

# **THE WORLD BANK**

## **Energy Sector Management Assistance Programme - ESMAP**

### **Independent Evaluation of the ILZRO/RAPS Diesel/PV Hybrid System in Padre Cocha, the Amazon Region of Peru**

#### ***CONSOLIDATED SUMMARY***

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# **Independent Economic Evaluation of the ILZRO/RAPS Renewable Energy System in the Amazon Region of Peru**

**And**

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## **CONSOLIDATED SUMMARY**

Padre Cocha is a typical village of the amazon jungle, located near the city of Iquitos, capital of the Department of Loreto and one of the main cities of the jungle, 1009 km north east of Lima. Padre Cocha's present population is 2500 inhabitants and 331 households. In June 2002, a diesel/PV hybrid system was installed in Padre Cocha, providing 24-hour of electricity services, where residents have no access to power services before the installation.

This ESMAP study intends to evaluate whether the RAPS system at Padre Cocha is sustainable and replicable, and provide recommendations on supply of electricity services to villages like Padre Cocha. This study consists two parts: 1) technical and economic evaluation; and 2) financial and institutional evaluation. This executive summary presents a consolidated synopsis of key conclusions of both parts.

## **I. EVALUATION OF THE PADRE COCHA RAPS SYSTEM**

### **1. Financial Evaluation**

#### **1.1 Capital Costs of the RAPS System and Sources of Funding**

In 1997 ILZRO and SEIA, two non-profit private organisations, promoted the development of the RAPS hybrid systems consisting of a solar PV and a diesel generating sets and a distribution microgrid<sup>1</sup>, in the amazon region of Peru. After performing studies, Padre Cocha and Indiana were selected for installing the first diesel/PV systems as pilot installations to evaluate benefits and applicability of this technology in isolated areas of the Peruvian jungle. The Regional Government of Loreto (GOREL) and the local Municipality and the Distribution Company Electro Oriente (EOSA) provided support.

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<sup>1</sup> The term rural microgrid is generally used for a low voltage grid that transfers a capacity level less than 50 kVA and it is powered by a micro power plant. In developing countries, and depending of the individual needs and geographical spread, this can mean from a very small hamlet a village of up to 300 households.

Until now, ILZRO RAPS Peru reports an expenditure of US\$2 million, in administration, promotion, studies and equipment acquisition. Table 1 shows the sources of funding. This figure does not include the GOREL contributions in the amount of US\$ 130,000 for the purchase of PV panels and \$120,000 for the cost of distribution grid, as well as EOSA's contribution of US\$40,000 for donation of the diesel genset.

**Table 1. Sources of Funds US\$**

Common Fund for Commodities (CFC)	540,000
Sandia Nat Lab (USDOE)	204,480
ILZRO & ILZRO RAPS Latin Amer.	1,349,050
<b>Total US\$</b>	<b>2,093,530</b>

In July 2003 the RAPS system at Padre Cocha started operations, with two RPS-150 type pre-assembled systems, each of 150kWh/day (totalling 300kWh/day) capacity. Each system consists of 180 solar PV panels of 80 Wp, 240 storage batteries of 375 Ah, rectifier systems, charger and 40 kW inverter. It includes a single diesel generator of 128 kW<sup>2</sup>. The system delivers electric energy to the distribution grid at 240 volts AC. The total cost of the system was US\$577, 000 with the following breakdown, as shown in Table 2:

**Table 2. Capital Costs of the Padre Cocha RAPS**

CONCEPT		Thousand Soles	Thousand US\$
<b>RAPS SYSTEM</b>	PV modules	436.33	128.33
	Batteries	195.84	57.60
	Control and power conditioning	417.07	122.67
	Building and materials	79.33	23.33
PROJECT DESIGN, COMMISSIONING AND LEGALIZATION		282.15	82.98
<b>SUB TOTAL RAPS EQUIPMENT, MATERIALS AND EXECUTION</b>		<b>1,410.72</b>	<b>414.92</b>
DISTRIBUTION GRIDS		413.72	121.68
GENERATOR SET		137.68	40.50
<b>1</b>	<b>TOTAL INITIAL INVESTMENT</b>	<b>1,962.12</b>	<b>577.10</b>
<i>Note: Change rate 3.4 Soles/US\$</i>			

In the initial months of operation (October 2003 to July 2004), a fixed charge tariff system of S/. 21.7/month (US\$ 6.4/month) was established, without consumption limit for 24 hours. This resulted in very high energy consumption per customer and frequent complaints from small consumers. Starting October 2004 a tariff for energy consumption (BT5B) was established. Although Padre Cocha is not integrated to any concession, it was decided to apply a regulated tariff (BT5B), the same that Electro Oriente applies to its customers in Iquitos. The energy price was fixed at S/.0.6976 kWh (US\$0.2114 /kWh) equal to the current price for Iquitos in July 2004<sup>3</sup>. Besides, the monthly charges per customer were fixed as the following. However, this new tariff did not increase revenue but it did increase the number of connections.

S/. 1.85 for fixed charge

<sup>2</sup> This unit is second hand and was supplied by Electro Oriente, because of a lack of funding to purchase a new unit of 100 kW as required in the system design.

<sup>3</sup> Electro Oriente prices are fixed by OSINERG which is the Regulator agency and are modified each time oil price adjustments, exchange rates or internal price increase occur.

S/. 2.50 for public street lighting and  
 S/. 0.63 for maintenance and replacement of meters  
**TOTAL FIXED MONTHLY: S/. 4.98 (\$1.51/month)**

Operational costs, including purchase of fuel and provision for battery replacement, are US\$ 37,704/year, as per the following breakdown, as shown in Table 3:

**Table 3. Operation and administration costs**

<b>EXPENSES BREAKDOWN</b>	<b>S/./month</b>	<b>US\$/month</b>	<b>S/./year</b>	<b>US\$/year</b>	<b>%</b>
Local salaries	2,550	750	30,600	9,000	
Spare parts and maintenance	504	148	6,048	1,776	
Administrative	150	44	1,800	528	
Technical support by IRP (estimated)	850	250	10,200	3,000	
<b>SUBTOTAL FIXED M&amp;O&amp;M</b>	<b>4,054</b>	<b>1,192</b>	<b>48,648</b>	<b>14,304</b>	37.9%
Provision for battery replacement	2,686	790	32,232	9,480	25.1%
<b>SUBTOTAL FIXED EXPENSES</b>	<b>6,740</b>	<b>1,982</b>	<b>80,880</b>	<b>23,784</b>	63.1%
Fuel and lubricant	3,728	1,097	44,736	13,164	
Fuel transport	213	63	2,556	756	
<b>SUBTOTAL VARIABLE EXPENSES</b>	<b>3,941</b>	<b>1,160</b>	<b>47,292</b>	<b>13,920</b>	36.9%
<b>Total M&amp;O&amp;M COSTS</b>	<b>10,681</b>	<b>3,142</b>	<b>128,172</b>	<b>37,704</b>	100.0%

Annual projected revenues based on invoicing between August 2004 and January 2005, will amount to US\$ 14,700/year which generates a deficit of 61%, which makes the system financially unsustainable, as shown in Table 4.

**Table 4. Revenues from the RAPS System**

	<b>S/./month</b>	<b>US\$/month</b>	<b>S/./year</b>	<b>US\$/year</b>	<b>% OF TOTAL</b>
<b>M&amp;O&amp;M costs</b>	10,681	3,142	128,172	37,704	100.0%
<b>Average Income</b>	4,152	1,221	49,824	14,654	38.9%

The currently applied tariff structure does not adequately reflect the ratio between fixed and variable costs (energy dependent) and thus is not robust to demand changes. It should be possible to establish a tariff higher than the requested tariffs within the user's willingness to pay that would collect sufficient revenue to pay at least for M&O&M costs. Apart from applying a higher new tariff structure, the fixed charge could include also the energy availability, particularly for the very low consumption customers in order to significantly reduce transaction costs.

## 2. Technical Evaluation

### 2.1 Demand Analysis for Padre Cocha

At present the system serves 240 customers out of a potential total of 344 and public street lighting. Almost all costumers are domestic. The daily total average energy consumption is near 220 kWh: 39% produced by the PV cells and the rest by the Diesel generator. The maximum peak load power is of 22 kW, which occurs in night hours (at 8 pm approx.). The demand distribution among costumers is typical of villages in the region. The average energy consumption per customer is of 18.6 kWh/month, with a large majority consuming less than 17 kWh/month, as shown in Table 5. Public street lighting consumption is high with respect to customer consumption, and distribution losses is in the range of 12% of the total consumption.

**Table 5. Padre Cocha Demand Segmentation**

Segments		Consumption range		Contracts		Segment Demand	
		Wh/day	kWh/mo.	No.	%	kWh/day	%
<i>Residential</i>	Very low usage	0 to 275	0 to 8.5	97	40	12.5	5
	Low usage	275 to 550	8.5 to 17	74	31	30.5	13
	Medium usage	550 to 985	17 to 30	35	14	25.6	10
	High usage	985 to 2200	30 to 67	18	7	26.1	11
	Very high usage	2250 to 3300	67 to 100	8	3	22.0	9
	<i>Subtotal residential</i>			<b>232</b>	<b>95</b>	<b>116.7</b>	<b>48</b>
<i>Non residential</i>		> 3300	> 100	<b>10</b>	<b>5</b>	<b>46.8</b>	<b>19</b>
<i>Subtotal residential and non residential</i>				<b>242</b>	<b>100</b>	<b>163.5</b>	<b>67</b>
<i>Public lighting</i>				-	-	<b>19.2</b>	<b>8</b>
<i>RAPS Power Plant and community hall</i>				-	-	<b>12.4</b>	<b>5</b>
<i>Distribution losses (average 2kW per hour)</i>				-	-	<b>48.0</b>	<b>20</b>
<i>Total Generation</i>				<b>242</b>	<b>100</b>	<b>243.1</b>	<b>100</b>

### 2.2 Sizing

While the present peak power load in Padre Cocha is 22 kW, and the demand of 220 kWh/day, the RAPS system was designed for a peak load of 80 kW and a production of 300 kWh/day, which resulted in oversized power supply components.

The distribution grid was also built for a total load of 250 KVA, oversized for the present load, which resulted in high transformer losses that initially surpassed 20% of produced energy. After changing the transformer size, losses were reduced to 12%.

Distribution should be done with a low voltage grid, and losses limited to the voltage drop in the lines. Since the PV part of the generation plant is not noisy or annoying, it could be located within the village to keep distribution lines compact. The diesel generator could remain, as it is common practice, at the outskirts.

### 2.3 Design and Installation

The RAPS system is of modern technology and properly installed. The project technology design is fairly sound. However, some design and construction aspects that increase installation costs and affect system performance should be corrected in similar projects.

Among these aspects the following have been detected:

- To utilize properly sized (smaller) and of higher efficiency diesel generators.

- The rectification, charge and discharge of batteries sequence and the conversion to alternate current, originate high losses and lower the overall efficiency. It should be considered the configuration of directly connecting the genset to the a-c distribution grid; a switch to connect the inverter when the genset is off; and the possibility of smaller parallel inverters to match demand and conversion efficiency.
- To install batteries in site constructions and not in factory containers.
- To install batteries with higher unit capacity.

Additionally, the use of variable angle PV panels should be evaluated to increase solar energy efficiency.

#### 2.4 Operation and waste treatment

The present daily operation cycle is suitable, given the system size characteristics in regard to the load and configuration. In addition, the recycling plan for used lubricating oil and the disposal of used batteries are technically adequate.

### **3. Institutional Evaluation**

Since its commissioning, a local community organization called ERPACO has been responsible for the administration and operation of the RAPS system and the commercial service at Padre Cocha. The local community fully participated in this institutional structure, however, their technical and management capacity is somewhat limited. ILZO RAPS provided the crucial technical and management support during this process. Unfortunately, since the revenues can not recover the O&M costs, ILZO RAPS continues to rely on ILZO for funding.

ERPACO organization, self-management based on the grounds of technical and administrative support provided by ILZRO/RAPS Perú, has provided positive results up to date. This institution, however, needs substantial capacity building to demonstrate that it can be self-sustainable and succeed without that support.

The participation of the central government has been very limited, while the regional government has provided some infrastructure; such lack of effective involvement by these Administrations can reduce the potential for successful replication of this initiative in other areas.

### **4. Summary of Evaluations**

In sum, the RAPS system in Padre Cocha received 100% grant funding for its capital costs, and its current tariff level can not recover the O&M&M costs. A primary reason for its high capital costs of \$2400/connection is that the RAPS system is way oversized compared to the peak power demand, which also resulted in high distribution losses. The RAPS system also has a high O&M cost, which the revenue does not recover. Therefore, it is not considered to be financially sustainable and replicable, under the current condition of sizing, costs, and tariff.

## II. RECOMMENDATIONS OF SUPPLY ELECTRICITY SERVICES TO VILLAGES LIKE PADRE COCHA

### 1. Cost evaluation of supply alternatives

For a village like Padre Cocha an economic analysis has been performed in order to determine which would be the least-cost convenient technological option and sizing.

Five technically feasible configurations have been evaluated:

- PV only
- Diesel direct
- Diesel/battery hybrid
- PV-Diesel-battery hybrid with 4 different PV array sizes
- PV-Individual home systems

For each option, except for solar home systems, the HOMER model is used, combined with the field experience of the consultants to design the size and configuration most economically convenient for the reference load at Padre Cocha.

With predetermined sizes, a cost comparison of different options was performed, including capital investment costs, costs of replacement of equipment, O&M&M costs, fuel costs and cost of distribution grid, over a 20-year period. The comparison parameter was the levelized cost for kWh consumed (customer plus public lighting), during all the evaluation period considering an annual discount rate of 10%.

#### 1.1 Optimum sizing results

The size of different system components for the 9 technological options for the microgeneration plant rendered the following results, as shown in Table 6:

**Table 6. Optimum sizing results**

		PV arrays kWp	Genset kW	Batteries kWh	Power conditioning	
					Rectifier kW	Inverter kW
Padre Cocha RAPS (optimized) <sup>4</sup>		30	128	360	80	80
1. Diesel only	1a. Alternative one stand by unit		1 x 36 kW	0	0	0
	1b. Alternative peak and off peak		2 x 18 kW	0	0	0
2. Diesel Battery hybrid			1 x 36 kW	310	20	10
3. Diesel PV hybrid	3a. PV 25% s.f.	25	36 kW	310	20	10
	3b. PV 50% s.f.	50	36 kW	310	20	10
	3c. PV 75% s.f.	75	36 kW	524	10	20
	3d. PV 85% s.f.	93	36 kW	524	10	20
4. PV 100% s.f.		140	0	765	0	25

#### 1.2 Levelized cost results

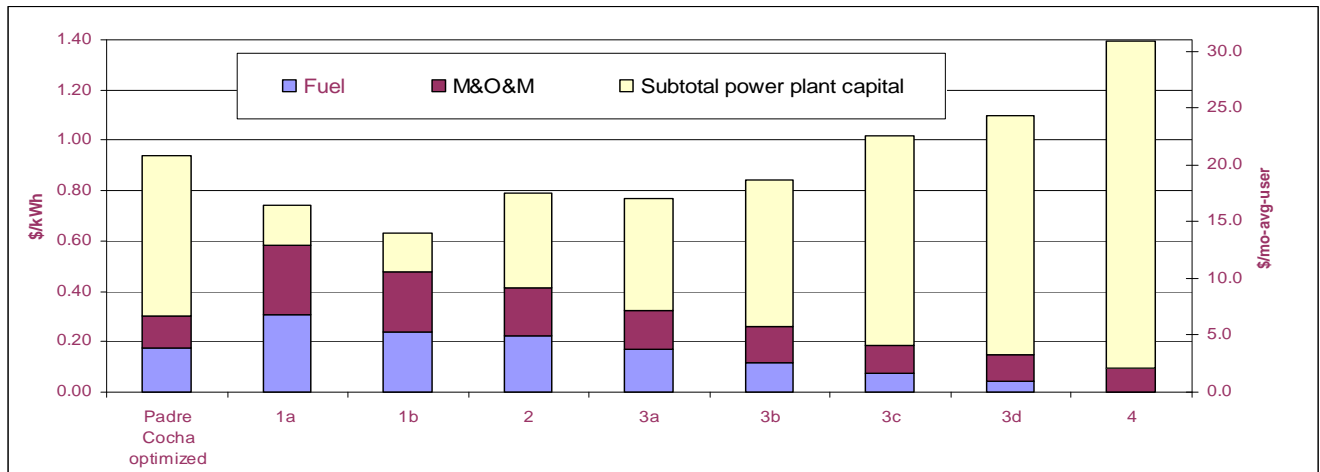
Cost evaluation results are shown in Table 7 and Figure 1.

<sup>4</sup> Actual figures from Padre Cocha but with improvements to reduce significantly distribution losses

**Table 7. Cost Evaluation Results**

	Levelized costs, break down \$/kWh						
	PV	Genset	Battery	Power conditioning	M&O&M	Fuel	Total
Padre Cocha optimized	0,148	0,066	0,094	0,167	0,127	0,174	<b>0,937</b>
1a Genset only (1 on + 1 back-up unit)	-	0,056	-	-	0,272	0,310	<b>0,740</b>
1b Genset only (2 on at peak and 1 on off peak)	-	0,054	-	-	0,240	0,237	<b>0,633</b>
2 Genset battery hybrid	-	0,025	0,198	0,056	0,186	0,225	<b>0,791</b>
3a PV-hybrid 25 kWp	0,146	0,020	0,122	0,056	0,155	0,170	<b>0,772</b>
3b PV-hybrid 50 kWp	0,293	0,016	0,122	0,056	0,142	0,116	<b>0,846</b>
3c PV-hybrid 75 kWp	0,439	0,013	0,206	0,076	0,110	0,074	<b>1,019</b>
3d PV-hybrid 95 kWp	0,556	0,013	0,206	0,076	0,105	0,043	<b>1,100</b>
4 PV only 140 kWp	0,819	-	0,301	0,076	0,098	-	<b>1,395</b>

**Figure 1. Comparison of Cost Break-down for Each Option**



fuel savings, at current fuel price. Figure 1 clearly shows that renewable energy systems have high capital investment costs but very low O&M and fuel costs, whereas diesel generators have quite low capital investment costs but very high O&M and fuel costs.

**Table 8. Comparison of Cost Break-down for Each Option**

	Levelised energy costs (\$ / average kWh)				Costs per contract ( \$ / contract month)			
	Capital initial and replacement cost	Fixed M&O&M	Fuel	Total	Capital initial and replacement cost	Fixed M&O&M	Fuel	Total
<i>Padre Cocha optimized</i>	0.636	0.127	0.174	<b>0.937</b>	13.98	2.80	3.84	<b>20.62</b>
<i>1a Genset only (1 on + 1 back-up unit)</i>	0.158	0.272	0.310	<b>0.740</b>	3.47	5.98	6.82	<b>16.28</b>
<i>1b Genset only (2 on at peak and 1 on off peak)</i>	0.156	0.240	0.237	<b>0.633</b>	3.43	5.28	5.21	<b>13.92</b>
<i>2 Genset battery hybrid</i>	0.380	0.186	0.225	<b>0.791</b>	8.36	4.10	4.94	<b>17.40</b>
<i>3a PV-hybrid 25 kWp</i>	0.446	0.155	0.170	<b>0.771</b>	9.81	3.41	3.75	<b>16.97</b>
<i>3b PV-hybrid 50 kWp</i>	0.588	0.142	0.116	<b>0.846</b>	12.93	3.12	2.56	<b>18.61</b>
<i>3c PV-hybrid 75 kWp</i>	0.835	0.110	0.074	<b>1.019</b>	18.37	2.43	1.62	<b>22.42</b>
<i>3d PV-hybrid 95 kWp</i>	0.952	0.105	0.043	<b>1.100</b>	20.95	2.32	0.94	<b>24.20</b>
<i>4 PV only 140 kWp</i>	1.297	0.098	-	<b>1.395</b>	28.54	2.15	-	<b>30.69</b>

## **2. Proposed Tariff Structures**

### **2.1 Willingness to pay**

According to reference WTP in the Peruvian Amazon, any proposed tariff could at least have a monthly charge of 20 S. (about 6 USD) for the very low consumption users, and about 30S. (about 10 USD) for the average consumption user (about 22 kWh/mo, including its share of public lighting).

### **2.2 Proposed tariff for the Padre Cocha RAPS System**

An adequate tariff structure for renewable energy-based microgrids should follow these principles:

- *Enable to pay at least M&O&M and equipment replacement costs;*
- *Reflect the cost structure* (i.e. include a higher fixed charge than in typical tariff structures applied in larger grids; and
- *Remain below users WTP.*

Following this principle, a fixed monthly fee may be a more appropriate tariff scheme for renewable energy microgrids, since it is more directly related to the cost structure of a renewable energy system and it provides the operator with a clearer financial forecast.

Given the high transaction costs and there large number of “very low” consumption contracts, the proposed monthly tariff to supply electricity services to villages like Padre Cocha is:

$$\left\{ \begin{array}{ll} T = 6 & \text{for contracts up to } 8.5 \text{ kWh/month} \\ T = 6 + 0.25 \cdot (x - 8.5) & \text{for contracts above } 8.5 \text{ kWh/month} \end{array} \right.$$

where T is the tariff (in \$/month) and x is consumption (kWh/month).

In the current case of Padre Cocha, this tariff would cover about 70% of M&O&M and replacement costs; to recover its current O&M&M the operator can consider three options:

- a) Apply the proposed general tariff, but reduce distribution losses and cut administrative costs; or
- b) Apply a higher tariff temporarily until improvements can be implemented, that should be no less than

$$T = \left\{ \begin{array}{ll} & \text{for contracts up to } 8.5 \text{ kWh/month} \\ T = 8 + 0.35 \cdot (x - 8.5)/\text{kWh} & \text{for contracts above } 8.5 \text{ kWh/month} \end{array} \right.$$

- c) In any case, it must try to get more customers, especially in the very low consumption segment.

### 2.3 Tariff and sustainability for Different Supply Alternatives and Subsidies

Table 9 shows that the tariff levels for diesel genset only and diesel battery hybrid systems (options 1a, 1b and 2) are higher than consumers' WTP, even with 100% capital subsidy. This implies that the diesel-based generation options would require subsidies for ongoing O&M&M costs to address affordability issue, which can not ensure financial sustainability of the systems. Diesel PV hybrid systems become attractive when capital subsidies are available.

As shown in Table 10, without any subsidies, the "full" tariffs (tariffs needed to recover the full costs including initial investment and O&M&M costs) of all the technological options would be above the users' WTP. Worldwide, all the rural electrification programs involve some form of subsidy. However, experience demonstrated that the subsidy should apply to capital costs, rather than O&M. This principle ensures the financial sustainability of the system. Table 9 and 10 compared the minimum tariffs under different subsidy levels to the users WTP.

With a 80% initial capital subsidy, PV hybrid options can offer an affordable tariff, while a 50% subsidy level is not sufficient to enable affordable tariffs, regardless the technological option considered.

**Table 9. The lowest hurdle tariffs with 100% capital subsidy**

	B \$/ kWh	A \$/ contract	C \$/ kWh	Tariff (\$ / contract) $T = A + (B+C) \cdot x$ ( x in kWh)	Tariff for average consumption contracts 22 kWh / mo	Required subsidy on initial investment	
						Total \$	per contract \$/contract
<b>Technological options</b>							
<i>Padre Cocha optimized</i>	0.090	2.80	0.174	<b>2.80 + 0.264·x</b>	\$ 8.61	461,829	1,358
<i>1a Genset only (1 on + 1 back-up unit)</i>	0.050	5.98	0.310	<b>5.98 + 0.360·x</b>	\$13.90	91,409	269
<i>1b Genset only (2 on at peak and 1 on off peak)</i>	0.052	5.28	0.237	<b>5.28 + 0.289·x</b>	\$11.63	88,034	259
<i>2 Genset battery hybrid</i>	0.147	4.10	0.225	<b>4.10 + 0.372·x</b>	\$12.28	196,997	579
<i>3a PV-hybrid 25 kWp</i>	0.067	3.41	0.170	<b>3.41 + 0.237·x</b>	\$ 8.63	320,735	943
<i>3b PV-hybrid 50 kWp</i>	0.062	3.12	0.116	<b>3.12 + 0.178·x</b>	\$ 7.05	444,473	1,307
<i>3c PV-hybrid 75 kWp</i>	0.085	2.43	0.074	<b>2.43 + 0.158·x</b>	\$ 5.92	634,571	1,866
<i>3d PV-hybrid 95 kWp</i>	0.085	2.32	0.043	<b>2.32 + 0.127·x</b>	\$ 5.12	733,562	2,158
<i>4 PV only 140 kWp</i>	0.111	2.15	-	<b>2.15 + 0.111·x</b>	\$ 4.60	1,003,317	2,951

**Table 10. Proposed Tariff Levels with 0%, 50%, and 80% Capital Subsidies**

	% Subsidy on initial investment						
	Tariff for average consumption contracts 22 kWh / mo	80 %		Tariff for average consumption contracts 22 kWh / mo	50%		Tariff for average consumption contracts 22 kWh / mo
		Total \$	per contract \$/contract		Total \$	per contract \$/contract	
<b>Technological options</b>							
<i>1a Genset only (1 on + 1 back-up unit)</i>	\$14.38	73,128	215	\$15.09	45,705	134	\$16.28
<i>1b Genset only (2 on at peak and 1 on off peak)</i>	\$12.09	70,428	207	\$12.78	44,017	129	\$13.92
<i>2 Genset battery hybrid</i>	\$13.30	157,598	464	\$14.84	98,499	290	\$17.40
<i>3a PV-hybrid 25 kWp</i>	\$10.48	256,588	755	\$12.90	160,368	472	\$16.97
<i>3b PV-hybrid 50 kWp</i>	\$ 9.60	355,579	1,046	\$12.83	222,237	654	\$18.61
<i>3c PV-hybrid 75 kWp</i>	\$ 9.57	507,657	1,493	\$14.17	317,286	933	\$22.42
<i>3d PV-hybrid 95 kWp</i>	\$ 9.35	586,849	1,726	\$14.66	366,781	1,079	\$24.20
<i>4 PV only 140 kWp</i>	\$10.38	802,654	2,361	\$18.01	501,658	1,475	\$30.69

### 3. RECOMMENDED BUSINESS MODELS

One of the key barriers to microgrid systems is the tragedy of common goods for scarce resources, that is the ownership and maintenance of the system. Experience with microgrids demonstrated two possible business models – utility model and community-based organization model, under which utilities or community-based organizations own and maintain the infrastructure and provide service.

The Table 11 contains a brief description of the two organizational schemes that have been found most feasible for the RAPS project for the provision of rural electricity service with decentralized RE based microgrids:

**Table 11. Typical models for the organization of a rural electricity service**

MODEL	FUNDING		RESPONSIBLE FOR MAINTENANCE
	Initial investment	M&O&M costs	
<b>A. Utility Model</b>	Users and public funds (municipalities and other governmental bodies).	Tariffs paid by users, with a cross-subsidy managed by a governmental body (for example, FOSE).	Utility (via a territorial concession).
<b>B. Community Model</b>	Principally, public funds. (Optionally, smaller contribution from users)	Tariffs paid by users (Possible subsidy from governmental bodies for equipment replacement costs)	Community organization, acting like an energy operator.
MODEL	MAIN ADVANTAGES	MAIN DISADVANTAGES	
<b>A. Utility Model</b>	<ul style="list-style-type: none"> <li>• Protection of legal framework and official bodies.</li> <li>• Technical expertise on M&amp;O&amp;M duties, monitoring, transaction, administration.</li> <li>• Larger experience on managing electricity service provision.</li> <li>• Availability of financial resources (better access to funds and financing mechanisms).</li> <li>• Centralised corrective maintenance service, stock of spare parts.</li> <li>• Availability of service regulations and formal contracts.</li> </ul>	<ul style="list-style-type: none"> <li>• Usually not interested in microgrids in remote areas, and slow response when the systems run into problems</li> <li>• High O&amp;M&amp;M costs.</li> <li>• Risk of distant perception by users, causing eventual rejection.</li> <li>• Risk of financial failure in the event of neighbours rejection – refusal to pay tariffs in one community, which may affect the service in other communities.</li> <li>• Current regulated tariffs need to recognize renewable energy-based microgrids</li> </ul>	
<b>B. Community Model</b>	<ul style="list-style-type: none"> <li>• Only organizational alternative in remote areas, where no utilities are operating.</li> <li>• High sense of ownership</li> <li>• Social acceptance, neighbours collaboration and co-responsibility for the equipment ownership and conduction of basic maintenance duties.</li> <li>• Creation of M&amp;O&amp;M jobs within the community.</li> <li>• Increased community self sufficiency, less bureaucracy needed to manage the service.</li> <li>• Possibility to apply specifically designed tariff structures.</li> </ul>	<ul style="list-style-type: none"> <li>• Lack of management, administrative and technical capacity and resources.</li> <li>• Need for specific training on M&amp;O&amp;M.</li> <li>• Limited access to spare parts stocks.</li> <li>• Little or no access to financial resources (funds and financing mechanisms).</li> <li>• Risk associated to required revenue transactions.</li> </ul>	

Given the limited technical and business skills of the community organization, the system is not operated on a financially viable basis. The distribution utility, on the other hand, is not interested in such a small system. A hybrid model is recommended as the first option for replication of RAPS systems. In Padre Cocha community, EOSA could own the renewable energy hybrid system and provide technical back-up, while ERPACO would be responsible for on-site basic maintenance and administrative duties. A major barrier to overcome for this model would be to improve the tariff restructure so that the replication projects would have sound financial sustainability to attract EOSA investments.

With the experience of Padre Cocha, the partnership IRP-ERPACO should be encouraged. The study recommended that IRP-ERPACO should replicate the RAPS systems to provide electricity services to other neighbouring villages, so that the M&O&M costs of such partnership can be funded by a larger portfolio of villages sharing the same technical and management assistance.

## 4. SENSITIVITY ANALYSIS

### 4.1 Sensitivity to price of fuel

A sensitivity analysis was performed on the technological options, varying two parameters: oil price and population size. Questions to be answered were:

- What is the price of fuel at which diesel stand alone is not the least cost option?
- What is the load for which the PV or diesel PV system become attractive?

From calculations performed it is concluded:

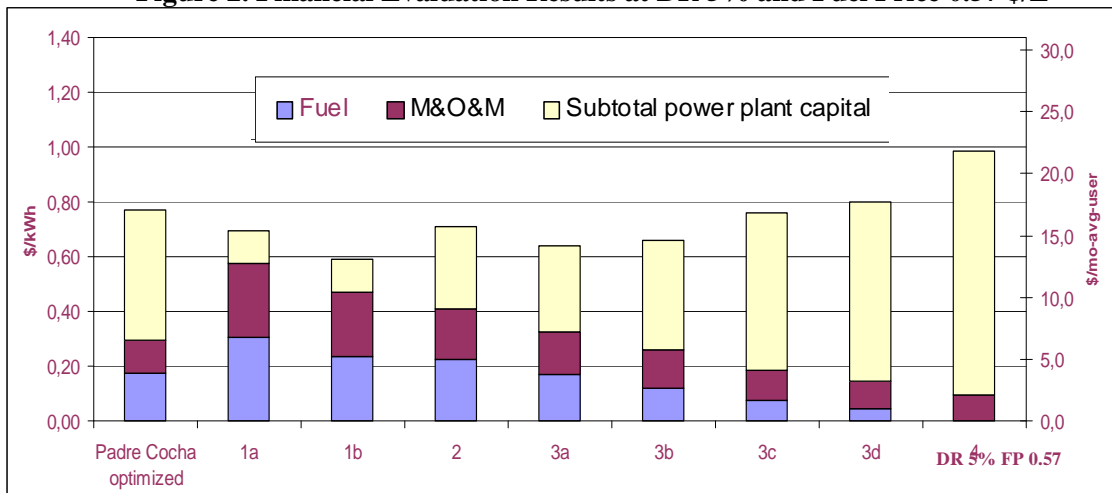
- The diesel price break-even point equals to US\$ 1.58/liter (US\$ 5.92/gallon) if compared with PV-diesel hybrid systems, and US\$2.38/liter (\$9.81/gallon) if compared with PV only systems.  
In the first case, the break-even point results 2.77 times the price used in the evaluation (US\$ 0.57/liter) and in the second time 4.2 times.
- In regard to population size, the break-even point is calculated for a 25-customer locality with a total daily average consumption of 25 kWh/day, including public lighting.

### 4.2 Sensitivity to discount rate

Levelized cost comparison for different technological options is sensitive to discount rates and fuel prices (especially for M&O&M intensive options, such as diesel gensets); future risks should carefully be evaluated for each specific case.

In this study, a discount rate of 10% is used. However, when a discount rate of 5% is used, the gaps in levelized costs for different supply options become smaller, and a diesel PV hybrid system with a large solar fraction of the load becomes more attractive (i.e. 3c and 3d options).

**Figure 2. Financial Evaluation Results at DR 5% and Fuel Price 0.57 \$/L**



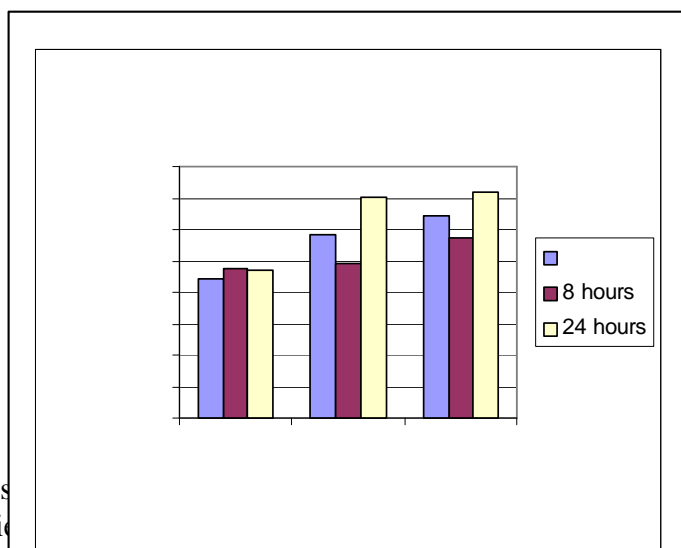
### 4.3 Supply Options of Daily Service of 5, 8, or 24-hour

The reduction of service hours reduces total energy supplied to the users, which affects the level of sales of the distribution company. In Padre Cocha, most of the uses of electricity during daytime are for refrigerators, freezers, and fans. Therefore, only a portion of consumption can be shifted to night hours, as shown in the projected figures for the year 2009:

5 hours service	122 kWh/day	51%
8 hours service	145 kWh/day	60%
24 hours service	241 kWh/day	100%

As shown Figure 3, without distribution grids, the levelized costs for 24-hour services are higher than 5-hour or 8-hour, particularly for diesel/battery hybrid or diesel/PV hybrid systems.

**Figure 3. Levelized cost \$/kWh without distribution costs**

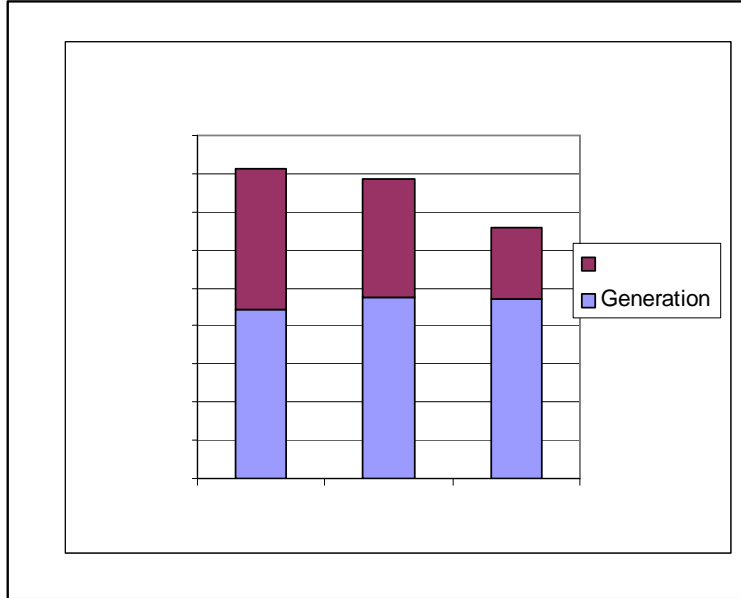


Since the least cost s  
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Figure. Since the distribution grid is the same regardless of how many hours service provided, the levelized cost with distribution grid for a 5-hour daily service results higher than that for 24 hours due to the less amount of energy supplied. The addition of generation and distribution costs results in a less kWh cost for a 24-hour service. The study concluded that the least levelized cost option is diesel-only generation to provide a service of 24 hours, due to the distribution grid costs.

stand alone, PV  
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**Figure 4. Levelized cost generation and distribution of diesel alone systems**



## **5. RECOMMENDATIONS ON ELECTRICITY SUPPLY OPTIONS FOR VILLAGES LIKE PADRE COCHA**

This study draws the following conclusions to provide electricity services to villages like Padre Cocha,:

- In terms of levelized life-cycle costs, diesel genset would be the least-cost option to supply electricity services in villages like Padre Cocha. The required technical configuration would be two properly sized units, one of them operating at off-peak hours and both of them in parallel at peak hours, directly connected to the distribution grid.
- An adequate tariff structure should be applied. For renewable energy microgrids, existing rural electrification tariffs may not be suitable, since they do not reflect the specific demand patterns and supply characteristics. An adequate tariff structure for renewable energy microgrids should follow these principles: 1) to recover at least O&M&M costs; 2) to reflect cost structure – a high fixed charge (higher than typical tariff structures applied in large grid systems) to reflect fixed O&M&M costs, a variable charge to reflect fuel costs, and a levelized capital cost charge partially reflect capital investment costs; and 3) to remain below consumers' ability to pay. Following these principles, a fixed monthly fee may be a more appropriate tariff scheme for renewable energy microgrids, since it is more directly related to the cost structure of a renewable energy system and it provides the operator with a clearer financial forecast. It can also reduce the administrative costs.
- Given the low consumers' willingness to pay, none of the supply options considered can offer a tariff level below user's WTP without any subsidies. Therefore, subsidies are required to cover partial capital investment.
- Following these principles, however, diesel genset based schemes are neither affordable nor sustainable, even with 100% capital subsidies. On the other hand, diesel/PV hybrid systems become more attractive, since they require lower tariffs compared to diesel only options, and are less exposed to fuel price volatility. For a village similar to the load demand in Padre Cocha, the study concluded that a properly designed diesel PV hybrid system (option 3a) can offer an affordable tariff level below consumers' WTP, with a 80% initial capital subsidy.
- System design should be properly sized to meet the peak demand, efficient gensets should be adopted, and distribution losses should be reduced.
- When possible, the use of local components should be prioritized.
- Include training of responsible use of energy by users and purchase of very high efficiency appliances in the project development.
- A hybrid of utility and community-based organization business model is recommended, since the utilities have the resources and technical capacity required to invest and provide technical back-up to such systems, while the community-based organization can provide day-to-day maintenance and administration to ensure community involvement. Regardless of the business model, it is important to clearly define the ownership and management issues of microgrid systems from the beginning to ensure technical and financial sustainability over the long-term.
- Efficient management of the system can also reduce O&M costs.

A strategic check-list for replication is provided in the Final Report.

