0%	100%
6	Legality	0%	0%	0%	0%	0%	100%
7	Convenience	0%	0%	0%	0%	0%	100%
9	Safety	0%	0%	0%	0%	18%	82%

Sumberwaru Village			
TIER	Access Score	Proportion %	Contribution to Access Index (AI)
(k)	(V_k)	(P)	($V_k \times P$)
0	0	0%	0,00
1	20	18,18%	3,64
2	40	0%	0,00
3	60	45,45%	27,27
4	80	36,36%	29,09
5	100	0%	0,00
		Access Index:	**60,00**

The results for Sumberwaru Village indicate that access to energy for productivity engagements has reached a relatively advanced stage under the MTF, though important structural gaps remain that limit the full realization of productive use potential. The capacity profile—where 45% of productive activities fall under Tier 3 and 36% under Tier 4—suggests that most enterprises and income-generating activities can operate medium-load appliances, and a substantial share can already support higher-load machinery. However, the persistence of 18% at Tier 1 indicates that a segment of microenterprises, home-based activities, or small-scale processing units remain constrained to very basic appliances. This capacity distribution demonstrates that while Sumberwaru has the foundations for diversified economic activity, the energy system still does not universally support more energy-intensive or growth-oriented enterprises.

Availability at Tier 5 for all respondents represents a major enabling condition for productivity. Continuous and predictable electricity access is critical for businesses that rely on refrigeration, machinery, or digital equipment. This places Sumberwaru in a comparatively strong position relative to many rural contexts where power interruptions are a common bottleneck to economic expansion. Reliability indicators reinforce this: 55% of productive users are already at Tier 5 and another 36% at Tier 4, meaning that outages and voltage drops infrequently disrupt business operations. Only 9% remain at Tier 3, suggesting that supply interruptions rarely reach levels that threaten the viability of productivity engagements.

Electricity quality is similarly robust, with 91% in Tier 5 and 9% in Tier 4. High voltage stability is particularly important for economic activities involving motors, welding equipment, or digital tools—underscoring the capability of the local system to support a wide range of productive uses without risk of equipment damage or operational downtime. The consistent Tier 5 scores for affordability, legality, and convenience further indicate that the institutional and financial environment allows enterprises to access electricity without excessive cost burdens or administrative barriers. This institutional foundation is especially important, as productive-use customers often face higher tariffs or complex permitting processes in other contexts; neither appears to be a constraint in Sumberwaru.

Safety indicators—82% at Tier 5 and 18% at Tier 4—also reflect strong technical readiness, with only minor improvements needed in wiring or protective systems for a small subset of productive sites. Overall, this technical environment aligns well with the increasing global emphasis on "productive use of energy" as a pathway for rural economic transformation.

Despite these strengths, the access index value of 60.00 reveals that the system has not yet reached its full productive potential. This is mainly driven by the continued presence of lower-tier capacity (Tier 1 at 18% and Tier 3 at 45%), which depresses the overall index because capacity is the binding constraint in the MTF framework. Even with excellent availability and quality, enterprises cannot expand production or diversify activities if their energy capacity remains insufficient for high-load equipment. Thus, the bottleneck in Sumberwaru is not supply reliability or quality, but rather the limited upgrading of internal electrical installations or the adoption of higher-capacity connections by enterprises.

In summary, Sumberwaru Village demonstrates a near-complete readiness in terms of supply-side attributes—availability, reliability, quality, affordability, and legality all align with Tier 5 standards. However, the capacity constraint remains the primary barrier preventing the transition from basic and moderate productive uses to more transformative economic activities. Addressing this gap—whether through facilitated upgrades, financial support for stronger connections, or enterprise-level capacity-building—will be pivotal in enabling the village to move toward higher-tier, energy-enabled economic development.

3.6. Hiligodu Village

3.6.1. Household Access to Electricity

No	ATTRIBUTES	Hiligodu Village					
		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1	Power Capacity	0%	57%	5%	23%	11%	5%
2	Availability	0%	0%	0%	0%	0%	100%
3	Reliability	0%	0%	0%	7%	55%	39%
4	Quality	0%	0%	0%	16%	0%	77%
5	Affordability	0%	64%	36%	0%	0%	0%
6	Legality	0%	0%	0%	0%	0%	100%
7	Health & Safety	0%	0%	0%	14%	25%	52%

Hiligodu Village			
TIER	Access Score	Proportion %	Contribution to Access Index (AI)
(k)	(V_k)	(P)	($V_k \times P$)
0	0	0%	0,00
1	20	70,45%	14,09
2	40	22,73%	9,09
3	60	0%	0,00
4	80	0%	0,00
5	100	0%	0,00
		Access Index:	**23,18**

The household electricity access profile of Hiligodu Village reflects a community that has achieved universal connection and strong supply-side performance but continues to face significant constraints in terms of household-level capacity and affordability—two attributes that are central in determining overall tier placement in the MTF and, consequently, the village's access index score.

Although all households benefit from Tier 5 availability, indicating electricity that is provided 24 hours per day, this high level of service does not translate into equally high functional access due to substantial limitations in power capacity. More than half of households (57%) fall within Tier 1, capable of powering only basic lighting and small devices. While modest progress is indicated by the presence of households in Tier 3 (23%), Tier 4 (11%), and even Tier 5 (5%), the predominance of Tier 1 underscores a structural bottleneck that severely restricts the range of appliances households can use. Under the MTF framework, capacity is typically the binding constraint in rural electrification contexts, and this pattern is evident in Hiligodu. Despite being connected, many households remain effectively under-electrified, unable to transition toward energy services that meaningfully enhance comfort, productivity, or well-being.

Supply quality indicators—reliability and voltage stability—show a considerably more positive picture. A combined 94% of households are in Tier 4 or Tier 5 for reliability, suggesting outages are limited and generally not severe enough to disrupt daily routines. The quality attribute mirrors this, with 77% of households reporting Tier 5 voltage stability, ensuring appliances can function without risk of damage. These results show that the central grid or local distribution infrastructure is capable of delivering high-quality electricity, and that the main constraints do not stem from the supply side.

Affordability, however, emerges as another critical limitation. A substantial proportion of households (64%) fall under Tier 1 for affordability, meaning that electricity expenditures exceed the benchmark threshold defined by the MTF. This implies that while households are legally and technically connected, electricity remains financially burdensome for many families. Combined with limited power capacity, these affordability constraints may deter households from upgrading their connections, purchasing appliances, or using electricity more extensively—reinforcing a cycle of low-tier access. The fact that 36% of households fall under Tier 2 affordability suggests some variation in economic capacity, but still highlights widespread financial constraints affecting the community.

Legality at Tier 5 across all households reflects a strong institutional environment where connections are formal, regulated, and compliant with utility standards. Likewise, health and safety indicators are moderately strong, with 52% at Tier 5 and another 25% at Tier 4. These results indicate proper wiring, adherence to safety norms, and limited exposure to electrical hazards. However, the 14% of households at Tier 3 suggest that a non-negligible minority still faces potential risks associated with outdated wiring or insufficient safety protections.

Taken together, these findings explain the relatively low access index score of 23.18. While the village benefits from universal, high-quality electricity supply, household-level access is constrained primarily by low power capacity and affordability challenges—two attributes that heavily influence the overall tier classification under the MTF. The results indicate that Hiligodu Village has moved beyond the initial challenge of basic connectivity, and now faces the more complex task of deepening access. Policies aimed at enabling affordable upgrades, subsidizing higher-capacity connections, and reducing the cost burden for low-income households will be essential to facilitate the transition from basic access toward meaningful, higher-tier electricity use.

In summary, Hiligodu Village demonstrates the common phenomenon where connection alone does not equate to functional, high-tier access. Strengthening both household-level capacity and affordability will be critical for translating universal availability into the transformative benefits that electrification is expected to deliver.

3.6.2. Access to Energy for Productivity Engagements

No	ATTRIBUTES	Hiligodu Village					
		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
1	Capacity	0%	42%	0%	25%	17%	17%
2	Availability	0%	0%	0%	0%	0%	100%
3	Reliability	0%	0%	0%	8%	42%	50%
4	Quality	0%	0%	0%	42%	0%	58%
5	Affordability	0%	0%	0%	0%	0%	100%
6	Legality	0%	0%	0%	0%	0%	100%
7	Convenience	0%	0%	0%	0%	0%	100%
9	Safety	0%	0%	0%	17%	17%	58%

Hiligodu Village			
TIER	Access Score	Proportion %	Contribution to Access Index (AI)
(k)	(V_k)	(P)	($V_k \times P$)
0	0	0%	0,00
1	20	33,33%	6,67
2	40	0%	0,00
3	60	50,00%	30,00
4	80	8,33%	6,67
5	100	0%	0,00
		Access Index:	**43,33**

The assessment of access to energy for productivity engagements in Hiligodu Village reveals a community that benefits from strong supply-side performance—particularly in availability, legality, affordability, and convenience—yet continues to face significant constraints in the very attributes that most directly shape the productive use of electricity under the MTF: capacity, reliability, and safety. These constraints collectively limit the village's ability to translate grid access into meaningful economic gains, resulting in a moderate access index score of 43.33.

The most prominent barrier lies in the capacity attribute. Despite the presence of higher-tier connections—17% of households each in Tier 4 and Tier 5—the dominant share of productivity users remains in Tier 1 (42%). This indicates that small enterprises or household-based income activities operate under very limited wattage, restricting them to basic appliances such as small lighting, charging devices, and perhaps low-power machinery. Only a quarter of the community has reached Tier 3, where energy services begin to enable more substantial productive activities. This distribution suggests a dual challenge: households may lack the financial resources to upgrade to higher-capacity connections, and existing economic structures may not yet create strong incentives for such upgrades. Under the MTF framework, capacity is often the defining constraint for productive engagements because it determines the range and scale of economic activities that electricity can support. In Hiligodu, this constraint clearly shapes the overall access outcome.

Reliability further reinforces these limitations. Although half of respondents are in Tier 5 and another 42% in Tier 4, the remaining 8% in Tier 3 indicate that outages and voltage fluctuations still affect a portion of productivity users. For businesses that rely on consistent power—such as refrigeration, mechanical tools, and small-scale digital services—intermittency increases operational costs and reduces efficiency. While the overall reliability profile is relatively strong, the presence of Tier 3 users signals that electricity-dependent enterprises may face occasional disruptions, discouraging expansion into electricity-intensive activities.

Quality also emerges as a mixed attribute. The fact that 42% of users remain in Tier 3 for voltage quality suggests that fluctuations are still common enough to pose risks for machinery and electronic equipment. Given that productive engagements typically require stable voltage to avoid damage or downtime, this limitation likely reduces users' willingness to invest in electrical appliances that could enhance productivity. The remaining 58% of users in Tier 5 do experience high-quality electricity, but uneven voltage stability across the community contributes to the fragmented nature of productive electricity use.

The strong performance in affordability, legality, and convenience—each at Tier 5—indicates that the institutional and regulatory environment for productive electricity use is robust. Households and enterprises are formally connected, the billing system is functioning and perceived as fair, and obtaining or modifying electricity connections appears straightforward. Affordability in particular is notable: unlike the household access assessment in some other villages where electricity expenditures exceeded MTF thresholds, productive users in Hiligodu face no cost-related barriers. This suggests that the constraint on productive electricity use is not financial access but rather technical suitability, especially capacity and quality.

Safety conditions are moderately strong, with 58% at Tier 5 and 17% each in Tiers 3 and 4. While most enterprises operate in safe electrical environments, the presence of lower-tier users indicates that some wiring systems, distribution points, or equipment may not meet safety standards. Safety concerns often discourage users from adopting higher-power appliances, reinforcing the limited utilization of electricity for economic purposes.

The resulting access index score of 43.33 reflects a system where supply-side fundamentals are strong, but the enabling conditions for meaningful energy-driven productivity remain underdeveloped. The relatively high contribution from Tier 3 (30.00) signifies that the village is in a transitional stage—moving beyond basic access but not yet positioned to unlock the full economic potential of electricity. Low-tier capacity remains the critical bottleneck, preventing households and local enterprises from scaling their activities or investing in more advanced technologies.

In sum, the findings from Hiligodu Village highlight a familiar pattern in rural electrification: achieving universal, high-quality grid connection does not automatically translate into enhanced economic productivity. To climb to higher tiers in the MTF framework, interventions must focus on increasing connection capacity, stabilizing voltage fluctuations, and addressing safety concerns for the minority still in lower tiers. Without these improvements, electricity will continue to serve essential functions but fall short of enabling the transformative economic impacts that rural electrification programs aim to achieve.

3.6.3. Access to Energy for Community Infrastructure

	Attributes	Prayer Facilities (Hiligodu Village) Tier 0	1	2	3	4	5
1	Capacity						✓
2	Availability						✓
3	Reliability					✓	
4	Quality						✓
5	Affordability						✓
6	Legality						✓
7	Convenience						✓
9	Safety						✓

Hiligodu Village			
TIER (k)	Access Score (V_k)	Proportion % (P)	Contribution to Access Index (AI) ($V_k \times P$)
0	0	0%	0,00
1	20	0%	0,00
2	40	0%	0,00
3	60	0%	0,00
4	80	100%	0,00
5	100	0%	0,00
Total		100%	**80,00**

The findings for community-level infrastructure in Hiligodu Village reveal an atypically strong performance across nearly all MTF attributes, positioning the village at the upper end of the access spectrum. Unlike the mixed or fragmented patterns often observed in rural electrification contexts—where community facilities frequently lag behind household or productive uses—the results here indicate that community infrastructure benefits from a highly mature and robust energy system, reflected in its Tier 5 scores for capacity, availability, quality, affordability, legality, convenience, and safety. Such uniformity suggests the presence of a well-established supply chain coupled with governance arrangements that prioritize essential services.

A defining strength in the dataset is the Tier 5 rating for capacity, which implies that community facilities have not only sufficient power for basic operations but are also capable of supporting more energy-intensive services. This level of provisioning is particularly significant because MTF literature emphasises capacity as a foundational enabler for advanced services in education, health, public administration, and security. When community infrastructure attains high capacity, it can support refrigeration for vaccines, ICT equipment in schools, street lighting, and water pumping—each of which contributes materially to human development outcomes.

Similarly, availability at Tier 5—indicating near-continuous supply—positions Hiligodu as an outlier relative to rural electrification challenges documented across low and middle-income countries, where community infrastructure frequently suffers from rationing or intermittent supply. The reliability tier score (Tier 4), though slightly lower, remains consistent with a system that experiences infrequent but non-negligible disruptions. This pattern is aligned with MTF expectations for maturing rural grids, where reliability often improves more slowly than availability due to constraints in distribution infrastructure, maintenance cycles, and fault-response mechanisms.

The consistently high ratings in quality, affordability, legality, convenience, and safety suggest institutional capacities that extend beyond hardware provisioning. For instance, Tier 5 affordability reflects not only that community institutions can meet tariff obligations, but also that the tariff structure, subsidies, or budget allocations are likely designed to ensure uninterrupted service for critical facilities. Likewise, legality and safety at Tier 5 demonstrate strong regulatory compliance and effective risk-management mechanisms—an outcome that often requires coordination between local authorities, utility providers, and community organisations. The strong performance in these attributes also implies a reduced risk of service downgrades, given that legal and safe connections help maintain long-term system stability and reduce operational losses.

Collectively, these high-tier assessments contribute to a total access index score of 80, anchored primarily by the Tier 4 contribution from reliability. In MTF interpretation, this level of performance indicates that community infrastructure in Hiligodu possesses characteristics typical of advanced energy systems that enable continuous service delivery and support socio-economic development. Importantly, the strong performance at the community level may generate positive spillovers for households and productive uses by strengthening institutional capacity, ensuring stable demand anchors for the electricity provider, and creating opportunities for integrated planning of energy services.

Nevertheless, the slight limitation in reliability highlights a potential bottleneck. Although Tier 4 reliability is relatively high, it still reflects vulnerability to interruptions that could impact critical services such as healthcare or digital systems. Future electrification strategies should therefore focus on improving fault resilience, backup supply mechanisms, and distribution network reinforcement to transition community facilities toward full Tier 5 reliability.

In summary, Hiligodu Village demonstrates one of the strongest community-infrastructure energy profiles observed within rural MTF contexts, and these conditions are likely to contribute substantially to local development outcomes. Strengthening reliability further would not only elevate the community infrastructure to full Tier 5 status but may also catalyze improvements across household and productive-use tiers, supporting a more inclusive and integrated energy ecosystem.

4. Discussion

The findings across the three study villages—Sillu, Sumberwaru, and Hiligodu—reveal a nuanced landscape of electricity access within rural electrification contexts under the Multi-Tier Framework (MTF). While all villages exhibit strong supply-side performance, especially in availability, legality, and voltage quality, their overall access trajectories diverge significantly due to persistent constraints in capacity and affordability at the household and productive-use levels. These variations underscore the critical distinction between *being connected to electricity* and *deriving meaningful, transformative benefits from electricity access*.

4.1. Supply-Side Strengths: Universal Availability but Divergent Outcomes

Across all sites, availability and legality consistently achieve Tier 5 ratings, confirming near-universal connectivity, 24-hour service, and formalized grid access. This reflects the success of electrification efforts in establishing the foundational infrastructure required for rural energy access. Voltage quality and reliability similarly show strong performance in Sumberwaru and Hiligodu, where most users fall within Tiers 4 or 5. Even in Sillu Village—though generally disadvantaged in capacity and affordability—voltage stability and service continuity remain robust.

However, while supply-side conditions are strong and relatively uniform across villages, they do not translate directly into high tiers of functional access. The data clearly demonstrate that technical availability alone cannot guarantee meaningful electricity use. Instead, household-level

Volume 2, Number 1, December 2025, E-ISSN 3090-1650
https://doi.org/10.33322/jtpeep.v2i1/173

constraints such as limited connection capacity and affordability determine actual energy service levels.

4.2. Low Capacity as the Dominant Bottleneck Across All Villages

The most pervasive constraint identified across all three villages is low power capacity, particularly among households and productive-use customers.

- **Sillu Village** shows the most extreme case, with more than two-thirds of households and 83% of productive users stuck at Tier 1, despite enjoying Tier 5 availability and reliability. This reveals a structural mismatch: strong grid presence but inadequate power delivered to households.
- **Hiligodu Village** reflects a similar pattern, with 57% of households and 42% of productive users at Tier 1. Even though supply quality is high, the limited household connection capacity prevents residents from using appliances beyond basic lighting and charging.
- **Sumberwaru Village**, while better positioned—with nearly half of productive users reaching Tier 3 or Tier 4—still shows significant household-level constraints, evidenced by the 19% of households at Tier 1 and only 29% achieving Tier 4. The village thus remains in a transitional phase where capacity has improved but is not yet universally adequate.

These patterns affirm that under the MTF, **capacity remains the binding constraint** determining tier classification and overall access scores. Without sufficient wattage to support medium- to high-load appliances, households cannot progress towards energy-enabled comfort or productivity, and enterprises cannot adopt machinery necessary for income growth.

4.3. Affordability as a Secondary but Critical Constraint

Affordability emerges as another major barrier in Sillu and Hiligodu:

- **Sillu Village** shows extreme affordability limitations, with 98% of households at Tier 1. This financial burden prevents households from upgrading their connections, purchasing appliances, or increasing consumption.
- **Hiligodu Village** exhibits similar challenges, with 64% of households at Tier 1 for affordability. These constraints reinforce under-utilization of electricity, despite universal availability.
- **Sumberwaru Village**, by contrast, shows improved affordability (dominantly Tier 2), yet a portion of households (14%) still fall under Tier 1. The economic barrier is less severe than in the other two villages but still influential in suppressing higher-tier access.

In productive engagements, affordability is less constraining—especially in Hiligodu and Sumberwaru, where productive users are universally at Tier 5. This suggests that enterprises may have different cost structures or income stability compared to households. However, the lack of affordability at the household level still indirectly affects productive potential, because households often serve as the base for home-based enterprises.

4.4. Reliability and Quality: Strong but Not Sufficient for Transformation

All three villages demonstrate high performance in reliability and voltage quality, especially Sumberwaru and Hiligodu. Although minor variations exist—such as the 21% of Sillu productive users at Tier 3 for voltage—these do not constitute the dominant barriers for moving up the MTF tiers.

https://doi.org/10.33322/jtpeep.v2i1/173

This reinforces a key insight: **the primary limitations in rural electrification are no longer outages or poor voltage but rather the inadequacy of customer-level infrastructure and economic capacity**. Upgrading the grid alone is not enough if households remain unable to afford or physically support higher-capacity connections.

4.5. Productive Use Readiness: Strong Institutional Conditions but Weak Technical Enablement

Across the three villages, the institutional attributes for productive electricity use—legality, convenience, and affordability—are consistently at Tier 5. This demonstrates that regulatory and administrative conditions are conducive for enterprise-level energy use.

However, productive capacity remains low or uneven:

- **Sillu Village** remains severely constrained, with 83% of productive users at Tier 1. This prevents the adoption of machinery essential for economic diversification.
- **Hiligodu Village** shows moderate readiness, with 42% at Tier 1 but a noticeable proportion (33%) reaching Tier 4 or Tier 5. Nonetheless, voltage fluctuation (42% at Tier 3 for quality) deters investment in sensitive equipment.
- **Sumberwaru Village** stands out as the most prepared, with 36% in Tier 4 and 45% at Tier 3. However, the remaining 18% at Tier 1 still drags down the overall access index and highlights persistent inequities in energy-enabled economic opportunities.

These findings illustrate a wider phenomenon: **productive-use electrification tends to lag behind grid electrification due to limitations in customer-level capacity rather than supply-side shortcomings**.

4.6. Community Infrastructure: High-Tier Access with Strong Development Implications

The community infrastructure analysis—particularly in Hiligodu Village—shows exceptionally strong performance, with nearly all attributes at Tier 5. This is atypical in rural electrification contexts, where community facilities such as health centers, schools, or water pumps often lag behind households.

The Tier 5 capacity and reliability of community services suggest:

- robust public infrastructure investments,
- prioritization of essential services,
- and a recognition that community facilities must maintain high performance regardless of household-level access disparities.

This high-tier performance offers opportunities for community-level transformation but also highlights the disconnect between institutional resilience and household limitations.

4.7. Cross-Village Comparison and Emerging Patterns

Taken together, the three villages represent stages of progress along the rural electrification continuum:

- **Sillu Village**:
  Grid-ready but functionally under-electrified.
  High supply quality coexists with extreme capacity and affordability constraints.
- **Sumberwaru Village**:
  Intermediate stage with promising productive-use readiness.
  Strong supply-side performance with moderate household capacity and limited affordability barriers.

- **Hiligodu Village**:
  Universal connection but limited functional access.
  High availability and reliability overshadowed by persistent household-level capacity and affordability limitations.

Across all villages, a clear pattern emerges: **the gap between supply and functional access is driven primarily by household and enterprise-level constraints**, not the grid itself.

4.8. Implications for Electrification Policy and Rural Development

The results highlight several critical implications:

1. **Capacity upgrades must be prioritized**, not only grid expansion. Without adequate household capacity, electricity cannot support higher-tier services.
2. **Affordability interventions are essential**, especially in low-income households. Subsidized upgrades, tariff adjustments, or targeted financial assistance may be required.
3. **Productive-use programs must focus on enabling customers**, not only strengthening supply.
   This includes microfinancing for equipment, support for upgrading wiring, and training.
4. **Community infrastructure can serve as a catalyst** for broader development, but only if households are supported to utilize electricity in meaningful ways.
5. **Electrification strategies must transition from coverage-based metrics to service-based and outcomes-based metrics**, aligned with the MTF philosophy.

4.9. Synthesis

In conclusion, the analysis of Sillu, Sumberwaru, and Hiligodu Villages demonstrates that rural electrification has achieved significant gains in terms of supply-side readiness. Yet these gains have not fully translated into high-tier, transformative access for households and enterprises. Capacity and affordability remain the dominant barriers across sites, limiting the developmental potential of electricity access. Addressing these bottlenecks requires a shift from infrastructure-centric approaches to user-centric strategies that enhance the ability of households, enterprises, and communities to meaningfully use electricity.

5. Conclusion

This study demonstrates that the Multi-Tier Framework (MTF) provides a more refined and meaningful interpretation of electricity access in Indonesia, complementing rather than replacing the national Electrification Ratio (ER). While ER remains essential for tracking connectivity progress, the MTF reveals the *quality* of access experienced by end-users—an aspect that cannot be captured by connection status alone.

Field assessments conducted in Barrang Caddi, Yarweser, Sillu, and Idas show that although all surveyed communities are officially "electrified," their actual electricity service levels vary widely. Key service gaps were observed in the attributes of **power capacity**, **reliability**, and in some cases **affordability**, depending on local socio-economic and geographic contexts. On-grid villages such as Idas and Hiligodu benefit from lower social tariffs and generally high availability, yet still face frequent outages. Off-grid SuperSUN sites in Barrang Caddi and Yarweser provide essential first-level access, but remain limited in capacity and duration due to system constraints.

By quantifying these variations through the Access Index (AI), the MTF helps reveal which attributes contribute most to low service levels and therefore require priority intervention. The AI also gives policymakers, PLN, and development partners a more grounded understanding of energy access conditions—one that aligns more closely with the real experiences of households, productive users, and community facilities.

Overall, this study concludes that integrating the MTF alongside Indonesia's ER can significantly strengthen national electrification planning. The combined approach supports more targeted policy formulation, helps PLN identify location-specific service improvements, and offers a clearer pathway toward achieving **SDG 7.1: universal access to affordable, reliable, and modern energy**. Future research may expand the sample size, explore temporal variations in electricity use, and test the integration of MTF indicators into Indonesia's broader energy-access monitoring framework.

References

[1] United Nations Department of Economic and Social Affairs (2025). The Sustainable Development Goals Report 2025. New York.

[2] Bhatia, Mikul; Angelou, Niki. 2015. ***Beyond Connections: Energy Access Redefined***. ESMAP Technical Report; 008/15. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/24368