Sustainably Electrifying Remote Rural Communities Through Bottom-up Approach in Remote Rural Papua New Guinea: A Case study of Telefomin, West Sepik Province-PNG

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This study assesses the current electricity situation and proposes a plan to increase electricity access towards more energy services in the three villages of Missinmin, Iginfumavip (Infuma) and Bogelmin in remote Telefomin District, Sandaun Province, Papua New Guinea (PNG). PNG ranks very lowly in many socioeconomic indicators in the Asia-Pacific region, and Telefomin District within PNG is ranked one of the least developed districts in Papua New Guinea with poor socioeconomic indicators culminating with a high poverty rate and low literacy ratio (Rogers, Bleakley, & Ola, 2011). This study uses a bottom-up data collection, proposed 13-part assessment framework and the World Bank developed Multi-tier Framework (MTF) to chart a more sustainable electrification strategy for 3 satellite villages on the outskirts of Telefomin station.

The local conditions particularly due to access to economic markets and geographic terrain render context-specific electrification strategies to increase access. Purely top-down economic approaches using GDP and related data simply do not work in developing countries like Papua New Guinea where the majority depend on the informal agriculture sector and only a small population benefits from the extractive industry which has a significant contribution to the GDP (Kopel, 2017; Kumar & Mourshed, 2018). The bottom-up approach in this study involved a simple but effective end-user survey, interviews with the community leaders and focus group discussions that were conducted for a larger donor-funded scoping mission on sustainable electrification interventions in Telefomin station and surrounding satellite villages(Ugwoke, Sulemanu, Corgnati, Leone, & Pearce, 2021). The MTF provides more information on the depth of electricity access at the community level (household, community facility, streetlights and productive uses) (Bhatia & Angelou, 2015). Lastly, the proposed 13-part assessment framework is an extension of the 7-Element Sustainable Energy Access Planning Framework developed by (Shrestha & Acharya, 2015) that involves bringing pertinent sustainability issues to the fore while also integrating other development challenges.

There is limited literature focused on addressing rural electrification challenges in PNG and this paper contributes to a slowly growing number of literature with focus on rural electrification. Just after independence in 1975 experiences were shared by a few researchers on the challenges of rural offgrid projects which revolved around operation and management, capital cost and affordability (Bowman, 1985; Greenwood & Robinson, 1982; Kinnell, 1982; Robinson, 1988). Some of the issues raised are still relevant today but technology has improved significantly, and the cost of the system has been drastically reduced with rural people now able to afford the most basic solar lantern, albeit low quality. From the 1990s to the present a few researchers have used advanced techno-economic tools to suggest electrification strategies, unfortunately, most appear to be more of an academic exercise of testing tools and models with a lack of socioeconomic context(Kaur & Segal, 2017; Nagai, Yamamoto, & Yamaji, 2010; Suryanarayanan, 2018). Sovacool highlighted the socioeconomic and technical challenges of increased uptake of solar, however, a few years after the paper were published solar uptake increased exponentially, especially Tier 1 systems (Engelmeier & Gaihre, 2019; Sovacool, D'Agostino, & Dambawale, 2011). Now the challenge is getting households to gradually jump to quality systems that have an increased capacity[1], availability[2] and reliability[3] while also being affordable, to ultimately lead to improved lives and livelihoods.

[1] Capacity-Number of Appliances that can be catered for

[2] Availability of service when needed

[3] Rate of interruptions energy service

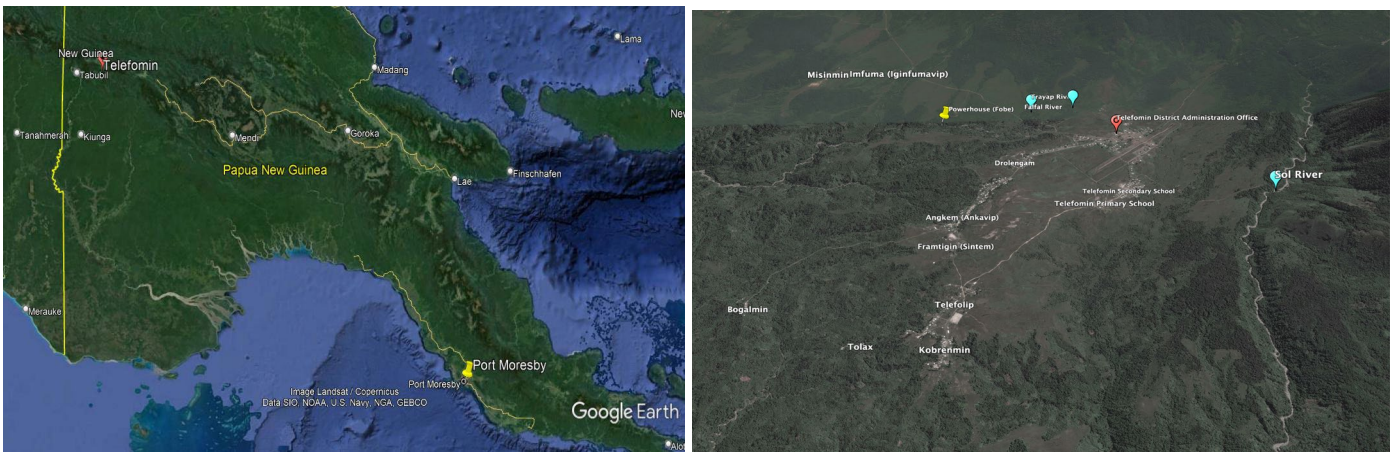

Figure 1: (a) Location of isolated Telefomin station in PNG (b) Villages with respect to the Telefomin District Administration Building

The 13-part assessment focuses on

1. establishing the baseline;
2. identify opportunities to :-
    a. ensure the energy intervention is appropriate, meets the needs and affordable.
    b. ensure long-term sustainability.
    c. integrate with other development challenges.
    d. chart the path towards increased capacity, availability, and reliability.

Table 1: 13-Part Assessment based on data collected

	Assessment	
1	Demand	• Based on the comprehensive MTF, about 95% of households are categorized at Tier 0 while the remainder are categorized between Tier 1 and Tier 2 due to the low-quality solar task lights that include low power mobile charging capabilities, single-use battery torches and shared amongst 6+ people in a household. In terms of streetlights, the communities fair well at around Tier 3 with the installation of at least 6 low-quality streetlights a few years ago and the only community elementary school at Missinmin is at Tier 0. In terms of productive uses, the shops, communal motorized tools powered by diesel generators and a diesel-powered mobile sawmill categorizes these communities in between Tier2 and 3. • The estimated daily demand of communities varies between 6.5 and 6.8 kWh per day with a total daily demand of between 3.3 and 3.5 KW. Occasionally during the day energy is used through a diesel generator to power communal motorized hand tools and the communal diesel-powered walkabout sawmill, while the low-quality solar lanterns come on at night for a few hours and charge the mobile phones during the day. • Future demand will strongly depend on the set-up of the markets (coffee, vanilla, rice etc) because of the road connection to the mining town of Tabubil in 2024. The demand for the next couple of years will be almost stagnant until 2024 and then a slow increase with the increase in household income.
2	Resource	• From ground-based monitoring, the lowest PSH [4]is around 3.68 in July and the highest is around 4.59 in March. It's not great but sufficient to run a system that is much cheaper in the long run than a diesel-based system. • Based on 16- year period of data from PNGNWS, Telefomin has two peak rainy seasons in March and September with over 350 mm of

[4] Peak Sun Hours

		rainfall. The low rainfall months are June/July with around 275 mm and in December around 225 mm. • Creek near Missinmin has a head height of about 212 m going upstream 2.2 km • Creek near Infuma has a head height of about 260 m going upstream about 2.2 km • Nearby Falfal and Trayap creek have flow rates of 0.752 cumecs and 0.510, respectively.
3	Electrification and Energy Technology	• Not too far from Missinmin/Infuma is the Telefomin Station 100 kW microhydro system which was set up in 1992 but unfortunately is not in operation now. • Minigrid distribution infrastructure in place with sufficient thermal generation (550 kW) to supply township (Pavg=250 kW) and these 3 nearby villages. • MAF households have been using inverter-based standalone solar PV systems and load-management for well over a decade. • Modular 12 V DC PV Systems: Adding panels, batteries, and appliances • Lead time for hydropower systems is much longer than solar and thermal generation • The lead time for minigrids and grid extension is much longer than standalone solar PV systems. • Energy efficient technology can play a significant role in increasing services with limited stress on demand
4	Cost	• Diesel is US$6/L • Based on 2 recently installed offgrid micro-hydropower minigrid systems in the highlands of PNG, the average cost of installation is around $11,250/kW. • Based on the only off-grid solar minigrid, it would cost around $5,625/kW • $102,000/km for 11 kV, $45,000/km for 450/240 V • Tier 1 12Vdc SHS at starting price of $400
5	Environmental	• Abundant renewables and more environmentally friendly • Rainfall predicted to increase over time in PNG • Hydropower construction is relatively more damaging to the environment • Expensive diesel assisting mitigation efforts
6	Land	• So much customary-owned grassland available for a solar farm • The community is committed to providing land if need be • Must be treated with extreme caution
7	Community Challenges	• Low incomes of between $70-90 per month due to limited market access • Safe access to clean water • Standard of living is relatively very low compared to the other communities in PNG • The community is desperate for better electricity services
8	Affordability and Willingness to Pay	• Limited income levels ($80-90/month) • Incomes should slowly increase after the road connection with Tabubil in 2024. • Communities, in general, cannot afford more appliances at the moment • The main energy costs are single-use batteries and diesel (about 10% of their monthly income) • Community not familiar with paying bills • Simple and accessible payment system especially for a predominantly cash-based economy
9	Gender Equity and Social Inclusion	• Women overworked • Women not involved in community decision-making • Women engage in selling garden vegetables and bilum-making for income-earning activities. • Girls often get married off while in school

10	Nexus with non-electricity infrastructure	• All 3 communities have mobile communications coverage, and at least every household has a mobile phone. • Bogelmin has a tap water supply, while Missinmin and Infuma depend on 2 rainwater tanks and the nearby creeks/streams • Open-fire cooking in a standalone kitchen • Communal tools/appliances for productive uses • Elementary school in Missinmin not electrified • 6 shops not electrified
11	Human Capacity	• The community is familiar with solar but still limited to larger inverter-based systems. • limited capacity to construct, operate and maintain hydro-based powerhouse/minigrids • MAF and its sister organisation MAF Technologies have implemented offgrid energy projects, both standalone and minigrid, throughout rural highlands of PNG
12	Institutional Capacity	• The set-up of the minigrid was funded by the government and managed by the Baptist Mission using a user-pay policy up until mid-2012 when the local government took over. • The local government took over and provided electricity with no tariff and could not maintain the system due to no funds and lack of capacity. • The local government does not want to engage the state-owned utility
13	Local political dynamics	• The Telefomin District Development Authority (Local Government) is the focal point. • The Telefomin member of parliament is quite influentially dues to community standing and has been the Chair of the TDDA Board • The Baptist Mission and Mission Aviation Fellowship are a well-respected authority in Telefomin • Village chiefs are held with high regard

Table 2:Technoeconomic Capital Cost Comparison of Standalone, Community Minigrid and Grid Extension

		Proposed Loads [5]		Standalone		Community Minigrid		Grid Extension[6]	
Villages	**QTY**	**Daily Demand kWh**	**Max Load kW**	**Total Cost US$**	**Cost per HH US$**	**Total US$**	**Cost Per HH US$**	**Total cost US$**	**Cost per HH US$**
Boglamin	35	44.8	10.05	$40,460	$1,226	$ 71,638	$2,171	$ 282,736	$ 8,568
Iginfumavip	35	50.8	12.05	$40,460	$1,348	$ 81,638	$2,721	$ 362,804	$6,047[7]
Misinmin	32	49.3	12.00	$41,834	$1,394	$ 84,628	$2,821		

Based on information from Table 1 the current household services are below MTF Tier 1 and the community are desperate for more improved services and therefore the energy intervention strategy going forward must contain the following temporal technoeconomic qualities:

1. In the immediate term, household electricity intervention must provide Tier 1 services at a minimum.
2. Plan for a gradual demand growth after 2024. 2024 Also defines the start of medium-term interventions.
3. Interventions must leverage off the communal tools through a community workshop. Utilize standalone community workshops to gradually introduce Tier 3-5 household appliances to the community.
4. Based on Table 2, in the immediate term, the electrification strategy should start with modular standalone PV systems that utilize community workshops(MY, 2014; Swenson & Baer, 2003) and then look towards minigrid/microgrid and grid extension in the medium to long term.
5. In terms of energy resource utilization, solar should be the focus of diesel generators for larger motorized loads in the short to medium term. In the medium to long term, the trend should head towards a mix of solar and hydro with the latter playing a more dominant role. In the short term, a

[5] IEA Minimum access demand + Community Workshop with additional appliances and Elementary School in Missinmin
[6] 4.7 km HV, 1.84 km LV
[7] Grid extension cost for both Infuma and Misinmin

hydro resource assessment must be implemented in preparation for hydropower intervention in the future.

6. Standalone PV systems must be customized to the resource availability or alternatively, the community are upskilled on load-management strategies.
7. Energy efficient technologies must be inclusive in the intervention.
8. Immediately start the dialogue. of using community customary land for the project.

In terms of the long-term sustainability and based on Table 1, the following are sustainability factors that should be captured in the planning and implementation stages to ensure successful implementation and just as importantly longevity of the interventions: -

1. The communities, the vulnerable demography (women, children and the marginalized), churches, local government, and member of parliament must be involved in the planning stages of any intervention.
2. Human capacity development programmes must be part and partial of any intervention, especially on operation and maintenance and load management. Including the involvement of the Telefomin Vocational Institute.
3. For any donor-funded intervention, the households must be encouraged to financially contribute through a monthly fee to ensure proper operation & maintenance and parts are easily accessible. In addition, communities take ownership of the intervention as well as get used to the concept of paying bills.
4. To strengthen community buy-in and drive a more holistic development agender, the interventions must attempt to integrate other community challenges which in this case in income-earning opportunities
5. To further ensure long term sustainability the “utility approach” should be considered with the experienced “operator” of the Telefomin Station minigrid to oversee the overall implementation and ongoing maintenance, and who have the capacity and more importantly are able to determine when to improve the energy services through the 3 electrification strategies in the future (Pérez-Arriaga et al., 2019).
6. The “operator” must involve a community-trusted authority such as the Baptist Mission, MAF and MAF Technologies (formerly CRMF).
7. The dynamic electrification pathway should be built on the MTF based on services provided, with a proposed example in Table 3.

Table 3: High-level plan

	Tier 0.5	**Tier 1**	**Tier 1.5**	**Tier 2**	**Tier 2.5**	**Tier 3**	**Tier 4**	**Tier 5**
Households	Low-Quality Task Lighting +mobile charring	Quality Task Lighting mobile charging	Low-quality Multiple lights	Good quality Multiple lights,	Computer, printer, TV, Radio and Fan	refrigerator, freezer, food processor, water pump, rice cooker, jug	Washing machine, iron, toaster, microwave	Air conditioner, space heater, vacuum cleaner, water heater, electric cookstove
Electrification	standalone	standalone	standalone	Standalone/Grid	Standalone/Grid	Standalone/Grid	Grid	Grid
Standalone Community Facility	Motorized Carpentry Tools	More motorized carpentry tools, mills, TV, Freezer, Refrigerator, Computer, Washing Machine, Sewing Machine, Water Pump						
Electrification	standalone						Grid Ext	
Streetlights	At least one functional low-quality street lamp in the neighbourhood	At least one functional quality street lamp in the neighbourhood	At least 25% of the neighbourhood is covered by functional low-quality streetlamps	At least 25% of the neighbourhood is covered by functional quality streetlamps	At least 50% of the neighbourhood is covered by functional low-quality streetlamps	At least 50% of the neighbourhood is covered by functional quality streetlamps	At least 75% of the neighbourhood is covered by functional quality streetlamps	At least 95% of the neighbourhood is covered by functional quality streetlamps
Electrification	standalone						Grid	
Time Frame	Immediate				Medium Term	Medium Term	Long Term	Long Term
Reliability								
Availability								

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