Kampung Capacity: Assessing the Potential for Distributed Energy Resources to Satisfy Local Demand in East Malaysia

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1. Distributed Energy Resources for Rural Energy Supply

1.1. Assessing Rural Energy Demand

While energy infrastructure can contribute to economic development goals, they differ in potential to contribute to local livelihoods. In discussion of distributed energy scenarios and trade-offs it is important to consider the importance of rural energy access especially in a state where the total rural population is so significant. Scale and localized needs are important considerations in energy planning. Most rural villages in East Malaysia are not grid connected, and rely heavily on high-cost diesel fuel for electricity and transportation. Improved rural energy access has been a key component of energy future discussions, however little quantitative data on demand and potential exists. We conduct a case study in the Baram Basin - the next basin to be flooded for a hydroelectric reservoir - which explores the potential of renewable energy as a bottom-up solution to satisfy the energy needs of these impacted communities.

In preparing this study we conducted multiple site visits to 12 villages along the Baram River (see Figure 1). Each village was surveyed using field observation, household energy audits and interviews. At each village we interviewed village leaders, household representatives and held a community meeting. We also did site visits to a number of local biogasification projects and conducted interviews with over 20 government agencies and NGO groups on small scale energy incentives, opportunities and limitations. Through surveying and data measurement we collected information on energy use and energy resource availability in various Baram villages. The Baram River is the second longest in Malaysia. There are over 20 villages along the Baram River upstream of the dam site representing different indigenous ethnic groups.

The Kenyah settlement of Long San for instance is one of the largest Baram villages, roughly 150 km southeast of Miri (the nearest major city). Long San is comprised of multiple *long houses* (single building comprised of adjoining rooms that houses all families within a community) totaling 160 *doors* (a single housing unit within a long house shared by two to three families of approximately five persons each) representing roughly 800 people. A major trading base for goods from the city, Long San has become a hub of the Baram community. Another Kenyah village Long Anap, 35 km from Long San, is medium sized with two long houses comprised of 54 doors total. Tanjung Tepalit is a much smaller village community located about 22 km south along the river from Long San. It comprises of a single long house with 25 doors. Trade in meat and produce creates the economic base which makes modern energy services available. Produce (fruit, vegetables and meat) from surrounding villages is taken to Long San along the river for trading and further transport.

Based on site visits and household interviews we recorded the number and type of generators operational within each village, along with time of use and total fuel consumption to estimate current energy supply. Aside from the long houses each village generally consists of a community church or clinic and a primary or secondary school, each with its own generator. Local state departments supply diesel to supply electricity to these public buildings. In Long San, for instance, there are four 20 kW generators for the school buildings and clinics which are maintained by government. We opt not to include these loads in our model as they do not impact domestic spending.

We also opt not to model ad-hoc loads which occur on a non-regular basis during the course of a year. Villages that plant hill rice primarily for subsistence, such as these Baram Villages, harvested rice is milled to separate grain from the husk after the harvest season. The number of mills, number of days and number of hours run are dependent on the strength of the season. Further, mills may be run at other times during the year when extra rice is needed – during large family visits, community celebrations or holidays. As such, it is difficult to create a daily and seasonal demand profile for this type of load. We are concerned primarily with the evening demand load.

We find on average across villages 60 – 70% of doors have access to electricity by owning small generators. A 3kW 220-V Chinese imported synchronous generator is the most common household generator across villages. Typically portable generators can achieve 15-20% total efficiency or 7-8 kWh/gal. Generators operate at low efficiencies in such circumstances due to ill-frequent maintenance and being run below rated capacity. However we assume generators in the village are operating at 15% efficiency to be conservative. The average door housing 2-3 families operates a generator from 6pm to 12pm consuming 0.5-1 gallon per night, the equivalent of 3.5 -6.5 kWh per night. Our electricity consumption and daily demand profile findings are very consistent with other village level energy audits published for Malaysia [53]–[56].

In surveying we audited the type and number of appliances as well as frequency of use for each door. Our survey shows that where available electricity is primarily used for lighting and fans while many households also have washing machines, televisions, DVD players and other appliances. A large number of the families that own generators note that they cannot afford a consistent monthly diesel fuel supply and thus run these additional appliances sparingly. Based on standard wattage ratings found in literature, we approximate nightly power demand at 0.7 kW per door. The types of appliances and their use patterns noted are consistent with those found in local and regional literature [53]. Beyond this daily profile we also use survey results to develop a seasonal demand profile which scales daily demand according to a monthly average. Demand is higher in the June-July holiday period when children are home from boarding school, and is at its peak in the December-January holiday period when family members from urban areas return to their villages.

At approximately 105 kWh per month per door, village load is relatively small compared to the average domestic electricity use in Sarawak of 205 kWh/month per household [17], [31] where primary loads can also include air conditioners, ceiling fans, refrigerators and water heaters [57]. Nevertheless, though sold at a standard retail subsidy of 1.8 RM/l (US$0.55/l) [58], electricity from diesel effectively costs 1.1RM/kWh (US$0.34/kWh) under our efficiency assumption, two and a half times more than the 0.31RM/kWh (US$0.10/kWh) domestic electricity tariff for state utility customers [31], [32]. A single village door may therefore spends roughly US$ 35/month on electricity where funds to purchase diesel are available compared to the average household in Malaysia which spends US$19/month [57].

Table 1 Diesel Fuel and Effective Electricity Cost

Diesel Energy Content (BTU/gal)	139,000
Assumed Average Generator Efficiency (%)	15%
Electricity per Unit Diesel (kWh/gal)	6.11
Standard Subsidized Diesel Price (US$/L)	0.55
Effective Cost of Electricity (US$/kWh)	0.34
SESCO Domestic Electricity Tariff (US$/kWh)	0.10

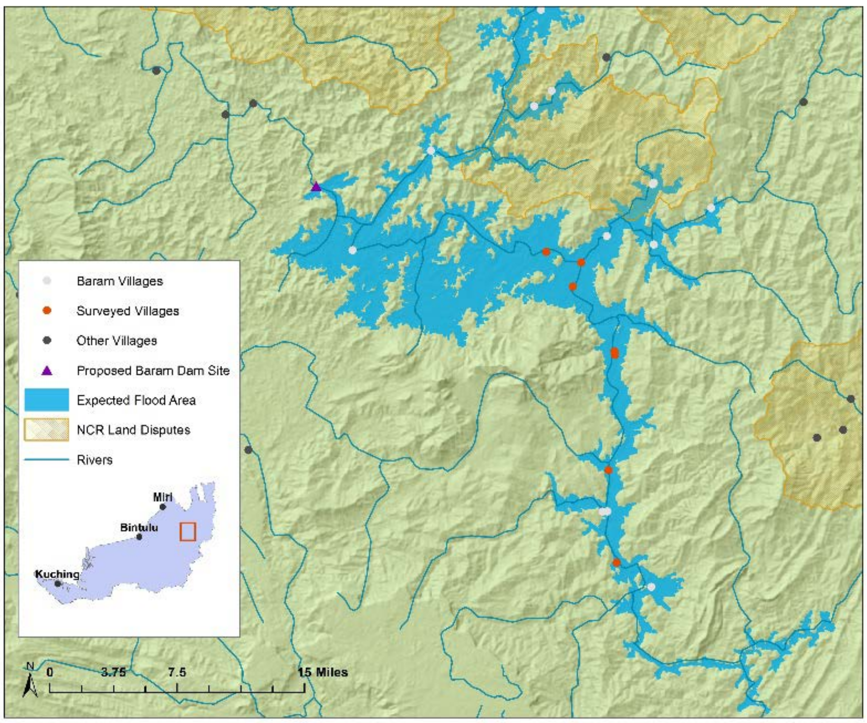

Figure 1 Map of Study Area: the Baram Basin, Sarawak, East Malaysia

3.2. Model Framework

We employ the Hybrid Optimization Model for Energy Resources (HOMER) developed by the National Renewable Energy Laboratory (NREL) [59]. HOMER simulates thousands of system configurations, optimizes for lifecycle costs, and generates results of sensitivity analyses on most inputs. Initially developed for application in developing countries, HOMER is now the most popular commercial design software for remote microgrids. We provide HOMER with resource and technology inputs for each village including monthly biomass residue availability, daily solar insolation and monthly averaged flow rates.

Micro-hydro sites within 5km of the longhouses are suitable for development. As most communities settle on river banks for each of transportation, this is particularly appropriate for rural Sarawak villages. Green Empowerment stream flow measurements were correlated with 40-year precipitation data [60] to estimate monthly average flow rates. Using NASA Surface Solar Energy data [61] and the coordinates of the villages we determine solar potential for the region. Annual averaged insolation is 5.34 $kWh.m^{-2}.day^{-1}$ in the Baram peaking at 6 $kWh.m^{-2}.day^{-1}$ in March.

We estimate the potential for small scale biogasification using rice husk as a feedstock. Baram villages are based on subsistence agriculture, with each family owning land used for hill paddy planting. A large family typically owns 6-7 acres of land within the village bounds while a smaller family might own 2-3 acres with a conservative average yield of 10 bags of rice per acre every year. Rice is stored in bags after the harvest and is milled for consumption as needed during the year. The rice husk waste produced during milling is not currently used. We can approximate rice husk distribution across the year based on monthly rice consumption. We do not consider rice straw under conservative assumption that waste from rice fields cannot be transported to the long house.

The higher heating value (HHV) of rice husk is 15.84 MJ/kg [62], [63]. Literature shows gas yield rate is between 1.63~1.84m^3/kg with gasification efficiency is between 80.8%~84.6% [63]. We assume 1.7m^3/kg gasification ratio and observe sensitivity. Lower gas yields have been recorded in [64]. Finally based on NASA data roughly 50% of the year wind speeds at 50m are below 2m/s because of the interior location and rugged geography of the region. We assume that given the low wind speed patterns in the region that wind is not a feasible energy option.

We provide HOMER input data on hydro-turbine design flow rate, biomass gasification feed rates, expected efficiencies, expected life, input capital, replacement and operation/maintenance costs for each technology. Hydro and solar capital cost figures (US$ 1300/kW and US$2,300/kW respectively) are based on data from Green Empowerment. Small scale biogasification capital costs (US$1500/kW) were taken from literature

Table 2 Estimated Energy Demand and Energy Resource Properties used for each Village

Location				Size			Estimated Household Demand					Non-Household Loads			
Village Name	Indigenous Group	Coordinates N Lat.	Coordinates E Long.	No. Doors	No. Families	No. People	Generation Capacity (kW)	Consumption (kWh/month)	Annual Consumption (kWh/year)	Diesel Consumption (gal/year)	Fuel Expense (US$/year)	Community Hall	School	Church	Clinic
Tanjung Tepalit	Kenyah	3 14 396	114 48 975	25	50	250	18	2,633	32,029	5,242	10,807	No	No	Yes	No
Long Anap	Kenyah	3 03 747	114 49 140	54	108	540	38	5,686	69,182	11,322	23,343	No	Yes	Yes	No
Long San	Kenyah	3 17 888	114 46 855	80	160	800	56	8,424	102,492	16,773	34,583	Yes	Yes	Yes	Yes

Location				Biomass Resource			Hydro Resource					Solar Resource		
Village Name	Indigenous Group	Coordinates N Lat.	Coordinates E Long.	Padi Acreage	Estimated Annual Rice Husk Waste (tonnes/yr)	Annual Biogas GenerationPotential (kWh)	Available Head (m)	Monthly Averaged Flow Rates (L/s) Max	Min	Avg	Nominal Capacity (KW)	Mthly Avg Insolation (kWh/m2-day)	Average Radiation (W/m2) Max	Min
Tanjung Tepalit	Kenyah	3 14 396	114 48 975	100	10.5	10,172	20	103	25	62	5.8	5.34	0.43	0.37
Long Anap	Kenyah	3 03 747	114 49 140	216	15.5	15,016	70	23	11	17	8	5.34	0.43	0.37
Long San	Kenyah	3 17 888	114 46 855	320	33.6	32,552	25	98	31	65	13.3	5.34	0.43	0.37

a. assumes Residue Ratio Rice:Husk is 1:0.3
b. Assumes Diesel Generator Efficiency is 15% in the villages
c. Assumes Hydro Turbine Efficiency is 60%
d. Assumes roughly 2 families living per door of a long house
e. Solar data available from NASA Surface meteorology and Solar Energy groups all three villages within the same resolution pixel

[65][66]. Diesel engine costs were reported in surveys (US$440/kW) which align with costs cited in literature [67], [68]. We take the diesel generator fuel curve from [69]. We use standard deep-cycle lead acid battery properties, already populated in HOMER (capital cost US$350/kWh). We assume an interest rate of 7%, set a maximum energy shortage constraint of 10% and a total system lifetime of 25 years. We use sensitivity analysis to observe outcomes with varying technology prices, resource availability and shortage constraint.

3.3. General Model Results

HOMER delivers optimal configuration for each possible technology combination ranked according to Total Net Present Cost (NPC). Here we present models of three *Kenyah* villages along the Baram River – Long San, Tanjung Tepalit and Long Anap. These three villages represent high, medium and low energy use based on size and village activity.

Tanjung Tepalit, the smallest village by number of doors, has a low level of demand but a larger hydro potential given the available head and relatively steady annual stream flow patterns. The least cost system for the village is a single 9kW hydro-turbine with 60kWh battery pack, with LCOE of US$0.15/kWh. The diesel base case is a 20kW diesel system with no battery back-up required. The hydro system is a third the total net present cost (NPC), with a fifth of its annual operating costs (predominantly fuel costs) and results in a levelized cost of electricity (LCOE) that is a third of the effective diesel LCOE. We find that the battery pack is the bulk of the cost in this system. The battery system maintains near 100% state of charge except for the drier summer months and in February. The next least expensive option adds a 5kW PV onto the hydro system showing the potential for solar to contribute to low cost systems. This is discussed more in the section below on Sensitivity Analysis.

Long Anap is a village with higher total demand but lower annual average stream flow. As such, though the least cost system for the village revolves around a 7kW hydro turbine, it also requires 20kW diesel and 120kWh of battery. The hydro unit produces 54% of total annual electricity. In fact all optimal configurations for Long Anap include at minimum a 20kW diesel backup. This least cost system is roughly four fifths the NPC and four fifths the LCOE of the diesel base case, which is a 40kW diesel system. It has a much lower annual operating cost due to much lower averaged fuel consumption per day. Due to larger population the rice husk waste resource is greater in Long Anap, thus biogas generators factor in to optimal design at lower cost than in Tanjung Tepalit. This can be seen in the section below on Sensitivity Analysis.

Long San has the largest population, with 80 doors, and an estimated demand of 45kW. The least cost system includes 11 kW of hydro-turbine and 40kW diesel where total electricity production is 60% hydro and 40% diesel. This system is roughly two thirds the NPC and LCOE of the 60kW diesel base case. The least cost system for Long San that does not call upon diesel generators would require significant battery storage (240kWh) and either PV or biogas generators. Thus diesel, even at the subsidized government retail rate, is the most expensive form of electric production for Baram villages given the recurrent fuel costs.

HOMER tracks system operability through annual energy shortage. This was the main fault of renewable systems, with NPC increasing significantly to meet a zero shortage constraint. Diesel systems are the most technically flexible and thus reliable - though fuel shortage is increasingly an issue as described in the survey.

The optimal configuration for meeting demand gradually becomes more expensive as the shortage constraint tightens, and while low cost, high renewable fraction systems are possible, they are more complex, requiring three or more fuel types and battery storage.

Overall, we find that systems which incorporate renewable energy technologies (RET) are less expensive than the standard system of individual household diesel generators. In each village case, despite the level of demand and despite availability of biomass waste and hydro resources, the least cost system incorporates an RET that will satisfy at least 50% of electricity production. In each case the NPC, LCOE and annual operating cost of these least cost systems are significantly less than their diesel base cases. We note however one limitation in interpreting these results is that the diesel sunk costs have largely already been incurred for households with existing generators. This highlights the potential role that local, small scale RETs can have in satisfying rural energy needs.

Table 3 Select Optimization Results for Each Village

Village	Category	System Specification	Initial Cost (US$)	Annual Operating Cost (US$)	Total NPC ((US$)	LCOE (US$/kWh)	Average Fuel per Day (L/day)	Capacity Shortage (%)	Annual Operating Cost Ratio	NPC Ratio	LCOE Ratio
Tanjung Tepalit	Least Total Cost	9 KW Hydro + 60kWh Battery	29,170	2,166	54,408	0.150	0.00	5.3	0.16	0.33	0.35
	Diesel Base Case	20kW Diesel	8,800	13,470	165,771	0.433	27.60	0.0	0.00	1.00	1.00
Long Anap	Least Total Cost	7kW Hydro + 20kW Diesel + 120kWh Battery	62,870	18,018	272,847	0.354	35.29	4.6	0.66	0.81	0.85
	Diesel Base Case	40kW Diesel	17,600	27,334	336,145	0.416	57.17	0.0	0.00	1.00	1.00
Long San	Least Total Cost	11kW Hydro + 40kW Diesel	18,900	27,444	338,723	0.306	57.74	5.8	0.68	0.68	0.72
	Diesel Base Case	60kW Diesel	26,400	40,650	500,115	0.426	84.00	0.0	1.00	1.00	1.00

3.4. Sensitivity Analysis

We observe the impact of variables with uncertainty on optimal system configuration. We perform sensitivity analysis for resource availability (biomass waste and average stream flow) and demand needs (scaled annual demand, shortage constraint). Though sold at a standardized price we also observe the effect of diesel fuel cost on systems to understand the implication of the existing government subsidy and potential future price increases. We also observe the effect of PV technology cost as the technology with the most rapidly changing capital costs.

We find that across all sensitivities hydro turbines are the most cost effective technology for village communities. As estimates of stream flow increase the need for battery support declines. However meeting load in dry months is a challenge for villages with higher demand and particularly under the zero shortage constraint, requiring additional technologies and cost increase. Studies show stream flow may become more extreme due to temperature and rainfall changes [70]. This is consistent with the literature's description of small hydro limitations [71]. There is a minimum biomass availability above which small scale gasification technology becomes cost effective in combination with hydro. This can be seen in Long Anap and Long San. PV is not often selected for optimal systems, largely due to evening loads, but can be cost effective at high diesel prices and low PV capital costs. Generally, increased diesel price and increased estimates of village demand improve the cost effectiveness of RET systems.

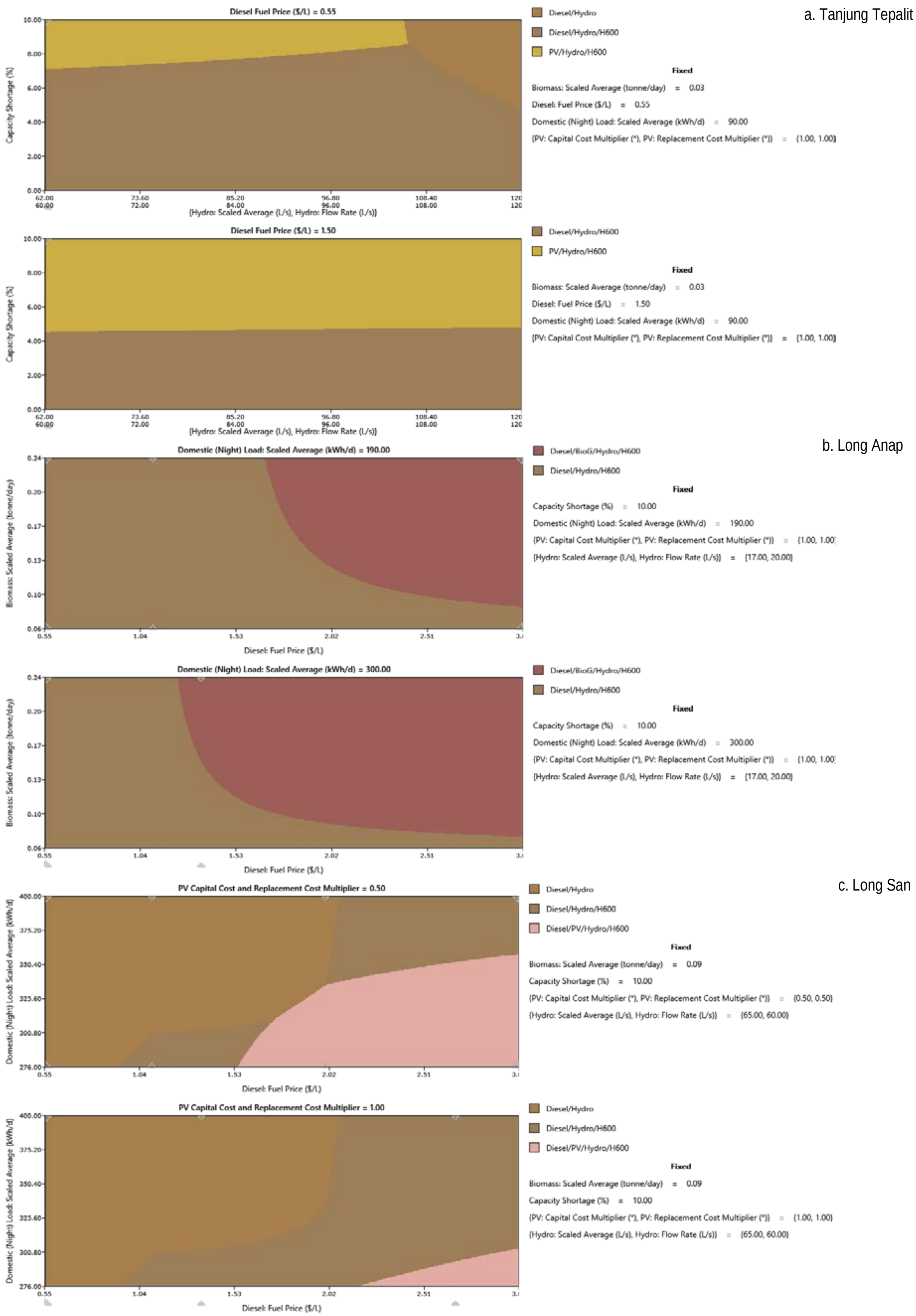

Figure 2 Optimal system configuration through sensitivity analysis on different variables

3.5. Opportunities in Providing Rural Energy Access

Our findings align with a number of recent studies which find PV, hydro-turbines and biogasification becoming more popular as micro-grid technologies [72]. Regional successes with rice husk biogasification, such as Husk Power in India, and other forms of biomass waste use more locally, such as Kina BioPower in the neighboring state of Sabah demonstrate the potential for deployment. The literature discusses barriers to development of these technologies, chiefly including maintenance issues [73]. There are also specific challenges of meeting load in dry season, demand side management and fee collection. Nevertheless these are feasible technologies, demonstrated by a number of successful installations across Borneo, some operating independently for over a decade [54], [55], [67]. Even SEB has cited the potential of micro-hydro in meeting remote load in the near future [31].

One of the most prominent Green Empowerment and Tonibung case studies is in Long Lawen, a village in which half of the residents rejected relocation plans during the inundation of the Bakun Dam in 1998 and moved to higher terrain within its ancestral land claim while the other half were resettled at the Asap Reservation. Eventually, after Green Empowerment and Tonibung completed survey works, a 8kW hydro-turbine and micro-grid network was commissioned in 2002 and is functional today. In line with our findings, the new micro-grid system cost 50% less than the total prior investment in generators by the community [74].

The village and its micro-grid also represent the role that local solutions play in social movements. In Sarawak, the micro-grid and more specifically micro-hydro, has come to take on social symbolism for the environmental movement that lobbies to save the Baram River. Even with plans for the development of large scale dams with high voltage transmission from rural areas in the state unfolding, this has never translated into electricity access for affected or upland river communities. The micro-hydro system is an explicit representation of alternative use of the very same river resource. It is thus more than an end in itself, but a means to community empowerment. There is an interesting political ecology that has grown around the spread of micro-hydro systems from village to village in East Malaysia because of this stark juxtaposition.

Green Empowerment and Tonibung are building significant momentum and in 2013 established a joint training center in Sabah, CREATE, with training space, technical curriculum, modules and facilities for product testing. The training center receives community members across Malaysia for vocational training. In collaboration with PACOS Trust, a local community-based organization, students are also trained in community leadership skills. This is a growing operation that has evolved from technology deployment to local capacity building, creation of a local, rural industry and involvement in the indigenous environmental movement. This case study represents a novel, practical real-time application of technology for bottom up solutions.

The Tenth Malaysia Plan and the National Fifth Fuel Policy highlight the importance of increasing electricity access and the share of renewable resources in the fuel mix [75]. Indeed SREP was designed to allow renewable projects of up to 10 MW to sell their output to the utility, though only 53 MW of capacity had been installed in the program by 2012. The SREP program has been replaced through the Renewable Energy Act of 2011 which provides for the establishment and implementation of a country wide Feed in Tariff (FiT) to catalyze investment in renewable resources. In increasing electricity access in largely rural states such as

Sarawak, however, a ‘two-track’ approach involving both centralized and decentralized solutions is necessary [76].

Furthermore, the fuel subsidy is 2% of Malaysian GDP and 11% of total government expenditure [58]. The subsidy is ineffectively distributed between urban and rural communities and across economic classes. It is thus in the government’s interest to reform subsidy spending [77]. Current incentive schemes in the state do not apply to off-grid project developers though a number of potential enabling policy tools for micro-grid systems exist such as maximum tariffs and establishing minimum quality-of-service standards [76]. Thus further study is required on designing policy appropriate to local developers and residential communities. Other writing on the governance of small scale rural energy projects and a case study of the Malaysian SREP program can be read here [78].

4. Conclusion

We contribute to the local and large-scale energy service debate through a study of villages along the Baram River in Sarawak, East Malaysia. We explore optimal fuel configuration for these villages based on cost and resource availability and find the least cost options for energy services to come from a mixture of locally managed small-scale hydroelectricity, biogas generators and accompanying batteries. A range of different renewable energy service scenarios are consistently less than the cost of diesel energy scenarios. Our demonstration highlights the need for further study of appropriate sites in other highland communities of Sarawak.

The findings emphasize the potential of villages in rural Sarawak to satisfy their own energy access needs with local and sustainable resources and suggest a need for adopting a radically different strategy for expanding rural energy access in light of current state government plans. While centralized plans for generation and grid expansion are necessary, it is important to explore the appropriateness of localized, bottom up and decentralized solutions to energy access. Expanding energy access will require a number of different technical innovations as demonstrated but will also require new policy, business development, financing tools and institutional mechanisms to facilitate the introduction of such technologies. There are a number of successful case studies and best practice examples of local and national innovation in government support of increasing access to modern energy.

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