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Energy Sector Management Assistance Programme - ESMAP

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

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CONSOLIDATED SUMMARY

DRAFT VERSION

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

And

Independent Institutional Evaluation of the ILZRO/RAPS Renewable Energy System in the Amazon Region of Peru

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. Iquitos is located 1009 km north east of Lima city. 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, which were not available 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 (solar PV and diesel generating sets), in the amazon region of Peru. After performing some studies, the localities of Padre Cocha and Indiana were selected for installing the first systems, which would perform as pilot installations to evaluate benefits and applicability of this technology in isolated areas of the Peruvian jungle. For this purpose it was committed the support and participation of the Regional Government of Loreto (GOREL), the local Municipality and the Distribution Company Electro Oriente (EOSA).

Until now, ILZRO RAPS Peru reports an expenditure of US$2 million, in administration, promotion, studies and equipment acquisition, which was funded by the following contributions:

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
Total US$	**2,093,530**

The previous figure does not include the GOREL contributions in the amount of US$ 130,000, for the purchase of PV panels, and the cost of distribution grid.
In July 2003 the RAPS system at Padre Cocha started operations, with two RPS-150 type modules, each of 150kWh/day (totalling 300kWh/day) capacity. Each module is composed by 180 solar panels of 80 Wp, 240 batteries of 375 Ah, rectifier systems, charger and 40 kW inverter. It includes a single generating set of 128 kW, which uses diesel type distilled oil[1]. 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:

Capital Costs of the Padre Cocha RAPS

CONCEPT		Thousand Soles	Thousand US$
RAPS SYSTEM	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
SUB TOTAL RAPS EQUIPMENT, MATERIALS AND EXECUTION		**1,410.72**	**414.92**
DISTRIBUTION GRIDS		413.72	121.68
GENERATOR SET		137.68	40.50
TOTAL INITIAL INVESTMENT		**1,962.12**	**577.10**
Note: Change rate 3.4 Soles/US$			

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The distribution grid was built by GOREL and by the Municipality of Punchana, whereas the genset was a donation of Electro Oriente.

1.2 Operation & Maintenance Costs and Revenues for the RAPS System

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, so, starting October 2004 a tariff system for energy consumption (BT5B regulated tariff, urban typical sector) was established, 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 [2]. Besides, the following monthly charges per customer were fixed:

S/. 1.85 for fixed charge approved by OSINERG
S/. 2.50 for public street lighting and
S/. 0.63 for maintenance and replacement of meters
TOTAL : S/. 4.98 ($1.51/month)

Nevertheless, this charge did not increase revenue but it did increase the number of contracts.

Operational costs, including purchase of fuel and provision for battery replacement, are calculated in US$ 37.7 thousand/year, as per the following breakdown:

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[2] Electro Oriente prices are fixed by OSINERG and are modified each time oil price adjustments, exchange rates or internal price increase occur.

Operation and administration costs

EXPENSES BREAKDOWN	S/./month	US$/month	S/./year	US$/year	%
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	
SUBTOTAL FIXED M&O&M	**4,054**	**1,192**	**48,648**	**14,304**	37.9%
Provision for battery replacement	2,686	790	32,232	9,480	25.1%
SUBTOTAL FIXED EXPENSES	**6,740**	**1,982**	**80,880**	**23,784**	63.1%
Fuel and lubricant	3,728	1,097	44,736	13,164	
Fuel transport	213	63	2,556	756	
SUBTOTAL VARIABLE EXPENSES	**3,941**	**1,160**	**47,292**	**13,920**	36.9%
Total M&O&M COSTS	**10,681**	**3,142**	**128,172**	**37,704**	100.0%

Annual projected revenues based on invoicing between August 2004 and January 2005, will amount to US$ 14.7 thousand/year which generates a deficit of 61%, situation that makes the system commercially unsustainable.

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

The current tariff structure does not reflect adequately the ratio between fixed and variable costs (energy dependent). It should be possible to establish a higher tariff 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 new tariff structure, such as establishing minimum fixed charge, that grant the right to a definite amount of energy, particularly for the very low consumption customers.

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, therefore, it is not financially sustainable.

2. Technical Evaluation

2.1 Demand Analysis for Padre Cocha

At present the system serves 240 customers out of a potential total of 344, almost all domestic, and public street lighting. The daily average consumption is near of 220 kWh: 39% produced by PV cells and the rest by the Diesel generator. The maximum peak load is of 22 kW, which occurs in night hours (at 8 pm approx.).

The average consumption per customer is of 18.6 kWh/month, being the consumption of the majority less than 17 kWh/month, according to the following table:

Padre Cocha Demand Segmentation

Segments		**Consumption range**		**Contracts**		**Segment Demand**	
		Wh/day	**kWh/mo.**	**No.**	**%**	**kWh/day**	**%**
Residential	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
	Subtotal residential			***232***	***95***	***116.7***	***48***
Non residential		*> 3300*	*> 100*	***10***	***5***	***46.8***	***19***
Subtotal residential and non residential				***242***	***100***	***163.5***	***67***
Public lighting				-	-	***19.2***	***8***

RAPS Power Plant and community hall			-	-	***12.4***	***5***
Distribution losses (average 2kW per hour)			-	-	***48.0***	***20***
Total Generation			***242***	***100***	***243.1***	***100***

Public street lighting consumption is near to 40% of customer consumption, and distribution losses is in the range of 12% of the total consumption.

2.2 Sizing

The system has been designed for a peak power of 80 kW and a production of 300 kWh/day. Therefore, it results in oversized power conversion components for the present load of 22 kW and 220 kW/day.

The distribution grid was also built for a total load of 250 KVA that results oversized for the present load, which turned out into high transformer losses that initially surpassed 20% of produced energy. After changing the transformer size, losses were reduced to 12%. Distribution must be 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 central, it could be located within the village to keep distribution lines compact. The diesel generator could remain as common practice at the outskirts.

2.3 Design and Installation

The RAPS system is of modern technology and properly installed, that result in a fairly sound construction. 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 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 consider 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 panels should be evaluated to increase the PV efficiency.

2.4 Operation and waste treatment

The present daily operation cycle results suitable, due to the system size characteristics in regard to the load and configuration.
Also the recycling plan of the used lubricating oil and the disposal of used batteries are also technically adequate.

3. Institutional Evaluation

Since its commissioning, the administration and operation of the RAPS system and the commercial service at Padre Cocha, remain in charge of a local community organization called ERPACO. 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, auto-management based on the grounds of technical and administrative support provided by ILZRO/RAPS Perú, has rendered positives results up to

the present time. This institution needs to be consolidated to demonstrate that can be auto-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.

In sum, the RAPS system in Padre Cocha was oversized compared to the peak load demand, which resulted in high capital costs of $2400/connection as well as high distribution losses of more than 20%. It 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. ECONOMIC EVALUATION OF SUPPLY ALTERNATIVES

For a village like Padre Cocha an economic analysis has been performed in order to determine which would be the more economically convenient technological option and sizing.
Five technically feasible configurations were evaluated:

- PV only
- Diesel only
- Diesel battery hybrid
- PV-Diesel hybrid (including batteries) and 4 different PV array sizes
- PV-home systems

For each option, except home systems, using the HOMER model and the field experience of the consultants it was determined the size and configuration, most economically convenient for the projected load at Padre Cocha.
With predetermined sizes, an economic comparison of different options was performed, that included distribution grid cost and O&M&M costs. The procedure was to project investments, the cost of reposition equipment and operational and administrative expenses, for a 20-year period. The comparison parameter was the levelized cost for kWh generated (customer plus public lighting), during all the evaluation period.

1.1 Optimum sizing results

The size of different system components for the 8 technological options rendered the following table results:

Optimum sizing results

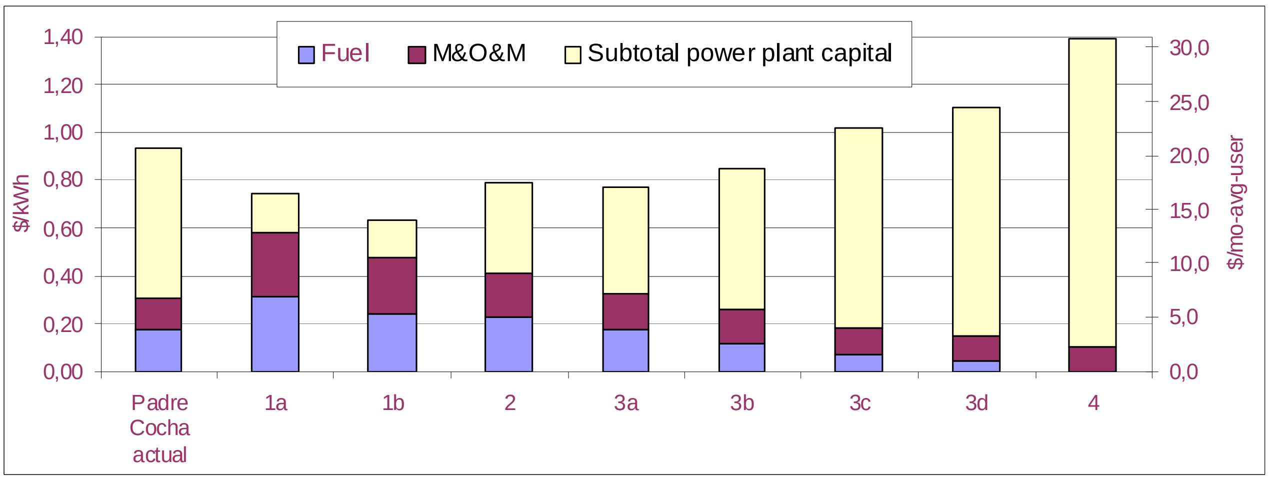
	PV arrays kW	**Generator kW**	**Batteries kWh**	**Rectifier kW**	**Inverter kW**
Diesel only					
1a. Alternative one stand by unit		1 x 36 kW	0	0	0
1b. Alternative peak and off peak		2 x 18 kW	0	0	0
2. Diesel Battery hybrid		1 x 36 kW	310	20	10
Diesel PV hybrid					
3a. PV 25%	25	36 kW	310	20	10
3b. PV 50%	50	36 kW	310	20	10
3c. PV 75%	75	36 kW	524	10	20
3d. PV 85%	93	36 kW	524	10	20
4. PV 100% (PV only)	140	0	765	0	25
Padre Cocha RAPS system	28	128			40

1.2 Levelized cost results

Economic evaluation results are shown in the following table:

Financial Evaluation Results

Levelized costs, breakdown $/kWh						
	PV	**Genset**	**Battery**	**Power conditioning**	**O&M**	**Fuel**
Diesel only						
1a. Alternative one stand by unit	-	0.056	-	-	0.272	0.310
1b. Alternative peak and off peak	-	0.054	-	-	0.240	0.237
2. Diesel Battery hybrid	-	0.025	0.198	0.056	0.186	0.225
Diesel PV hybrid						
3a. PV 25%	0.146	0.020	0.122	0.056	0.155	0.170
3b. 50%	0.293	0.016	0.122	0.056	0.142	0.116
3c. 75%	0.439	0.012	0.206	0.076	0.110	0.074
3d. 85%	0.556	0.012	0.206	0.076	0.105	0.043
4. PV 100% (PV only)	0.819	-	0.301	0.064	0.098	-



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

As it is shown the 2x18 kW diesel only system results as the least cost option. PV-diesel hybrid options have higher levelized costs, because the high initial investment costs cannot be offset by the fuel savings, at current fuel price.

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. (~ 6 USD) for the very low consumption users, and about 30S. (~ 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 should:

- *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.*

Given the high transaction costs and there large number of "very low" consumption contracts, the proposed tariff is:

$T = 6$ *for contracts up to 8.5 kWh/month*
$T = 6 + 0.25 \cdot (x - 8.5)$ *for contracts above 8.5 kWh/month*
where T is the tariff (in \$/month) and x is consumption (kWh/month).

In the particular case of Padre Cocha, this tariff would cover about 70% of M&O&M and replacement costs; then, the operator can consider 2 options:

a) Apply the proposed tariff and improve the technical design - especially to reduce losses; or
b) Apply a higher tariff temporarily until improvements can be implemented, for instance

$T = 8$ *for contracts up to 8.5 kWh/month*
$T = 8 + 0.35 \cdot (x - 8.5)$/kWh *for contracts above 8.5 kWh/month*

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

2.3 Proposed Tariff Structure for Different Supply Alternatives

All the rural electrification programs around the world involve some form of subsidy. Similarly, none of the technological options considered here can be sustained without some form of subsidy because the “full” tariffs (tariffs needed cover the full costs including initial investment) would be above the users’ WTP. However, worldwide experience demonstrated that subsidy should apply to capital costs, not O&M. This principle ensures the financial sustainability of the system.

The tariff structures required to cover M&O&M and replacement capital costs would be:

Lowest hurdle tariffs that would be needed with 100% subsidy for capital initial

	B $ / kWh	**A $/contract**	**C $ / kWh**	**Tariff ($ / contract) T = A + (B+C)·x (x in kWh)**	**Tariff for average consumption contracts 22 kWh / mo**	**Tariff for very low consumption contracts 8.5 kWh /mo**
Padre Cocha optimized	0.090	2.80	0.174	**2.80 + 0.264·x**	$8.61	$5.04
1a Genset only (1 on + 1 back-up unit)	0.050	5.98	0.310	**5.98 + 0.360·x**	$13.90	$9.04
1b Genset only (2 on at peak and 1 on off peak)	0.052	5.28	0.237	**5.28 + 0.289·x**	$11.63	$7.73
2 Genset battery hybrid	0.147	4.10	0.225	**4.10 + 0.372·x**	$12.28	$7.26
3a PV-hybrid 25 kWp	0.067	3.41	0.170	**3.41 + 0.237·x**	$8.63	$5.42
3b PV-hybrid 50 kWp	0.062	3.12	0.116	**3.12 + 0.178·x**	$7.05	$4.64
3c PV-hybrid 75 kWp	0.085	2.43	0.074	**2.43 + 0.158·x**	$5.92	$3.78
3d PV-hybrid 95 kWp	0.085	2.32	0.043	**2.32 + 0.127·x**	$5.12	$3.40
4 PV only 140 kWp	0.111	2.15	-	**2.15 + 0.111·x**	$4.60	$3.09

The technology options that do not enable a lowest hurdle tariff below user's WTP can be automatically discarded. This is the case of the diesel genset based options.

3. RECOMMENDED BUSINESS MODELS

One of the key barriers to mini-grid systems is the tragedy of public goods for scarce resources, that is the ownership and maintenance of the system. Worldwide experience with mini-grids demonstrated two common business models – utility model and community model, under which utilities or community organizations own and maintain the mini-grid systems.

The following table 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 RES based micro-grids:

Typical models for the organization of a rural electricity service

MODEL	FUNDING		RESPONSIBLE FOR MAINTENANCE
	Initial investment	**M&O&M costs**	
A. Utility Model	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 Community Model	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.

The Utility Model (model A) is recommended as the first option for replication of RAPS systems. In Padre Cocha community, EOSA would hold the concession and subcontract ERPACO for on-site basic maintenance and administrative duties.

In case that PV hybrid systems are not regulated under concessionaire regime, or that no concessionaire can be appointed, an alternative Community Model (Model B) can be followed.

With the experience of Padre Cocha, the partnership IRP-ERPACO should be encouraged. A strategy is to scale up the electricity service provision to other neighbouring villages, so that the M&O&M costs of such partnership can be funded by a larger portfolio of contracts.

4. SENSITIVITY ANALYSIS

4.1 Sensitivity to price of fuel

A sensitivity analysis was performed on the evaluated solutions of the previous section, 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:

a) The oil 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.

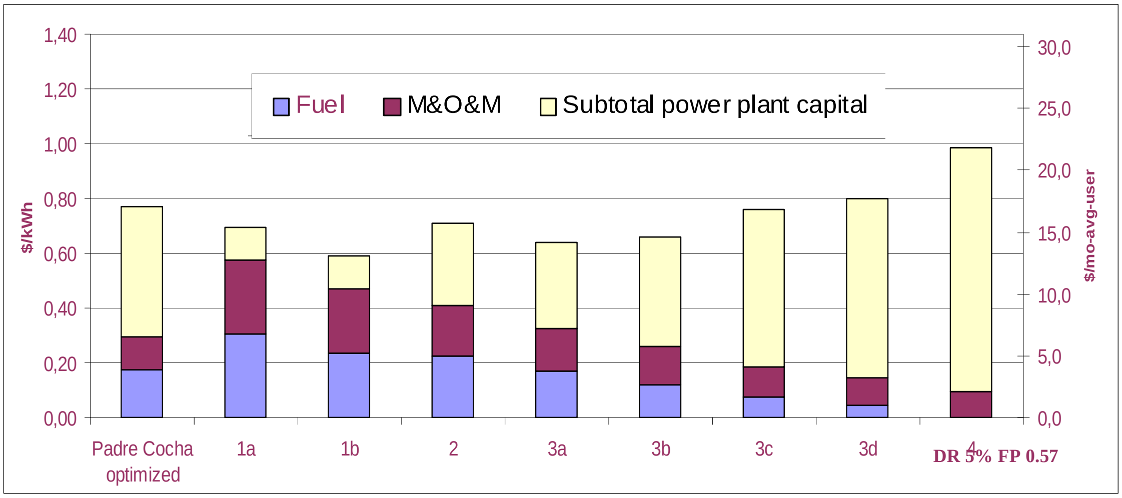
b) In regard to population size, the break-even point is calculated for a 25-customer locality with a total daily average consumption of 25 kWh/day, including public lighting.

4.2 Sensitivity to discount rate

Levelized cost comparison between technological options is very 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.

The options are so close at 5% discount rate that it is obvious that under those conditions one should clearly chose a PV hybrid with a large solar fraction of the load to ensure sustainability. That is 3c, 3d or even 4 if other parameters like the environmental are considered.

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

4.4 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,:

- Diesel genset is the least-cost option to supply electricity services in villages like Padre Cocha. It will be required two properly sized units to let one of them operate at off-peak hours, and both of them in parallel at peak hours, directly connected to the distribution network.
- However, following the principle that tariff should recover O&M costs, while subsidy should buy down initial investment costs, diesel/PV hybrid system can become more attractive, because they require lower tariff compared to diesel only option, and are less exposed to fuel price volatility.
- System design should be properly sized to meet the peak demand, efficient genset should be adopted, and distribution losses should be reduced.
- Adequate tariff structure should be applied
- Subsidy is required to cover partial capital investment

- A utility model, working closely with local communities, is recommended as the business model, since the utilities have the resources and technical capacity required to maintain such systems. Efficient management of the system can also reduce O&M costs.

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