# 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.

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## 1.1. Introduction: The Value of Energy Access

Beyond their share of population, rural communities are widely acknowledged as vital to developing economies, being the foundation of agrarian society, industry and cultural identity. Rural agriculture comprises the largest share of the work force in India, for instance, and since more than two-thirds of the population of India is rural, it has widely been acknowledged that increased rural purchasing power is a valuable stimulus to industrial development at the national scale (Patil, 2010). There is significant evidence linking provision of energy services with achievement of social objectives and generation of economic growth, as noted by the FAO (FAO, 1987), the United Nations (Modi et al., 2006) and through cost-effective design and implementation efforts (Casillas and Kammen, 2010). A lack of energy access stifles both small scale cottage activity and larger scale rural agriculture; hampers commercial trading opportunities; and inhibits the provision of basic social services such as health care and education. Expanding rural energy access is a key solution to achieving a number of the United Nations Millennium Development Goals (Flavin et al., 2005).

Poverty in Malaysia is largely, though not entirely, a rural phenomenon. The Malaysian economy was originally very dependent on the rural sector for early development. In the 1970s agricultural exports accounted for 30% national GDP and roughly 70% of the rural population was engaged in agriculture. However Malaysia is now transitioning to an economy dependent on industry and large-scale commercial farming of crops such as palm oil, with significant impact on the livelihoods of the still dominant rural population. The Government of Malaysia acknowledges the importance of stimulating rural economy and through the Ministry of Rural and Regional Development has launched a program called 'the Government Transformation Program' to increase rural energy access, clean water access and road infrastructure networks across the country (Ministry of Rural and Regional Development, 2012). However to date there is limited private sector participation in rural electrification and energy entrepreneurship and micro-enterprise, representing a major barrier to the spread of rural energy solutions (UNDP, 2007).

Poverty rates are highest in the rural states of Kelantan, Terengganu, Sabah and Sarawak (UNDP, 2005). Sarawak is the fourth most populous state in Malaysia with a population of 2.3 million people. However, accounting for roughly a third of Malaysian landmass, it also has the lowest population density in the country of 22 people per $km^2$. Sarawak also has one of the lowest population growth rates in the country at 1.2% per annum (State Planning Unit, 2012). With over 600 villages, rural communities represent 47% of total population in the state. This is one of the lowest levels of urbanization in the country (Department of Statistics, 2010). Amongst other issues including the acknowledgement of native customary rights to land, logging and palm oil concession infringement and urban migration, the common lack of affordable and reliable energy access poses a barrier to development in village communities. A majority of rural villages in the state are not grid connected and rely heavily on diesel fuel for all electricity and transportation needs. However political attention often comes to these communities only when larger national or international geopolitical forces come into play, as they have done in Sarawak, East 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 (see Figure 1).

Picture of Mundung Abun, showing Transmission Lines for Bakun Dam running overhead while village has no grid connected Electricity

In this study we focus specifically on villages of the Baram River Basin in Sarawak, as the basin next scheduled for large scale hydroelectricity development under the state government plan SCORE (Sarawak Corridor of Renewable Energy)(Sarawak Energy Berhad, 2010). The particular Baram Villages surveyed do not necessarily fall into the category of lacking energy access - transportation routes are open enough such that fuel and infrastructure can be brought to village communities. Trade in meat and produce creates the economic base which makes modern energy services available. Diesel fuel cost, while not entirely prohibitive, is a barrier which creates exclusion. We find 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 (Suruhanjaya Tenaga, 2012). Most of the villages in the Baram have a significant number of families that do not own generators and a larger number of families that have generators cannot afford a consistent fuel supply over the course of a month. While in some villages such as Long San, the fraction of doors (term for a single housing unit shared by two to three families) with generators was quite high, there were a number of villages such as Long Liam and Long Keluan where this share is less than 50%. Indeed a number of Penan villages have a single generator for the entire village. The average we observed in the villages surveyed is roughly 60 – 70% of doors with a generator. The results of our current assessment show that Sarawak's rural economy could benefit from higher penetration of renewable energy projects.

The total installed generation capacity on Sarawak's state-owned utility (SESCO) grid in 2010 was roughly 1,345 MW generating over 5,700 GWh in electricity sales. The industrial sector was the main user of electricity with 45.2% of total sales, followed by the commercial sector at 30.2% and the residential sector at 23.3%. Over the entire decade, growth rate in total electricity sales thus averaged 7.3% per annum (Sarawak Energy Berhad, 2010). Despite a 7.3% average annual growth rate over the past decade, rural electrification has expanded much more slowly. Even with plans for the development of large scale dams with high voltage transmission from rural areas in the state unfolding, this has rarely translated into electricity access for affected or nearby communities. Thus designing more cost effective ways to meet current electricity demand will relieve an economic burden while simultaneously creating potential for new economic revenue streams. We thus present a contrasting paradigm to SCORE's large scale, extraction-based development regime (Sovacool et al., 2012) through locally appropriate energy solutions and create a case study of energy opportunities that enhance the savings and growth potential of village communities. In the sections that follow we explore optimal system designs for electricity supply in villages of the Baram. We determine that lower cost, higher reliability options are available for the villages given current resource potential.

## 1.2. Rural Energy Use and Resources in Selected Baram Villages

The Baram originates in the Kelabit Highlands, a watershed demarcated by the Mountains of East Kalimantan, which form a natural border with Sarawak. The Baram, which is the second longest river in Malaysia, flows westwards through tropical rainforest to the South China Sea and has a catchment area of 22,930 $km^2$. There are over 20 villages along the Baram River. Here In preparing this research 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.

### 1.2.1. General Description

The Kenyah settlement of Long San is one of the largest Baram villages and is one of the villages closest to the site proposed for the Baram Dam. It is roughly 150 km south east of Miri and can be accessed by 5 hours driving along logging tracks. Long San is comprised of 160 families representing roughly 800 people. Being a major base for trading goods from the city, Long San has become a hub of the Baram community. Long San would be the first village flooded and destroyed by the Baram Dam if it is built. Tanjung Tepalit is a much smaller Kenyah village community located about 22 km south along the river from Long San. It comprises of a single long house with 25 doors. Currently a new 60 door long house is being constructed for the housing of extended families. This is being entirely financed by village families. Produce (fruit, vegetables and meat) are taken to Long San along the river for trading. Long Anap is the furthest village from the Baram Dam site and is 34.5km from Long San. Another Kenyah village, Long Anap is medium sized with two long houses comprised of 54 doors total. Aside from the long houses there is a community church (with generator) and a primary and secondary school.

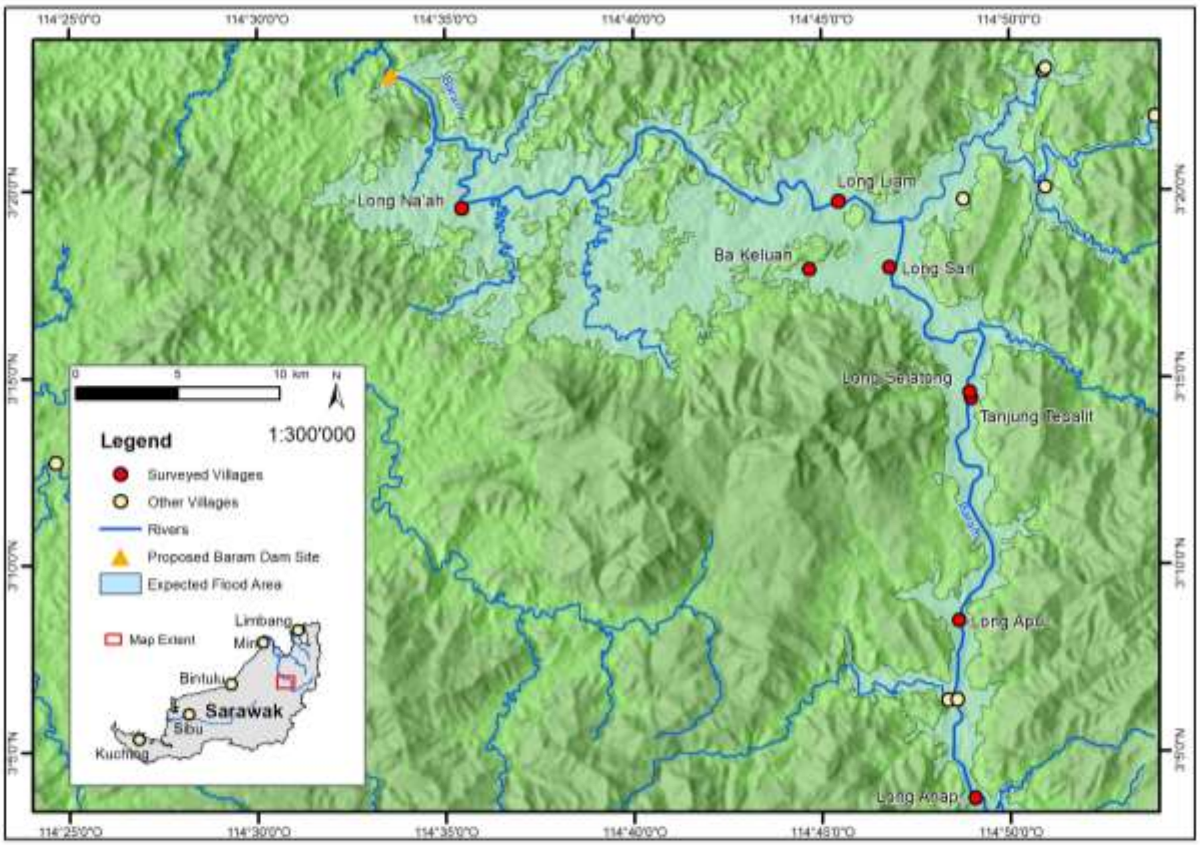


Figure 1 Map showing villages of the Baram River Basin

### 1.2.2. ENERGY USE IN THE VILLAGES

Based on interviews and site visits we were able to record the number and type of generators operational within each village to estimate current energy supply. Before this discussion we should note that the local state department supplies diesel to meet electricity demand for public buildings. In Long San, for instance, there are a number of 20 KW generators for the school buildings and clinics which are maintained and fueled by the government. We do not include these loads in our model as they are satisfied through government funding. In these villages, the average ‘door’, which houses 2-3 families operates generators from 6pm – 11pm or midnight, consuming about 2 gallons a night. Based on reports of daily fuel usage it appears that most generators are operating at almost half of maximum load. Electricity is primarily used for lighting and fans. Most households also have refrigerators and washing machines while well off families also own televisions, DVD players and other electronic devices Almost all of the 80 doors in the Long San village own a 3kW diesel generator, however we estimate 85% of doors in Tanjung Tepalit and 70% of doors in Long Anap own generators however we extrapolate demand and assume that all doors in a village would require electricity. Our assumptions for calculating typical electricity use during evening time are explained in Table 1 below.

In the villages, with less regular maintenance, generators run at lower efficiencies. We assume 16% efficiency for generators or 9-10 kWh/gal (where generators can normally achieve 25% or higher). Diesel electricity use in the Baram therefore represents a US$0.67/kWh cost of electricity while the residential rate from SESCO is 0.31 RM/kWh (Sarawak Energy Berhad, 2010). The average village door in the Baram uses approximately 3 kWh per night or approximately 83 kWh per month. Entire villages then can use roughly 130 kWh per night or 4,000 kWh per month. This compares to an average electricity use per household in Sarawak of 205 kWh/month (Sarawak Planning Unit, 2011) (SEB, 2011) where primary loads are air conditioners, ceiling fans, refrigerators, lights and water heaters (Kubota et al., 2011). A single village door currently spends ~ 50 US$/month and thus over 600 US$/year on diesel. We estimate the average household in Malaysia spends ~ US$19/month on electricity based on electricity rates.

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) | 60 | 6 | 5 | 30 | 1 | 4,320 |
| Light Bulb (Tube) | 100 | 5 | 5 | 30 | 1 | 6,000 |
| Electric Fan | 40 | 2 | 5 | 30 | 1 | 960 |
| Television | 400 | 1 | 4 | 10 | 0.2 | 256 |
| 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 | 13,504 |
| | | | | | Average kW | 90 |

Pictures from left to right: (a) Government Secondary School at Long San, (b) a typical rice mill house and (c) view of the Long San River

### 1.2.3. Description of Energy Resources

*Hydro Potential:* Our team visited potential microhydro sites at each Baram village and measured stream flow at each site. These measurements were correlated with precipitation data to estimate monthly average flow rates (see Figure 1 below). Based on previous Green Empowerment installations in other villages we estimate the complete capital cost of microhydro infrastructure[i].

*Solar Resource:* Using NASA Surface Solar Energy data and the coordinates of the villages we determine solar potential for the region (see Figure 2 below). That annual averaged insolation is 5.34 kWh/m$^2$-day, peaking at 6 kWh/m$^2$-day in March. Average annual radiation is 0.4W/m$^2$.

Assuming an available area of 100m$^2$ and a 23% efficiency, a typical long house community could support a 15kW solar installation which could generate about 45 MWh/year for day time use.

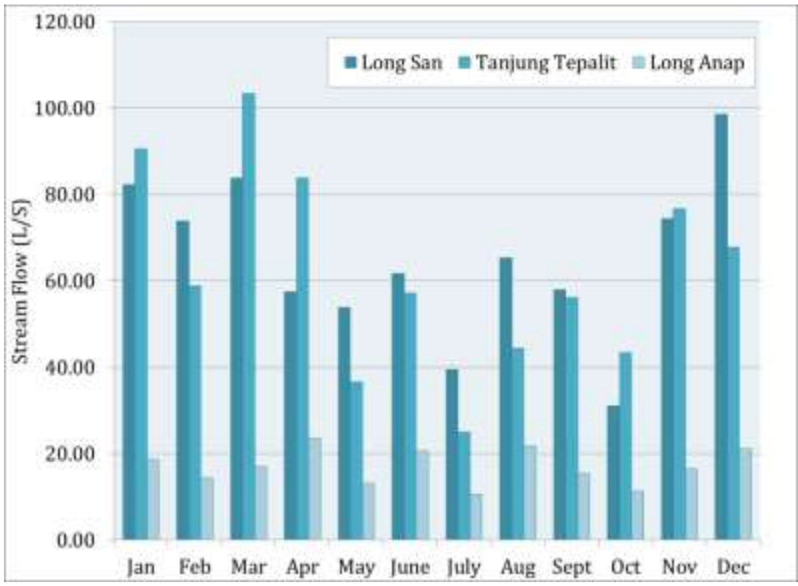


Figure 2 Monthly Averaged Stream Flow in Baram Region

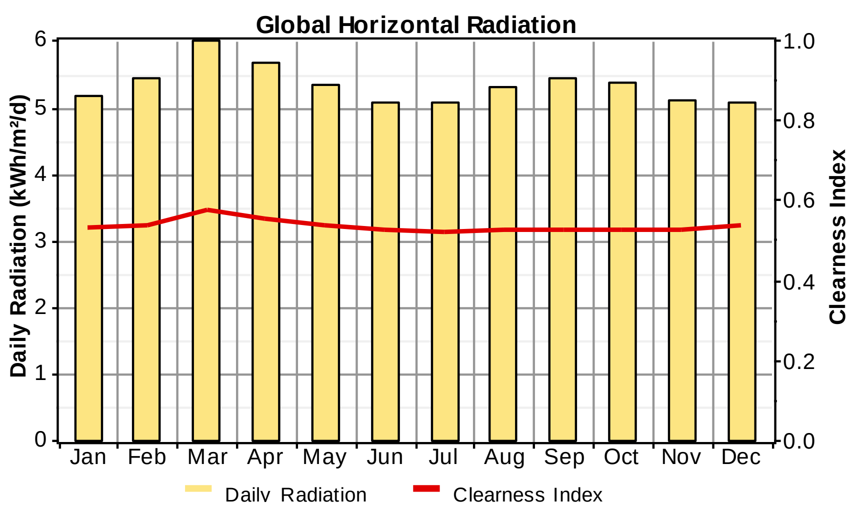


Figure 3 Monthly averaged Daily Insolation Levels in Baram Region

*Biomass Resource:* We also 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 might own 6-7 acres of land within the village bounds while a smaller family might own 2-3 acres. The average family owns roughly 5 acres of land with a conservative average yield of 10 bags of rice per acre every year. We approximate how rice husk availability is distributed throughout the year based on monthly rice consumption (see Figure 3 below). The higher heating value (HHV) of rice husk is 15.84 MJ/kg, while the LHV of produced gas is approximately 7 MJ/kg (Yi et al., 2009) and (Lim et al., 2012). We do not consider rice straw as a conservative assumption that biomass material cannot be transported to the long house site of electricity generation. Literature shows gas yield rate is between 1.63~1.84$m^3$/kg and gasification efficiency is between 80.8%~84.6% (Yi et al., 2009). Assuming 30% electrical conversion efficiency, a standard biogas generator would require 1.2kg/hr-$KW_{output}$. This depends strongly on the gasification ratio assumed. The gasification ratio is the amount of biogas produced for a given amount of biomass residue ($m^3$ biogas/kg biomass residue). To be conservative we assume 1.7$m^3$/kg biomass residue but experiment with this value through sensitivity analysis.


Figure 4 Monthly Averaged Daily Rice Husk Available

*Wind Resource:* Based on NASA data roughly 50% of the year wind speeds 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 turbine are not a feasible energy option and they are not considered in the study (see Figure 4 below).

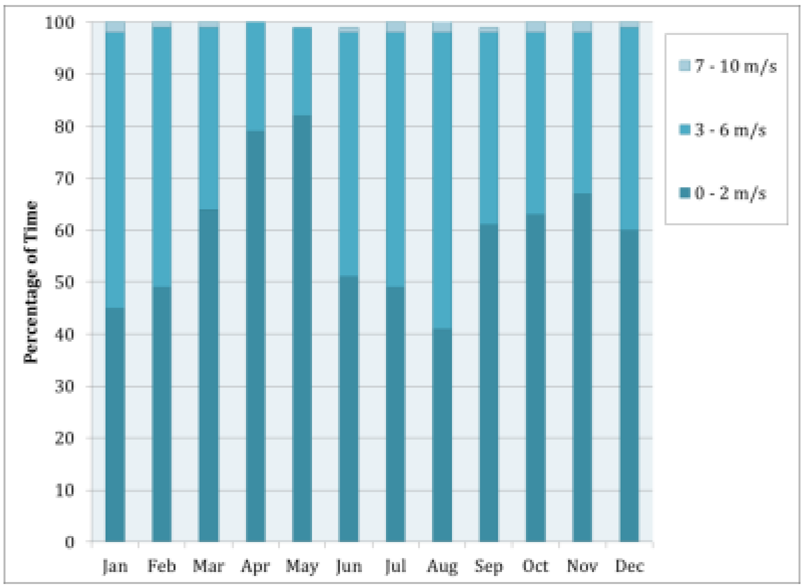


Figure 5 Monthly Averaged Percent Of Time The Wind Speed At 50 m Is Within The Indicated Range

Pictures from Left to Right of (a) Village women of Tanjung Tepalit standing with a typical family's padi yield in a good harvest (b) Surveying villagers in Tanjung Tepalit

Pictures from Left to Right: (a) Rice Mill in Long Anap, (b) Proposed Micro hydro site at Long San and (c) Solar System for Cellular Communication Satelite in Tanjung Tepalit

## 1.3. Energy Modeling of the Baram Villages

### 1.3.1. Optimization Model Framework

Our project used NREL's HOMER resource optimization model to determine the most economically feasible electricity fuel mix for each village. In order to find the least cost combination of components that meet electrical and thermal loads, HOMER simulates thousands of system configurations, optimizes for lifecycle costs, and generates results of sensitivity analyses on most inputs (Lilenthal, 2005). We provide HOMER with a number of resource and technology inputs for each village (see Table 2 below). We provide monthly biomass residue availability, daily solar insolation and monthly averaged flow rates as described in the section above. We also provide data on hydro turbine design flow rate, expected PV efficiencies, biomass gasification ratio and feed rates for the biogas generator. We provide data on converter size and give the model a number of battery options. Finally, we input capital, replacement and operation/maintenance costs for each technology. Hydro and solar cost figures (US \$1300/$kW_{installed}$ and US \$2,300/$kW_{installed}$ respectively) are based on data directly from Green Empowerment, Green Power and Sungevity, which specialize in installations for small scale and remote applications. Small scale biogasification costs were taken from literature (Sieger et al., 2002) (IRENA, 2012). Diesel engine costs were reported in surveys and biogas cost data is taken from literature. However we use sensitivity analysis to observe outcomes with varying technology prices. In HOMER we assume an interest rate of 7% and a system lifetime of 25 years.

Table 2 Energy Demand and Resource Characteristics of the Baram Villages modeled

| Location | | | | Size | | | Estimated Household Demand | | | | | Non-Household Loads | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Coordinates | | | | | | | | | | | | | |
| Village Name | Indigenous Group | N Lat. | E Long. | No. Doors | No. Families | No. People | Gen Cap (KW) | kWh/month | kWh/year | Diesel Use (gal) | Diesel Expense ($/year) | Community Hall | School | Church | Clinic |
| Long San | Kenyah | 3 17 888 | 114 46 855 | 80 | 160 | 800 | 45 | 6,688 | 80,256 | 13,777 | 54,557 | Yes | Yes | Yes | Yes |
| Long Anap | Kenyah | 3 03 747 | 114 49 140 | 54 | 108 | 540 | 28 | 4,180 | 50,160 | 8,610 | 34,096 | No | Yes | Yes | No |
| Tanjung Tepalit | Kenyah | 3 14 396 | 114 48 975 | 25 | 50 | 250 | 14 | 2,090 | 25,080 | 4,305 | 17,048 | No | No | Yes | No |

| Location | | | | Biomass Resource | | | Hydro Resource | | | | | Solar Resource | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Coordinates | | | | | | Monthly Averaged Flow Rates (L/s) | | | | | Average Radiation (W/m2) | |
| Village Name | Indigenous Group | N Lat. | E Long. | Padi Acreage | Rice Husk (tonnes/yr) | Annual Potential (kWh) | Head (m) | Max | Min | Avg | Capacity (KW) | Mthly Avg Insolation (kWh/m2-day) | Max | Min |
| 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 |
| 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 |
| 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 |

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

## 1.3.2. General Model Results

HOMER delivers results which show the optimal system for each possible technology configuration ranked according to Total Net Present Cost (NPC). For our analysis of all three villages there are a number of major conclusions. Here we discuss the least cost options in terms of NPC and LCOE. We describe the least cost system configuration given each village's resource availability. We also describe the results of sensitivity analysis on stream flow, biomass resource and diesel cost.

*Tanjung Tepalit.* Tanjung Tepalit is the smallest village and has a low level of demand but a large hydro potential given the head available and steady annual stream flow patterns. The least cost system for the village is a single 7KW Hydro plant, a 90 12V battery pack and a complementary 10kW inverter. The LCOE is $0.196/kWh. Above $0.5/L diesel is too expensive and does not figure into any optimal systems. Diesel consumption declines gradually as the average stream flow available increases. Once diesel costs more than $1.00/L then total diesel consumption can drop to less than 800L/year. Diesel is sold at a standard subsidized retail rate of $1.07/L. Biomass Resource is the lowest in this village, given its population. Sensitivity analysis shows that above 0.05 tonnes rice husk per day (double the assumed current capacity) biogas becomes viable. The optimal system would then change to 7kW hydro and 10kW biogas generator (LCOE of $0.167/kWh) and in this system no battery is required. The hydro provides 84% and the biogas 16% of annual generation. We also note that photovoltaics do not figure into any optimal systems at the current cost. Batteries, biogas generators and diesel generators are all selected before photovoltaic (PV) panels. Below are graphics that depict these results (see Figures 5,6,7).

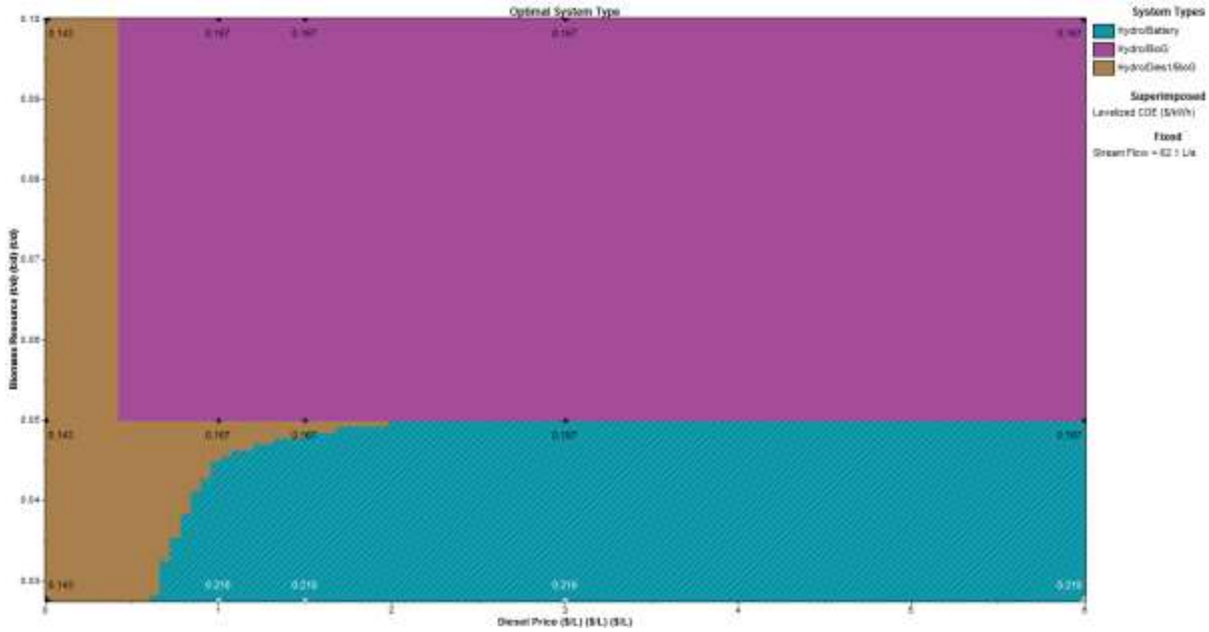


Figure 6 Tanjung Aru Optimal System Types

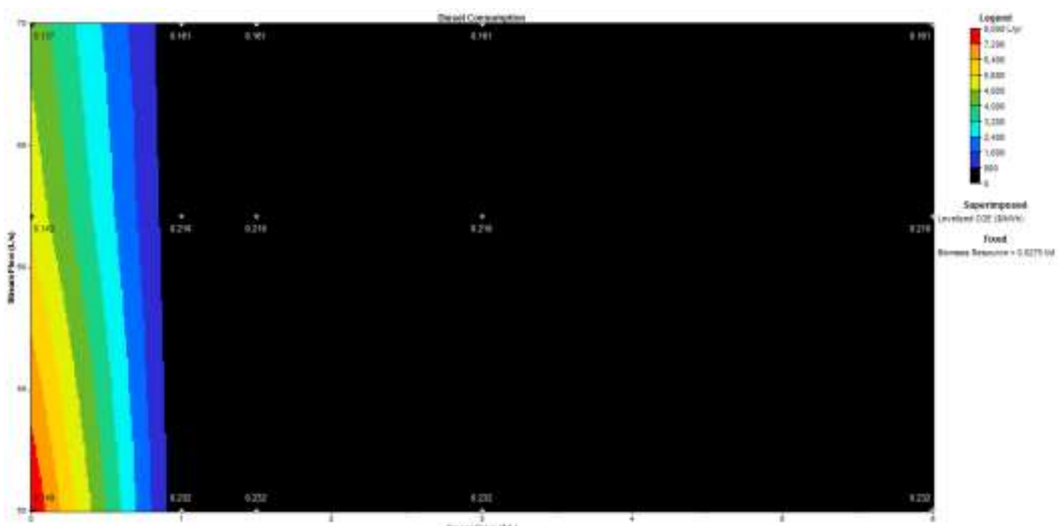


Figure 7 Changes in Diesel Consumption with Stream Fl

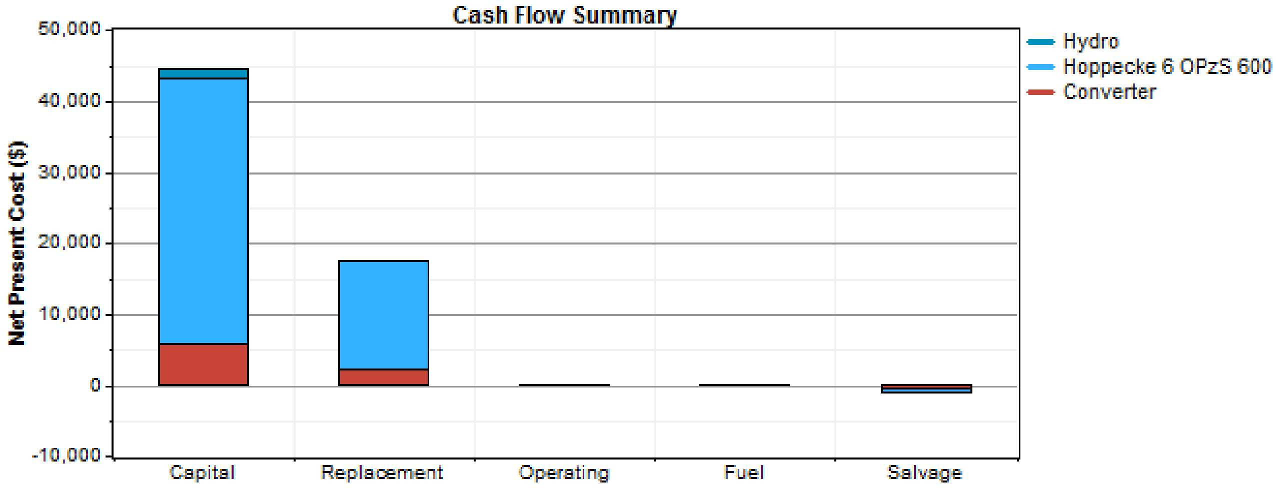


Figure 8 Least Cost System Design for Tanjung Aru (7kW Hydro and Battery System)

*Long Anap.* Long Anap has 54 doors and an estimated demand of 28kW but a lower annual average stream flow according to our measurements. However sensitivity analysis on stream flow shows that as average stream flow increases, the hydro production increases steadily from 62,000 kWh/yr at 17L/s to 80,000 kWh/yr at 30 L/s. Since biomass resource is higher in Long San, 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 90 piece 12V battery pack system. This system has a LCOE of $0.225/kWh with the Hydro turbine and biogas generator providing 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 $0.33/L. After this price point the Hydro, Biogas generator and Battery system described above dominates.

*Long San.* Long San has the largest population with 80 doors and an estimated demand of 45kW. Like Tanjung Tepalit, Long San has high average stream flow. Like the other two villages assessed, the least cost system includes 8.83 kW of hydro and like Long Anap, because of the biomass resource available to the village, the least cost system also includes a 20 kW biogas generator and battery pack. At a price of $0.4/L a hydro, biogas, battery and diesel system is optimal. However beyond a price point of $0.8/L, diesel fuel drops out and the optimal system is the Hydro turbine, biogas generator and battery system described above. The PV panels are not selected in any least cost systems at its current cost. A hydro turbine and diesel system (without battery) would have a NPC of $783,057, a LCOE of $0.819/kWh and an operating cost of $65,573/year due to the expense of diesel.

### 1.3.3. Results Analysis: Designing Systems for Village Communities

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. In each case this least cost option was 20% or less of base case (diesel) NPC, though these sunk costs have already been incurred. The LCOE of these renewable options were also all less than 20% of their diesel base case scenarios (see Figure 8 below).

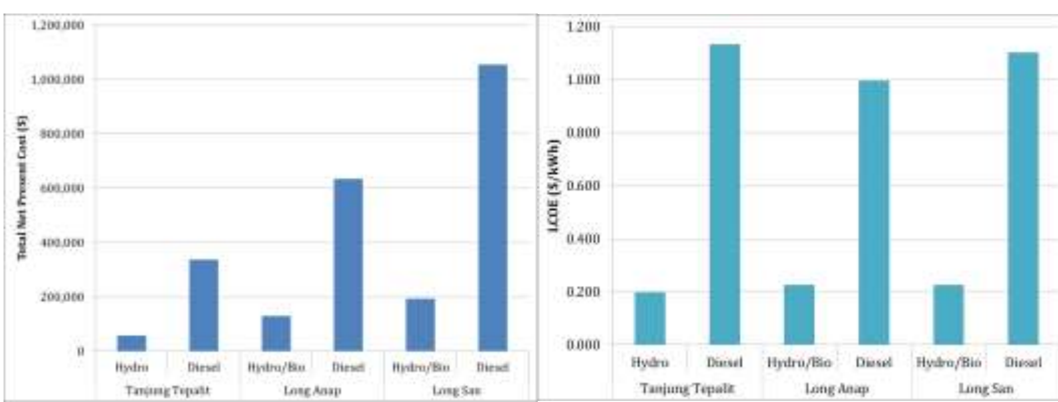


Figure 9 Differences in NPC and LCOE for Least Cost Options and Base Case (Diesel)

- **Hydroelectricity is selected in every simulation, meaning that it is the lowest cost means of electricity production available to each village**. Based on its low upfront and O&M costs the hydro search space is actually insufficient in the models, meaning that villages would benefit from even more hydro capacity than our head and flow measurements show is available. In each village and under almost every scenario modeled, hydro provides at least 50% of the total electricity supply. Thus the benefit of cheap and dispatchable electricity will exceed the upfront cost of expanding existing systems, designing larger (or multiple) systems.

- **Small scale biogasification is financially feasible and profitable for village communities**. Even in Tanjung Tepalit where rice husk availability is the lowest, biogas substitutes for diesel during the three months that biomass is available. This is because the cost of installation and maintenance of the biogasification unit is similar to that of a diesel generator however the fuel is virtually free. It should be noted that this does not include the devaluation of systems over time. Given low usage, it would seem that the biogasifier would devalue more quickly and have to be replaced more often. We approach this by performing sensitivity analysis on the lifetime (number of operating hours) of a biogasifer which affects how often it has to be replaced. Even when the number of operating hours is reduced to one third, which is significantly lower than a diesel engine, the gasifier is chosen in the least cost scenario. There are a number of technical barriers to the deployment of small scale biomass technologies as described above and these should be considered alongside cost.

- **Despite the cost of diesel fuel, photovoltaic systems (PV) are not cost effective for the village communities**. In every village modeled the cheapest PV scenario is at least 12%% more expensive than the lowest NPC scenario. In Tanjung Tepalit, after hydro and biogas resources are maximized, it is more actually cost effective to add additional diesel capacity than to add solar. Even when a 10 kW PV system is introduced it does not produce more than 15% of total electricity supplied. This trend only changes under sensitivity analysis when the cost of diesel is very high and we select prices for PV that are below current market prices. Nevertheless in each village PV scenarios are still cheaper than 100% diesel only scenarios.

- **Capital and replacement costs of battery packs are often the major cost component for Least Cost systems.** Battery packs of 90-180 12V batteries are often selected in the lowest cost options but represent most of the cost. For each of the villages modeled a battery pack was selected for the least NPC and least LCOE scenario and cost at least 40% of total net present cost. In Tanjung Tepalit where there the most optimal system is a hydro turbine and battery pack alone, the battery is 90% of the total system cost. This is due to high upfront cost and the replacement cost of batteries.
- **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**. A 100% diesel generator system in Long San, the largest village demand modeled, would require 60 kW of diesel capacity and though having one of the lowest capital costs (US $26,400), the annual fuel cost cause it to be one of the most expensive NPC scenarios. To meet smaller loads the generators will often be under capacity leading to increased fuel consumption and a lower overall mean electrical efficiency. In every village modeled the

diesel only scenario was at least five times more expensive than the least NPC scenario. This means that the current system of 100% diesel generation is the most expensive option that village communities could design.

- **The Payback Period on Hydro and Biogas systems can be two years or less compared to 100% Diesel base case scenarios.** In Long San, which requires the largest system capacity, the 8.8 kW Hydro and 20 kW Biogas Scenario has a year simple pay back and beyond a year the cash flow from this system is positive relative to a 100% diesel scenario. In Tanjung Tepalit, the simple pay back on the 7kW Hydro system is 1.30 years. The simple payback on a system with PV would be 2.5 years. In Long Anap, the 6kW Hydro and 20kW biogas system has a simple pay back of 1.35 years.

## 1.4. 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. In these villages 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.

Optimization modeling provides insight into the comparative economics of various rural electrification systems. We observe that hydroelectricity 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 the majority of 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 and suggest a need for adopting a radically different strategy for expanding rural energy access in light of current state government plans. 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 of local and national innovation in government support of increasing access to modern energy (Patil, 2010), (Monroy et al., 2008), (Bazilian et al., 2012). The potential for micro-finance, mobile money or other market oriented approaches could support this initiative to make the local energy market equally accessible and attractive to local investors and communities.

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[i] Tonibung and Green Empowerment have been installing micro-hydro systems in Malaysia for over a decade. They have already installed micro-hydro plants in a number of Sarawakian villages including Long Lawen and have plans for multiple installations in Baram River villages and the Kelabit Highlands