Republic of the Marshall Islands Energy Future

Electricity Roadmap

Technical Note 08: Demand Side Energy Efficiency and Conservation Potential

Final version, December 2018

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NEW ZEALAND
FOREIGN AFFAIRS & TRADE
Aid Programme

The development of the Marshall Islands Electricity Roadmap and related analysis was supported by the New Zealand Ministry of Foreign Affairs and Trade.

Summary

This technical note summarises a high-level estimate of overall electrical energy use in Majuro and Ebeye, which in turn forms the vast majority of electricity consumed by RMI. It highlights estimated end uses of electrical energy across sectors and by application. It then estimates the technical potential for reductions in customer electricity demand resulting from various demand side energy efficiency initiatives and energy conservation measures. It does not assess the economic or social potential for these measures, which may be less than the technical potential.

Analysis is based on mean annual production and consumption across financial years 2014 – 2016. This is to smooth out the impact of billing anomalies in any given year, at the expense of capturing the most recent trends. By definition, this analysis is broad-brushed and directional only. It is not intended to provide accurate load forecasts for generation planning purposes.

Based on this estimate, a large proportion of electricity in Majuro and Ebeye is consumed by air conditioners, refrigeration, and lighting (in that order).

Energy efficiency and conservation measures have been identified which are estimated to have the technical potential to reduce electricity consumption on Majuro Atoll by 15% and Ebeye Island by 14%, which together are thought to account for around 94% of RMI electricity demand.

Significant contributors to these gains include significant and targeted facility/appliance upgrade projects for large electricity consumers (e.g. hospitals, government departments, schools, and accommodation providers), introducing national Minimum Energy Performance Standards and labelling, commercial refrigeration improvements/upgrades/maintenance, and widespread replacement of inefficient appliances in the residential and light commercial sectors of Ebeye Island.

Given the presented contribution from commercial refrigeration and the uncertainty in the technical and economic potential, robust audits of supermarket and fish processing refrigeration should be undertaken to better understand the potential.

Given the high proportion of electricity dedicated to air conditioning, in the short term, effort should be focused on the efficiency of air conditioners. We note that an import tax exemption on energy efficient appliances is already making gains here. In the long term, effort should be focused on developing a building code to improve the building envelopes into which significant cooling energy is being directed. Gains are also possible from changing behaviour around air conditioning, particularly set points and hours of use.

Within the RMI roadmap techno-economic analysis, we have made the assumption that two thirds of these identified measures should be achieved by 2025 as part of the significant efforts required for RMI to achieve its nationally determined contributions to greenhouse gas emissions reduction. This resulted in a modelled reduction in demand of 10% (tempered by new electricity loads – see technical note *Techno economic modelling inputs and assumptions* for further details). We have made the further assumption that to achieve RMI's even more ambitious 2030 goals, further measures than those identified here, or new technology, will need to be adopted. We have thus modelled demand side measures which will reduce current demand by 20% by 2030.

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1 Background

The purpose of the RMI Electricity Roadmap is to identify the most effective and appropriate pathways to reduce GHG emissions in the RMI electricity sector. Reducing GHG emissions will be achieved by reducing the use of diesel fuel to produce electricity. Potential initiatives to reduce diesel fuel use include energy efficiency measures and change in electricity consumption behaviours.

Taking figures from previous consultant reports, audits and Marshalls Energy Company reporting, this technical note summarises the current end use of electricity in the RMI and then estimates the potential to reduce electricity consumption. Consideration is given to trends, programs and studies on electricity industries around the Pacific and the world. These findings are then applied to the RMI's specific power sector composition (residential, commercial and government load entities) on the two largest island grids, Majuro and Ebeye.

As of early 2018, an energy efficiency action plan for the RMI has been commissioned by the World Bank; this technical note does not attempt to double up on efforts in that respect, nor does it go into the same level of accurate detail and costing. By definition, this analysis is broad-brushed and directional only.

2 Majuro electricity use

2.1 Overview

In financial years 2014 to 2016, the Majuro power station generated an annual average of 56.4 GWh of electricity, primarily from diesel generators, with the following sector split [1]:

- Electricity sold to the residential sector accounted for 36% of MEC electricity generated (18.6 - 22.8 GWh annually)
- Electricity sold to the commercial sector accounted for 29% of MEC electricity generated (16.0 - 16.4 GWh annually)
- Electricity sold to the Government sector accounted for 12% of MEC electricity generated (6.7 – 7.4 GWh annually)
- Technical losses together with unmetered and/or unbilled electricity consumption accounted for 22% of MEC electricity generated (7.6 – 16.2 GWh annually)

The four-year trend to 2016 is a decrease in total GWh generated, with the commercial sector recently unchanged, residential sector increasing, and losses/unbilled decreasing significantly (suggesting a shift from unbilled to the residential sector) [1].

Technical losses along with unbilled and/or unmetered electricity use appear to constitute somewhere between 14% and 28% of generated electricity, including powerplant auxiliary loads and technical losses through transformer distribution and lines [1]. This quantity of electricity (reported generation less reported sales) varies significantly from year to year, possibly suggesting billing period/reporting anomalies (for example late payments), or possibly metering improvements.

The Pan Pacific Foods (PPF) Tuna processing factory has its own diesel power generation; this has been estimated to be around 4.4 GWh annually, based on their annual fuel bill from MEC (2014 – 2016) and an assumed generation efficiency of 14 kWh/USG. This PPF power usage will contribute to the commercial sector in the calculations below.

2.2 Electricity consumption by end-use categories

Of the metered electricity, an estimated breakdown of consumer end use has been split into four categories; lighting, air conditioning, refrigeration and others. The 'others' category includes applications such as cooking equipment, computers, TVs, radios and industrial process electricity.

Table 1 presents the estimated breakdown of Majuro residential electricity by application. The method used to develop this estimate is described in Appendix 8.2

Table 1 – Broadly estimated household electricity use in Majuro

Category	% of electricity consumption
Refrigeration	15
Air conditioning	48
Lighting	17
Other	20

A breakdown of approximately 7% of commercial electricity use and 65% of government electricity use was estimated using the data from energy audits undertaken by the RMI Government Energy Planning Division. A breakdown of a further 50% of commercial electricity use and 25% of government electricity use was estimated using representative audits or studies of similar applications in similar climates. These breakdowns were applied to the largest customers on the Majuro Grid (Table 2) and the PPF factory. See Appendix 8.3 for more detail.

Table 2 – Large Majuro electricity users (2014 - 2016)

Account Name	Sector	2014 - 2016 mean annual consumption (MWh)	Source used to estimate end-use breakdown	Assumed % refrigeration	Assumed % AC	Assumed % lighting	Assumed % other
Majuro Hospital (combined with new Hospital meter)	Govt	2,340	Energy audit [3]	5	68	8	19
K&K Island Pride Supermarket	Comm	1,606	Estimate from [8]	60	15	18	7
Combined Ministry of Education facilities	Govt	1,248[1]	Energy audit [2]	2	53	32	12
Capitol Building Complex[2]	Govt	995	Estimate from	15	35	30	20
National Telecom New complex	Comm	857	Energy audit [4]	0	75	3	22
Marshall Islands Resort (MIR) East	Comm	726	Estimate from [5]	1	50	5	44
Payless Supermarket	Comm	692	Estimate from [8]	60	15	18	7
College of Marshall Islands	Govt	690	Estimate from [2]	2	53	32	12
MIFV Inc (Former Ting Hong) Fishing	Comm	551	Estimate from [9]	82	4	1	13
Tobolar copra processing	Comm	475	Assume 100% other	0	0	0	100
Marshall Islands Resort (MIR) West	Comm	359	Estimate from [5]	1	50	5	44
Robert Reimers Complex 3 office	Comm	287	Energy audit [5]	1	50	5	44
Formosa Shopping Center (M1)	Comm	274	Estimate from	60	15	18	7
Robert Reimers store 2	Comm	263	Estimate from [8]	60	15	18	7
Formosa Supermarket	Comm	210	Estimate from [8]	60	15	18	7
K&K Island Pride Supermarket #1	Comm	200	Estimate from [8]	60	15	18	7
PII Rock Crusher 2	Comm	195	Assume 100% other	0	0	0	100
MSTCO Reefer Block	Comm	187	Assume 100% refrigeration	100	0	0	0
MIFV ice machine	Comm	185	Assume 100% refrigeration	100	0	0	0
Majuro Int'l Convention Center	Comm	156	Estimate from [5]	1	50	5	44
RRE Cabins	Comm	104	Estimate from [5]	1	50	5	44

[1] From [2] 2012, rather than 2014 - 2016
[2] This facility appears to have reduced energy consumption dramatically each year

A further end use of electricity that was categorised for the government sector is utility pumping. This refers to the pumping of fresh water, salt water (used for toilet flushing) and waste water by the utility Majuro Water and Sewer Company (MWSC). This was estimated using billing data from 2014/2015.

For the remaining government and commercial use of electricity, Table 3 presents the estimated breakdown by application. The method used to develop this estimate is described in Appendix 8.3.

Table 3 – Broadly estimated commercial and government electricity use in Majuro (excluding largest consumers)

Category	% of electricity consumption
Refrigeration	17
Air conditioning	40
Lighting	21
Other	22

2.3 Current use of electricity on Majuro

The combined breakdowns of electricity use described in previous sections is consolidated graphically in Figure 1 below. This diagram uses a series of nodes and flows to visually demonstrate the estimated pathway of electricity from generation to end-use in Majuro. This is from electricity generation output (i.e. not from heating value of diesel fuel) to appliance electricity input (i.e. not to energy service provided). This diagram includes significant uncertainty on the right-hand side.

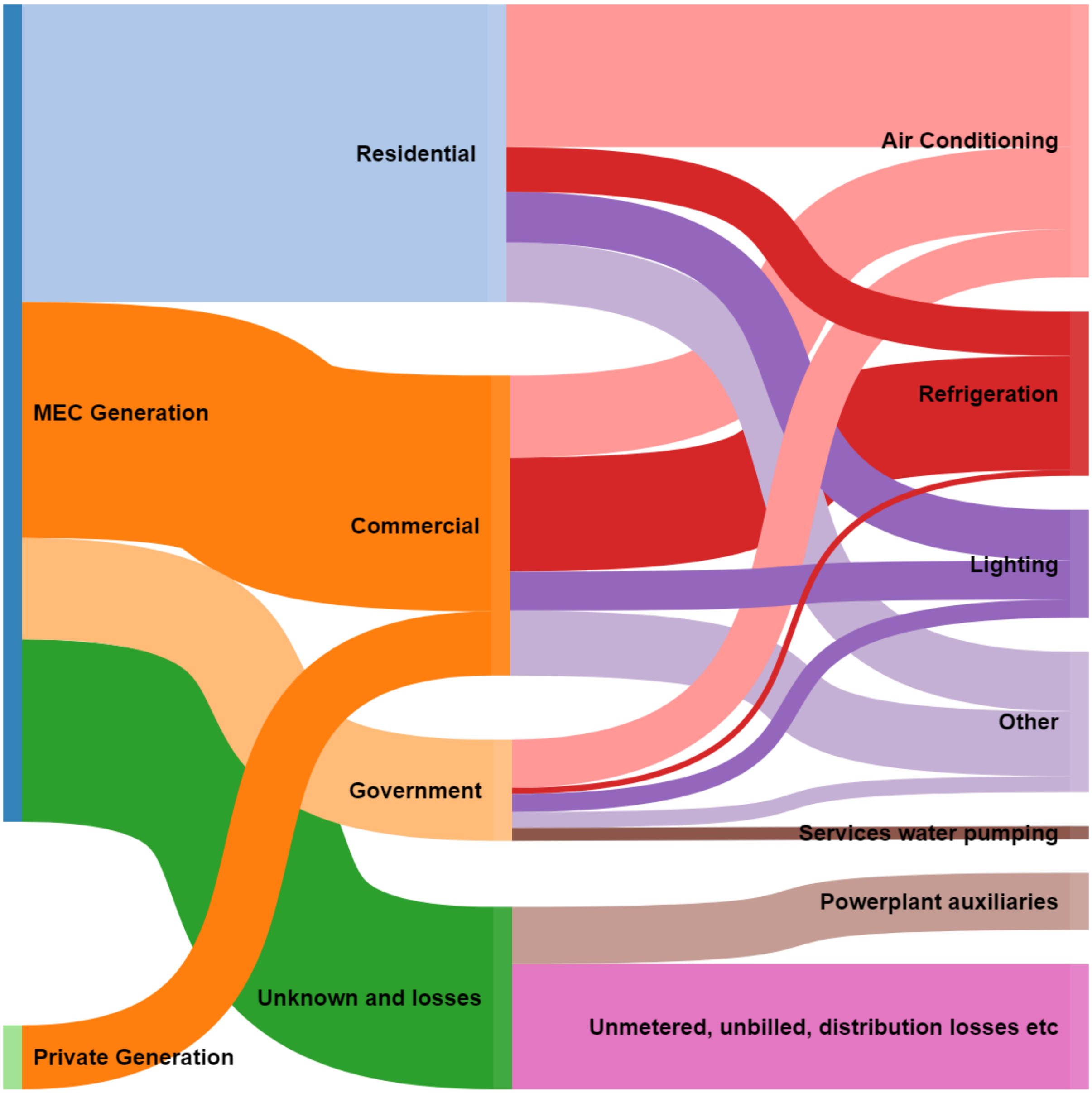

Figure 1 – Estimated Majuro Electricity End-use by sector, categorised.

From Figure 1, the largest single end use category of electricity in the Majuro grid was air conditioning, followed by refrigeration and then lighting. Residential air conditioning (this is based on a very rough estimate) and commercial refrigeration (supermarkets, fish processing, and shipping or storage containers) were significant consumers of electricity.

3 Ebeye electricity use

3.1 Overview

According to KAJUR records [17], in financial years 2014 – 2016 an annual average of 15.95 GWh of electricity was recorded as generated, however the annual average of the recorded transmitted and distributed electricity was higher than this, indicating metering inaccuracies. The approach taken by KAJUR was to accept the generation record and estimate 15% losses to the point of supply[3]. 6.4% of electricity generated was reported to be consumed as power station auxiliary loads [18].

In the period FY2014 - 2016, an annual average of 11.9 GWh of electricity was sold [19], including commercial, government, residential, post-paid and prepaid customers; suggesting that a significant quantity of electricity is unmetered.

Many large customers have private backup generation which is often run to allow KAJUR to perform load shedding for maintenance. The resulting quantity of electricity generated by private generators is unknown and has been ignored for this analysis.

36% of electricity sales were to commercial customers, 15% to Government customers, and 49% to residential customers [19].

3.2 Government energy use

An energy audit of the Leroij Kitlang Memorial Health Centre (Ebeye hospital) was undertaken in 2016, suggesting an annual consumption of 1.2 GWh [20]. This consisted of negligible refrigeration, 79% air conditioning (including chillers and air handling units), 11% lighting, and 10% other.

KAJUR are also the water utility of Ebeye. Water utility electricity use in 2016 consisted of approximately 0.41 GWh [21], including water pumping and desalination.

The hospital plus KAJUR together accounted for most of the 2016 government sales. Any remaining consumption was assumed to have a breakdown per Table 3. In late 2017, a new water desalination plant was commissioned on Ebeye. The annual consumption of this was not known, however an estimate of 0.5 GWh was added to both generation and government consumption from 2016 levels, based on three days of kWh meter readings in June 2018.

3.3 Commercial energy use

The Ebeye Electrical Masterplan [22] estimated the average demand of the Triple J supermarket as 60 kW, or 0.53 GWh annually. This is assumed to have the same supermarket electricity use breakdown as used for Majuro (60% refrigeration, 15% air con, 18% lighting, 7% other). This report also suggested that the remaining commercial use will consist of various

[3] We note that most of the Ebeye network is compact, and so distribution losses may not be as high as this KAJUR estimate.

offices, small shops, lighting for schools and restaurants. These were assumed to have an electricity use breakdown as in Table 3.

3.4 Residential energy use

Table 4 presents the estimated breakdown of Ebeye residential electricity by application. The method used to develop this estimate is described in Appendix 8.4.

Table 4 – Broadly estimated household electricity use in Ebeye

Category	% of electricity consumption
Refrigeration	13
Air conditioning	52
Lighting	16
Other	19

3.5 Current use of electricity on Ebeye

The above information and analysis is reflected graphically in Figure 2 below. This diagram uses a series of nodes and flows to quantitatively demonstrate the estimated pathway of electricity from generation to end-use in Ebeye. This is from electricity generation output (i.e. not from heating value of diesel fuel) to appliance electricity input (i.e. not to energy service provided). This diagram includes significant uncertainty on the right-hand side.

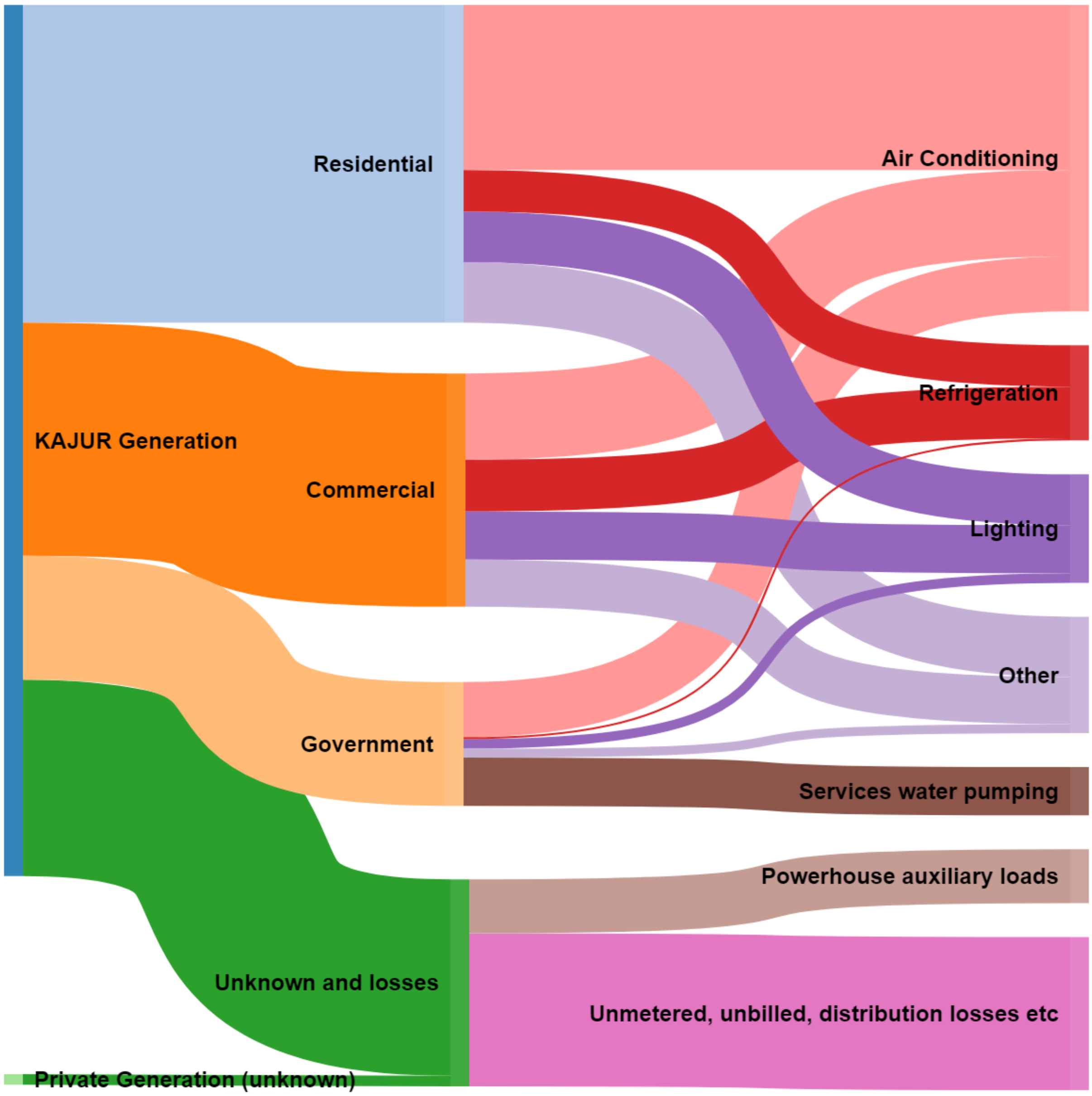

Figure 2: Estimated Ebeye Electricity End-use by sector, categorised

From Figure 2, the largest single end use category of electricity in the Ebeye grid was air conditioning, followed by lighting and then refrigeration. Residential air conditioning (this is based on a very rough estimate) was a significant consumer of electricity. Technical and non-technical losses appear to be high, but this is based on limited data and should be measured or modelled in more detail.

4 Other islands' electricity use

The proposition to power RMI islands outside of Majuro and Ebeye with predominantly renewable energy (see RMI roadmap techno-economic report) means that the cost of generating electricity (including initial capital costs) is likely to be high. This provides further good reason to implement energy efficiency measures and appliances in those locations.

However, based on MEC fuel sales data [23] it is estimated that Majuro and Ebeye electricity production together account for up to 94% of national electricity. As a result, the energy efficiency measures on outer islands will not have a large impact on national emissions reductions, and so were not included in the following analyses.

5 Potential demand-side Energy Efficiency or conservation measures

5.1 Overview of potential initiatives

Opportunities to reduce electricity demand through energy efficiency and energy management measures include:

a. Air Conditioning
    i. Behavioural changes (closing doors, reducing thermostat setpoints)
    ii. Minimum Energy Performance standards (MEPS) and labelling
    iii. Insulation of households and commercial premises
    iv. Regular maintenance of air conditioning units
b. Refrigeration
    i. MEPS and labelling
    ii. Right-sizing freezers and refrigerators
    iii. Insulation improvements
    iv. Improved maintenance of seals and gases
c. Lighting
    i. Replacing incandescent with CFLs/LEDs or longer-form fluorescents (according to recent energy audits, this has already proliferated though RMI government facilities)
    ii. Installing lighting timers
d. Others
    i. MEPS and labelling (for ovens, washing machines, dishwashers and TVs
    ii. Pressure cookers (reduce 66% of stovetop energy use, reducing emissions whether the energy is gas or electric)

Based on the conclusions of ADB [24], the estimated potential for reduction in electricity demand for typical Pacific Island countries through the implementation of demand side measures are summarised in Table 5 below.

Table 5 - Energy Conservation Measures applied to typical Pacific Island Countries [24]

ECM	Annual Savings Potential			Total Estimated Investment	Annual Emission Reduction	2011-2020 CO_2 Reduction	Simple PBP
	%[16]	MWh	USD M	USD M	TCO_2	TCO_2	Years
Energy Efficiency in Government Buildings	10.2	7,121	2.1	7.3	4,583	36,690	3.5
Energy Efficiency in Street Lighting	66.2	4,396	1.5	8.1	2,877	23,011	5.5
CFL in Residential Sector	5.0	9,315	1.7	0.75	5,976	53,830	0.5
Energy Efficiency in Hotel Sector	20.7	8,786	2.7	24.6	5,524	44,190	4.0
Energy Labeling and MEPS	2.0	18,145	5.8	6.0	11,758	93,400	1.0
Power Factor Correction Systems	0.4	423	0.1	0.8	275	2,480	5.7
Energy Efficiency in Pumping Stations	5.0	267	0.1	0.47	184	1,650	4.7

It is noted that the 'annual savings potential' in the table above are calculated by end use category, not necessarily overall for each country. For example, replacing streetlights for energy efficiency could save on average 66% of streetlight energy requirement in any given country. However, the Energy labelling and MEPS initiative is an average % saving potential across the region's entire electrical grid energy use. The initiatives with the fastest payback periods are the CFL initiative and the Energy Labelling/MEPSI.

5.2 Initiatives identified by previous energy efficiency studies - Majuro

Previous energy audits [2-7] identified and recommended significant opportunities for energy efficiency and energy conservation gains in large electricity consumers on Majuro, through measures such as the following:

- Right sizing air conditioners
- Air conditioners with improved EER and corrosion resistant fins
- Air conditioner installation
- Air conditioner fan, temperature setpoint and timer optimisation
- Air conditioner servicing
- Air ducting repairs
- Shade shelters over outside aircon condenser units
- Building envelope air leaks
- LED lighting
- Removing unnecessary lighting
- Motion detectors and/or daylight sensors for lighting
- Energy monitoring/management

- Energy star rated laptops rather than desktop computers
- Heat pump water heaters
- Solar water heaters
- Ceiling insulation
- Thermal paint
- Shading, tree planting
- Energy star refrigeration once due for replacement
- Outdoor clothes drying

It is not known how many of these recommendations have been implemented to date, but the following estimate was based on recent electricity billing.

Table 6 - Previously identified energy savings in Majuro facilities

Audited facility	Annual consumption at audit (MWh)	Suggested opportunities (MWh)	Recent annual consumption (MWh)	Estimated remaining opportunities (MWh)
Ministry of Education (2012)	1,960	882	Unknown	Unknown
Ministry of Health (2011)	3,073	1,444	2,500	871
National Telecommunications Authority (2014)	946	359	825	238
Robert Reimers Hotel (2011)	394	205	352	163
University of South Pacific, Majuro campus (2011)	73	22	73	22
Australian Navy compound (2011)	128	42	130	42
Total	**6,570**	**2,950**	**3,880**	**1,780 (assumed)**

This would suggest that perhaps 40% of the identified measures might have already been implemented (depending on demand growth), leaving 1.8 GWh of potential for further gains, which is equivalent to 3% of generated electricity on Majuro.

5.3 Energy efficiency in other Majuro Govt buildings

Table 5 suggests the potential for a 10% reduction across all government buildings surveyed in the South Pacific in 2011. Since that time, many energy efficiency measures may have already been implemented in Majuro. For example, since an energy audit [3] identified opportunities for 47% electricity use reduction in the Ministry of Health in 2011, a 19% reduction has been realised – this may be due to energy efficiency, dependant on load growth.

However, if 10% reductions are still able to be made in government electricity use across all facilities excluding the Ministry of Health, Ministry of Education, and water pumping; a reduction of 0.5% of generated electricity on Majuro would result.

5.4 Energy efficient lighting in Majuro residences

Switching from incandescent lighting to Compact Fluorescents (CFL) or Light Emitting Diodes (LED) as indicated in Table 4 could be effective for the RMI, although many gains will have already been made.

Assuming that 70% of Majuro homes have already moved to energy efficient lighting (Appendix 8.2), and that 50% of the remaining fixtures could be eligible for significant improvements: if switching from incandescent to CFL/LED saves 80% of annual energy per bulb [25], 12% of lighting load could be reduced. Residential lighting load is estimated to account for approximately 6% of Majuro's generated power, saving 12% of this is 0.7% overall for the grid.

5.5 Energy efficiency in the Majuro commercial sector

Table 5 suggests the potential for a 20% reduction across all hotel buildings surveyed in the South Pacific in 2011.

It is not known what fraction of Majuro electricity demand is attributed to the hotel sector, other than those facilities in Table 2 (RRE and MIR). RRE is already included in Section 5.2. A 20% reduction in MIR electricity use is equivalent to 0.4% of generated electricity on Majuro.

The MEC 2016 Power Report [1] stated that commercial customers were 11% of total customers but used 36% of electricity, suggesting that many commercial customers used significant quantities of electricity.

The Southern California electricity utility [26] suggested that it is possible for supermarket refrigeration energy use to be reduced by 24% using the following measures:

- Install refrigeration curtains and auto door closers on refrigeration units
- Add temperature controllers
- Insulate bare suction lines
- Add display shields
- Replace existing shaded pole on evaporator fans with electrically commutated motors

If this level of electricity reduction was able to be achieved in the commercial refrigeration sector of Figure 1 - excluding the MSTCO Reefer Block, RRE and MIR - a 3% reduction in Majuro electricity would result. A large proportion of this would be attributable to the PPF fish factory, however no energy audit has yet been performed on this facility to identify whether there is the technical and economic potential to achieve this. The refrigeration equipment may already be more efficient than supermarket refrigeration. We would recommend this audit as a worthwhile exercise.

5.6 MEPS and Labelling nationwide

We estimate that immediately introducing MEPS and labelling to appliances in the RMI could result in demand reduction nationwide of around up to 7%. This estimation is taken from the recorded impact of the MEPS introduction in Australia and NZ in the early 2000s and includes some effect of appliance modernisation [13]. In the Cook Islands for example, the ADB report estimated that MEPS implementation will save 3.8% of the country's electrical energy per annum [24]. From Table 4, the average effect of MEPS across the Pacific is only 2%. Our estimate of 7% for RMI is far higher due to greater appliance proliferation, (only 11% of Cook islanders had air conditioners [24], whereas 50% of Marshallese did [14]). Also, Pacific Island Nations that are on 50Hz electricity have likely already benefitted from MEPS as their appliance imports chiefly come via Australia and NZ, therefore further benefits would almost be negligible for these nations, however RMI is 60Hz and do not source their appliances from AUS/NZ.

5.7 Energy efficiency in MWSC water pumping

Table 5 suggests the potential for a 5% reduction in utility water pumping, based on reducing leaks, installing high-efficiency motors, reviewing pump curves and better matching of motors and pumps, and optimising operating hours according to actual water demand profiles. A 5% reduction in MSWC water pumping electricity equates to 0.1% of generated electricity on Majuro. Further reductions may be possible with variable speed drive motor controllers, although these would need to be suitable for the corrosive environment. A concurrent World Bank energy efficiency project has identified that MWSC's pumps are well beyond their useful life and have identified replacement of pumps as a key priority for energy efficiency. The consultant has yet to quantify expected savings.

5.8 Summary of potential savings for Majuro

Sections 5.2 through 5.7 identify (at a very high and approximate level) an estimated 15% of technical potential for electricity reduction on Majuro.

Table 7: Summary of identified demand side measures, Majuro

Energy efficiency/conservation measures	Estimated technical potential for electricity reduction within scope assessed (%)	Estimated resulting reduction in Majuro electricity consumption (%)
Implement recommendations from previous RMI energy efficiency studies and audits	31	2.9
Undertake energy audits and implement energy efficiency and conservation in other Govt buildings	10	0.5
Incentivise or grant more efficient lamps for residential lighting	12	0.7
Undertake energy audit and implement energy efficiency and conservation in the MIR hotel	20	0.4
Undertake energy audits and implement energy efficiency measures for users of commercial refrigeration	24	3.0
Introduce national MEPS and labelling	7	7
Undertake energy audit and implement energy efficiency measures for MWSC water pumping	5	0.1
Total		**15**

5.9 Inititatives identified by previous energy efficiency studies – Ebeye

5.9.1 Ebeye Hospital

An energy audit of the Leroij Kitlang Memorial Health Centre (Ebeye hospital) [20] identified and recommended significant opportunities for energy efficiency and energy conservation gains, which together could reduce electricity consumption in that facility by approximately 59%, through measures such as the following:

- Replacing the chiller unit with split type air conditioners with improved EER and corrosion resistant fins (we would suggest also evaluating an efficient central unit)
- Air conditioner installation (e.g. sealing wall penetrations)
- Air conditioner fan, temperature setpoint and timer optimisation
- Air conditioner servicing
- Shade shelters over outside aircon condenser units
- Replacing fluorescent lighting with LED lighting
- Removing unnecessary lighting
- Motion detectors for lighting
- Energy monitoring/management
- Building envelope air leaks
- Shading, tree planting

As this study was relatively recent (June 2016), it was assumed that these measures have not yet been implemented. If implemented in full, these measures would result in a reduction of Ebeye electricity by 4%.

5.9.2 Ebeye residences

An energy audit performed on an Ebeye residence [16] identified the potential for savings of 37%, based on the following measures:

- Replacing air conditioners with inverter split types with high EER
- Replace incandescent and fluorescent lamps with LED lamps
- Install ceiling insulation
- Install electricity monitoring system for occupant education/behaviour

These savings align with the findings of the Ebeye Electrical Masterplan [22], which suggested 30% savings in all residences based on the following measures:

- Replace AC with inverter type
- Replace refrigerators with 5 star
- Replace lamps with LED
- Replace general appliances with high star rating appliances

Assuming that 30% savings are possible in 80% of residences, this would result in a reduction of Ebeye electricity by 9%.

5.10 Energy Efficiency in Ebeye Govt buildings

Table 5 suggests the potential for a 10% reduction across all government buildings surveyed in the South Pacific in 2011.

If 10% reductions are able to be made in government electricity use across all facilities excluding the hospital and water pumping, a reduction of 0.1% of generated electricity on Ebeye would result.

5.11 Energy efficiency in the Ebeye commercial sector

Table 5 suggests the potential for a 20% reduction across all hotel buildings surveyed in the South Pacific in 2011, however there are not many hotels on Ebeye.

The Southern California electricity utility [26] suggests that it is possible for supermarket refrigeration energy use to be reduced by 24% as described in Section 5.5

If this level of electricity reduction was able to be achieved at the Triple J supermarket, an estimated 0.8% reduction in Ebeye electricity would result.

5.12 Energy efficiency in KAJUR water pumping

Table 5 suggests the potential for a 5% reduction in utility water pumping, based on reducing leaks, installing high-efficiency motors, reviewing pump curves and better matching of motors and pumps, and optimising operating hours according to actual water demand profiles. Further savings may be possible through other measures such as variable speed drives; however, these introduce electronic controllers into potentially corrosive island environments.

The new water desalination plant on Ebeye includes state of the art energy efficient equipment, such as pressure exchangers, and so was excluded from this.

A 5% reduction in KAJUR water pumping electricity equates to 0.1% of generated electricity on Ebeye.

5.13 Ebeye summary

Sections 5.9 through 5.12 identify (at a very high and approximate level) an estimated 14% of technical potential for electricity reduction on Ebeye.

Table 8: Summary of identified demand side measures, Ebeye

Energy efficiency/conservation measures	Estimated technical potential for electricity reduction within scope assessed (%)	Estimated resulting reduction in Ebeye electricity consumption (%)
Implement recommendations of previous hospital energy efficiency study	59	4.3
Undertake energy audits and implement efficiency and conservation in other Govt buildings	10	0.1
Undertake sample energy audits and incentivise energy efficiency and conservation in residences	24	8.8
Undertake energy audits and implement energy efficiency measures for users of commercial refrigeration	24	0.8
Undertake energy audit and implement energy efficiency measures for KAJUR water pumping	5	0.1
Total		**14**

6 Conclusions

A large proportion of electricity in RMI is consumed by air conditioners, refrigeration, and lighting (in that order).

Energy efficiency and conservation measures have been identified which are estimated to have the technical potential to reduce electricity consumption on Majuro Atoll by 15% and Ebeye Island by 14%, which together are thought to account for around 94% of RMI electricity.

Significant contributors to these gains include significant and targeted facility/appliance upgrade projects for large electricity consumers (e.g. hospitals, schools, and accommodation providers), introducing national Minimum Energy Performance Standards and labelling, commercial refrigeration improvements/upgrades/maintenance, and widespread replacement of inefficient appliances in the residential and light commercial sectors of Ebeye Island.

Given the presented contribution from commercial refrigeration and the uncertainty in the technical and economic potential, robust audits of supermarket and fish processing refrigeration should be undertaken to better understand the potential.

Given the high proportion of electricity dedicated to air conditioning, in the short term effort should be focused on the EER of air conditioners. We note that an import tax exemption on energy efficient appliances is already making gains here. In the long term, effort should be focused on developing a building code to improve the building envelopes into which significant quantities of cooling energy are being directed.

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8 Appendix

8.1 Estimated breakdown of Majuro technical losses

Powerhouse auxiliary loads averaged around 450 kW [10], i.e. 3.9 GWh/yr or 7% of electricity generated in 2016.

KEMA [11] suggested that distribution line losses prior to 2010 were around 4.15% with 0.19% in the low voltage network giving 3.96% in the medium voltage network. However recent (2017) analysis by EPR suggests an estimated 2.3% line losses in the MV network now, but this was against a lower average network load of 6.4 MW compared to the 8.5 MW average used in the 2010 study. As losses increase with the square of line current, a correction factor of $(6.4/8.5)^2$ may be applied, which then exactly equates the two models. The KEMA report also suggested 2010 transformer losses of 1,445 MWh annually, consisting of 1,277 MWh no-load losses and 168 MWh load losses. The reduction in electricity demand from 2010 to 2017 will have reduced the load losses, and the no-load losses will form a slightly larger proportion of electricity generated. An advanced metering project is under consideration to better identify the magnitude and location of these technical losses.

8.2 Estimated breakdown of Majuro residential electricity consumption

MEC records suggest that mean household annual energy consumption is around 6,500 kWh [12], or 18 kWh/day. However, as no recent household sample audits or surveys are available for Majuro, the end use applications of this electricity must be estimated by other means. A study into the costs and benefits of introducing standards and labels for electrical appliances in Pacific Island countries [13] published in 2011 included an estimated breakdown of RMI household electricity (shown in Table 9).

Table 9 – Estimated household electricity use by category in RMI 2006 (from [13])

Category	% of electricity consumption
Refrigeration	15
Air conditioning	40
Lighting	23
Other	22

This estimate was based on appliance ownership in 2006 as determined by census, the Pacific Islands Renewable Energy Programme (PIREP), or other unnamed sources.

The 2011 Census [14] reported that in 2011 45% of Majuro homes had aircon and 60% of Majuro homes had refrigeration. However, it is possible that appliance ownership has changed since that time. Based on discussions with energy experts in RMI, we believe air conditioning may now constitute a larger proportion of residential electricity consumption on Majuro.

Air conditioner performance and electricity consumption depends on the building envelope. With no building code, there is a wide variation in housing quality, from well designed and built buildings to shacks erected with whatever second-hand materials are at hand. The latter will be built with the basic requirements of shelter and privacy foremost rather than cooling performance (whether aircon or ventilation).

Figure 3: Majuro houses

The 2011 census reported that in 2011 68% of Majuro homes were of concrete, brick or stone construction, with others being of wood construction or a few of metal cladding. Although many homes have louvre type windows for ventilation, RMI energy experts suggest that the increased density of housing has limited the breeze available causing many to retrofit air conditioners.

Medium and high-quality buildings appear to predominantly use late model inverter split air conditioners for temperature regulation. Air cons in government offices and commercial buildings seem to usually be set around an optimal 77°F/25°C, occasionally lower for those who prefer the sensation of lower temperatures.

Although some of the poorer quality buildings will rely on natural ventilation alone, many appear to use window type air conditioners, typically installed using a sheet of plywood and packed with timber offcuts. They may be installed in a poor envelope, such as in rooms with louvre windows.

Figure 4: Majuro window style aircon installation, next to louvre windows

Figure 5: Majuro window style aircon installation, next to window covered in plastic sheet

Although these are less efficient than split type, they have a lower purchase cost and are easier to install as DIY.

Figure 6: Efficient split-type air conditioner for sale on Majuro ($460+)

Figure 7: Window-type air conditioner for sale on Majuro ($170)

In addition to an increase in air conditioner ownership, it is possible that lighting efficiency will have increased in many homes. LED and CFL lamps are widely available, and costs have reduced significantly over recent years.

Figure 8: Energy efficient lamps for sale on Majuro

Within Majuro, after discussions with RMI energy experts, we assume that air conditioning ownership will have more recently risen to around 70%, and that efficiency improvements in air conditioning, lighting, and to a lesser extent refrigeration technology will have been made. We assume that 50% of air conditioner installations will have made efficiency improvements of 25% [15], and that 70% of homes will have moved to energy efficient lighting. Lower income family homes will still buy incandescent lamps (even if they are aware that they are more expensive long term) due to available cash flow. There have been some programmes distributing free energy efficient lamps. We assume that household lighting demand will have reduced by 75% in 35% of fixtures. Cooking is currently predominately provided by gas (66% of homes according to the 2011 census) and hot water needs are low.

Based on this - admittedly incomplete - information, we have made a resulting "best guess" estimate of current day Majuro household electricity use, given in Table 100.

Table 10 – Broadly estimated household electricity use in Majuro

Category	% of electricity consumption
Refrigeration	15
Air conditioning	48
Lighting	17
Other	20

This also aligns well with an RMI household energy audit [16] which identified 12% of electricity use to refrigeration, 47% to air conditioning, 13% to lighting, and 20% to other. Although this audit is for an Ebeye home, it is a concrete block home with both a split type aircon and a window type aircon and so may be representative of a typical Majuro home.

8.3 Estimated breakdown of Majuro Commercial and Government electricity consumption

Over the past decade, energy audits have been conducted for various large electricity users in the RMI. Majuro audits include the Ministry of Education (including schools) [2], the Ministry of Health (including hospital buildings) [3], the National Telecommunications Authority [4], the hotel Robert Reimers [5], the University of the South Pacific [6] and the Australian Navy Compound [7]. Specific billing data was available for a number of the largest electrical energy users on the Majuro grid [1]. Representative audit data from other geographic regions was estimated for other RMI hotels and industry such as copra processing and water desalinisation. Supermarket energy use was estimated from NREL figures for industry averages [8] and a Finnish study on fish processing factories [9] was used to generate figures for the PPF factory. Large users and their assumed audit data are summarised in Table 2 .

A further end use of electricity that was categorised for the government sector is utility pumping. This refers to the pumping of fresh water, salt water (used for toilet flushing) and waste water by the utility Majuro Water and Sewer Company (MWSC). Twelve months of individual billing data from these meters (excluding office buildings) over 2014/2015 were combined to produce a figure of 890 MWh per annum (assuming that pumping demand has not changed since then).

The cumulative MWh provided by Table 2, along with the pumping consumption above, accounts for much of commercial and government Majuro electricity use. Remaining government and commercial premises which are not listed in Table 2 will typically be office type buildings, shops and restaurants. For these premises, estimated use was based on a generic estimate of commercial and government electricity use in Pacific island nations provided in the previously mentioned 2011 report [13].

Table 11 – Estimated electricity use in commercial and government buildings in pacific island nations in 2006 (from [13])

Category	% of electricity consumption
Refrigeration	15
Air Conditioning	35
Lighting	30
Other	20

Most commercial and government buildings in Majuro use energy efficient lighting. This may represent a change since 2006, although fluorescent lighting will have been in use then too. We make the assumption that government and commercial lighting demand will have reduced by 75% in 50% of fixtures. As such, we have modified the proportions presented in Table 11 accordingly, with the resulting “best guess” estimate of current day Majuro commercial & government electricity use (excluding largest consumers) given in Table 12.

Table 12 – Broadly estimated commercial and government electricity use in Majuro (excluding largest consumers)

Category	% of electricity consumption
Refrigeration	17
Air conditioning	40
Lighting	21
Other	22

The above estimation entails a large portion of the overall Majuro electricity use and we are confident that significant power users have been captured in the representative audit data, particularly those that use significant refrigeration (many commercial buildings also rent refrigeration trailers).

Figure 9: Refrigeration trailer on Majuro

8.4 Estimated breakdown of Ebeye residential electricity consumption

FY2016 sales data from KAJUR [19] suggested that 5.76 GWh was sold to 1060 residential customers, a mean household annual energy consumption of around 5,400 kWh [10], or 15 kWh/day. A single household energy audit [16] reported 12% of electricity use to refrigeration, 47% to air conditioning, 13% to lighting, and 20% to other, however this was not necessarily representative of a typical Ebeye home.

The 2011 Census [14] reported that in 2011 50% of Kwajalein atoll homes had aircon and 66% had refrigeration. However, it is possible that appliance ownership has changed since that time. We believe air conditioning may now constitute a larger proportion of residential electricity consumption on Ebeye, particularly window type air conditioners. Discussions with residents on

Ebeye island suggested that most homes now own between one and three window type air conditioners.

Air conditioner performance and electricity consumption depends on the building envelope. The housing stock on Ebeye appears to be in worse condition than Majuro. A higher proportion of homes are simple shacks in poor condition. Also, the proportion of homes using window type air conditioners appears to be much higher than on Majuro.

The 2011 census reported that in 2011 56% of Ebeye homes were of wood construction.

Figure 10 Ebeye houses

Figure 11 Ebeye air conditioner

Within Ebeye, after discussions with RMI energy experts, we assume that air conditioning ownership will have since risen to around 75%, without significant gains in energy efficiency. We make the assumption that 50% of homes will have moved to energy efficient lighting. Lower income family homes will still buy incandescent lamps, even if they are aware that they are more expensive long term, due to available cash flow. We make the assumption that household lighting demand will have reduced by 75% in 25% of fixtures. Cooking is currently predominately provided by gas (67% of homes according to the 2011 census) and hot water needs are low.

As such, we have modified the proportions presented in accordingly, with the resulting "best guess" estimate of current day Ebeye household electricity use given in Table 13,

Table 13 – Broadly estimated household electricity use in Ebeye

Category	% of electricity consumption
Refrigeration	13
Air conditioning	52
Lighting	16
Other	19