Kampung Capacity
Local Solutions for Sustainable Rural Energy in the Baram River Basin, Sarawak, Malaysia

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Abstract

Limited energy access constrains the economic and social opportunities of up to 1.5 billion people worldwide. As a critical case in point, most rural villages in East Malaysia are not grid connected, and rely heavily on high-cost diesel fuel for all electricity and transportation needs, hampering economic productivity and development. Political attention often comes to these communities only when larger national or international geopolitical forces come into play, as they have done in Sarawak, Malaysia, where plans for a series of mega-dams have dramatically raised the profile and the stakes in local energy services versus a larger development agenda. We examine the local and large-scale energy service debate in villages (or kampungs) along the Baram River in Sarawak, East Malaysia where electricity from diesel effectively costs 2.24 RM/kWh ($0.70/kWh), compared to a 0.31 RM/kWh ($0.10/kWh) domestic electricity tariff for state utility customers. Using a hybrid energy resource optimization framework, we explore optimal configuration for these villages based on cost and resource availability. We find the least cost options for energy services to come from a mixture of locally managed small-scale hydroelectricity, biogas generators and accompanying batteries instead of a claim of service provision based on large-scale regional electrification. A range of different renewable energy service scenarios are consistently 20 percent, or less, than the cost of diesel energy scenarios, without the social, economic, and environmental disruptions that would come with a large-scale hydropower plan for the river basin.

Keywords: South East Asia, Malaysia, Rural Energy Access, Local Solutions

Executive Summary

In this study we explore the potential for rural renewable energy supply through a focus on villages of the Baram River Basin in Sarawak as the basin next scheduled for mega hydroelectricity development by the state government of Sarawak. For the Baram villages (or kampungs) diesel fuel cost, while not entirely prohibitive, is a barrier which creates exclusion. Designing more cost effective ways to meet current electricity demand will relieve an economic burden while simultaneously creating potential for new economic revenue streams. As such we have explored optimal system designs for electricity supply in villages of the Baram and determine that lower cost, higher reliability options are available for the villages given current resource potential. The average village household uses 41 kWh/month compared to 205kWh/month for urban Sarawak households. Currently electricity from diesel effectively costs 2.24 RM/kWh in village communities, compared to a 0.31 RM/kWh domestic electricity tariff for utility (SESCO) customers.

We model three Kenyah villages along the Baram River – Long San, Tanjung Tepalit and Long Anap - representing high, medium and low energy use based on size and village activity. Their size ranges from 50 to 25 houses and total energy demand ranges from 45kW to 14kW. We find these villages to have significant energy resource potential with monthly averaged insolation of 5.34 kWh/m^2-day, high river flow rates and about 0.2 tonnes rice husk/family per year. We developed a set of inputs to HOMER that cover a number of resource and technology inputs for each village. The study shows that there are significant savings which could come from using renewable technologies for electricity generation. In each village modeled the least cost option was some combination of hydro, biogas generators and accompanying batteries (see Figure 1 as an example). In each village case this least cost option was 20% or less of a diesel base case cost. The Levelized Cost of Electricity (LCOE) of these renewable options was also all less than 20% of their diesel base case scenarios (see Figure 2).

We observe that small scale hydroelectricity (less than 20kW in these cases) is the lowest cost means of electricity production available to each village. Small scale biogasification is financially feasible and profitable for village communities however the technical feasibility of maintaining a biogas system must be considered. Despite the cost of diesel fuel, photovoltaic systems (PV) are not cost effective for the village communities. When employed they do not act as dominant energy sources. Capital and replacement costs of battery packs are often the major cost component for many least cost systems. Despite this, diesel, even at the subsidized government price, is the most expensive form of energy for Baram villages, given the recurrent annual fuel costs that it implies. In fact, we find that the Payback Period on Hydro and Biogas systems can be two years or less compared to 100% Diesel base case scenarios. These findings highlight the potential of villages in rural Sarawak to satisfy their own energy access needs with local and sustainable resources. This conclusion supports a state-wide energy development strategy that considers small scale energy solutions and technologies as an important part of providing rural energy access and rural development opportunity.

Contents

1. Introduction

Southeast Asian nations, along with China and India, are ‘shifting the center of gravity of the global energy system’. According to the International Energy Agency (IEA) in their World Energy Outlook for Southeast Asian nations, Southeast Asia’s energy demand has more than doubled since 1990, and is expected to increase by another 80% by 2035, a rise equivalent to current Japanese energy demand (IEA, 2013). The power sector accounts for 52% of this expected increase in primary demand, highlighting the importance of region’s electricity fuel mix, currently in transition.

At the same time that such large scale state-led energy developments are underway, over one-fifth of the region’s population still lacks access to grid connected electricity. In regions like East Malaysia much of the population lives in rural villages that are not grid connected and currently rely heavily on diesel for all electricity and transportation needs. Political attention often comes to these communities only when larger national or international geopolitical forces come into play, as they have done in the state of Sarawak, East Malaysia, where recent energy related mega-project plans (Sovacool, 2012) have dramatically raises both the profile of these communities and the stakes for local energy services. The backbone of this State development plan is a series of 12 hydroelectric dams with a capacity of 20 (GW) (RECODA, 2013). Thus far two dams – the 2400 MW Bakun Dam and the 944 MW Murum Dam - have been built using federal pension funds (Oh et al., 2011), with the entire plan estimated to cost US$105 billion by 2030 (BMF, 2012).

Sarawak is currently one of the world’s predominant producers of palm oil and timber, while being home to some of the few remaining stands of the oldest forest in the world. Southeast Asian economies such as this well-endowed with resources, burgeoning demand and based on large scale primary industries represent an ideal opportunity for exploring synergies between sustainable energy futures and abundant exploitable natural resources.

2. Bottom Up and Top Down Energy Solutions

These development plans are representative of a contemporary boom in mega-dam developments now unfolding in developing countries - from China, to Brazil to East Africa. A growing literature on mega dam economics is emerging (Sovacool, 2013; Kwak et al., 2014; Ansar et al, 2014). In a recently published Oxford study (Ansar et al.; 2014) researchers analyze a sample of 245 large dams built between 1934 and 2007, finding “overwhelming evidence that budgets are systematically biased below actual costs” and that, without suitable risk management, large dams in most countries are “too costly in absolute terms and take too long to build to deliver a positive risk-adjusted return”. In consistent fashion, Bakun Dam was built over two decades at a final cost of US$ 2.28 billion, double the most liberal of government estimates (Oh et al., 2011).

Previous literature provides critical appraisal of dam development specific to Sarawak with respect to economic rationale (Keong, 2005), technical efficiency (Oh et al., 2011) and social impact (Sovacool, 2011) and we are currently conducting a study on commercial scale energy alternatives for the state to be published soon. As such, we do not pursue analysis of large scale energy projects any further in this study. However the United Nations through their *Sustainable Energy For All* Initiative (United Nations, 2013) underscore the importance of decentralized and small scale alternatives in creating universal energy access.

While the scope for micro- and mini-grids as a viable alternative or complementary energy development plan in East Malaysia has been qualitatively discussed (Sovacool and Valentine, 2011), we contribute to this literature (i) a quantitative estimate of village level energy demand, (ii) assessment of optimal micro-grid system design for Baram village communities, (iii) a discussion on the role of micro-grids not only as technical solutions to energy access but as an arm of social movements. Further, we highlight the work and progress of the two main micro-grid developers in Sarawak - Tonibung and U.S. Based NGO Green Empowerment. Our study thus emphasizes the potential and application of bottom-up solutions in contributing to the energy agenda and their larger role in social movements and paradigm change.

3. Rural Energy Development in East Malaysia

Tonibung and Green Empowerment have been operating together in East Malaysia since 2000. They collectively raise capital for installations, train community members and support villages in the management and maintenance of systems. Thus far they have installed twelve systems in Malaysia, with over 120 KW total capacity, serving roughly 1000 families. A full description of Tonibung and Green Empowerment, their business model, financing and coverage can be found in (Schnitzer et al., 2014) - a micro-grid practitioners guide recently prepared through collaboration with members of our laboratory for the United Nations.

We focus specifically on villages of the Baram River Basin in Sarawak (see Figure 1) where Tonibung and Green Empowerment are planning their next group of installations. This is also the next basin scheduled for mega-dam construction (1200 MW Baram Dam) which will affect 36 settlements and displace an estimated 20,000 people. The contrast of pursuing micro-hydro in the face of inundation provides a powerful symbolism of resistance and inspiration of rural potential to surrounding villages. This is thus a telling case study.

In preparing this study we conducted site visits to 12 villages along the Baram River (see Figure 1). Through surveying and data measurement we collected information on energy use and energy resource availability in various Baram villages. 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. We also did site visits to a number of local biogasification projects and did interviews with over 20 government agencies and NGO groups on small scale energy incentives, opportunities and limitations.

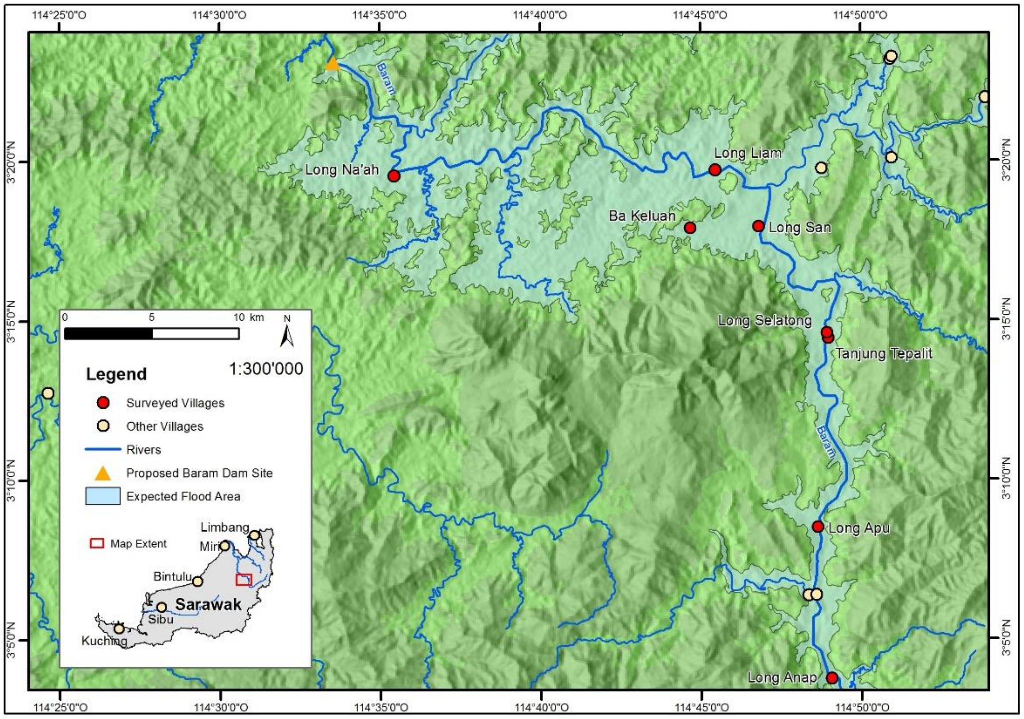

Figure **1** Map of Study Area: the Baram Basin, Sarawak, East Malaysia

3.1. Estimating Energy Demand in the Baram

The Baram, which is the second longest river in Malaysia, flows westwards through the Borneo Rainforest to the South China Sea. There are over 20 villages along the Baram River representing many different indigenous ethnic groups. The settlement of Long San is one of the largest Baram villages, roughly 150 km southeast of Miri (the nearest major city) and can be accessed by five hours driving along logging tracks. Long San is comprised of multiple long houses (single building comprised of adjoining rooms that houses all families within a community) totaling 160 *doors* (term for a single housing unit within a long house shared by two to three families) representing roughly 800 people. A major trading base for goods from the city, Long San has become a hub of the Baram community. Long Anap, 35km 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.

Based on interviews and site visits we record 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 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 do not include these loads in our model as they are do not impact domestic spending.

At present 60 – 70% of *doors* on average have access to electricity. Almost all of the 80 doors in the Long San village own a generator, while 85% of doors in Tanjung Tepalit and 70% of doors in Long Anap own generators. However a large number of the families that own generators cannot afford a consistent monthly fuel supply. Where available, electricity is primarily used for lighting and fans while many households also have refrigerators and washing machines and a few families own televisions, DVD players and other miscellaneous devices. A 3kW 220-V Chinese imported synchronous generator is the most common amongst villages. Based on survey data, the average *door* in the Baram, which houses 2 to 3 families, operates generators from 6pm to 11pm or midnight consuming about 2 gallons each night - the equivalent of 2-3 kWh per night per *door*. Our assumptions for calculating evening time energy use are explained in Table 1 below.

At approximately 83 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 (Sarawak Planning Unit, 2011 and SEB, 2011) where primary loads are air conditioners, ceiling fans, refrigerators, lights and water heaters (Kubota et al., 2011). Typically portable generators can achieve 15-20% total efficiency or 7-8 kWh/gal. Due to ill-frequent maintenance and being run below rated capacity, generators in the village are operating at less than 10% efficiency.

Nevertheless for our calculations we assume 15% efficiency to be conservative. Under this assumption, though being sold on retail subsidy for 12RM/gal (US$3.96/gal), electricity from diesel effectively costs 2.24 RM/kWh (US$0.70/kWh), compared to a 0.31 RM/kWh (US$0.10/kWh) domestic electricity tariff for state utility customers (Suruhanjaya Tenaga, 2012 and Sarawak Energy Berhad, 2010). A single village *door* therefore spends roughly US$50/month on electricity compared to the average household in Malaysia spends US$19/month (Kubota et al., 2011).

Table 1 Evening Energy Use in Long San Households

Household Loads	Wattage (W)	Number	Hours/Night	Nights/mth	Fraction of Doors	Total (kWh/mth)
Light Bulb (CFL)	18	6	5	30	1	1,296
Light Bulb (Tube)	40	5	5	30	1	2,400
Electric Fan	40	2	5	30	1	960
Television	50	1	4	20	0.2	64
DVD Player	30	1	2	5	0.2	5
Ice Box	115	1	5	30	0.7	966
Washing Machine	445	1	4	10	0.7	997
No. Doors	80	Total Monthly Energy Demand for Village (kWh)				6,688
		Total Capacity Required for Village Load (kW)				45

3.2. Description of Energy Resources

Hydro Potential: We visited potential micro-hydro sites at each Baram village, measuring stream flow at each site. These measurements were correlated with 40-year precipitation data (Sarawak Integrated Water Resource Management, 2008) to estimate monthly average flow rates (see Figure 2.a. below). Micro-hydro sites within 5km of the longhouses are suitable.

Solar Resource: Using NASA Surface Solar Energy data and the coordinates of the villages we determine solar potential for the region (see Figure 2.b. below). Annual averaged insolation is 5.34 kWh/m^2-day, peaking at 6 kWh/m^2-day in March.

Biomass Resource: 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 (Yi et al., 2009; Lim et al., 2012). Literature shows gas yield rate is between 1.63~1.84m^3/kg with gasification efficiency is between 80.8%~84.6% (Yi et al., 2009). We assume 1.7m^3/kg gasification ratio and observe sensitivity.

Wind Resource: 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.

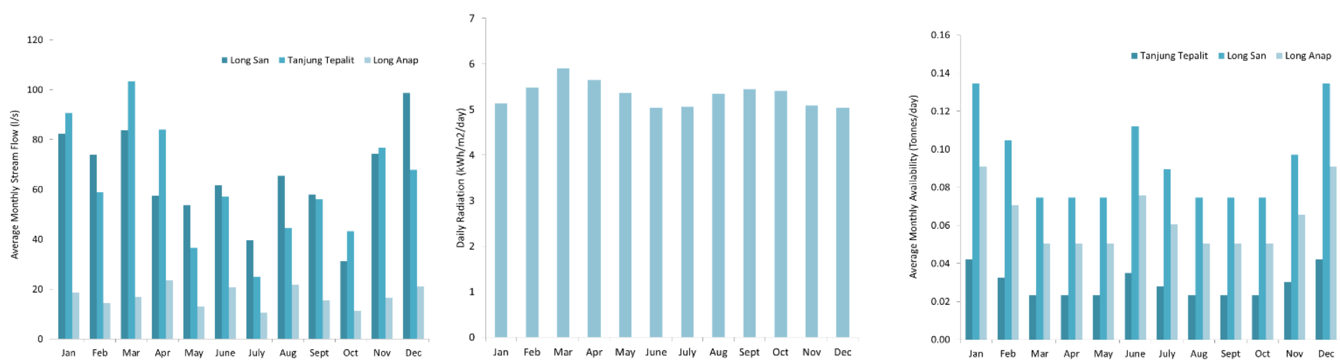

Figure 2(a) Monthly Averaged Stream Flow in Baram Region; (b) Monthly averaged Daily Insolation Levels in Baram Region; (c) Monthly Averaged Daily Rice Husk Available

Table 2 Energy Demand and Resource Characteristics of Baram Villages

Location		Size			Estimated Household Demand						Gov't Supported Loads		
Village Name	Ind'nous Group	No. Doors	No. Families	No. People	Gen Cap (KW)	Energy kWh/mth	Energy kWh/year	Diesel Use (gal)	Diesel Expense ($/year)	Com Hall	School	Church	Clinic
Long San	Kenyah	80	160	800	45	6,688	80,256	13,777	54,557	Yes	Yes	Yes	Yes
Long Anap	Kenyah	54	108	540	28	4,180	50,160	8,610	34,096	No	Yes	Yes	No
Tanjung Tepalit	Kenyah	25	50	250	14	2,090	25,080	4,305	17,048	No	No	Yes	No

Location		Biomass Resource			Hydro Resource					Solar Resource		
Village Name	Ind'nous Group	Padi Acres (ha)	Rice Husk (ton/yr)	Ann Potential Energy (kWh)	Head (m)	Monthly Averaged Flow Rates (L/s) Max	Min	Avg	Potential Capacity (KW)	Mthly Avg Insolation (kWh/m2-day)	Average Radiation (W/m2) Max	Min
Long San	Kenyah	320	33.6	32,552	25	98	31	65	13.3	5.34	0.43	0.37
Long Anap	Kenyah	216	15.5	15,016	70	23	11	17	8	5.34	0.43	0.37
Tanjung Tepalit	Kenyah	100	10.5	10,172	20	103	25	62	5.8	5.34	0.43	0.37

a. assumes Residue Ratio Rice:Husk is 1:0.3
b. Assumes Diesel Generator Efficiency is 16% 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

3.3. Optimal System Design for Village Demand

3.3.1. Model Framework

We employ the Hybrid Optimization Model for Energy Resources (HOMER) developed by the National Renewable Energy Laboratory (NREL) (Lilenthal, 2005). HOMER simulates thousands of system configurations, optimizes for lifecycle costs, and generates results of sensitivity analyses on most inputs (Lilenthal, 2005). Initially developed for application in developing countries, HOMER is now the most popular commercial design software for remote microgrids (HOMER, 2013). We provide HOMER with resource and technology inputs for each village including monthly biomass residue availability, daily solar insolation and monthly averaged flow rates as described above (see Table 2 below). We provide 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 costs were taken from literature (Sieger et al., 2002) (IRENA, 2012). Diesel engine costs were reported in surveys. 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.

3.3.2. General Model Results

HOMER delivers optimal configuration for each possible technology combination ranked according to Total Net Present Cost (NPC). Summaries of simulation results and additional outputs can be found in our supplemental report (Shirley and Kammen, 2013). Tanjung Tepalit, the smallest village, has a low level of demand but a large hydro potential given the head available and relatively steady annual stream flow patterns. The least cost system for the village is a single 7kW hydro-turbine with battery pack and inverter, with LCOE of US$0.21/kWh. Above $0.5/L diesel becomes too expensive for inclusion in Tanjung Tepalit's optimal system (see Figure 3).

Long Anap has a higher total demand but lower annual average stream flow. 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. Unlike Tanjung Tepalit, biogas is selected in the least cost option, which is a 6.2kW Hydro, 20kW biogas generator, converter and a battery system with LCOE of US$0.229/kWh. The hydro-turbine and biogas generator provide 72% and 28% of annual production (kWh/yr) respectively. In this configuration the biogas generator capital cost is the biggest cost over the lifetime of the project. Diesel generators drop out of optimal system types in Long Anap at a diesel price of US$0.33/L. Long San has the largest population with 80 doors and an estimated demand of 45kW. The least cost system includes 9 kW of hydro-turbine, a 20 kW biogas generator, converter and battery pack, with LCOE of US$0.225/kWh . The hydro-turbine and biogas generator provide 71% and 29% annual production respectively (see Table 3).

In each case this least cost option NPC was 25% or less of base case (diesel), though the diesel sunk costs have already been incurred. The LCOE of these renewable options were also all less than 25% of their diesel base case scenarios (see Table 3). HOMER tracks system operability through annual energy shortage. This was the main fault of renewable systems, with NPC increasing on average 30% to meet a zero shortage constraint (see Table 3). Diesel systems are the most technically flexible and thus reliable - though fuel shortage is increasingly an issue as described in the survey. This is reflected in Figure 4, which shows that 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 (see Figure 4).

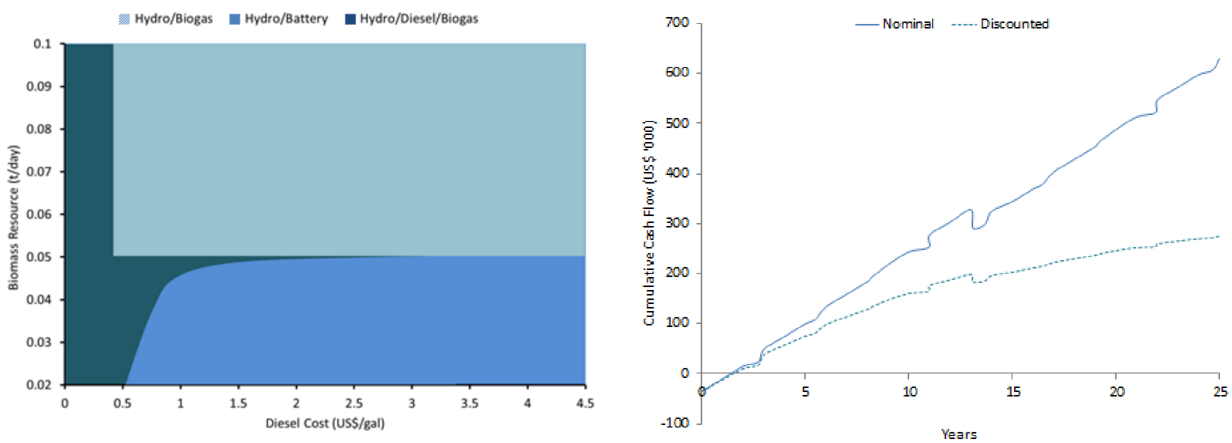

Figure 3 Optimization Results for Tanjung Tepalit: (a) Optimal System Type based on Diesel Cost and Biomass Availability; (b) Cumulative Cash Flow for 7kW Hydro System Relative to 20 kW Diesel Base Case

Table 3 Select Optimization Results for Each Village

Village	Category	System	Specification	Initial Cost (US$)	Annual Operating Cost (US$)	Total NPC (US$)	LCOE ($/kWh)	NPC Ratio to Diesel	LCOE Ratio to Diesel	Capacity Shortage (%)
Tanjung Tepalit	Least Total Cost	Hydro	7kW Hydro + 100kWh Battery	44,590	1,416	61,092	0.21	0.18	0.19	2.1
	No Capacity Shortage	Hydro/Bio	7kW Hydro + 10kW Biogas + 100kWh Battery	58,590	1,195	72,285	0.243	0.21	0.21	0.0
	Diesel Base Case	Diesel	14kW Diesel Gen + 14,500 L/yr	8,800	28,164	337,000	1.132	1	1	0.0
Long Anap	Least Total Cost	Hydro/Bio	6kW Hydro + 20kW Biogas + 100kWh Battery	72,590	5,800	140,182	0.229	0.22	0.23	4.2
	No Capacity Shortage	Hydro/Bio/PV	6kW Hydro + 10kW Biogas + 10kW PV + 100kWh Battery	94,040	7,587	182,453	0.286	0.29	0.29	0.0
	Diesel Base Case	Diesel	30kW Diesel Gen + 29,000L/yr	13,200	5,332	634,713	0.995	1	1	0.0
Long San	Least Total Cost	Hydro/Bio	9kW Hydro + 20kW Biogas + 100kWh Battery	72,590	10,369	193,423	0.225	0.18	0.2	10.0
	No Capacity Shortage	Hydro/Bio/PV	9kW Hydro + 20kW Biogas + 20kW PV + 100kWh Battery	173,760	10,693	298,377	0.313	0.28	0.28	0.0
	Diesel Base Case	Diesel	45kW Diesel Gen + 45,700 L/yr	26,400	88,186	1,054,087	1.101	1	1	0.0

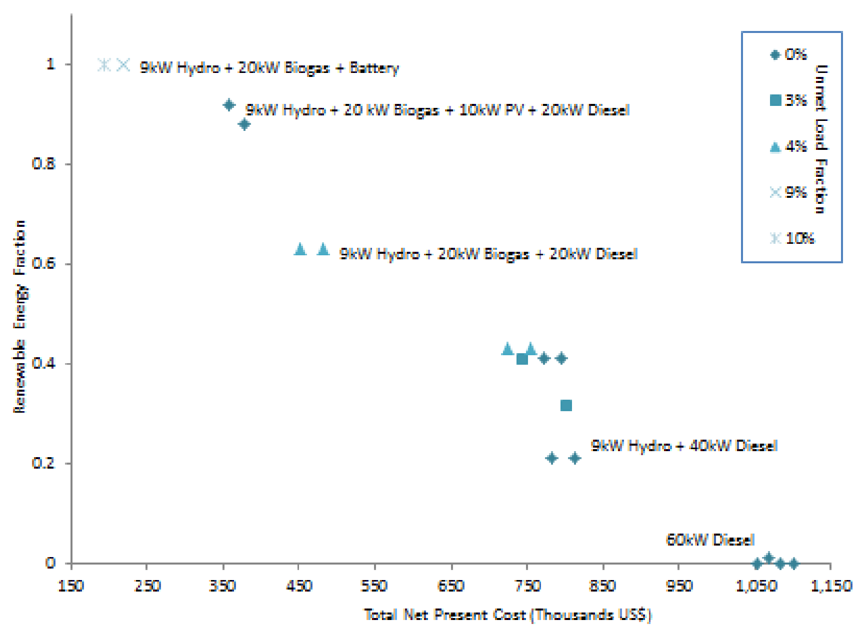

Figure 4 Renewable Energy Fraction and Total NPC meeting Different Shortage Constraints for Long San Village

3.3.3. Analysis: Designing Systems for Village Communities

Here we discuss a number of findings generalizable across villages studied. Despite the cost of diesel fuel, photovoltaic systems (PV) are not cost effective for the village communities. PV is rarely selected for optimal systems due to cost and even under sensitivity analysis low costs do not significantly increase PV production, due in part to evening demand.

Because of high average stream flow, a hydro-turbine is selected for all optimal systems and is selected under reduced average flow during sensitivity analysis. 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. This is consistent with Green Empowerment's experience of hydro limitations (Schnitzer et al., 2014). Biogasification is also a feasible technology. Sensitivity analysis also shows biogasification to be highly dependent on resource availability, and it is selected in optimal systems in larger villages that meet a minimum waste supply threshold. This highlights the need for more detailed study on rice husk supply and gasification ratios attainable in remote conditions.

Capital and replacement costs of battery packs are often the major cost component for least cost systems that meet a zero energy shortage constraint, representing on average 40% NPC in these systems. Batteries may also face lower than expected lifetimes under remote conditions, increasing cost. Nevertheless, we fine the payback period on hydro-turbine and biogas systems can be two years or less compared to diesel base case scenarios (see Figure 3b).

Diesel, at the subsidized government retail rate, is the most expensive form of electric production for Baram villages given the recurrent fuel costs (see Table 3). To meet these smaller loads, generators are often operated well under capacity leading to increased fuel consumption per unit output and a lower overall mean electrical efficiency. In every village modeled the diesel only scenario was at least three times more expensive in total net present term than the optimal scenario under zero shortage constraint, though having a fifth of the initial cost.

4. Limitations and Opportunities

A number of recent studies find PV, hydro-turbines and biogasification becoming more popular as micro-grid technologies (Coelho and Goldemberg, 2013). 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 including maintenance issues (Sovacool, 2012). Furthermore there are specific challenges of meeting load in dry season, demand side management and fee collection (Schnitzer et al., 2014). Nevertheless these are feasible technologies as demonstrated by a number of Green Empowerment and Tonibung successful installations, some operating independently for over a decade. UNIMAS, a local university is now beginning micro-grid installations and the local utility company (SEB) has cited the potential of micro-hydro in meeting remote load in the near future (SEB, 2014).

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 present in the community (Green Empowerment, 2004). 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 (Maulud and Saidi, 2012). Indeed a state-level program launched in 2001 - the Small and Renewable Energy Programme (SREP) - allowed renewable projects of up to 10 MW to sell their output to the utility, under 21-year license agreements though, due to a number of technical and financial barriers, 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 (Tenenbaum et al., 2014). 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 (Tenenbaum et al., 2014). Thus further study is required on designing policy appropriate to local developers and residential communities.

5. Conclusions

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 20 percent, or 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 (Schnitzer et al., 2014) (Monroy et al., 2008).

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