Republic of the Marshall Islands
Energy Future

Electricity Roadmap

Technical Note 12: Supply of Electricity to Outer Islands

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Summary

The purpose of this note is to estimate the cost to operate and maintain electricity supplies to the outer atolls and islands of RMI that do not have reticulated electricity, the capital cost to increase access to electricity, and the resulting change in the cost to operate and maintain.

The estimated cost to operate and maintain the existing RMI outer island[1] stand-alone power supplies and solar home systems, if annualised, is around $1m per year.

To complete access to electricity in the outer islands (by powering more schools, health clinics, fish bases, telecoms etc. by solar) is estimated to require at least $3.7m investment. Once complete, the annualised replacement costs are estimated to then double to be around $1.7m per year.

Household solar/battery systems could be upgraded to provide more services to residents, but this would be subject to a study to determine if this necessary or is an appropriate approach (compared to say community facilities). A quick "what-if" example suggest this could require an investment in the order of $28m, and increase annualised replacement costs by a further 1.7m.

It is considered timely to undertake a study on the energy aspirations of outer island communities, rural development objectives, and cost recovery vs subsidisation of the ongoing costs of outer island energy supplies.

[1] In this document, the word islands also applies to the islets of atolls

1 Introduction

Where electricity distribution networks already exist on the islands of RMI (for example Majuro, Ebeye, Wotje, Jabwor, Kili, Rongelap), the most appropriate pathway to emissions reduction will be a centralised renewable energy hybrid system integrated with the existing powerhouse. While on some other islands there may be a case for a detailed study into the economics of a developing a distribution network, in general the households of more remote islands with low population density will be best served by stand-alone solar home systems (SHS), along with certain shared community facilities. In most cases SHS have already been installed in homes of the outer islands. However the ongoing maintenance and operation of these systems will require ongoing funding (whether by user, utility, government or a mix); particularly given that components will have a finite lifespan (which will depend on many environmental and operational factors), requiring periodic replacement, and given the remoteness and distance of the installations.

2 Existing supply of electricity to outer islands

2.1 Households

The most up to date published information available on RMI SHS suggests that in 2014 there were 2,790 SHS spread across the islets of 22 atolls [1]. The size of each of these systems is not known but typically appear to be around 200Wp PV with a 12V (or 2x 6V) 305Ah battery, supplying three interior lights, one exterior light, one nightlight, and a DC power outlet [2,3] - although there are some larger systems which also include refrigeration [4]. This has since grown to at least 3,000 systems, representing an almost complete rollout of electricity access to RMI residents [3], and SHS focus should now centre more on viable operation and maintenance.

Most solar home systems are currently maintained by Marshalls Energy Company (MEC) which is based in Majuro. MEC have trained on-island technicians and pay them an honesty wage to maintain a number of systems, based on a few hours per week. These technicians are capable of identifying and replacing any failed component, if they have no spares in stock then MEC will send parts from Majuro on a next available boat or plane. The technicians are also responsible for collecting fees from customers (currently $5/month) which is intended to be topped up by the RMI Government to cover the costs of maintenance. In some cases the outer islands' local governments are becoming involved in managing fee collection (including items to sell at market in lieu of cash) and enforcing disconnection due to non-payment, due to the many obvious challenges involved in managing this.

2.2 Schools

In addition to SHS on outer islands, seven solar/battery Stand Alone Power Systems (SAPS) have been installed to provide electricity to schools [3], including those listed in Table 1. It is not clear whether there is currently any financial provision allocated for the maintenance of these systems.

Table 1: SAPS for RMI schools [5]

	PV array (kWp)	Inverter capacity (kW)	Battery capacity (Ah at 48V)
Ine Elementary School, Arno Atoll	6	8	2,100
Ebon Elementary School, Ebon Atoll	10.7	NA[2]	1,750
Take Elementary School, Ebon Atoll	9	NA	3,000
Namdrik Elementary School	12.8	NA	3,100
Mejit Elementary School	9	8	2,100
Majkin Elementary School, Namu Atoll	6	8	2,100

2.3 Health centres

There are 56 health care centres in the outer islands. At least eleven of these have (or had) solar/battery SAPS providing power to lights, a vaccine refrigerator, ceiling fan, water pump and radiotelephone. Most systems had 770 Wp of PV and 9.4 kWh of battery capacity, although one had 2,200 Wp of PV and 21.6 kWh of battery capacity [6].

2.4 Fish bases

There are currently three fish bases for processing and storing local catch to send to the Kwajalein Atoll Fish Market Center (KAMFC) for sale, located within Ailinglaplap, Likiep and Namu atolls. Each of these consists of three freezers, lighting for processing, and a radiotelephone. They are powered by a combination of solar/battery SAPS, each fish base has a total of 8.4 kWp PV and 138 kWh battery capacity [6]. These systems are operated by the Marshalls Islands Marine Resource Authority.

2.5 Communications

Many outer islands are likely to have at least one SSB (HF) radio for communications. The power supply for these is assumed to be included in the systems above. At least ten islands also have remote satellite telecommunications access (DAMA Tele-Centers) to provide voice, internet, and fax communications [7]. Although details of the power supplies for the DAMA sites are not known at the time of writing, these are operated by the National Telecommunications Authority (NTA).

2.6 Other

Some shops may run freezers, either from larger SAPS or from portable gasoline generators.

In drought years reverse osmosis water desalinators (with associated electric water pumps) were required in some areas to provide fresh water. However these are typically portable temporary units are not included in the installed infrastructure considered here. As a basic minimal-electricity alternative many islands were provided solar evaporators along with solar pumps to purify brackish water.

[2] Not assessed

2.7 Assumed O&M costs of existing systems

Although the total number of outer island electricity supplies is not known, Table 2 is assumed to include many of the installations.

Table 2: Assumed existing outer island SAPS installed capacities

	Qty	Average PV capacity (kWp)	Total (kWp)	Average inverter capacity (kW)	Total (kW)	Average battery capacity (kWh)	Total (kWh)
SHS	3,000	0.2	600	0		3.7	11,100
Schools	7	9	63	8	56	113	791
Health centres	11	0.9	10	1[3]	11	10.5	116
Fish bases	3	8.4	25	5[4]	15	138	414
DAMA telecoms	10	NA[5]	NA	NA	NA	NA	NA
Total	**3,031**		**698**		**82**		**12,421**

The major operating and maintenance costs of these systems will be incurred through component replacement, particularly batteries. We assume that in a 21 year period, the whole system will need to be replaced once[6]; and that the charge controllers and any inverters will need to be replaced an additional time, and the batteries will need to be replaced a further two times (assuming a seven year life[7]). The cost of logistics to replace batteries can vary – in some cases an individual battery or battery pair can be placed on a govt field trip vessel to deliver to an on-island technician, in other cases a vessel will be chartered to deliver pallet loads of batteries to replace those from a whole generation of SHS. For the estimated annualised costs of component replacement below, we assume the latter and focus on the logistics to systems maintained by MEC.

[3] Assumed (not known)
[4] Assumed (not known)
[5] Not assessed
[6] Existing SHS mounting structures are typically aluminium pole-mount and have proven durable [3].
[7] Note that some existing SHS are still apparently functioning acceptably on original batteries 14 years later, given the low load relative to battery capacity [3].

Table 3: Annualised replacement costs of existing SAPS

	Per unit cost	Qty	Replacements/ visits over 21 year period	Replacement costs over 20 years (USDk)	Annualised replacement costs (USDk)
Entire system materials excluding batteries, inverters, and charge controllers	$2,800 per kWp	698	1	1,954	93
Charge controllers	$200 per kWp	698	2	297	13
Inverters	$400 per kW	82	2	66	3
Batteries	$300 per kWh	12,421	3	11,180	532
Logistics	$400 per system[8]	3,031	3	3,637	173
Total					**815**

The costs of component replacements in Table 3 exclude costs other than component replacement, for example labour. Other annual costs are assumed to be $159,000[9] [8], resulting in a total annual operating cost of **$974,000** (irrespective of who pays this cost).

3 Future growth in electricity supply to outer islands

3.1 Households

The existing stock of SHS is thought to provide more or less full access to basic household electricity, with very few new installations still required. Typical global experience had been that when households are introduced to a basic capped supply of electricity, after becoming accustomed to the benefits of the service access to more uses of electricity (e.g. TV watching, clothes washing, refrigeration etc.) is then desired. However the challenge is that upsizing SHS significantly increases the recurring component replacement costs. To find the appropriate trade-off between appropriate and productive uses of electricity and economically sustainable operation should be further investigated with a detailed study in consultation with all affected stakeholders (an example of the increased costs from a hypothetical larger system is provided in Appendix A for illustrative purposes). Until this study has been undertaken, we assume that the existing systems provide an appropriate level of service to households, and further productive uses of electricity (e.g. washing clothes) can be provided by new community facilities (e.g. community laundromat).

[8] Based on previous experiences of installing SHS in RMI [13]. The logistics of maintaining systems not maintained by MEC are ignored.
[9] These annualised operating costs (including labour but excluding replacements) have been taken from the outer islands solar MEC operating costs reported in 2015 [8] excluding depreciation and amortization. Although the work required will vary from year to year the labour costs are assumed to be fixed. Any non-MEC labour has been ignored.

3.2 Schools

Following the rollout of SHS to outer islands, the next major phase of outer island electrification was to be schools. There are 61 outer island public elementary schools [9], excluding Kili Elementary School, Wotje Elementary School, Eniburr Elementary School, Jabor Elementary School, the schools of Majuro Atoll, the schools of Ebeye Island, and secondary schools (all of which are on islands with reticulated electricity). However issues around financing the maintenance of the existing seven systems have to date caused a barrier to the implementation of the 54 remaining systems required.

To determine the appropriate capacities of these future systems will require a detailed study of the schools' needs which is not provided here - instead, capacities are assumed to be similar to the existing systems (average of 9 kWp PV and 2,360Ah battery storage at 48V). These existing systems have been providing adequate service provided unexpected loads are not added to them [3].

3.3 Health centres

All health centres should have some amount of access to electricity, to at least maintain the cold chain for vaccines and for communications to a hospital for health advice. Detailed design will be required but in the meantime it has been assumed that the system sizes required will be similar to the existing systems (770 Wp and 9.4 kWh battery).

Note that USAID [10] suggest that a "Category 1" Health Clinic (0-60 beds, lighting and maintaining the cold chain for vaccines etc.) may require 5 – 10 kWh/day. A quick back of envelope calculation (Appendix A) suggests a system with 3 kWp PV and 50 kWh batteries would be required for a 5 kWh/day load, which is much larger than the existing systems – presumably the electricity needs for RMI health clinics are more modest.

3.4 Fish bases

Enabling outer islands to sell local catch to market is of obvious economic benefit to those islands. Although it is not known how many atolls and islands it is practical to collect local catch from, it is assumed that a fish base in a further 23 atolls/islands should be aspired to. One is already intended to be built on Utrok Atoll [11]. It is assumed that the sizing of the existing fish bases is adequate and that future fish bases will be of the same size.

3.5 Communications

Access to satellite telecommunications can allow residents of outer islands to access remote services such as distance education, and so installation of more DAMA centres would be of advantage to the outer islands. However discrepancies between the ability of residents to pay for the service and the high logistical cost of maintain these systems would need to be addressed.

3.6 Other

The overlap between energy supply and water supply on the outer islands is a complex topic. Traditional hand operated wells have the advantage of more carefully managing the precious fresh water lens.

Reportedly the most common request for further household services is for washing machines for laundry. Solar powered community laundromats could be investigated. Some public lighting may also be of benefit.

The largest systems described have been for elementary schools – these facilities may be able to double as disaster recovery areas, in addition these power supplies may be able to be specified/sized to provide additional community services as well.

These and other additional uses of energy should be included in a further study into outer island energy supplies, and are not included here.

3.7 Additional capital cost required

Under the assumptions described, the additional installed SAPS capacities required to provide future energy services to the outer islands are as follows, at an estimated cost of $3.7m:

Table 4: Additional SAPS capacities which may be installed as part of future growth

	Qty	Average PV capacity (kWp)	Total (kWp)	Average inverter capacity (kW)	Total (kW)	Average battery capacity (kWh)	Total (kWh)
Schools	54	9	486	8	432	113	6,102
Health centres	45	0.77	35	1	45	9.4	423
Fish bases	23	8.4	193	5	115	138	3,174
Communications hubs	10	NA	NA	NA	NA	NA	NA
Total	**132**		**714**		**592**		**9,699**

Table 5: Estimated capital cost of additional SAPS

	Per unit cost	Qty	Subtotal (USDk)
Entire system materials excluding inverter and batteries	$3,000 per kWp	714	214
Inverter	$400 per kW	592	237
Batteries	$300 per kWh	9,699	2,910
Logistics	$400 per system	132	53
Labour	$2,000 per system[10]	132	264
Total			**3,679**

This cost may in reality be larger as it excludes upsizing health clinic systems and additional community facilities such as laundromat, streetlights etc.

[10] Based on 5 person-days per system including travel and testing

3.8 Assumed O&M costs following future growth

Table 6: Annualised replacement costs of SAPS following future growth

	Per unit cost	Qty	Replacements/ visits over 21 year period	Replacement costs over 20 years (USDk)	Annualised replacement costs (USDk)
Entire system materials excluding batteries, inverters, and charge controllers	$2,800 per kWp	1,412	1	3,954	188
Charge controllers	$200 per kWp	1,412	2	565	27
Inverters	$400 per kW	7,674	2	6,139	293
Batteries	$300 per kWh	22,120	3	19,908	948
Logistics	$400 per system	3,163	3	3,796	190
Total					**1,646**

The costs of component replacements in Table 6 exclude costs other than component replacement, for example labour. Although the total capacities have greatly increased, the number of systems to manage have not. As a result, the other annual costs are assumed to remain $159,000, resulting in a total annual operating cost of **$1.8m** (irrespective of who pays this cost). This is almost double the maintenance cost of existing systems

4 Conclusions and Recommendations

The estimated cost to operate and maintain the existing RMI outer island stand-alone power supplies and solar home systems, if annualised, is around $1m per year.

To complete access to electricity in the outer islands (by powering more schools, health clinics, fish bases, telecoms etc. by solar) is estimated to require at least $3.7m investment. Once complete, the annualised replacement costs are estimated to then double to be around $1.8m per year.

Household solar/battery systems could be upgraded to provide more services to residents, but this would be subject to a study to determine if this necessary or is an appropriate approach (compared to say community facilities). This would require an estimated investment of $29m, and increase annualised replacement costs by a further 1.7m.

It is considered timely to undertake a study on the energy aspirations of outer island communities, rural development objectives, and cost recovery vs subsidisation of the ongoing costs of outer island energy supplies.

5 References

[1] Chen Y., Gönöl, G., Wade, H., 2015. *Republic of Marshall Islands Renewables Readiness Assessment*. IRENA.

[2] http://mecrmi.net/renewable%20energy.htm

[3] Personal communications, MEC solar staff.

[4] http://islandeco.com/solar-projects/rural-usda/usda-project-updates/

[5] Isaka, M., Mofor, L., Wade, H., 2013. *Pacific Lighthouses, Renewable energy opportunities and challenges in the Pacific Islands region*. IRENA.

[6] Wade, H., 2005. *Pacific Regional Energy Assessment 2004: An assessment of the key energy issues, barriers to the development of renewable energy to mitigate climate change, and aid capacity development needs to removing the barrier: Marshall Islands National Report.* PIERP/SPREP.

[7] http://www.ntamar.net/index.php/news/37

[8] Marshalls Energy Company, Inc. Financial Statements, Additional Information and Independent Auditor's Report, FY2015.

[9] http://pss.edu.mh/en/public-schools

[10] USAID. *Powering health: Electrification options for rural health centers*.

[11] http://marshallislandsjournal.com/?p=6122

[12] http://globalsolaratlas.info/?c=10.093262,168.925781,7&s=7.124354,171.489195

[13] Personal communications, Arieta Rakai (IRENA)

6 Appendix A: Back-of-envelope calculations

6.1 Example of alternative larger household system

The solar home systems described in previous sections are of a very basic nature. These may be appropriate for outer island lifestyles and increasing the level of service will increase operating and maintenance costs. A comparison follows to examine the effect.

Solar home systems currently provide power for a few lights and a DC power outlet, presumably for device charging, radio/speakers etc.

A significantly larger system with AC provision would be able to power a larger range of appliances (Table 7).

Table 7: An illustrative example of household electricity loads with extra appliances

	Peak power (W)	average power (W)	average daily run time (hrs)	average daily electricity consumption (Wh)
Small inverter refrigerator	120	33	24	800
4x lights (average number on)	28	28	5	140
Fan	50	50	5	250
Laptop	70	50	5	250
Speakers	10	2	5	10
Communications	50	6	18	108
Total	**328**			**1,558**

6.1.1 Alternative larger household system sizing

Average daily load: 1,558 Wh

Peak load: 400W

Average daily DC electricity production required: 1,948 Wh (assuming 75% of energy through battery at 80% roundtrip efficiency, 95% inverter efficiency

PV capacity chosen: 1.1 kW (average daily production 3.9 kWh with 5 kWh/m^2 average daily incident insolation [12] and assuming 2.5% derating due to panel temperature, 2% derating due to soiling, 2% derating due to cable losses, 20% degradation at end of panel life, 98% charge controller efficiency, oversupply coefficient of 2 for critical load without generator)

Useable battery capacity required: 6.6 kWh (assumes 4 days autonomy required and 20% capacity degradation at end of battery life.

Battery capacity chosen: 13 kWh (assumes 50% DOD, i.e. lead acid chemistry)

6.1.2 Alternative larger household system capital cost

Table 8: Estimated cost of example larger household power supply

	Per unit cost	Qty	Subtotal
Entire system materials excluding batteries and inverter	$3,000 per kWp	1.1	3,300
Inverter	$400 per kW	1	400
Batteries	$300 per kWh	13	3,900
Logistics	$400 per system	1	400
Labour	$1,500 per system	1	1,500
Total			**9,500**

As part of an upgrade, it was assumed that existing systems would be wholly replaced. 3,000 of these systems have a capital cost of $29m

6.1.3 Alternative larger household system O&M cost

Table 9: Estimated annualised replacement costs of upgraded household systems

	Per unit cost	Qty	Replacements/ visits in 21 year period	Replacement costs over 21 years (USD)	Annualised replacement costs (USD)
Change in entire system materials excluding batteries and charge controllers	$2,800 per kWp	3,300 (larger) – 600 (existing)	1	7,560,000	360,000
Change in charge controllers	$200 per kWp	3,300 (larger) – 600 (existing)	2	1,080,000	51,429
Change in inverters	$400 per kW	3,000	2	2,400,000	114,286
Change in batteries	$300 per kWh	39,000 (larger) – 11,100 (existing)	4	25,110,000	1,195,714
Total					**1,721,429**

This suggests that upgrading household systems to the example size considered here would cost $29m and would increase annual operating and maintenance costs of outer islands electricity supplies from $974,000 to $2.7m per year – a significant increase.

6.2 Health clinic – alternative larger type

Assumed average daily load: 5 kWh

Average daily electricity required: 5.6 kWh (assuming 50% of energy through battery at 80% roundtrip efficiency, DC loads)

PV capacity chosen: 3 kW (average daily production 11 kWh with 5 kWh/m^2 average daily incident insolation [7] and assuming 2.5% derating due to panel temperature, 2% derating due to soiling, 2% derating due to cable losses, 20% degradation at end of panel life, 98% charge controller efficiency, oversupply coefficient of 2 for critical load without generator)

Useable battery capacity required: 25 kWh (assumes 4 days autonomy required and 20% capacity degradation at end of battery life.

Battery capacity chosen: 50 kWh (assumes 50% DOD, i.e. lead acid chemistry)

Table 10: Estimated cost of health clinic power supply (alternative larger type)

	Per unit cost	Qty	Subtotal (USD)
Entire system materials excluding batteries	$3,000 per kWp	3	9,000
Batteries	$300 per kWh	50	15,000
Logistics	$1,800 per system	1	1,800
Labour	$2,000 per system	1	2,000
Total			**27,800**

45 of these systems have a capital cost of $1,251,000