Navigating our Energy Future:

Marshall Islands Electricity Roadmap

December 2018

Republic of the Marshall Islands Energy Future

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Foreword

Minister-in-Assistance to the President and Environment Minister, Republic of the Marshall Islands (RMI)

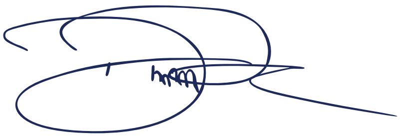
The Republic of the Marshall Islands is calling for ambitious action by all countries to reduce greenhouse gas emissions (GHG). And we are leading the way. Our commitment to 'walking the talk' is demonstrated by our adoption of a pathway to a low-carbon energy future.

In our Nationally Determined Contribution, the Republic of the Marshall Islands has committed to reducing GHG emissions to achieve net zero emissions by 2050, with two significant milestones along the way – by 2025 our emissions will be at least 32 percent below 2010 levels, and 45 percent below by 2030.

While all sectors of our society need to reduce emissions, the electricity sector is where the most developed and cost-effective technologies are already available, and therefore the greatest opportunities. To achieve our goal of zero emissions by 2050, we need to have more than half of our electricity coming from renewable sources in just seven years.

There is much on our side. Our islands are blessed with steady trade winds and sunshine, the basis of our energy future. But the wind does not always blow, the sun does not always shine. Both are intermittent and variable sources of energy – we can't switch them on when we need them. Additionally, our islands are tiny, and renewable energy – solar panels, wind turbines, and batteries – take up large amounts of space. This means we need to find innovative ways to use proven technology, such as exploring the possibility of floating solar panels in our lagoons.

The Marshall Islands was one of the first countries to prepare and submit a long-term decarbonization pathway to the United Nations Framework Convention on Climate Change (UNFCCC), as called for under the Paris Agreement. Our Electricity Roadmap once again shows how even the smallest and most isolated of nations can lead the way to a safe and prosperous future for all people.



HONORABLE DAVID PAUL
Minister-in-Assistance to the
President and Environment Minister,
Republic of the Marshall Islands (RMI)

Foreword

Chief Secretary, Republic of the Marshall Islands (RMI)

This long-term Electricity Roadmap for the Marshall Islands presents costed, technically sound, renewable energy pathways for our electricity sector, to help achieve our ambitious climate change targets for 2025 and 2030, and to have 100 percent renewable energy by 2050.

To achieve our targets, it falls to the electricity sector to do most of the heavy lifting, and quickly. Over the next 7 years, we will need to go from the very modest 2 percent renewables we have today, to over 50 percent renewables, at a cost of around USD$170 million.

As we go through this process of understanding the technological transition we need to make, we are getting to grips with the scale of the challenge. It is ambitious, and expensive, and we need to work together closely with our partners to find the financing and the world-class expertise needed.

We also need our women and men to become engineers, technicians, and managers. With these skills we will be better resourced to navigate the many other challenges climate change brings – drought, storms and sea-level rise. By meeting these challenges we can see a cleaner, brighter future for Marshallese people.

BEN GRAHAM
Chief Secretary,
Republic of the Marshall Islands (RMI)

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Acronyms, symbols and abbreviations

ADB	Asian Development Bank
AC	air conditioner
BAU	business as usual
BESS	battery energy storage system
CAPEX	capital expenditure
CMI	College of the Marshall Islands
CO_2-e	carbon dioxide equivalent
DIDA	RMI Division of International Development Assistance
EU	European Union
gallon	US liquid gallon
GWh	gigawatt hours
GCF	Green Climate Fund
GHG	greenhouse gas
HR	human resources
ICDF	Taiwan International Cooperation of Development Fund
IPP	independent power producer
IRENA	International Renewable Energy Agency
JICA	Japan International Cooperation Agency
KAJUR	Kwajalein Atoll Joint Utilities Resource Inc.
kt	kilotonne
kW	kilowatt
kWh	kilowatt hour
LCOE	levelized cost of electricity
MEC	Marshalls Energy Company
MIDB	Marshall Islands Development Bank
MW	megawatt
NDC	Nationally Determined Contribution
NEP	National Energy Policy
NTC	National Training Council
NZ MFAT	New Zealand Ministry of Foreign Affairs and Trade
PPF	Pan Pacific Foods Inc.
PV	photovoltaic
RMI	Republic of the Marshall Islands
SAPS	stand-alone power system
SHS	solar home system
STEM	science, technology, engineering and mathematics
SEDeP	World Bank Sustainable Energy Development Project
SAIDI	system average interruption duration index
UNFCCC	United Nations Framework Convention on Climate Change
USG	US liquid gallon
USP	University of the South Pacific
WB	World Bank
$	All dollar figures used in this report are 2018 US Dollars

01.

About this Roadmap

Why do a long-term Electricity Roadmap?

The Roadmap provides a strategic framework for the Republic of the Marshall Islands (RMI) electricity sector, to enable us to meet our climate change targets and to strengthen our role as a climate leader. This Roadmap will allow the RMI and our development partners to work together to achieve a common vision for the RMI electricity sector.

As one of the countries most vulnerable to the impacts of climate change, the RMI is a global voice for ambitious action to reduce greenhouse gas (GHG) emissions. We are committed to 'walking the talk' in our climate leadership role by demonstrating a pathway to a low-carbon energy future. We want to show how even tiny, remote islands with limited means can navigate the journey to a low-carbon energy future.

The Marshall Islands is highly dependent on imported diesel and faces significant fuel and transportation costs. Around half of our GHG emissions come from burning diesel for electricity. While many of our outer islands have 100 percent renewable generation, our main towns still rely on diesel. Not only does using diesel produce emissions, it makes us very vulnerable to oil price shocks, such as the one that nearly bankrupted us in 2009.

We want to show how even tiny, remote islands with limited means can navigate the journey to a low-carbon energy future.

In our Nationally Determined Contribution (NDC), the RMI has committed to reduce GHG emissions by 32 percent below 2010 levels by 2025, 45 percent by 2030, and to have net zero emissions by 2050. While all sectors need to reduce emissions, the electricity sector will contribute the most towards the GHG targets for 2025.

Over the last 15 years, progress has been made to develop renewable energy for the Marshall Islands. Almost all households on the outer islands, previously without electricity supply, now have solar home systems, and several larger solar projects totaling around 1 megawatt (MW) have been built on Majuro.

However, while targets have been in place aiming for 20 percent renewable generation by 2020, the funding and projects to achieve this were not defined. As a result, in 2018, the level of generation from renewables is only around two percent. At the same time, existing electricity systems are dilapidated. Significant ongoing investment in the foundations of generation and distribution infrastructure is needed to enable our renewables journey.

There is substantial funding and support available for our energy sector from development partners who have committed to improving the coordination and effectiveness of aid. However, in practice, in the last decade, RMI has experienced a dramatic increase in the number of development partners and projects without the necessary shared vision and coordinated approach to enable these investments to be clearly directed towards our targets.

This long-term Electricity Roadmap for the RMI aims to address this. It presents costed, technically sound pathways for the sector to help achieve our 2025 and 2030 NDC targets, and briefly outlines the longer-term pathways required to achieve total decarbonization of the electricity sector by 2050. These steps could be accelerated to help us get to our goals faster, but will require significant international support and strong political leadership.

The Roadmap also presents our strategies for policy, institutional development, and the human resources required to ensure successful rollout of the technology. It brings together the steps we are already taking and makes clear the next steps we need to take towards a completely decarbonized electricity sector by 2050 – or earlier.

It is necessarily a broad and high-level analysis, providing a framework and principles to guide investment and decision-making. In doing this, it provides the basis for the RMI to work with our development partners to achieve a common vision for the RMI electricity sector.

Scope of this Roadmap

This Roadmap imagines the RMI electricity sector's decarbonization journey, as we progress toward targets set for 2025, 2030 and 2050. It covers technology pathways, human resource strategies, enabling policies, and financing and implementation arrangements.

TECHNOLOGY PATHWAYS

Geographically, the Roadmap covers all of the RMI, and considers three types of systems:

- Main grids of Majuro and Ebeye.
- Mini-grids (e.g. Jaluit, Wotje, Rongrong, Kili).
- Individual solar home systems or stand-alone power systems.

For different stages along the pathway to net zero emissions the analysis identified the technologies suitable for use in the RMI, the appropriate mix of renewable generation and enabling technologies, and opportunities for supply and demand side efficiency.

HUMAN RESOURCE STRATEGIES

Of critical importance to the success of the Roadmap is ensuring an adequate, skilled workforce to support the technology rollout. The Roadmap presents key strategies for addressing the human resource needs, both in the short and long term.

FINANCING AND IMPLEMENTATION ARRANGEMENTS

The Roadmap outlines the financing and implementation arrangements required to realize the RMI's ambitions. The details of these arrangements are being discussed with key development partners.

ENABLING POLICIES

The Roadmap proposes ways to overcome barriers and create enabling conditions for the rollout of renewable energy, and includes efficiency and demand side management measures.

TIME HORIZONS

The Roadmap looks at the Marshall Islands' electricity future over four time horizons, aligning with the GHG emissions reduction targets for 2025, 2030 and 2050, and also roughly aligning with tranches of funding from development partners, as described in Figure 1.

Horizon 01
2018–2022

- Existing projects underway.
- Urgently required works, including upgrade of diesel generation, network and control systems to be 'renewables-ready'.

Horizon 02
2025 TARGET

- Programming pipeline funding to achieve 2025 target.
- Known, cost-effective technologies, with some reducing in cost (e.g. battery storage, solar panels).
- Best value for money with an eye on 2030 targets.
- Detailed workplan.

Horizon 03
2030 TARGET

- Uncertain funding.
- Mostly known technology, with some emerging applications (e.g. floating solar) and costs coming down.
- Low-detail plan.

Horizon 04
2050 TARGET

- High uncertainty on technology and cost.
- Options to be further explored at a later date.

Figure 1: The four planning time horizons covered in this Roadmap

What is not included in this Roadmap

This Roadmap covers only electricity generation and supply. For other major GHG-emitting sectors, this Roadmap considers only that significant electrification of transport is required resulting in increased demand for electricity over time, and that there is some potential for a waste-to-energy plant to reduce waste sector emissions. We recognize the need to develop similar long-term plans to achieve the necessary GHG reductions in other sectors – particularly in these areas of land and sea transport, and waste. The significant overlap in policy, monitoring, human resource, and financing needs across these various sectors highlights the need to develop a more integrated approach over time.

How was this Roadmap developed?

The process we used to develop this Roadmap intended to improve energy sector planning and coordination to support achievement of the RMI's renewable energy and climate change goals.

> A diverse group of organizations and individuals have contributed to and critiqued the work underpinning this Roadmap...

This Roadmap has been developed over a year, beginning in December 2017, and draws on an analytical process with a team of experts, and a collaborative process with RMI stakeholders and key development partners. A diverse group of organizations and individuals have contributed to and critiqued the work underpinning this Roadmap, including elected leaders, government officials, utility managers, energy engineers, staff of development partners, educators, and policy, commercial and national finance experts.

A large amount of detailed analysis sits behind this Roadmap and, as with any forward-looking planning process, a number of assumptions. The pathways outlined here capture the thinking at the end of the process but should not be considered 'final'. The assumptions, scenarios and context of the Roadmap are necessarily high-level, and will shift with time. Detailed design work is required to determine specific investment plans for each stage of the transition. Prices of technologies will come down, emerging technologies will mature, new technologies may emerge, and the price of diesel may go up, possibly making a rapid transition more economically attractive.

The Roadmap will need to be re-done before 2025 based on what progress has been made, lessons learned, the development of local human resources, what finance is available, and developments in technology.

	Technical and expert process	Governance and stakeholder collaboration
DEC 2017	• Determine scope • Engage team leader • Identify and engage experts	• Establish Tile Til Eo and Working Group • Recruit Energy Advisor • Identify stakeholders • Convene development partners
JAN		
FEB	• Review existing studies and collect baseline information on technology, policy, HR and financing	
MAR	• Revise national GHG inventory • Establish electricity GHG targets	
APR	• Assess suitable technologies • Develop scenarios • Techno-economic analysis • Recommend pathways	• Key choices presented to RMI for discussion
MAY		
JUN	Revise technology pathways analysis based on expert review and new information	• Expert review of technical advice by development partners
JUL	• Identify financing needs, future workforce needs, barriers, and enabling conditions	• Policy, human resource and financing strategies developed with stakeholders
AUG	• Draft Summary Roadmap and working papers	
SEP		
OCT		• Review, discuss and finalise with stakeholders
NOV	• Design and publish	• Discussions ongoing with partners on financing and implementation
DEC 2018		

Figure 2: Process for developing this Roadmap

02.

What goals are we heading towards?

Defining GHG targets for the RMI electricity sector[1]

To achieve the RMI's NDC, the electricity sector must reduce diesel use by at least 50 percent below 2010 levels by 2025, and 65 percent by 2030, assuming that other sectors also achieve the reductions indicated in the NDC.

The RMI's Nationally Determined Contribution (NDC) commits us to reducing GHG emissions economy wide by 32 percent below 2010 levels by 2025, with additional targets of 45 percent by 2030, and net zero emissions by 2050.

National emissions in 2010 are estimated to have been around 116 kt CO_2-e and 121 kt CO_2-e in 2016 (when fishing is excluded from the total)[2]. Emissions from the RMI electricity sector in 2010 were around 60 kt CO_2-e, or 52 percent of 2010 national emissions. In 2016, electricity sector emissions were around 57 kt CO_2-e, or 47 percent of national emissions.

Achieving the electricity sector targets of a 50 percent reduction in GHG and a 50 percent reduction in diesel use means that, in 2025, the sector must use fewer than 2.9 million gallons, and in 2030, fewer than 2.0 million gallons.

Assuming that waste, transport and other sectors meet emission reduction targets as indicated in the RMI's NDC, in order to meet our national emissions reductions targets the RMI electricity sector will need to reduce GHG emissions, and therefore diesel use, to at least 50 percent below 2010 levels by 2025, and 65 percent by 2030[3]. At the same time, demand for the services provided by electricity will be going up.

In 2010, around 5.8 million gallons of diesel was used for electricity. Achieving the electricity sector targets of a 50 percent reduction in GHG and a 50 percent reduction in diesel use means that, in 2025, the sector must use fewer than 2.9 million gallons, and in 2030, fewer than 2.0 million gallons [1][4].

The 2050 target has been variously referred to as 'net zero emissions', or '100% renewable'. This Roadmap develops technical options to get as close to that target as possible, although current day technologies mean this is both difficult and expensive. It is expected that, over time, technologies will improve, and costs will decrease, putting these targets in closer reach.

In the efforts to limit global warming to 1.5°C, the RMI is actively encouraging all countries to increase their ambitions under the Paris Agreement and, as such, we have a desire to increase our own ambition by reaching these targets even sooner, if possible.

1. Note that previous targets for the electricity sector, including those in current projects, were stated in terms of % renewables contribution to overall energy. It is considered that '% renewables' is not useful as a target in the context of achieving the NDC as this depends on the changing demand for electricity. More useful targets are stated in terms of '% reduction of GHG', 'kilotonne of carbon dioxide equivalent (CO_2-e)', and maximum amount of diesel to be used.
2. The RMI's GHG inventory was recalculated as part of the development of the Roadmap, to develop meaningful emission reduction targets for the electricity sector. The sector and total numbers developed for the Roadmap differ substantially from numbers included in the RMI Second National Communication and the INDC, largely due to obtaining more accurate fuel sales data. See [1] for a detailed discussion of the differences.
3. The targets calculated assume that sectors achieve the percentage reduction set out in the NDC even though the sector emissions amounts differ. This means: transportation (including domestic shipping) by 16 percent in 2025 and 27 percent in 2030; waste by 20 percent by 2030; and 15 percent from other sectors (cooking and lighting) by 2030.
4. References to documents are indicated throughout this document as a number in square brackets. The list of documents can be found at the back. Electronic copies of Roadmap documents may be obtained by visiting www.rmienergyfuture.org

		NDC TARGET % REDUCTION GHG ECONOMY WIDE	NATIONAL EMISSIONS (KT CO_2-E/ YEAR) (EXCL FISHING)[5]	TARGET % REDUCTION GHG ELECTRICITY	ELECTRICITY (KT CO_2-E/ YEAR)	DIESEL USE MILLION USG/YEAR
2010 (baseline)	Actual	0	116	0	60	5.84
2016		–	122	–	57	5.6
2025	Target	32%	79	50%	30	2.9
2030		45%	64	65%	21	2.0
2050		100%	0	100%	0	0

Table 1: Targets for the RMI electricity sector, derived from RMI's Nationally Determined Contribution (NDC) targets under the UNFCCC Paris Agreement

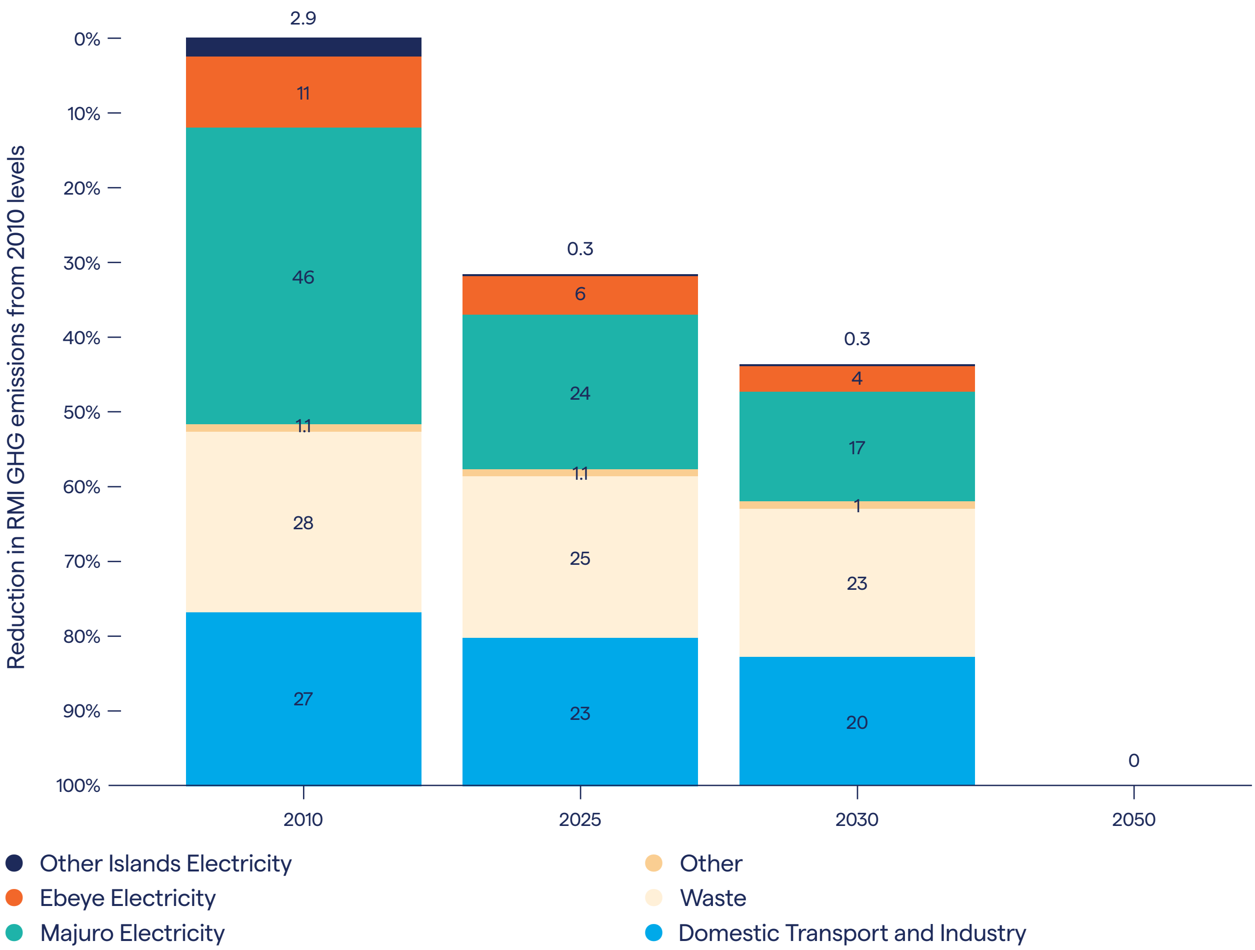


Figure 3: Targeted greenhouse gas (GHG) emissions in electricity on Majuro, Ebeye and other islands, and in the other key national sectors of waste and transport [1]

5. From the GHG inventory carried out as part of this project. See RMI Roadmap Technical Note 04: Greenhouse gas inventory and targets [1]. Previous inventory for 2010 included in the Second National Communication and the NDC were found to be in error.

Other objectives for electricity

Aside from helping to achieve the RMI's climate change targets, objectives for electricity addressed by this Roadmap include improving affordability, energy efficiency, energy security, reliability of service, and quality of life.

AFFORDABILITY
Affordable electricity, both for consumers and for the RMI Government, is a key objective of this Roadmap. While renewable energy can reduce fuel costs, we must fully recognize and plan for the increased costs of maintaining and replacing equipment. Affordability must consider equity issues and different users' ability to pay.

IMPROVED ENERGY EFFICIENCY AND REDUCED LOSSES
Reducing losses in the supply of electricity, and reducing use through energy efficiency and behavior change, will reduce the amount of investment required for generation equipment, saving money overall. By reducing waste and being smarter with the use of energy, customers will also save money.

INCREASED ENERGY SECURITY
Transitioning to renewables will reduce reliance on imported fossil fuels and our vulnerability to oil price shocks, such as that which prompted the RMI to declare a state of economic emergency in 2009. The switch to using local solar and wind resources will provide a higher level of energy security and resilience to global changes in oil price. At the same time, equipment should be resilient to the growing risks from climate change.

RELIABLE POWER SUPPLY
There is room to improve the reliability of the grids on Majuro and Ebeye, as well as the serviceability of systems on the outer islands. A reliable high-renewables grid requires attention to the entire system, including network upgrades, maintenance, and retaining essential diesel generation capability for years to come.

'DIESEL-OFF' CAPABILITY BY 2025
The reason RMI is being so ambitious with our targets is to demonstrate that transition to a low-carbon world is doable, and to lead the way. One of the targets is therefore to cross a technical threshold by 2025, enabling our major grids of Majuro and Ebeye to run in 'diesel-off' mode. This means that sometimes during the day, at particular times of year, while the sun is shining and the wind is blowing, we will be running on 100 percent renewable energy.

IMPROVING THE QUALITY OF LIFE ON OUTER ISLANDS
Over the last 15 years, thanks to various development partner projects, the Marshall Islands have connected over 99 percent of households to electricity, across all atolls, by installing stand-alone household systems on outer islands and in rural areas. However, many systems are now not in service. There is a pressing need to increase the service reliability of all systems, and to explore the aspirations of outer islanders for energy services and the role of energy in rural development.

A reliable high-renewables grid requires attention to the entire system, including network upgrades, maintenance, and retaining essential diesel generation capability...

03.

Mapping out the technology journey

How do we achieve those targets and objectives?

Decarbonizing RMI's electricity means reducing losses in generation and supply, improving energy efficiency and conservation, and installing wind and solar generation, plus associated enabling technologies.

In the first instance, the most cost-effective way to reduce electricity emissions is by reducing losses and improving energy efficiency and conservation. Majuro and Ebeye offer significant opportunity on the supply side to improve the efficiency of generation and reduce distribution losses. Businesses, government and households on these islands also offer significant opportunities for energy savings through energy efficient appliances, better maintenance, improved building design and construction, and changing the way people use energy.

The bulk of further reductions in diesel use, and therefore emissions, on Majuro and Ebeye will come from grid-connected wind and solar photovoltaic (PV) renewables generation, supported by diesel generators, batteries, and other enabling technologies. On outer islands, solar will be the primary form of energy, either in solar-diesel hybrid mini-grids or stand-alone solar-battery systems.

Further GHG savings can be made by matching demand to supply, such as by running some equipment at times of excess renewable energy – for example, ice banks for cooling buildings and refrigeration, electric vehicle chargers, and desalination plants.

Figure 4 shows the relative contributions these actions will make to reducing GHG emissions caused by electricity generation, leading to net zero emissions by 2050. Overall electricity demand is forecast to increase over time, due to some population growth on the main grids of Majuro and Ebeye, industrial growth, and the electrification of both land and sea transport. Reductions in electricity emissions will come from early efforts at energy efficiency and demand side management, wind power and solar power, as well as a final step, possibly provided by biodiesel.

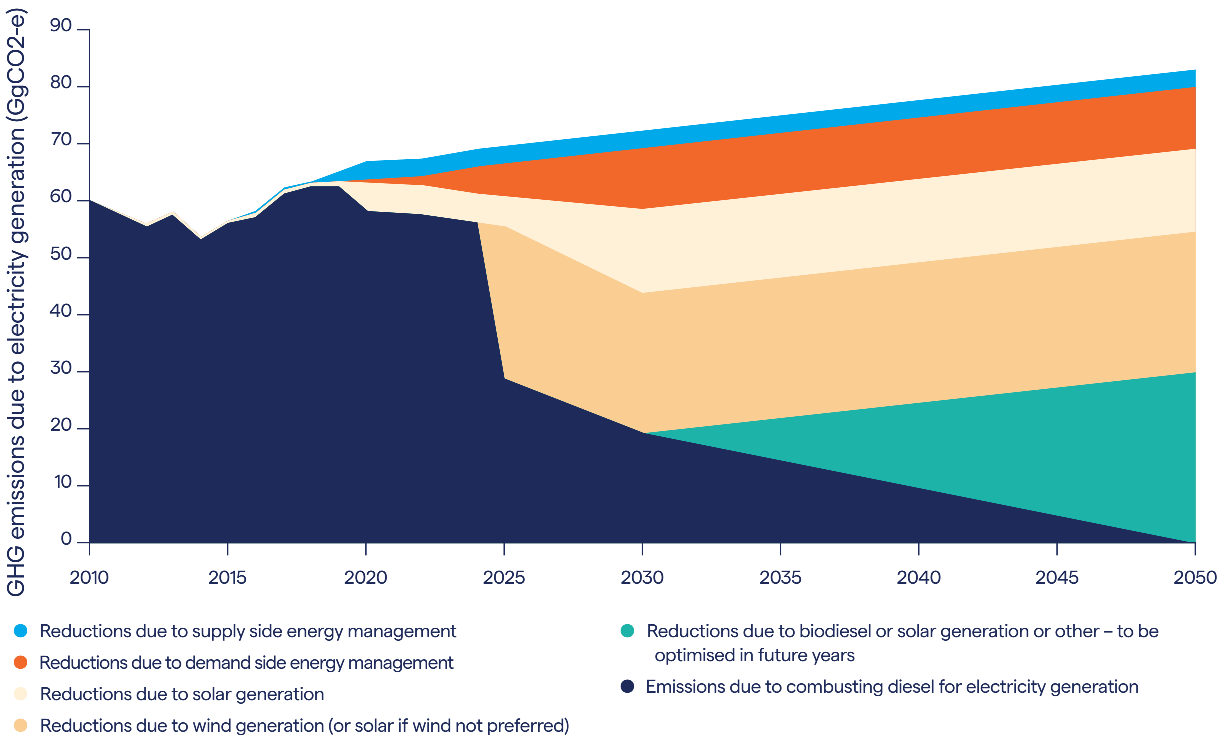


Figure 4: Summary of our modelling and analysis for least-cost pathways to the GHG electricity targets by 2025, 2030, and to net zero emissions by 2050 [2]

Different approaches for different island systems

The Marshall Islands has three main types of electricity systems: the main grids on Majuro and Ebeye; outer islands mini-grids; and stand-alone solar home systems. Each requires a different approach.

The Marshall Islands has three types of island electricity systems: main grids of Majuro and Ebeye; outer island mini-grids; and small stand-alone systems. Each system has its own characteristics, including geography, population and population density, load profile, availability of renewable energy resources, availability of land, utility staff, and people's ability to pay for services. Each situation calls for a different approach to implementing renewable energy.

The main grids on Majuro and Ebeye service RMI's two major population centers of around 30,000 and 15,000 people respectively. They are relatively sophisticated grids with requirements for high service levels and reliability. These two systems represent the vast majority of electricity generation and diesel use, and therefore hold the greatest potential to significantly reduce national emissions: Majuro's grid currently produces 74 percent of electricity sector GHG emissions, and Ebeye 22 percent.

Islands such as Jabor on Jaluit, Wotje, and Kili are home to several hundred residents, and a school. These communities are compact enough to currently have a small diesel mini-grid.

Most other outer island households are supplied with electricity from small stand-alone solar systems suitable for isolated customers with only basic power needs.

The following chapters explore the pathways for the three electricity systems, and the challenges and opportunities we face for each.

Majuro's grid currently produces 74 percent of electricity sector GHG emissions, and Ebeye 22 percent.

04.

Technology pathways for Majuro and Ebeye

The challenges that need to be overcome

Remote atolls bring challenges for renewables including: not being connected to a larger grid for 'overflow' or backup; having only intermittent renewable energy resources (solar and wind); lack of space; limited transport; and lack of access to technicians, hardware, and education and training facilities. In this context, the RMI's climate change targets are very ambitious.

The production and use of electricity on small, remote islands brings particular challenges and much of the conventional wisdom for developing renewable energy systems on a mainland does not apply. There are inefficiencies inherent in smaller, high-renewables island systems. While extra capacity is needed to meet peak demand, it also means that at times when a lot of our power is produced from renewable sources (known as 'high renewables penetration') there is nowhere for any excess energy to 'overflow' or be exported to. Other challenges include the vast area over which our population is scattered, limited transport, and the lack of access to technicians, hardware, and education and training facilities.

It is technically and economically challenging to take island grids of this size to high levels of variable renewables.

Assuming progress is made converting outer island mini-grids to renewables, to meet our targets, Majuro and Ebeye should each reduce diesel consumption from 2010 levels by at least 48 percent by 2025, 64 percent by 2030, and 100 percent by 2050 [1].

These goals for the major grids of Majuro and Ebeye are clearly highly ambitious and world leading. It is technically and economically challenging to take island grids of this size to high levels of variable renewables. The grids will move from manually dispatched aged diesel generators to automated systems that allow stable operation with little or no diesel generation, running during periods of high renewable energy resource. Other enabling technologies will include battery storage to provide operating reserve. Meeting the targets by 2025 means this dramatic shift needs to happen in fewer than seven years. On Majuro, in particular, there is very little space readily available for the footprint required by large renewable projects.

The Marshall Islands have wind and solar resources providing variable renewable energy, but lack dispatchable renewables that can generate on demand, such as hydroelectric power. Integrating high levels of fluctuating energy sources while maintaining grid stability and security of supply will involve high levels of innovation and challenge.

These islands of Majuro and Ebeye are the country's centers of government and commerce and therefore require high reliability of service. Existing generation plants and networks are dilapidated and suffer from frequent outages, so as much attention needs to be given to the systems' security and reliability as to the addition of renewable energy.

How we approached technology pathways for Majuro and Ebeye

A typical island journey toward renewables

Diesel generators provide island systems both with energy when it is required, and with grid stability services. Solar and wind energy don't do this and therefore must be complemented by enabling technologies. Island power systems can go through several distinct stages in the transition from diesel to 100 percent renewables.

This section outlines the general approach for introducing renewable energy generation into a typical island power system. It describes at what stages renewable energy and enabling technologies are introduced, and the limits and opportunities for how much of the electricity supply will be provided by renewable energy at any one time (that is, its level of penetration). This provides a framework to address the question of which technologies need to be implemented at each stage, and why. Based on this general outline, specific pathways for the RMI have been developed.

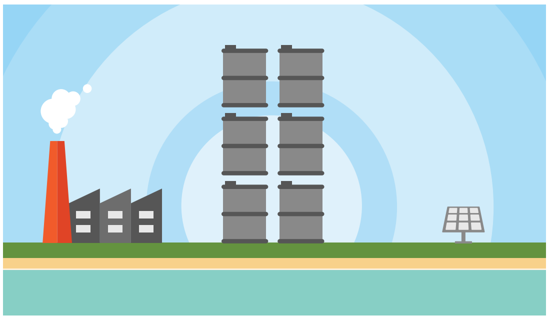
Diesel generators are a reliable and well-understood technology that can provide energy when it is needed, as well as all the other services required for a stable and reliable grid, such as voltage and frequency control and spinning reserve. This means that the island customers connected to diesel-powered grids can receive a level of service comparable to that which customers in large interconnected systems enjoy.

On the other hand, variable renewable energy generators, such as wind turbines and solar panels, generate electricity only during favorable conditions and do not have the same capability to provide highly reliable service or support grid stability. For this reason, complementary 'enabling technologies' need to be introduced alongside wind and solar to match both the availability of energy and the grid stability service traditionally provided by diesel generators.

As the contribution from variable renewable energy sources increases, the contribution from the diesel generator decreases, and so more enabling technologies are required. The transition to renewable energy power systems from typical island diesel power systems can be broken down into the five distinct stages described in Figure 5.

However, to achieve RMI's ambitious GHG targets for 2025, the grids of Majuro and Ebeye will need to move very rapidly from stage 1, where they are now, directly to stage 4. The most efficient and cost-effective pathway for the outer island mini-grids is to transition immediately to stage 4 or 5.

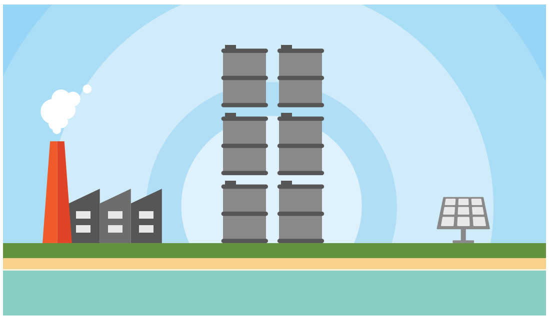
... complementary 'enabling technologies' need to be introduced alongside wind and solar to match both the availability of energy and the grid stability service traditionally provided by diesel generators.



Stage 1

RE CONTRIBUTION 0% TO 10%

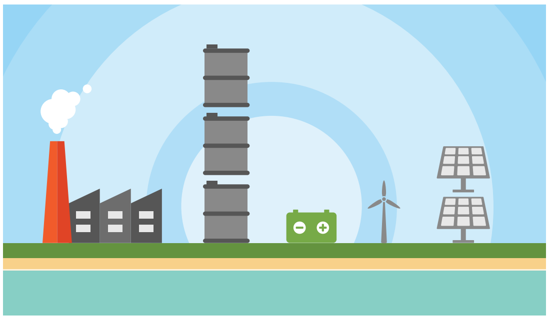
Stage 1 is where all island power systems initially based on diesel generation start their renewable energy journey. The amount of renewables has no noticeable impact on the grid.



Stage 2

RE CONTRIBUTION UP TO 30%

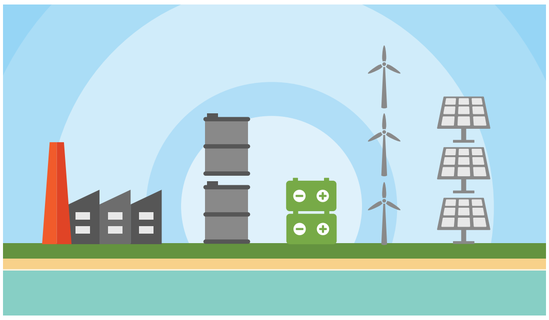
In Stage 2, renewable energy is introduced in significant amounts and noticed by diesel generators as reduction of island power system load. The must always be enough running diesel capacity to cover full load, therefore the amount of renewables is limited by the diesel minimum load. Any sudden changes in renewable generation may result in grid instability.



Stage 3

RE CONTRIBUTION UP TO 50%

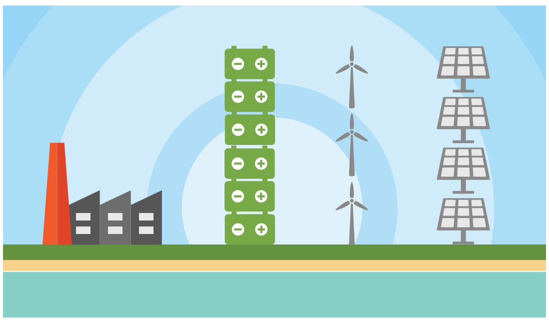
In Stage 3 enabling technologies are introduced to solve the problem introduced in Stage 2: when there is not enough running diesel generation to cover the current island load. Additional enabling technologies such as batteries support renewable generation by providing power system stability and reliability.



Stage 4

RE CONTRIBUTION UP TO 70%

In Stage 4, during the periods of sufficient renewable energy, a system can completely switch off the diesel generation fleet, with newly installed enabling technologies providing stability services. Renewable energy generation is increased further with additional solar and wind. Additional enabling technologies such as larger dump loads, sophisticated control systems and synchronous condensers are added.



Stage 5

RE CONTRIBUTION UP TO 100%

In the final stage of the journey, sufficient energy is generated from renewable energy sources, stored for low RE periods, and sufficient enabling technologies exist for stable and reliable power operation without diesel generation. Diesel generators might still be present in an island system but are mostly used in stand-by or emergency situations.

Figure 5: Stages of a typical island journey from diesel to 100% renewable energy [2]

Design philosophy

For Majuro and Ebeye, the Roadmap adopts a design philosophy of simplicity, efficiency, and scalability, to give us the best chance of meeting the technical challenge of integrating high levels of variable renewables. In practice this means deploying utility-scale, centralized generation, using proven technologies.

As described, for the main grids of Majuro and Ebeye, the rapid achievement of high levels of renewable energy while maintaining adequate service levels will be technically challenging.

In considering this, the Roadmap adopts a design philosophy of simplicity, efficiency, and scalability to give us the best chance of achieving the very challenging targets. In practice this means reducing technical and operational complexity, reducing cost, and implementing at scale through:

- Centrally planned and controlled utility-scale generation – plants greater than 100 kW.
- Using fully commercial, proven, and off-the shelf generation technologies – the application and integration of those technologies will be challenging enough.
- Simplifying, streamlining, and reducing transaction costs of policies, implementation, and financing arrangements.

Methodology

Using the RMI's NDC targets as the frame, the technical team identified technologies suitable for use in the Marshall Islands, devised possible scenarios based on experience, and modelled pathways with HOMER software using data on solar and wind resources, electricity demand, and equipment prices.

Cost-effective and technically sound technology pathways for Majuro and Ebeye were determined using techno-economic analysis. The approach is detailed in [2] and [3]. The steps taken were to:

1. Determine the service levels required for Majuro and Ebeye.
2. Define targets for Majuro and Ebeye to reduce diesel fuel use by 2025 and 2030, based on the NDC.
3. Determine which technologies are suitable for RMI island power systems by reviewing a range of technologies against criteria, including availability of energy resources. Only proven, well-understood, cost-effective, and commercially available technologies were selected.
4. Devise possible scenarios for Majuro and Ebeye to move towards 100 percent renewables using those technologies. Develop two major scenarios—systems with wind generation and systems without—into pathways.
5. Define assumptions and inputs. Any attempt to look into the future requires assumptions to be made. Key assumptions included the cost of technologies now and in the future, and forecast daily load profiles.
6. Use the HOMER energy modelling tool to identify the mix of electricity generation technologies that would cost-effectively meet the targets for reducing GHG emissions for each scenario. The pathways described in this Roadmap were selected as those with the lowest capital expenditure (CAPEX) and, for the most part, these pathways also yielded the lowest levelized cost of electricity (LCOE).

A wide range of scenarios was initially explored, and then refined and developed to the pathways presented below. While these pathways capture the technical team's thinking at the end of the project, they should not be considered 'final'. The assumptions, scenarios, and context of the Roadmap are necessarily high-level, and will shift with time. Feasibility studies and detailed design work are required to determine specific investment plans for each stage of the transition, and the most suitable and cost-effective mix of technologies may change over time.

In identifying the costs for upgrading the network, the analysis has relied on previous work in the National Infrastructure Investment Plan [4] and KAJUR Master Plan [5].

What technologies are suitable for the Marshall Islands?

A range of technologies were reviewed for their suitability for use in the Marshall Islands. The technologies that will be used for the first stages of the journey to 2030 are wind turbines and solar PV for generation, together with high-speed diesel generators, batteries, advanced control systems, and other enabling technologies. Biodiesel is likely to be useful at later stages of the journey.

Many energy technologies have been proposed for the RMI over the years. None of these are a silver bullet – all have their benefits and trade-offs, and some are far more suitable than others. A range of technologies have been systematically reviewed to identify those most suitable for the RMI in the short to medium term. As investment in renewables continues to increase, the technology landscape is expected to change over time – emerging technologies will mature, prices will come down, and new technologies will appear. There are therefore some technologies that, while not suitable now, may come to maturity over time, at which point they could be revisited. A summary of the suitability of different technologies can be seen in Figure 6. For further information see [6].

Many energy technologies have been proposed for the RMI over the years. None of these are a silver bullet – all have their benefits and trade-offs, and some are far more suitable than others.

How were technologies assessed?

Technologies were assessed for suitability using several criteria:

- **Maturity of the technology:** technology is proven and commercially available.
- **Cost:** technology is cost-effective when compared to other energy technologies.
- **Resource availability in the RMI:** preference is for indigenous energy resources where possible to improve energy security and resilience.
- **GHG emissions:** the technology assists the RMI to meet GHG emission reduction targets (note that life-cycle emissions including manufacture and shipping are not considered).
- **Grid stability/power system impact:** whether the technology supports grid stability and the achievement of service levels.
- **Local capacity for operation and maintenance:** the technology is generally suited to local operation and maintenance capability.

What technologies are most suitable for RMI?

The technologies recommended for the RMI in the first large steps of the energy transition, from now to 2030, include: wind turbines and solar photovoltaics (PV) for generation; battery energy storage systems (BESS); advanced control systems; and other enabling technologies, such as synchronous condensers and dump loads. Controllable loads and thermal storage, in the form of ice banks for cooling buildings or hot water, could also be used.

Waste-to-energy is a technology that requires further consideration and a feasibility study to determine whether it can be applied in the short term. Biodiesel generation is considered a key technology for cost-effective achievement of the 2050 target in Horizon 4.

Wind turbines

Wind generation looks promising for both Majuro and Ebeye. Detailed wind monitoring is needed to confirm the wind resource for Majuro, along with a full feasibility and design study for both grids.

Wind turbines are a well-proven technology. Wind data from Kwajelein and Jaluit, along with the Roadmap techno-economic modelling, indicate that wind generation is an attractive technology for the RMI. Utility-scale turbines are expected to be most suitable for Majuro and Ebeye (500 kW or larger), in line with the design philosophy and because of the space available. Wind turbines have a small area footprint and could be installed in RMI onshore (on the atolls of Majuro and Ebeye), or on the reef flats, where adequate foundations could likely be manufactured to support wind turbines. Offshore wind turbines could possibly be installed in the lagoon, although they are currently more expensive than onshore turbines.

Wind turbines need regular minor maintenance, occasional major maintenance, and constant operational oversight. While major maintenance is best performed by a manufacturer or authorized servicing crews under a service contract, minor maintenance and operations will fall onto local workforce who will need to be trained.

Detailed wind monitoring is needed to confirm the wind resource on Majuro, and a full feasibility and design study will consider all siting, construction and maintenance issues. For more information on wind see [7].

Solar photovoltaics (PV)

Solar PV is low maintenance and cheap at lower levels of renewable contribution. It works well together with wind, but if wind can't be used, solar PV takes up a lot of space and gets expensive at high levels of renewables due to the requirement for large batteries.

Solar PV technology is a very well established and widely used technology with which we already have considerable experience. The RMI's solar resource is good at around 5 kilowatt-hours per square meter per day (kWh/m^2/day) [3]. In the last few years, a megawatt of solar PV systems has been installed in Majuro and more than half a megawatt will soon be installed in Ebeye. Thousands of stand-alone solar PV systems have been installed on outer islands. Compared to other generation technologies, solar PV systems require little maintenance, and are usually automatically operated in an island system.

The drawback of solar PV technology for the RMI is that it requires a lot of space – 1 megawatt of solar requires around 2.5 acres (1 hectare) of area. Land and suitable rooftop structures are scarce in RMI, especially on the urban center of Majuro, so alternative solutions such as floating lagoon solar may need to be further explored.

Solar and wind can work well together. Solar is available only during the daytime, whereas wind can blow day and night, but tends to be seasonal. If wind is not included in the energy mix, then solar requires a much larger battery to store the energy generated during the day for evening and night-time use. At high renewables contribution, the battery storage required will significantly increase the cost of solar generated power. Complementing solar generation with wind generation reduces the need for storage.

Standalone solar home systems are currently the primary source of electricity on most of our outer islands and are very suitable for remote households with modest electricity needs. Solar home systems may also be used on Majuro and Ebeye, although they are not allowed to feed into the grid, at least in the short term, due to the technical and operational complexity and additional cost involved.

Biodiesel

Biodiesel has potential as a 'last mile' fuel in later stages of the RMI's renewable journey. While there are issues with cost and environmental impacts, the use of biodiesel significantly changes the economics by eliminating the need for 'oversizing' renewable energy generation and storage to achieve the last few percent of diesel replacement.

Biodiesel fuels can be used in standard diesel generators, and, as such, provide both renewable energy generation and good power system stability. The downsides to biodiesel are the cost, which is currently around two times higher than diesel, and the environmental impacts and GHG emissions during production and transport. If using biodiesel, we need to be aware of the reputational implications (as climate leadership is the reason we are attempting to reduce emissions to zero). Further, if imported, it is not an indigenous resource and the RMI will be subject to the same vulnerability to world prices and supply.

The Roadmap indicates that, if these downsides are managed, biodiesel can be part of a 'least cost' mix of renewables on Majuro and Ebeye, along with wind and solar. At very high levels of renewable energy contribution – above say, 75 percent on the main grids of Majuro and Ebeye – the use of biodiesel significantly changes the economics by eliminating the need for 'oversizing' renewable energy generation and storage to achieve the last few percent of diesel replacement.

Diesel generators

Diesel generators will remain a core part of the Majuro and Ebeye electricity systems throughout most, if not all, of the RMI's renewable energy journey. The right kind of diesel generators are the key to enabling renewables on Majuro and Ebeye, and they will continue to provide backup and can be used later on with biodiesel.

Diesel generators will remain a core part of the Majuro and Ebeye electricity systems throughout most, if not all, of the RMI's renewable energy journey. The important thing is to make sure they are the right kind of generator to be able to respond to rapid changes in solar and wind generation. At high levels of renewables (say, 50 to 70 percent contribution), the diesel generators will sometimes be completely off – they will operate when there is insufficient renewable energy. In the very last stages of the journey to net zero emissions, or 100 percent renewables, diesel generators can continue to provide service by using biodiesel as the fuel.

On outer island mini-grids, diesel generators will continue to provide backup energy when the wind and solar resources are low. Diesel generators are therefore both a core generation technology and a key enabling technology for increasing renewables in island grids.

Enabling technologies

With substantial variable renewable energy generation, ‘enabling technologies’ are needed to ensure the high level of service once provided by conventional diesel generation. These include batteries, automatic control systems and other grid-stabilizing technologies.

With substantial variable renewable energy generation, additional technologies are needed to ensure the continued high level of service once provided by conventional diesel generation. Because these additional technologies enable renewable energy sources to replace conventional generation, they are called ‘enabling technologies’.

To supplement renewable energy generation, and to provide necessary stability services, the technologies recommended for the RMI are batteries and inverters, advanced control systems, synchronous condensers, and dump loads.

BATTERY ENERGY STORAGE

Batteries can be used in two ways. They can provide short-term power, or operating reserve, to a power system. And they can store energy, to provide energy during longer periods of low wind and low sunshine. Batteries are used in conjunction with power inverters, which connect the batteries to the power system. Battery storage systems will be an essential part of the power systems for Majuro and Ebeye and also of outer island mini-grids. There are several commercially viable battery energy storage technologies; lithium-ion batteries are the technology used in this Roadmap analysis. We currently have very little know-how for operating and maintaining grid-connected batteries and inverters, so increasing the skills of our local workforce will be essential.

AUTOMATIC CONTROL SYSTEMS

Traditionally, island power systems are supplied from a single power station of several diesel generators supplying slowly varying load. With the introduction of renewable energy generators, the number of generating sources increases, and, as renewable generation is variable, the load the diesel generators serve becomes highly variable. Automatic control systems are used to closely coordinate all generation sources across the entire power system in real time, manage distribution network power flows and, sometimes, controllable loads. In high renewable penetration power systems, they are essential to enabling renewable energy while maintaining power system stability. Automatic control systems will be an integral part of the systems on Majuro and Ebeye.

OTHER ENABLING TECHNOLOGIES

Dump loads can be one of several technologies that support grid services by providing quick access to spinning reserve during times of renewable energy surplus. Synchronous condensers are a similarly useful, well-proven technology, which can provide the benefits of a rotating mass (reactive power support, voltage regulation, necessary fault currents, and inertia) to an island power system, replacing the reduced use of the rotating mass of diesel generators. Both of these technologies are expected to be used for Majuro and Ebeye.

Automatic control systems are used to closely coordinate all generation sources across the entire power system in real time, manage distribution network power flows and, sometimes, controllable loads.

Utility-scale controllable loads and thermal storage

There are several options for utility-scale controllable loads on Majuro and Ebeye, which might be used to match grid load to times of higher renewable energy generation. This will enable more energy to be used productively instead of being 'spilled' or discarded, and reduce the load in times of low renewable generation.

Further work can be done to look at controlling desalination plants, refrigerated containers, and electric vehicle charging banks. Another area worth exploring is 'thermal energy storage', particularly the use of ice banks for cooling buildings, and hot water for industrial use.

Technologies that need further assessment

Waste-to-energy on Majuro

Waste-to-energy has been proposed for Majuro as a way to address the significant municipal solid waste problem. In the medium term, it may be possible to use this technology to incinerate general household waste, along with waste oil from diesel generators and the international fishing vessels coming through Majuro lagoon, and at the same time produce electricity.

However, the technical and economic feasibility of this is not yet established at the scale appropriate for Majuro. In 2018/19 an Asian Development Bank (ADB) project is carrying out this assessment. Further, the GHG implications of waste-to-energy plants are complex and depend on the composition of the refuse-derived fuel used in the plant. There is potential for significant emission reductions in the waste sector if a large amount of biogenic material is burned, rather than left in landfill[6]. However, the degree to which emissions in electricity are reduced depends on how much plastic and waste oil are combusted.

While some reduction of GHGs may be expected, a waste-to-energy plant does still emit GHGs and therefore does not form part of our long-term zero emissions or 100 percent renewable electricity system. It could, however, be used as a transition technology, and decommissioned before achieving a zero emissions target.

6. Biogenic waste in landfill produces methane, which is 25 times more potent a GHG than CO_2. If the biogenic waste is combusted, mainly CO_2 is produced, which reduces waste sector emissions.

What technologies are not suitable, at least in the short term?

Technologies considered unsuitable for Horizons 1 and 2 (before 2025) are listed in Table 2. These include ocean thermal energy conversion (OTEC), ocean wave, current and tidal energy, and smart grids (including vehicle-to-grid storage). These technologies are all in the early stages of their development, and our very ambitious targets will instead need to be met through well established and cost-effective technologies. Taking on experimental, early stage, or unsuitable technologies would distract from the focus needed to achieve these targets.

Some of these technologies could be reassessed closer to 2025 to see what role they might play, if any, in future stages of our energy journey.

One technology that is often promoted for the RMI is grid-tied household solar – that is, small-scale solar home systems that export surplus electricity to the grid. While this technology has been used in many places as part of an organic trend, it achieves relatively low levels of renewable contribution. Further, when these small systems are tied to the grid, it introduces additional cost and unwanted technical and administrative complexity. As discussed earlier, a more rapid, centrally planned, and controlled deployment of renewable generation is necessary to achieve our targets.

TECHNOLOGY	DESCRIPTION	ACTION TO BE TAKEN
Ocean thermal energy conversion (OTEC)	Uses temperature difference between ocean surface and deep water. Early stage technology, unproven for generating electricity.	Monitor development of technology and possibly revisit after 2025 or 2030 if commercially viable.
Wave, current, and tidal energy	Uses the energy of the ocean. Most technologies are early stage and require high levels of expertise and maintenance.	
Smart grids	Smart grids are an emerging, technically complex technology.	
Grid-tied household PV	At high levels of grid-connected renewables (above say, 30%) household PV would require smart grid technology to maintain grid stability.	
Vehicle-to-grid storage	As for household solar, this is more expensive than centralized utility-scale storage and requires a smart-grid.	

Table 2: Summary of technologies not suitable for RMI in the near term

Suitable

WIND TURBINES
Good wind resource, proven technology and least-cost generation

SOLAR PV
Good solar resource, proven technology, cost-effective generation, complementary to wind

DIESEL GENERATORS
Necessary enabling technology for renewables

BATTERIES AND INVERTERS
Key enabling technology for increasing amounts of renewable generation

BIODIESEL
Recommended for consideration as "last-mile" technology towards the net zero target after 2030

OTHER ENABLING TECHNOLOGIES
Advanced centralised control systems, dump loads, synchronous condensers

CONTROLLABLE LOADS AND THERMAL STORAGE
For example, hot water and ice

To be assessed

WASTE TO ENERGY
GHG emissions dependent on type of waste combusted

Not suitable (monitor and revisit in future)

OTEC
Early stage technology, unproven for generating electricity

WAVE, CURRENT AND TIDAL ENERGY
Early stage technology, difficult to operate and maintain

SMART GRIDS AND DISTRIBUTED STORAGE
Emerging, technically complex and more expensive than centralised storage

GRID-TIED HOUSEHOLD-SCALE PV
More expensive than utility-scale PV and too technically and operationally complex at high levels of renewables

Figure 6: Summary of suitability of different technologies for use in the Marshall Islands [6]

Majuro pathway

Where we are in 2018

Currently around 98 percent of Majuro's electricity is generated in the Marshalls Energy Company's (MEC) diesel power station. The existing supply chain begins with delivery of diesel fuel to the island's storage tanks, which is then converted in diesel generators to electric energy and distributed to end users. If any link in this chain fails, the system fails. It is important to note that this supply chain is likely to remain central to Majuro's future energy system even under a 2050 net zero emissions scenario.

The remaining 2 percent of electricity is renewable energy or waste heat recovery from:

- 140 kW waste heat to power generator in the power plant.
- 600 kW United Arab Emirates funded PV system, located near the Airport.
- 205 kW Japan International Cooperation Agency (JICA) funded PV system on the hospital roof.
- 111 kW PV system at the College of Marshall Islands (CMI) (privately owned).
- 35 kW PV system at the University of South Pacific (USP) campus.
- A few small privately-owned grid-connected PV systems (under 5 kW each).

By 2022, an additional 7–9 percent renewables will be added under the World Bank Sustainable Energy Development Project (SEDeP) project.

At present much of the infrastructure in Majuro's electricity supply chain is decrepit. The fuel tank farm is at risk of catastrophic failure – a situation being addressed by an ADB project that began in 2018. The aging Majuro diesel power station has been plagued with problems, with all generators near or beyond their useful life, frequent and long outages, and very limited reserve capacity. None of the existing diesel generators are able to support significantly larger penetration of renewable energy into the Majuro power system [8] [9] [10].

Electricity is distributed to customers from the power station and larger solar sites via the existing power network, which on Majuro is long and linear, travelling a distance of around 30 miles. Most of the existing network facilities are at least 30 years old and are not designed to support large-scale distributed generation. Losses on the distribution grid are estimated at around 15 percent of electricity generated, [8] possibly comprising around 7–8 percent technical losses and 7–8 percent unmetered electricity use.[7] At present, several sections of the network need repairs and/or upgrades. Depending on the scale and location of the future renewable generation, some distribution grid sections will need major redesigns and upgrades. Although upgrades can happen over time, it is a significant investment.

Grid-connected loads have decreased since 2010, mostly attributed to tariff increases and the introduction of pre-paid meters. Typical daytime loads are around 6–7 MW. Total annual generation on Majuro in 2016 was 54 gigawatt hours (GWh).

There is also some private off-grid generation, notably the Pan Pacific Foods (PPF) fish processing plant, which is powered by diesel generation. In 2016, PPF diesel consumption for electricity generation was 8 percent of that for the Majuro grid.

At present much of the infrastructure in Majuro's electricity supply chain is decrepit.

Reliability measures for Majuro over recent years show a typical SAIDI[8] of several thousand minutes per year. With outages worsening in 2018, it is possible that more businesses and households may be installing private diesel generators to provide back-up.

7. Data on this is somewhat unreliable. These numbers have been calculated on the basis of power sold to power generated, and large uncertainties arise from both the Cashpower meter system and bills not paid. This estimate is taken by averaging several years of data.

8. System Average Interruption Duration Index (SAIDI) is the average duration of outages experienced by any customer in a year.

Forecast changes to grid-connected electricity demand for Majuro

In the near term, we expect grid-connected loads to increase, with the addition of 1–2 MW of refrigerated containers for port activities, and the possibility of the PPF fish processing plant connecting to the grid (thought to be around 0.5 MW average demand). Achieving reductions in transport emissions will include electrification of vehicles and boats – bringing additional demand in the medium term. This provides us with a 'business-as-usual' forecast for electricity demand, before energy efficiency and conservation improvements as seen in Figure 7.

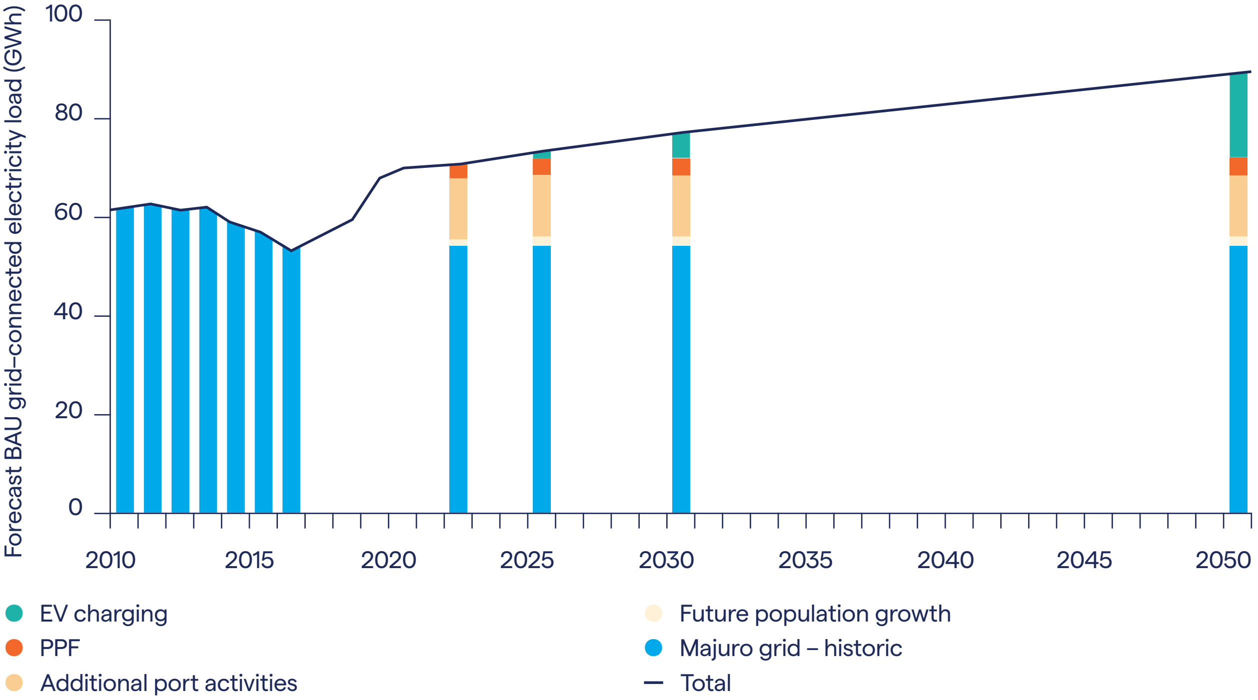


Figure 7: Electricity demand forecast – Majuro (before proposed loss reduction, energy efficiency, and conservation measures, or load offset from private generation) [3]

REDUCING LOAD BY REDUCING LOSSES AND IMPROVING ENERGY EFFICIENCY

Supply side

Powerhouse auxiliary loads on Majuro are currently around 450 kW, or 7 percent of electricity generated, and it is expected we can reduce these to 2–3 percent with new generators and new powerhouse equipment [8]. The current generators are derated and therefore have poor fuel efficiency, so some improvement in fuel efficiency is expected when new diesel generators are commissioned. However, this is not quantified.

There are around 15 percent losses on the Majuro distribution grid. Around half is thought to be unbilled electricity use, and the other half technical losses. An advanced metering project being implemented in 2018/19 by the ADB will help understand where those losses can be reduced. It is expected the technical losses could be reduced to about 5 percent.

In total, there is the potential to reduce supply side losses by around 7–8 percent of electricity generated, with new generators and powerhouse, and upgrading of the grid where losses are identified.

Demand side

On the demand side, for both Majuro and Ebeye we have set a nominal target of reducing electricity demand by 10 percent by 2025, compared to business-as-usual, and 20 percent by 2030. Opportunities to improve energy efficiency and demand side management are detailed in Chapter 05: Energy efficiency and demand side management for Majuro and Ebeye. Further reductions in load may come from some private solar installations. If these targets are achieved, demand in 2025 is forecast to be similar to current demand.

Majuro renewables pathway

This Roadmap focuses on the stage to 2025 and the achievement of the RMI's current NDC, with a view to the 2030 and 2050 targets. In the relatively short time frame to 2025, Majuro's grid will go from being almost entirely dependent on diesel generation, to over 50 percent renewables. There is an additional objective for the system to be capable of diesel-off mode by 2025. This is a significant technical threshold that makes subsequent steps more straightforward. Subsequent stages to 2030 and 2050 will focus on adding additional generation capacity and taking advantage of maturing technologies, but the most dramatic change in Majuro's system will occur between now and 2025. The technologies and costs for these pathways are illustrated in Figure 8.

HORIZON 1 TO 2022

In this period, the addition of refrigeration containers and a fish processing plant is expected to increase Majuro's load by up to 2 MW.

The pathway for Majuro in Horizon 1 focuses on implementing existing and planned projects, replacing diesel generators and associated equipment, and carrying out the studies needed to lay the foundation for Horizon 2 to 2025.

Projects include an ADB-funded project to refurbish the tank farm, and a World Bank SEDeP project that will add 3–4 MW of solar PV to the grid (bringing the total to more than 4.1 MW) and replace some diesel generators. Investment in network and general assets, and replacement of all remaining diesel generators with new renewable-ready machines is also required in this phase. Other ADB projects will carry out a feasibility study on waste-to-energy, and identify opportunities to reduce network losses. Wind monitoring and wind feasibility design studies for Majuro, and deployment of a pilot floating solar installation in Majuro lagoon are required before the next steps can be undertaken in Horizon 2.

In the relatively short time frame to 2025, Majuro's grid will go from being almost entirely dependent on diesel generation, to over 50 percent renewables. There is an additional objective for the system to be capable of diesel-off mode by 2025.

A scheme to provide loans to householders for energy efficient appliances and solar home systems, funded with a loan from Taiwan is also being deployed. If fully subscribed, the amount of solar PV may contribute around 1-3 percent of total electricity for Majuro, and will reduce load on the grid.

HORIZON 2 ONWARDS

For Horizon 2 onwards, two viable pathway options exist for Majuro.

Pathway 1: wind, solar, biodiesel, and batteries

A pathway using wind, solar, biodiesel, and batteries offers us the least-cost pathway for Majuro, assuming that wind is feasible. It leaves flexibility in the system for different types of renewables to be added in the future.

The high-level techno-economic analysis suggests an optimal mix of wind, solar, and batteries, and provides a further option to use biodiesel as a 'last-mile' technology to achieve some portion of the last 30 percent or so of emission reductions. The steps in this pathway are:

HORIZON 2 TO 2025

In Horizon 2, around 12 MW of wind turbines and 20 MWh[9] of lithium-ion batteries are added to Majuro's system, along with sophisticated control systems, synchronous condensers, dump loads, and other enabling technologies to maintain system stability in diesel-off mode. Further investments in network and general assets are made. The total capital cost in this period is around $70 million.

HORIZON 3 TO 2030

In Horizon 3 to 2030, around 13 MW of PV is added, along with additional network upgrades, at a cost of around $38 million. No additional batteries are required at this stage because the battery previously installed facilitates further renewable energy penetration.

HORIZON 4 TO 2050

The pathway for Horizon 4 is highly speculative. Biodiesel is potentially introduced as a cost-effective 'last mile' solution to remove the need to oversize variable renewables and storage. It requires no additional capital (as it uses standard diesel generators), but the operating cost will depend on the future price of biodiesel. Prices of existing renewable technologies may have come down or newer technologies may become commercially available. Analysis should be done after 2030 to select an optimized, least-cost mix of wind, solar, batteries, and biodiesel, or other new technologies.

If biodiesel is not used, the mix will likely require at least 73 MW PV, 42 MW wind, and 300 MWh battery storage to provide the expected service levels. The capital cost required might be around $350 million (in 2018 dollars, at expected 2050 prices) in addition to previous expenditure. However, this does not account for the fact that new technology, such as large capacity flow batteries, may be available at low cost by then.

Pathway 2: solar and batteries

The techno-economic modelling for Pathway 2 looked only at solar PV for generation. The significant difficulties with this pathway are the very large amount of space required for solar PV and batteries, and the very high cost of capital, and therefore of electricity.

Pathway 2 will only receive further consideration if wind feasibility studies show that wind turbines are not suitable for Majuro.

9. This assumes the BESS have a maximum discharge rate of 0.5C (ie, 10 MW) to meet peak loads during diesel-off generation. BESS with a different discharge capability will require a different storage capacity to provide this power capacity.

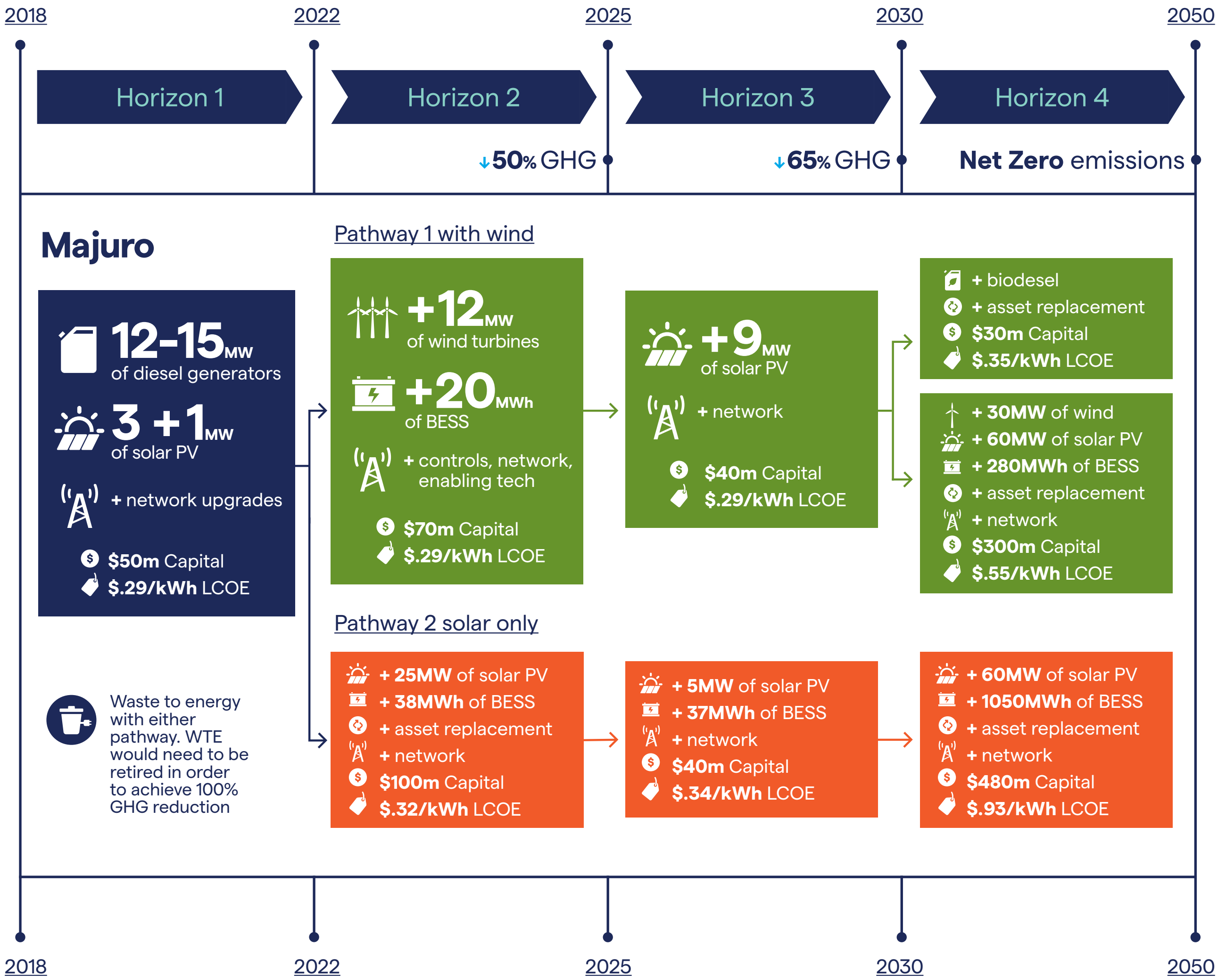


Figure 8: Majuro renewable energy pathways to 2025, 2030 targets and to net zero emissions by 2050 [2]

Ebeye pathway

Where we are in 2018

Currently all of Ebeye's electricity is generated in the Kwajalein Atoll Joint Utilities Resource Inc. (KAJUR) diesel power station. Some businesses – supermarkets and hotels – have their own backup generation. The existing supply chain begins with delivery of diesel fuel to the island's storage tanks, which is then converted in diesel generators to electric energy and distributed to end users. As for Majuro, the Ebeye supply chain is likely to remain fundamental to the future energy system even under a 2050 net zero emissions scenario.

The power station usually runs three generators, which are able to serve the load but with no redundancy. Load-shedding occurs every few days for oil and filter changes. Breakdown of one generator during late 2018 left Ebeye with rolling outages. Two other generators are going to be rebuilt in 2019, with an aim of giving Ebeye N-2 redundancy[10].

From the power station, electricity is distributed to customers via the existing power network, which is quite compact given the small size and density of Ebeye island. The network was significantly upgraded in 2004/05. Due to difficulties with metering data, total distribution losses are unknown but technical losses are assumed to be relatively low. The World Bank SEDeP project includes a loss study on Ebeye.

While information is somewhat unreliable, it does show that loads have fluctuated since 2010, with constant increases since 2014. Typical daytime loads are now around 1.7–2.1 MW. Total annual generation on Ebeye in 2016 was 16.9 GWh. The amount of energy supplied by backup private generation is not known.

Forecast changes to grid-connected electricity demand

Future electricity demand growth is assumed to be minor for Ebeye, as seen in Figure 9.

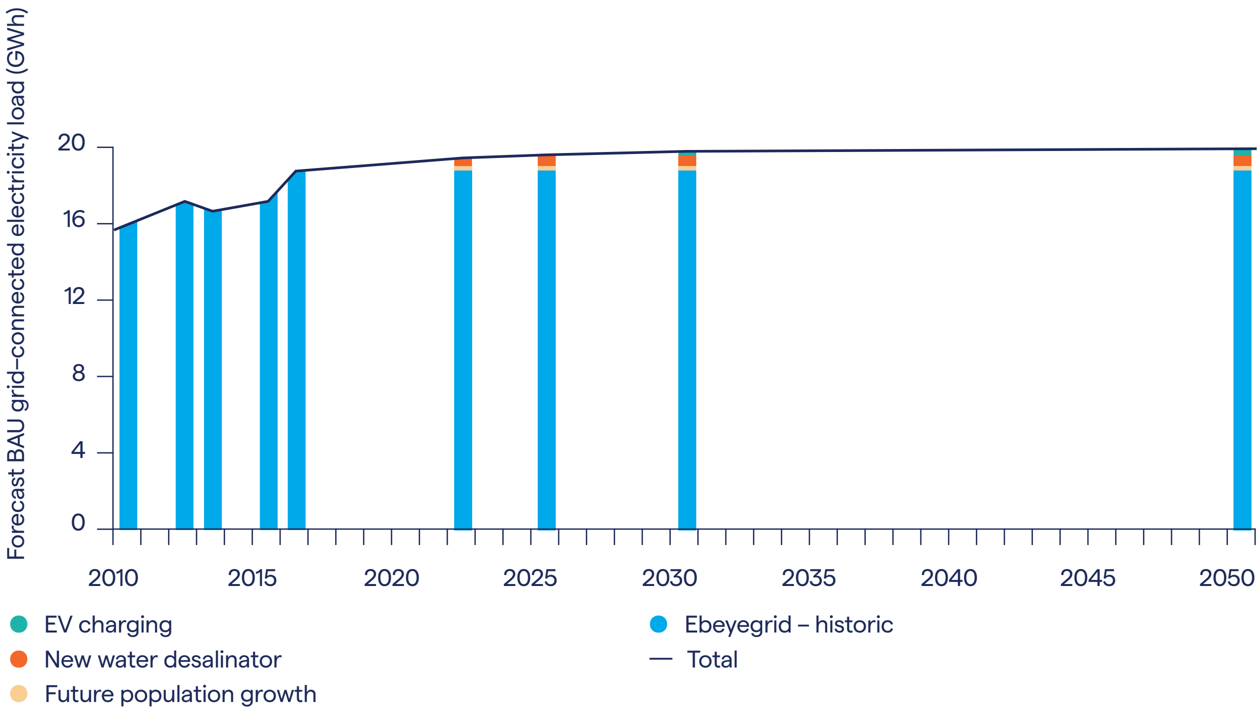


Figure 9: Electricity demand forecast – Ebeye (before loss reduction, energy efficiency, and conservation measures). Years 2010–2016 are based on fuel purchases not kWh metering [3]

10. N-2 redundancy means that there are 2 more generators than required to meet load. This enables scheduled maintenance to take place while ensuring the generators can still provide the full load, even with unplanned breakdown of another generator.

REDUCING LOAD BY REDUCING LOSSES AND IMPROVING ENERGY EFFICIENCY

As for Majuro, using the business as usual load forecast for Ebeye as a baseline, we estimate some reductions in load based on reducing losses and improving efficiency and energy conservation on both the supply side and the demand side.

Supply side: It is not clear what savings there may be in the Ebeye power station, but technical losses on the distribution grid are expected to be relatively minor due to the compact size of the grid and its comprehensive upgrade in 2004/05. The World Bank is doing a study on Ebeye in 2019 that will provide a clearer picture of the opportunities to reduce grid losses.

Demand side: On the demand side, we have set a nominal target of reducing electricity demand by 10 percent by 2025, compared to business-as-usual, and 20 percent by 2030. Opportunities to improve energy efficiency and demand side management are detailed in Chapter 05: Energy efficiency and demand side management for Majuro and Ebeye. Opportunities on the demand side for Ebeye center on the hospital cooling, residential air conditioning, and improving the poor building stock.

Ebeye renewables pathway

In a relatively short time frame to 2025, Ebeye's grid will go from being entirely dependent on diesel generation, to over 50 percent renewables. There is an additional target for the system to be capable of diesel-off mode by 2025, which is a significant technical threshold that will make subsequent steps more straightforward. Subsequent stages, to 2030 and 2050, will focus on adding additional generation capacity and taking advantage of maturing technologies, but the most dramatic change in Ebeye's system will need to occur between now and 2025. The technologies and costs for these pathways are illustrated in Figure 10.

HORIZON 1 TO 2022

The Ebeye pathway in Horizon 1 focuses on implementing existing and planned projects and the studies needed to lay the foundation for Horizon 2 to 2025.

Projects include 600 kW of solar PV and associated batteries (funded by JICA), investment in network and general assets, and two new replacement diesel generators that will be installed before 2022. The design of the Ebeye system, including wind and enabling technologies, will be carried out in preparation for deployment in Horizon II.

HORIZON 2 TO 2025

In Horizon 2, around 3 MW of wind turbines and 6 MWh[11] of lithium-ion batteries is added to the system. In addition, sophisticated control systems, synchronous condensers, dump loads, and other enabling technologies are installed to maintain system stability in diesel-off mode. These investments, along with further network and general assets have a total cost of around $14 million.

11. This assumes the BESS have a maximum discharge rate of 0.5C, i.e. 3MW to meet peak loads during diesel-off generation. BESS with a different discharge capability will require a different storage capacity to provide this power capacity.

HORIZON 3 TO 2030

In Horizon 3 to 2030, around 2 MW of PV is added along with additional network upgrades at a cost of around $6 million. No additional batteries are required as the battery installed previously facilitates further renewable energy penetration.

HORIZON 4 TO 2050

The pathway from 2030 to 2050 is highly speculative, and suggests biodiesel as the most cost-effective solution from the technologies that exist today. As for Majuro, analysis should be done after 2030 to select an optimized, least-cost mix of wind, solar, batteries, and biodiesel, or other new technologies.

If biodiesel is not used, the mix will likely require an additional 5 MW PV, 4.5 MW wind, and 150 MWh battery storage to provide the expected service levels. The capital cost required might be around $80M (at expected 2050 prices), in addition to previous expenditure. As for Majuro, this does not account for the fact that new technology, such as large capacity flow batteries, may be available at low cost by then.

In Horizon 2, around 3 MW of wind turbines and 6 MWh[11] of lithium-ion batteries is added to the system. In addition, sophisticated control systems, synchronous condensers, dump loads, and other enabling technologies are installed to maintain system stability in diesel-off mode.

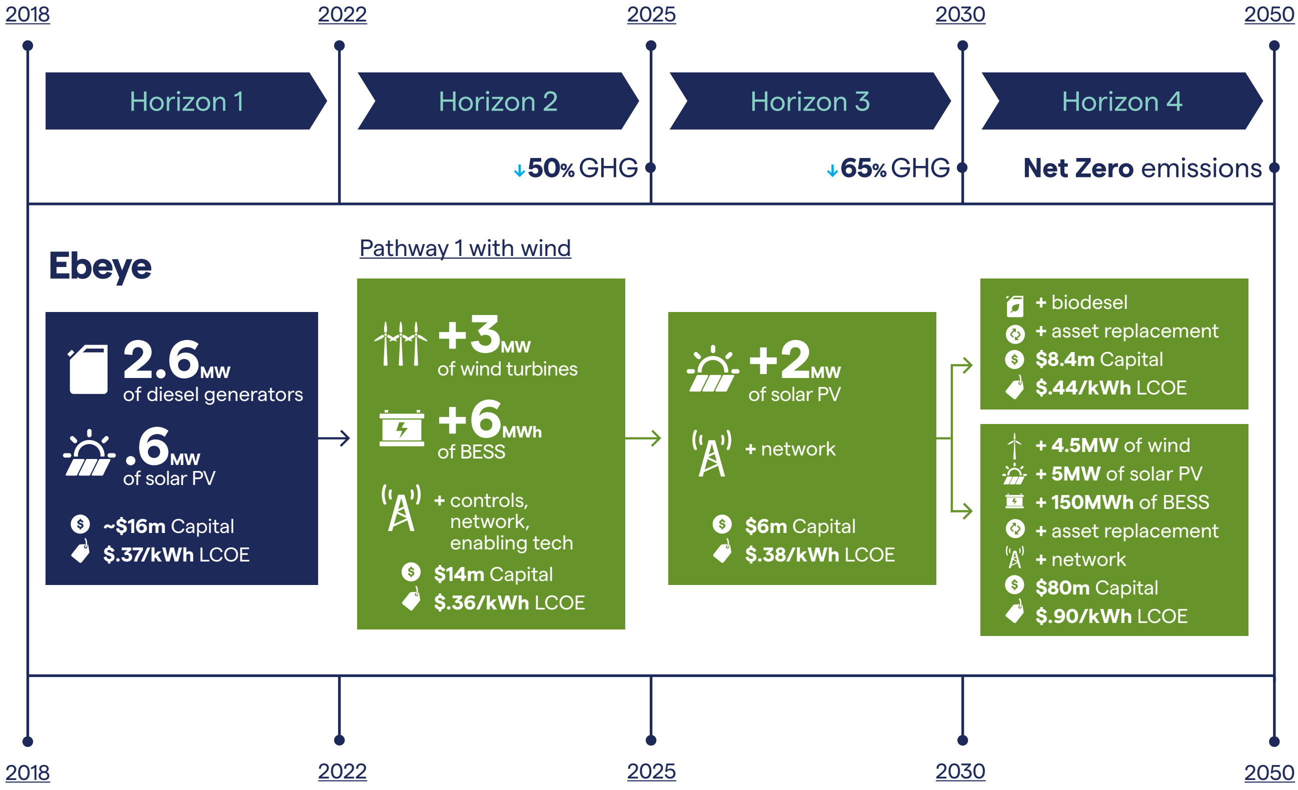


Figure 10: Ebeye renewable energy pathways to 2025, 2030 targets and to net zero emissions by 2050 [2]

05.

Energy efficiency and demand side management for Majuro and Ebeye

Where we are now: energy use on Majuro and Ebeye

The largest uses of energy on Majuro and Ebeye are air-conditioning and refrigeration, followed by lighting. We have significant opportunities to improve energy efficiency through: large capital-intensive projects; by improving the efficiency of smaller appliances; and by changing individuals' behavior.

Although it probably won't be possible to measure, the Roadmap sets nominal targets to reduce energy use on Majuro and Ebeye by around 10 percent in 2025, and 20 percent in 2030, over business-as-usual.

In the near term, that will contribute to a reduction in diesel use, and, in the longer term, it will reduce the need for investment in renewable generation. As discussed previously, investment in energy efficiency is generally going to be cheaper than investment in renewables. This chapter discusses the key opportunities for energy savings and proposed measures.

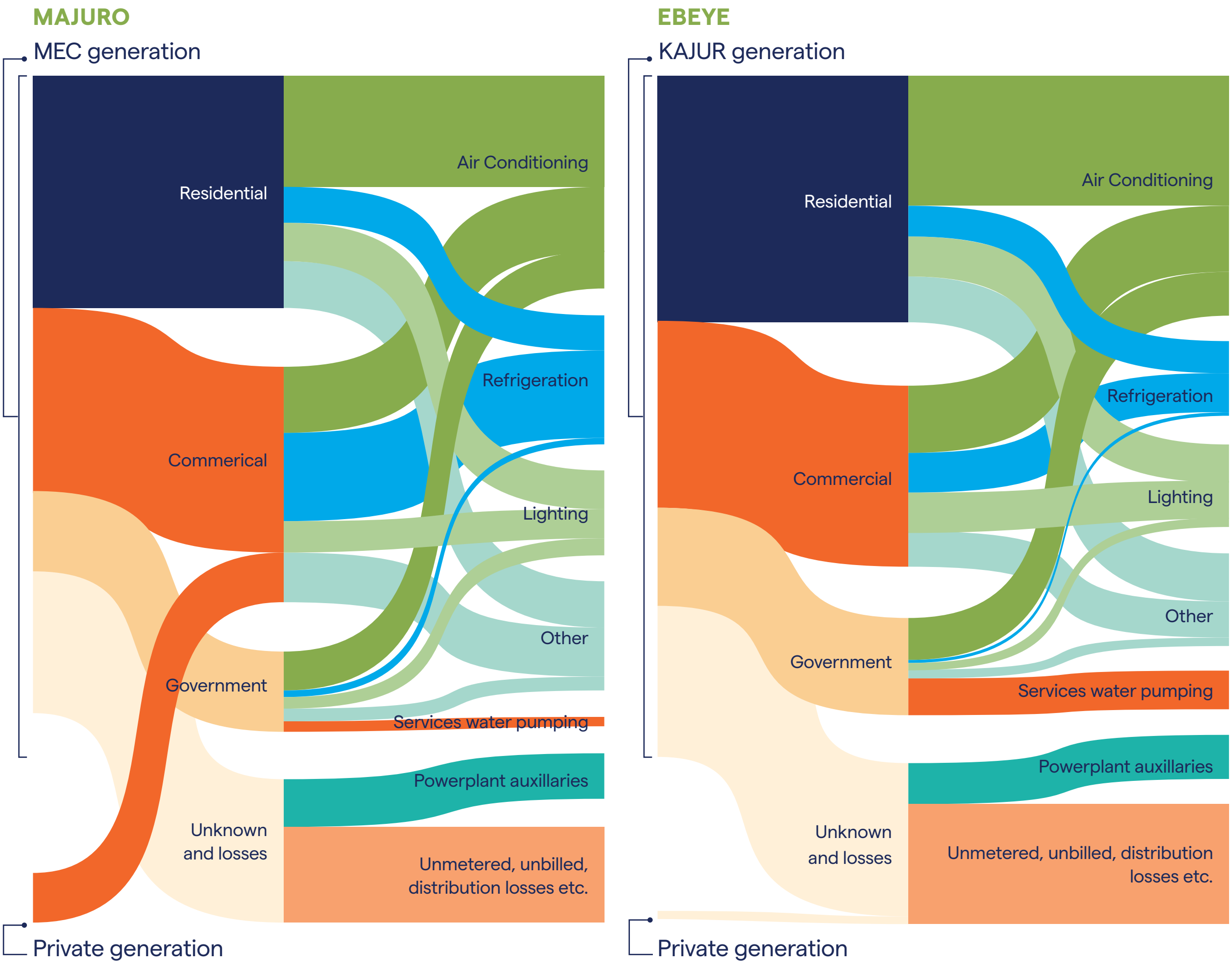


Figure 11: Flows of electrical energy in the Majuro (L) and Ebeye (R) electricity systems from powerhouse, to customers, to end uses [11]

Figure 11 indicates the amounts of electricity used in Majuro and Ebeye by different sectors and different end uses. Relative amounts of electricity in GWh are represented by vertical proportion. From the left hand side we can see the amount of electricity generated both on and off-grid. Majuro is based on 56 GWh generated annually, and Ebeye on 16 GWh generated annually. As we follow the flows toward the right, we can see how much electricity each customer group uses, based on billing. The right hand side then shows an estimate of the end uses that electricity. The estimation is explained in [11]. Although there are considerable uncertainties, looking at the relative size of energy use and customer can help us focus our energy efficiency and conservation efforts.

> After 2025, when Majuro will have a high level of renewables (as described below), well designed heating, ventilation and air-conditioning (HVAC) systems can contribute to even less diesel use by employing ice banks, enabling the matching of load to times of high renewables.

AIR-CONDITIONING

The largest use of energy overall is for air-conditioning. How much energy is used depends on: how efficient the technology is; servicing and maintenance of equipment; sizing of the system for the space; temperature set points; and how well insulated and draft-proof the building envelope is. For example, an Energy Star[12] labelled inverter type air conditioner can be up to 30 percent more efficient than those not labelled, and changing the setpoint up by six degrees Fahrenheit (F) can save 30 percent of energy. Addressing issues with the building stock and leakage may be a longer-term problem.

Some specific opportunities have also been identified. For example, the hospital, the Nitijela and the International Conference Center (ICC) complex together use around six percent of energy generated on Majuro, and most of this is for air-conditioning. These are large building complexes suited to custom designed, high-efficiency ventilating and air-conditioning systems. At present, many of these buildings are equipped with split inverter air conditioners designed for much smaller spaces, which makes them much more expensive over the life of the buildings. After 2025, when Majuro will have a high level of renewables, well designed heating, ventilation and air-conditioning (HVAC) systems can contribute to even less diesel use by employing ice banks, enabling the matching of load to times of high renewables.

REFRIGERATION

Refrigeration is the second largest use of energy and may be expected to increase on Majuro with the addition of large numbers of refrigerated containers for the export of fish. The energy efficiency of large commercial and industrial refrigeration systems depends on the design, operation, and maintenance of the systems, as well as on leaks and insulation in refrigerated areas. With high contribution of renewables, refrigeration systems could also use ice banks to improve their efficiency and maximize the productivity of renewable energy. In residential systems, energy efficient labelled appliances can save energy but even more important is to ensure the seals are in good condition and condenser coils are clean.

LIGHTING

Lighting is the next largest power use. While the switch to energy-efficient lighting is well underway, it is relatively inexpensive to make the most of modern technology by banning incandescent lightbulbs and providing subsidies for people to change.

SERVICES WATER PUMPING

The World Bank has identified water and sewer pumps on Majuro as a priority energy efficiency project and has allocated funding to upgrading them as part of the SEDeP.

12. Energy Star is the US Environmental Protection Agency's efficient appliance labelling program.

Figure 12: Example of a 'leaky' building envelope and poor efficiency appliance. This window-style air-conditioning unit on Majuro has corroded cooling fins, and is mounted next to louvered window

Key measures for energy efficiency and conservation

To achieve the nominal targets of reducing energy demand by 10 percent by 2025 and 20 percent by 2030, compared to business as usual, the following measures will be applied. Some specific opportunities are summarized in Table 3.

GOVERNMENT WHOLE-OF-LIFE INVESTMENT DECISIONS

The Government will invest in appliances and HVAC based on whole-of-life costs, including electricity costs, rather than the cheapest upfront cost. This will be applied by:

- Requiring all government departments to purchase Energy Star (or similar) labelled equipment when buying new equipment.
- Requiring designs for major buildings and renovations to include a whole-of-life energy/cost study of options, and selecting designs based on whole-of-life costs and their impact on RMI's GHG targets.

GOVERNMENT LEADERSHIP

The Government will demonstrate leadership in energy efficiency and conservation behaviors. This can be applied by mandating temperature setpoints for air conditioners in government offices, and ensuring air-conditioning, lights, and computers are off when people are not in the room or building.

SUPPORT A PRIVATE SECTOR ADVISORY INDUSTRY

Government and development partner support and training assistance will help build local energy efficiency advisory services. In particular, Government or grant monies will be used to support widespread energy efficiency audits across the commercial, residential, and government sectors.

LOW-INTEREST LOANS AND SUBSIDIES FOR ENERGY EFFICIENT APPLIANCES

The Marshall Islands Development Bank (MIDB) will offer a program of loans to householders on Majuro, beginning in 2018, funded by the Taiwan International Cooperation and Development Fund (ICDF). The loans will to enable Majuro residents to buy energy efficient appliances, which are more expensive than other options. These loans will help overcome the capital constraint faced by many Marshallese, who may otherwise opt to buy a cheaper appliance, even though the electricity costs will be much greater over time.

There is a particular opportunity on Ebeye where most air conditioners are window-style and the building stock is poor. A program has been proposed, to be managed by KAJUR, where Ebeye residents can trade-in window-style air conditioners for new split inverter units, with repayments on the cost of the new appliance to be made over time through power bills.

One inexpensive program we can consider is a scheme swapping incandescent bulbs for high quality LED bulbs, at no charge. While a similar program was undertaken around a decade ago, it is timely to repeat this. Energy efficient appliances are currently exempt from RMI import duty, which also offsets their higher upfront costs.

REMOVE DISINCENTIVES TO SAVING ENERGY

In general, the almost 1000 households on Majuro that receive 1000 kWh/month of free power use more power than households that do not receive the free allocation. A principle of achieving energy efficiency will be to ensure all customers face appropriate incentives to conserve electricity.

SECTOR	ENERGY USE	SHORT-TERM MEASURES (BEFORE 2025)	LONGER-TERM MEASURES (POST-2025)
Commercial	**REFRIGERATION:** Refrigeration is a large user of energy in supermarkets, refrigerated containers, and hotels.	Energy audits of significant commercial premises. Energy efficient design when it comes time to replace. Improved maintenance, seals, gas.	Ice banks when time to replace (post-2025, when they can be used to match renewables).
Commercial	**ICE MAKING, WATER PURIFICATION:** These can be controllable loads that run during times of excess renewable energy.	–	Shift production to times of higher renewables (post-2025).
Government and commercial	**AIR-CONDITIONING:**		
Government and commercial	Large building HVAC systems.	When air conditioner to be replaced, invest in right-sized, high efficiency design systems.	Building envelope – insulation and leakage.
Government and commercial	Temperature set points (each degree F higher can save around 5% energy).	Mandate government offices temperature set point.	Ensure all large buildings have fit-for-purpose systems using ice banks.
Government and commercial	Energy Star appliances – Energy Star air-conditioning can be 30% more efficient than others.	Energy efficient technology – mandate all government agencies to buy Energy Star (or equivalent). i.e. Cost is based on whole-of-life, including energy use, not just on capital cost.	
Residential	**AIR-CONDITIONING EBEYE:** Air conditioners on Ebeye are typically inefficient window-style, in drafty and uninsulated buildings.	Swap inefficient window-style air conditioners for energy efficient inverters – Government or utility to provide upfront capital loans which can be paid back via power bills. Education on leakage of building envelope and cost.	Improve building stock and envelopes. Orient and plan new building developments to ensure flow through of breeze.
Residential	**LIGHTING:** Lighting has shifted to energy efficient lighting, but incandescent bulbs are still being sold. Banning these will provide some benefit at low cost.	Ban incandescent lightbulbs. Provide free LED or CFL lightbulbs to people when they trade-in their incandescent lightbulbs.	

Table 3: Summary of key opportunities and measures for energy efficiency

06.

Technology pathways for outer islands

Mini-grids

Several outer islands have existing diesel mini-grids. The pathway for these is the single-step addition of solar PV and batteries to form a hybrid system of up to 90 percent renewables.

Island mini-grid power systems are used on islands with communities ranging from a few families up to several hundred people living near to each other. Most of the loads are still of a basic, residential nature. The usual devices used in these small systems are lights, fans, televisions, computers, and small kitchen appliances. Some can be more sophisticated, such as occasional air conditioners, freezers or washing machines. Mini-grid power systems can also support small commercial or limited industry operations.

How we approached pathways for mini-grids

The service levels required for mini-grids are lower than for the main grids of Majuro and Ebeye. The cost of fuel is very high due to transport costs. The proposed pathway is to move directly to almost 100 percent renewables in the RMI mini-grids rather than small expensive iterative projects. This is because of the high costs and subsidization of diesel generation in these grids, our ambitious national emissions targets, and the high fixed logistic costs of outer island projects.

Where we are in 2018

Reticulated electricity distribution networks supplied by diesel generation already exist on several outer islands in the RMI, including on the main islets of Jaluit and Wotje atolls and the island of Kili. Typically, these mini-grids provide electricity for several hundred people. These grids face very high diesel transport costs and are heavily subsidized, either by the national or local governments. Together they use around 326,000 gallons of diesel per year, and produce around 5 percent of national electricity sector emissions.

Pathway

The most appropriate pathway to reducing diesel and emissions for these mini-grids will be a centralized renewable energy hybrid system integrated with the existing powerhouse (Figure 13).

The main small – or medium-sized mini-grids are Wotje Island (Wotje Atoll), Jabor Island (Jaluit Atoll), Rongrong Island (Majuro Atoll), and Kili Island. In addition, Eniburr Island (Kwajalein Atoll), also known as Santo island, does not currently have a distribution network but, with around 1000 residents currently served by private household generation, may be a candidate for a new mini-grid system. Establishment of a mini-grid system for Santo would also require the establishment of a utility-type entity to operate and maintain it.

Previous studies estimate that a high renewables system for Jaluit may cost around $2.5m, around $4m for Wotje, and $0.5m for Rongrong [11] [12]. In our Roadmap it is assumed $20 million investment will establish all mini-grids, but this will be the subject of detailed design studies. Even with increased operation and maintenance cost, and reservation of funds for capital replacement costs, these mini-grids are expected to result in modest savings over the existing systems due to the high cost of fuel on outer islands.

In order to achieve our 2025 target, the mini-grids of Jaluit, Wotje and Kili at least will need to be converted to around 90 percent renewable by 2025, at a capital cost of around $10 million. Other mini-grids should follow at some point. Once installed, they will require operation, maintenance, and replacement over time.

Current Stage

RE CONTRIBUTION ~0%

Next Stage

RE CONTRIBUTION ~90%

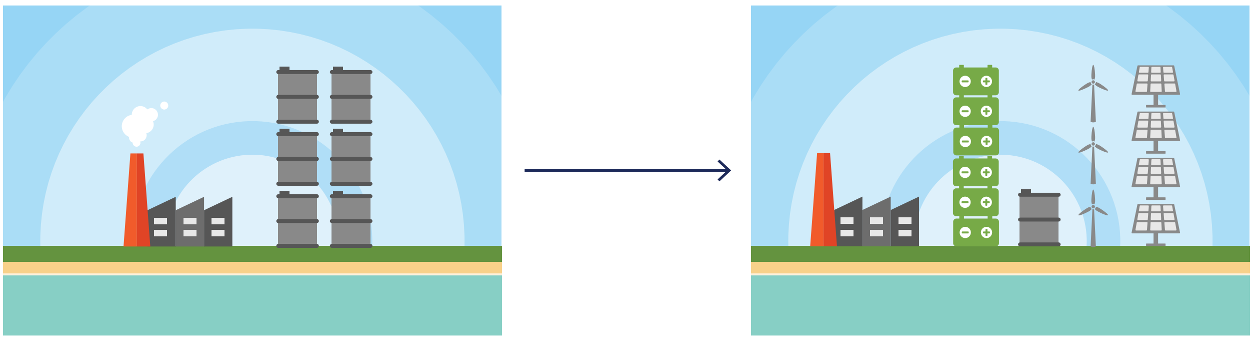


Figure 13: Mini-grids will move from all diesel to almost 100% renewables in a single step [2]

Outer islands without grids

RMI has successfully electrified almost all households on outer islands with solar home systems. Attention is now focused on improving servicing and replacing these systems, and ensuring their financial sustainability. A study is proposed to look at energy use aspirations and how additional energy services might contribute to a better quality of life for outer islanders.

Where we are in 2018

There are at least 3000 solar home systems installed across the islets of 22 atolls, representing an almost complete rollout of electricity access to RMI residents. The size of each of these systems is typically around 200 Wp PV, with a 12V, 305Ah battery, supplying a few lights and a direct current power outlet. A few larger systems also include refrigeration.

Most outer island solar home systems are currently maintained by MEC. Local people were trained during the installation of these systems and are now employed as maintenance technicians, and to collect the $5 monthly fee from customers. The collection of this fee has been problematic. Some local governments are now getting involved in managing fee collection and enforcing disconnection due to non-payment. Local governments can accept items to sell at market in lieu of cash.

In addition to solar home systems on outer islands, solar/battery stand-alone power systems have been installed to provide electricity to 7 schools (of a total of 61 schools without reticulated power). Plans to bring stand-alone systems to the remaining 54 schools, the next major phase of outer island electrification, have currently stalled due to issues with financing the maintenance of the existing 7 systems.

Many of the more than 50 health dispensaries in the outer islands, have (or have had) solar/battery stand-alone systems providing power to lights, a vaccine refrigerator, ceiling fan, water pump, and radiotelephone. Although there has been no official survey, it is understood that most of these systems are no longer in service.

There are currently several outer island fish bases for processing and storing local catches for sale at the main markets of Majuro and Kwajalein. Some of these have standalone power systems to run freezers, lighting for processing, and a radiotelephone, including on Arno, Aur, Maloelap, Likiep, and Namu atolls. These systems are operated by the Marshalls Islands Marine Resource Authority.

In addition, some shops may run freezers, either from larger stand-alone power systems or from portable gasoline generators. In drought years reverse osmosis water desalination plants are required in some areas to provide fresh water. However, these are typically portable temporary units with their own power generation and we have not included them in the installed infrastructure considered as part of the Roadmap.

Financial sustainability

The outer island systems for schools and homes have consistently had issues with financial sustainability. MEC has calculated the actual cost of maintaining and replacing a solar home system to be around $19 a month. Collecting the $5 fee from the household has been problematic, and disconnecting customers for non-payment has been difficult for local technicians based in the same close-knit community. The national Government provides a top up payment of $7 per month per system to the MEC, although for many years this was not paid. This has led to significant financial sustainability issues for MEC and no means with which to service and replace systems as required. Even with full collection, the monthly $5 fee with the $7 top up ($12 total) a per solar house system does not cover the expected replacement and maintenance costs of these systems.

When development partners provide grant-funded equipment, such as these solar home and stand-alone power systems, there is a need to work with RMI stakeholders in the relevant government ministries and communities to ensure they understand the ensuing costs for maintenance and replacement, and the magnitude of those costs.

Pathway

On some outer islands without existing grids, such as Santo on Kwajalein, there may be a case for a detailed study into the economics of developing a distribution network. However, in general, the households of more remote islands with low population densities will be best served by the existing stand-alone solar home systems. Our focus should be on ensuring the financial sustainability of these systems, whether by payments from user, utility, Government, or a mix, particularly given that components require periodic replacement.

It is possible that improved energy services will enhance the quality of life of outer island communities and make living there more attractive. Options include providing shared community services, such as laundromats, or increasing the size of some household systems, for those willing to pay. It is considered timely to do a study on the energy aspirations of outer island communities and our rural development objectives.

07.

Human resource strategies

The implementation of our Roadmap will only be achieved with a capable workforce. The first step is to hire an experienced Human Resource professional to establish apprenticeship and internship programs, and vocational training, and to mentor Marshallese to study engineering. Highly skilled jobs will initially need to be filled by expatriates while we build a local skilled workforce.

The challenge

The RMI's electricity journey will require a wholesale transformation from diesel generation, with which we have a great deal of experience, to automatically controlled, high-tech renewable energy systems, with which we have almost no experience. The process of transformation requires the rapid design and build of large amounts of wind and solar generation, battery storage, advanced control systems, new high-speed automated diesel generators, and other enabling technologies as laid out in previous sections. The success of this ambitious program of work and the achievement of the RMI's climate change targets depends entirely on the skill and commitment of the people who work on these systems.

The RMI shares many challenges with other island states as a result of our smallness, isolation, and 'island-ness'. We are characterized by a small population and therefore limited human capital. Remoteness and small size mean there are few local education facilities and a severe lack of specialized skills. The lack of scale in the job market means there are limited opportunities for employment. The close relationships and social structures of our small island communities often bring challenges in managing employees. With the right to live and work in the United States, around one-third of the total Marshallese population has moved to the United States seeking education and employment opportunities.

This section provides a high-level overview of the key strategies planned for our human resources. For further detailed discussion see the Human Resource Working Paper [13].

The success of this ambitious program of work and the achievement of the RMI's climate change targets depends entirely on the skill and commitment of the people who work on these systems.

Future workforce requirements

New generation technologies, coupled with advanced control systems and other enabling technologies, will require significant international expertise, new Marshallese staff with new sets of skills, and new training for existing staff, in order to maintain safe and reliable electricity supply. Operators will continue to require traditional skills in fuel management, diesel operations and maintenance, and electricity distribution, along with these new capabilities in new technologies. Management and supervision skills will be required to ensure these systems are financially sustainable, well staffed, and have consistent and adequate operation and maintenance.

Similarly, demand side management and energy efficiency involves policies and programs that require particular expertise. This area will need significant attention both in government and utilities, and, as with the supply side, we will require new skilled staff, and existing staff with new skills.

A review of the tasks and roles required to build, operate, and maintain the new systems show a need to rapidly increase the number of skilled people across the sector (including MEC, KAJUR and government agencies) by around 40 in the next few years. This is an increase of around 16 percent from the current 265 staff, to a total of 308 by around 2022. Additional personnel are mainly required in three areas:

1. Project management and implementation personnel to deliver the planned projects.
2. An increase in staff in the National Energy Office to have the resources necessary to manage the sector.
3. Specialist operations and maintenance engineering skills for wind, solar, battery, and control systems technologies.

The specialized skills required in these three categories mean that many of the positions will need to be filled from overseas for up to 10 years. We intend to transition specialist positions to Marshallese staff as they gain the required qualifications and experience. Note that these numbers do not include external project design engineers or construction contractors, who typically work for short periods in the delivery of specific projects.

Smaller increases in numbers of people are needed in utility administration and the other operations teams, with a view to improving the reliability and service levels of some of the outer island systems. As the scope of this work does not review the existing staffing levels of the utility, it is assumed that current staffing remains, and that there is capacity for existing staff to carry out some of the operation and maintenance tasks required by the new systems, with little or minor upskilling.

MEC already has a large team of solar system technicians for small-scale remote solar systems. The training of these technicians will need to continue and be upgraded as systems are replaced with newer, larger, and more automated systems.

How do we get there?

Principles

While it is clear that a workforce with the right skills and capability is essential, this set of principles provides us with a framework to think about the best way to do things.

BUILD THE SKILLS AND CAPABILITY OF MARSHALLESE PEOPLE

Navigating a renewable energy future provides an opportunity to develop Marshallese people with science, engineering, and management capability. This requires a long-term view and dedication to this outcome, as there are many barriers (described below).

ENCOURAGE COLLABORATION AND STRONG SECTOR LEADERSHIP

The way in which the people at the top show leadership and work together, across the government, utilities, education, and the private sector, will determine the success or otherwise of the RMI Electricity Roadmap, and of our Human Resource program.

IMPLEMENT A COHESIVE RATHER THAN AD HOC PROGRAM

Personnel working in the sector should be able to see a career and development path. The pathway should include job progression based on competencies and experience, and, ideally, a qualifications framework. A program in which training is context-specific and opportunities build on each other is greatly preferred over ad hoc one-off training.

ENCOURAGE AND ENABLE MORE WOMEN IN THE SECTOR

Currently there are a few women leaders in the sector. While some administration staff are women, in general women's participation is low. Strategies to promote more women in the sector will be integrated into the program – some suggestions follow.

ENABLE CHOICE AND MOBILITY FOR PERSONNEL

A human resource development program for the energy sector should encourage local people who have gained an education overseas to return and apply their skills to the energy sector. It should also empower Marshallese by building skills that will be valued elsewhere, and that will support them getting jobs in the United States.

USE RENEWABLE ENERGY AS A PLATFORM/DRIVER FOR EDUCATION IN 'SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS' (STEM) AND TO DEVELOP HUMAN RESOURCES IN OTHER SECTORS

As young people see the potential for careers as technicians, engineers, and managers in this sector, and undertake appropriate education, there is potential for spillover into other STEM-related sectors, such as marine and civil engineering, and medicine.

Key strategies and initiatives

There are three approaches to obtaining the human resources required to implement our RMI Electricity Roadmap:

'Make' new entrants to the sector: The long-term solution is to invest in educating and training Marshallese to build the necessary skills and knowledge. This approach focuses on new entrants to the sector, mostly young people, but also attracting experienced and skilled professionals from other sectors.

'Grow' the existing workforce: We need to identify and nurture talent and provide opportunities for further education, training, development, and promotions. We also need to improve management and supervision capability.

'Buy' expertise and additional capacity: In the short to medium term, we will need to hire expertise from outside the RMI. Some international expertise will also be required in the long term due to the inherent small size of the Marshallese workforce, and because some skills are highly specialised.

Key strategies and initiatives that we need to develop are:

- Mechanisms for sector **leadership and coordination** in HR development.
- **Apprenticeship schemes** at MEC and KAJUR.
- **Internships** at MEC and KAJUR and support for professional qualifications.
- A cohesive **in-country vocational training** program.
- Personal career, education, and training mentoring for individuals.
- **Management support** through leadership and management training, and ongoing support from trusted advisors.

One further idea with great potential is to establish a **'twinning'** relationship with another utility that is more experienced with renewable energy. This could involve extended exchanges of staff between utilities to gain experience and knowledge both in technical and management areas.

INTERNSHIPS AND QUALIFICATIONS

- Coordinated support for the development of engineers and managers

'MAKE' NEW ENTRANTS TO THE SECTOR

- Build profile of energy careers
- Targeted recruitment
- Apprenticeships and vocational training
- Internships and professional qualifications

APPRENTICESHIPS

- Coordinated training and experience for skilled technicians

'GROW' EXISTING WORKFORCE

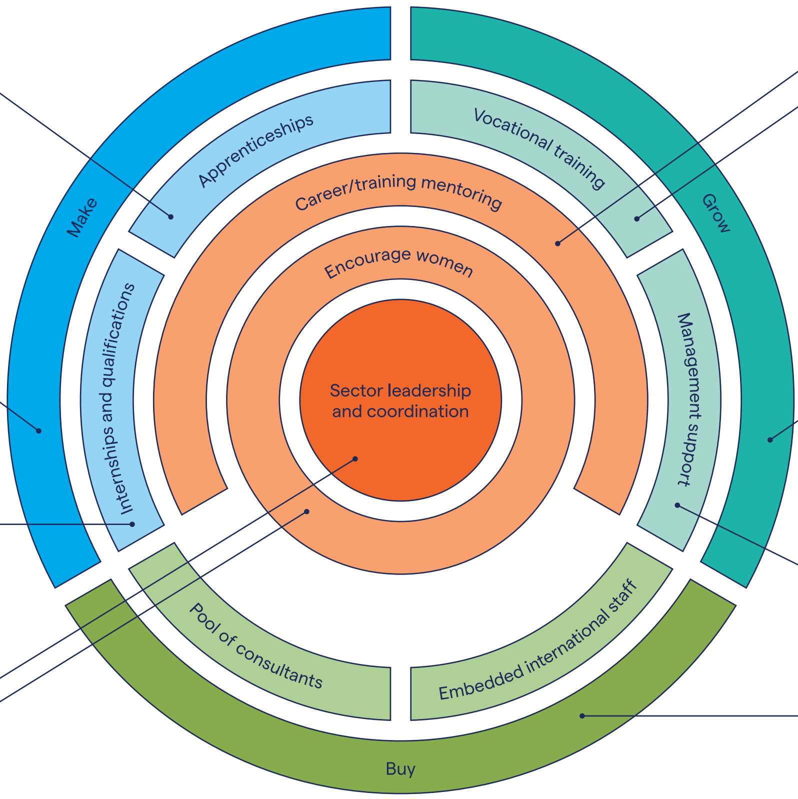
- Identify and nurture talent
- Improve supervision and management
- Ongoing training

COHESIVE PROGRAM OF VOCATIONAL TRAINING

- Build a program of in-country training
- Transferable qualifications framework
- Reduce ad hoc, off-island training

CAREER MENTORING

- Personal one-to-one support for individuals to pursue training, education and career development



ENCOURAGE WOMEN

- Remove barriers for women
- Actively encourage more women to join workforce in all roles

SECTOR LEADERSHIP AND COORDINATION

- Human resource coordinator role
- Electricity Sector HR Working Group from MEC, KAJUR, CMI, USP, EPD and NTC

'BUY EXPERTISE AND CAPACITY

- Expert staff in utility and government in early years
- Remote technical support
- Pool of trusted consultants and advisors

ONGOING MANAGEMENT SUPPORT

- Leadership, management and supervision training
- Ongoing support from trusted advisors

Figure 14: Summary of key human resource strategies [14]

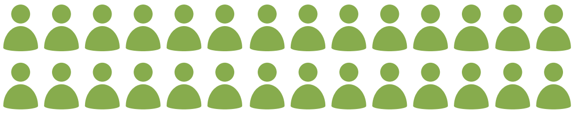
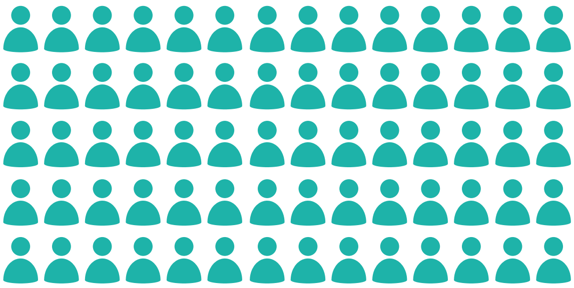
Needs		How needs will be met
Highly specialised skills in system design, power system modelling, control system programming, technical specifications etc.	e.g. design engineers, control system experts, finance and organisational experts	**Level 4** **EXPERT SPECIALISTS** • 'Buy' – Required for design, commissioning or troubleshooting • Fly-in-fly-out • Remote monitoring of systems 
+7 new engineers from 2020 (+5 interns) + 5 project implementation specialists Upskilling of managers +4 experts in policy/ planning	e.g. electrical, renewable energy and control systems engineers, IT specialists, procurement specialists, technical and general managers	**Level 3** **ENGINEERS AND TECHNICAL MANGERS** • 'Buy' – first few years, hire international staff • 'Make' – new entrants study engineering and undertake internships to achieve this skill level • 'Grow' – identify and support existing staff to pursue further action 
+6 wind and solar specialist technicians by 2025 Upskilled diesel operators	e.g. diesel plant operators, shift supervisors, mechanics, wind and solar technicians	**Level 2** **SKILLED OPERATORS, TECHNICIANS AND SUPERVISORS** • 'Make' – new entrants undertake apprenticeships and vocational training to level 2 • 'Grow' – suitable individuals from level 1 to level 2 with vocational training 
Assume no major change in numbers with some personnel redeployed to general maintenance of renewables with minor upskilling	e.g. linemen, outer island solar technicians, all other semi-skilled workers and trainees	**Level 1** **LEVEL 1 SEMI-SKILLED TECHNICIANS** • 'Make' – new entrants undertake apprenticeships and vocational training to level 1 only if needed • 'Grow' –minor upskilling in basic maintenance of solar and wind (e.g. cleaning, clearing vegetation, painting, etc.) 

Figure 15: Summary of workforce needs at increasing levels of skills, and how these needs will be met [14]

Sector coordination

A working group focused on HR development in technical and engineering disciplines will be formed, including the key institutions MEC, KAJUR, CMI, USP, National Training Council (NTC), National Energy Office (NEO), the Division of International Development Assistance (DIDA), and the RMI Scholarships Board. An experienced and motivated HR development professional will be hired with responsibility to do the following:

- Convene and facilitate the HR Working Group.
- Establish MEC and KAJUR apprenticeship and internship programs.
- Carry out targeted recruitment.
- Facilitate funding and resources to establish a cohesive vocational training program.
- Work with development partners to access funding for the HR program.
- Mentor and counsel individuals to undertake apprenticeships and training, and to access scholarships and undertake professional qualifications.

Crosscutting strategies

CAREER AND TRAINING MENTORING

Support will be provided to individuals to help them map out their career aspirations and pathway, including education, internships or apprenticeships, and training. While scholarships provide incentives and enable the student financially, other challenges also exist. These include navigating the application process for scholarships and course entry, and adapting to studying at an academic institution. The heavy workload and difficulty of engineering courses can be an additional barrier. The same support will also be given to individuals who show promise in pursuing a more vocational path, through apprenticeships and training, and by taking on increasing levels of responsibility at a utility.

ENCOURAGING WOMEN

Our first step to encouraging women to join the RMI's energy sector will be to ensure adequate separate toilet facilities and a safe working environment for technical and field jobs. A quota for the number of women included in apprenticeship intakes will be considered. Interested women will be encouraged to apply for roles, apprenticeships, and engineering study through social media and personal contacts. Women already in the sector will be advocates to encourage more women to work in the sector – attending career and science fairs, providing presentations to university and school students, and engaging through social networks, in person and online. Links will be established with the Pacific Power Association (PPA) Gender Champions Initiative.

'TWINNING' WITH ANOTHER UTILITY

MEC/KAJUR will explore the possibility of a twinning arrangement, perhaps with Kaua'i Island Utility Cooperative or another Hawaiian electricity company. Working with a utility in Hawai'i will have multiple benefits. It is close to the RMI and easy to get to, it has a similar 110V system, and Hawai'i has equally ambitious renewable energy targets for island systems, promoting shared learning. Renewable energy and electrical engineering courses are available at University of Hawai'i – a university that many Marshallese already attend.

‘Make’ new entrants to the sector

A highly skilled Marshallese energy workforce requires long-term planning and sustained effort. For this to work, the RMI electricity sector must commit to recruiting, employing, and developing the best employees available in the job market. Beyond that, it is important to increase the quality of teaching and students’ interest in STEM subjects at high school and elementary school.

RAISE THE PROFILE OF THE SECTOR AND MAKE IT ATTRACTIVE

We need to raise the profile of the electricity sector as an exciting place to work, with good career opportunities.

TARGETED INDIVIDUAL RECRUITMENT

We need to seek out capable and motivated individuals in RMI, and Marshallese overseas, as potential recruits.

GOOD RECRUITMENT PROCESSES AND CAREER PATH PLANNING

We need to make recruitment processes for apprenticeships and jobs simple and transparent, prioritise the skills required, and seek the best people for the RMI’s future electricity system.

START WITH SCHOOLS

We need to get school students interested in STEM subjects through science fairs, by prioritizing good science and math teaching in key schools, and by identifying and supporting interest early. It is important to highlight the opportunities for exciting careers in renewable energy and energy efficiency.

INTERNSHIPS AND PROFESSIONAL QUALIFICATIONS

The National Energy Office and utilities will establish an internship program, enabling interns to work during study vacations have real-world experience and career support at the same time as pursuing professional level qualifications in engineering. Counselling and support will be provided to support Marshallese undertaking engineering study, which is typically more difficult than other areas of study. Scholarships will be targeted to engineering qualifications. Only a few engineers are required, but the goal should be to train at least double the required number to enable professional mobility.

APPRENTICESHIPS

A group of new entrants who are interested in engineering, renewable energy, or information technology (IT) will be identified using a targeted approach in high schools, the College of the Marshall Islands (CMI), and in Marshallese communities living in the United States. Selection will be based on aptitude, interest, and motivation.

As for internships, a good recruitment process will support getting the best apprentices. Apprentices will be rotated through different work departments and then select the areas of electrical (generation), mechanical, distribution, renewable energy, and IT that they are most interested in [14]. Working with more experienced technicians and engineers will be complemented with structured vocational training. We will support apprentices who make excellent progress and show aptitude with career pathway planning, scholarships, and mentoring to undertake higher level engineering study at a technical college or university.

We need to seek out capable and motivated individuals in RMI, and Marshallese overseas, as potential recruits.

'Grow' the existing workforce

IDENTIFY AND NURTURE TALENT

Often there are exceptional and competent people in the existing workforce. They may already be performing well, or they may be underperforming for a variety of reasons, including poor management or supervision. We will identify, mentor, and further develop these people using the ideas presented here, including apprenticeships and internships.

COHESIVE IN-COUNTRY VOCATIONAL TRAINING

At present there are many ad hoc training courses and meetings offered by development partners and as part of projects. As a rule, short training courses, either international or in-country, offer no follow up or the opportunity to bed in what has been learnt. Training is often poorly targeted, both for relevance and skill level, lacks context, and/or is too short to have lasting impact. (Note: the longer training offered by JICA is seen as an exception to this and is considered by RMI stakeholders to be useful and relevant).

We need to implement a cohesive program of skill development in which training opportunities build on each other, with a strong preference for training be carried out in the Marshall Islands. One proposal is to establish a vocational training facility at CMI. This could be a physical space where demonstration equipment is installed and worked on. This will provide for regular scheduled training for apprentices by in-house trainers (for example the pool of experts working on the RMI's systems), and visiting trainers. It will also provide a venue for continuing professional development for other staff, including management.

PROVIDING SUSTAINED SUPPORT FOR MANAGEMENT

Ongoing management support will be beneficial across the government sector and in MEC and KAJUR. ADB consultants are undertaking a comprehensive organizational review of MEC in the second half of 2018, and further specific recommendations on improving its management will result. A pool of trusted consultants and advisors, along with specific technical assistance projects, can be used to provide ongoing support, as they are for many utilities around the region.

We need to implement a cohesive program of skill development in which training opportunities build on each other, with a strong preference for training be carried out in the Marshall Islands.

'Buy' required expertise and additional capacity

Most of the needed new skills do not currently exist in the RMI, therefore many of the roles will be filled by expatriates until we have built the required skills and experience internally. Beyond that, there will be an ongoing need for some international expertise due to our inherently small size. We prefer relationships with external consultants, trainers, and specialists to be developed for the long term.

POOL OF TRUSTED CONSULTANTS AND ADVISORS

Consultants and service providers come with deep expertise in renewable energy systems and in island renewable energy systems. By maintaining long-term relationships, they also develop detailed knowledge of our RMI systems and can be retained for troubleshooting. It would be of great benefit to the RMI to establish a pool of trusted consultants and advisors who are familiar with our systems and context and who have established working relationships, rather than bring in new consultants for each piece of work.

REMOTE TECHNICAL SUPPORT

The technology planned for the systems of Majuro and Ebeye, and also for the solar hybrid mini-grids, will enable remote support over the internet. This means technicians located in Australia or the United States (for example) can view the same information as technicians in Majuro or on Wotje or Jaluit, and can assist in troubleshooting remotely. This in turn means that specialised engineers do not need to be on-island, but can work remotely, and only fly in when necessary for troubleshooting or repairs.

We prefer relationships with external consultants, trainers, and specialists to be developed for the long term.

08.

Financing and implementation arrangements

The financing and implementation challenge

Financing and implementation arrangements will be geared to achieve rapid and effective rollout of the Roadmap, minimizing transaction costs and ensuring good development partner coordination.

This section of the Roadmap outlines the key considerations and broad approaches to financing and implementation arrangements. The specific details of these arrangements are the substance of ongoing discussions within the RMI and with development partners.

Meeting our ambitious NDC targets involves a challenge that cannot be met through a business-as-usual approach to financing and implementation. We need a significant increase in the rate of disbursement of investment funds in the electricity sector, and this can only be achieved with a significant increase in absorptive capacity at the project implementation level. In the short to medium term, this capacity will have to come from external sources. To be executed successfully, the Roadmap requires a centrally planned and centrally overseen investment program.

We recognize that pursuing our GHG targets for electricity must be balanced with the broader needs for financing across all critical sectors. We will work to achieve the targets through existing and new sources of financing, and through appropriate allocations across sectors, including for the increasing costs of adapting to the impacts of climate change.

Meeting our ambitious NDC targets involves a challenge that cannot be met through a business-as-usual approach to financing and implementation.

What is the current financing situation for electricity?

Development partners

RMI has large amounts of grant funding from existing development partners in the pipeline – particularly the World Bank and the Asian Development Bank (from which the RMI are only eligible for grants, not loans); and the European Union (EU) under the current Cotonou Agreement, which ends in 2020. These large amounts of financing directed towards electricity have only come about in the last few years with the scaling up of development partner allocations to Small Island States.

The reason we are developing this Roadmap is to better coordinate and direct these investments towards the achievement of our goals.

The RMI Government has relatively high debt, and development banks are urging restraint on loans to preserve their current level of grant support.

Tariffs and government subsidies

At present, basic operating costs are covered by tariffs, but not the funds needed for adequate maintenance and replacement of systems. While financial performance has improved in recent years, MEC and KAJUR are still without a fully integrated asset management framework that ensures regular maintenance and sets aside funds for asset replacement. This is clearly demonstrated in the difficulty in funding urgently needed new diesel generators, and the rundown nature of the networks. It is also demonstrated in the shortfall in funding to maintain and replace outer island solar home systems.

Income to the utilities for electricity is in the form of tariffs and government subsidies. Currently these two sources of income – tariffs and subsidies – are not adequate for the long-term financial sustainability of MEC and KAJUR as they do not allow adequate investment in maintaining network infrastructure and do not provide for replacement of assets.

At present, the fiscal position of the Government is also relatively weak with limited surpluses. Having said this, the Government provides heavy subsidies to parts of the electricity sector, some of which could be better directed to help achieve the electricity GHG targets and other objectives for the sector. Currently, Government subsidies of around $5 million per year to the utilities are:

- Around $250,000 a year to support operation and maintenance of outer islands solar home systems.
- Around $600,000 a year in fuel subsidy to the outer island grids of Jaluit and Wotje.
- Around $3–4 million a year in free power to almost 1000 landowners on Majuro.

How much will it cost to achieve the 2025 targets?

Capital costs

Around $130 million of additional funding for capital investment is needed to meet our 2025 target. Beyond that, $45 million more is needed to meet our 2030 target.

In the period from now to 2025, a total of around $120 million capital investment is needed for renewable energy across the RMI (assuming the least-capital cost pathway using wind, batteries, and enabling technologies). Around $30 million of that is being invested under existing projects, leaving a gap of around $90 million.

Around $12 million is needed for generator replacements, and a further $40 million for network and general assets. Around $10 million of this has been committed in current projects by the ADB for the tank farm, and the World Bank for diesel generators, leaving a gap of around $40 million.

In the period from 2025 to 2030, an additional $45 million for new capital is needed to achieve our 2030 target, including investment in network and general assets.

Recurring annual costs

Diesel savings in 2025 could be around $7–10 million a year compared to current fuel consumption. At the same time, other recurrent annual costs increase by around $10–15 million a year. This means annual costs in 2025 could be around $5 million a year higher than today.

Annual savings from reduced diesel from 2025: $7–10 million a year. From 2025, diesel savings of around $7–10 million a year are expected (assuming a constant price of $2.45). In addition, diesel operation and maintenance costs could fall by around $0.5 million per year.

New annual costs in 2025: $10–15 million a year. Recurring annual costs in 2025 are expected to increase over current costs as follows:

- Investment in network and general assets, around $2–5 million a year.
- Capital replacement reservation fund for renewable energy, around $4 million a year; and for diesel generation, around $1.3 million a year.
- Operation and maintenance on renewable energy to cost around $2 million a year (excluding replacement costs).
- The sustainable cost of operating, maintaining and replacing 3000 outer island solar home systems is estimated at around $20/month/system. Current fees ($5/month) and subsidies (Government top up at $7/month) leave a shortfall of around $8/month/system, or around $300,000 a year.
- The need for expertise and additional staff across the sector will increase staffing costs by $2–4 million a year, depending on the salaries for international staff.
- Implementing the HR program is expected to cost around $1 million a year.

Total annual costs in 2025 are projected to be around $5 million a year higher than today.

How will we finance the implementation of the Roadmap to 2025?

Financing for initial capital investment will come primarily from development partner grants. Financing for operations, maintenance, and replacement will come primarily from electricity tariffs, diesel savings, and Government subsidies. Costs for international staff and the human resource development program will be sought from development partners.

How we will finance new capital investments?

The successful execution of the RMI's rapid transition to renewables means a centrally planned and managed capital investment program that implements large projects concurrently. The RMI has access to relatively large amounts of grant financing but beyond this we have capital constraints due to the restrictions on loans.

In a centrally-planned capital investment program, the process will be to design a cost-effective technical system to meet the objectives, and then to identify available finance, beginning with development partner grants. New sources of grant funding will be pursued. If there is still a shortfall, then we will, as a last resort, pursue concessional loans or arrangements with private operators (e.g. independent power producers (IPPs)).

Some development partners have stated preferences to invest only in certain types of capital, such as renewable generation equipment. Other development partners provide welcome support for critical infrastructure, or even budget support, giving us much needed flexibility. We intend to work with all partners to support investment holistically and programmatically in the entire electricity system, using this Roadmap as the framework. For example, we cannot increase renewables past a modest level without new diesel generation and significant network investment.

The RMI has access to relatively large amounts of grant financing but beyond this we have capital constraints due to the restrictions on loans.

We need to continue to allocate a significant proportion of World Bank and ADB pipeline funding to the electricity sector, and also seek additional climate-related grant funding.

DEVELOPMENT PARTNER GRANTS

There is a considerable amount of development partner grant-finance available to start implementing the Roadmap. The largest potential sources of funding for capital are the World Bank and ADB. Financing the Roadmap means we need to allocate at least 50 percent of the pipeline funding from these two partners. This finance can be supplemented by bilateral partners and the EU (depending on mechanisms developed after 2020).

Other sources will be pursued through the Green Climate Fund and other financing mechanisms for mitigation under the UNFCCC. Working to develop this development partner financing is a key priority that needs to be given adequate human resources.

LOANS

Debt sustainability analysis undertaken by the International Monetary Fund (IMF) and the World Bank [15] concluded that the RMI is at high risk of debt stress. The ADB and World Bank are urging restraint on loans, and only concessional loans can be considered by the Government.

If the electricity sector takes on loans or enters into other contractual arrangements, there is the risk that it could affect the RMI's financing from multilateral development banks across all sectors.

There is therefore a need for a formal process to ensure the RMI Ministry of Finance reviews any loan proposal and undertakes a full risk analysis before entering any loan agreements.

INDEPENDENT POWER PRODUCERS (IPPS), OR OTHER PRIVATE OPERATORS

In the case that there is a capital shortfall, an alternative mechanism to loans is an arrangement with a private operator. This can be an IPP arrangement, or a build-own-operate-transfer (BOOT) arrangement. The benefits of these types of arrangements are that they can overcome capital constraints and provide necessary expertise and experience in running plant. If the process of assessing investment need and available finance means there is a case for private investment, that private investment will need to be actively procured, based on the specific requirements of the system (technology compatibility, timely delivery, pricing sustainability, etc). as opposed to responding to unsolicited proposals. Great care must be taken to apply due diligence to these arrangements, especially for island variable renewable systems.

How will we finance capital replacement costs?

The greatest risk to the long-term success of the Roadmap and the RMI's transition to renewable energy is funding for equipment replacement and maintenance over time. Regular and adequate deposits to a capital replacement reserve fund are necessary to ensure funding is available when needed.

In implementing this Roadmap, we are moving from a system based on consuming fuel, to a capital-intensive system. This means the RMI faces far greater costs in capital replacement, and this will be exacerbated at higher levels of renewables. Typically, our experience is that the process of budgeting for capital replacement has not been well managed in the sector, evidenced by the lack of capital to replace generators, or to pay for replacement parts for outer island solar home systems.

To remedy this, Government subsidies will need to be redirected to deposits in a capital replacement reserve fund, as will some portion of diesel savings by the operator. Reserving funds for the future is our only way to guarantee that capital is available when needed for replacement, and setting up such a fund will be a condition for utilities to gain access to the large amounts of grant financing available. The risk in moving to a capital-intensive system is that if we cannot replace equipment when the time comes, we risk failure of the electricity system, or having to revert back to diesel generation.

Diesel savings and redirected subsidies will enable MEC and KAJUR to fund the true maintenance and replacement costs in the longer term to ensure sustainable asset management. Without redirection of subsidies, it is likely tariffs would need to be increased.

	ITEM	CAPITAL NEEDED TO MEET 2025 TARGET	ADDITIONAL ANNUAL COSTS IN 2025	PROPOSED FINANCING	METHOD FOR ESTIMATING
CAPITAL	Capital for renewable energy systems	$120 million ($90 million still needed)		Development partner grants. IPPs or concessional loans only if and when grants have been exhausted.	HOMER model least-cost pathway for Majuro and Ebeye using wind, solar, batteries, and enabling technology. Mini-grids for several outer islands.
	Capital for diesel generators	$12 million (~$7 million still needed)			Based on replacement of generators and powerhouses on both Majuro and Ebeye.
	Capital for network and general assets	$40 million ($30 million still needed)		Development partner grants. Concessional loans or IPPs only if and when grants have been exhausted.	Based on list of infrastructure investment required in National Infrastructure Investment Plan.
ADDITIONAL ANNUAL COSTS	Investment in network and general assets		$2–5 million	Government subsidies to 2024 and then MEC/KAJUR through diesel savings.	Roughly estimated based on the need for significant investment to bring the network and general assets to an acceptable standard, with costs reducing to a maintenance level after that. This estimate would be updated with an asset management plan.
	Deposits in capital reserve fund (for major equipment: diesel generators and renewable energy generators)		$ 5 million	Government subsidies redirected from fuel and Majuro landowners. Operator from diesel savings.	Calculated based on future replacement costs of technologies at the end of their designed life, annualized. Interest assumed 0%.
	Operation and maintenance of renewable energy		$2 million	MEC/KAJUR from diesel savings.	Detailed assumptions were included in the HOMER model – see TN-03 [3].
	Operation, maintenance, and replacement of outer islands SHS		$300,000	Increased Government subsidies and/or user fees.	Replacement and maintenance costs of outer islands systems estimated in TN-12 Solar home systems. Shortfall between estimated cost, monthly service fee, and current level of Government subsidy is around $8/month/system.
ADDITIONAL ANNUAL COSTS	Additional skilled personnel		$2–4 million	Development partner grants/ technical assistance.	From workforce needs assessment done as part of the Human Resource strategy – see [13] . This cost for 2025 assumes most specialist roles are filled by expats. Cost will come down as Marshallese people gain qualification and experience and take on these roles.
	Human resource development program		$ 1 million	Development partner grants/ technical assistance.	Rough estimate from Human Resource Strategy – see [13].
ANNUAL SAVINGS	Savings from reduced diesel use (compared to present day, and based on current price)		$7–$10 million	All savings from avoided diesel use are allocated to network investment and capital replacement fund deposits.	Assumed savings from forecast if diesel is displaced by renewable generation, using current diesel price of $2.45/ gallon.
	TOTALS	~$130 million needed	~$5 million/ year net increased costs		

Table 4: Summary of costs and financing sources to implement Roadmap, using 2025 as a sample year

How will the Roadmap be implemented?

Achieving the targets requires coordination and collaboration

A serious transition to renewables requires whole-of-system thinking and a program approach. This will require strong RMI leadership and willingness to work collaboratively across the electricity sector and with development partners.

Current project-based ways of working with development partners are burdensome, slow, and transaction costs are too high to be able to achieve the RMI's targets. While development partners have committed to improving coordination and aid effectiveness, in practice, in the last decade, RMI has experienced a proliferation of development partners and projects, with a concomitant increase in burden on RMI personnel to engage with these individual projects. Projects tend to be stand-alone, with limited coordination.

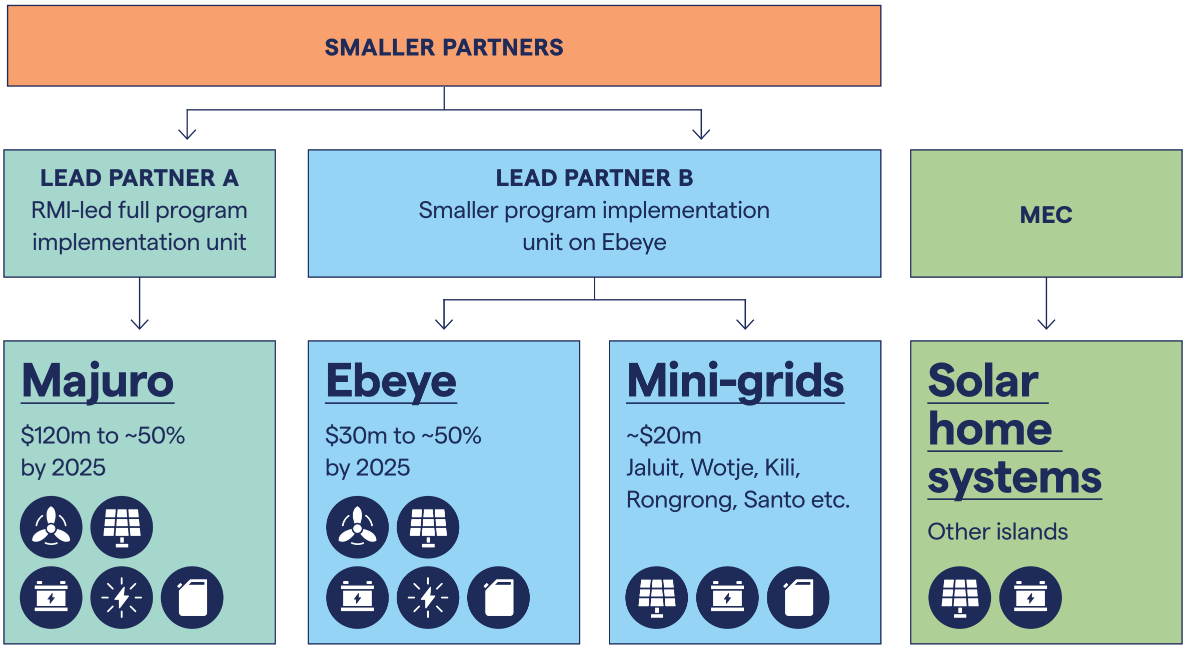
To have any chance of meeting the RMI's targets, the way of working in the sector will need to be qualitatively different than in the past, both for sector stakeholders in the RMI and for our development partners. Our ambitions mean we need to plan and deliver big projects, all at once, moving decisively in line with our shared vision. It will require outstanding leadership and collaboration.

Our ambitions mean we need to plan and deliver big projects, all at once, moving decisively in line with our shared vision.

A whole-grid approach to Majuro and Ebeye

The design philosophy of centrally-planned utility-scale generation, and the rate and scale of change, invites a whole-grid approach to the transformation of the Majuro and Ebeye grids.

Our key strategy for financing and implementation arrangements is to focus on an integrated approach to the grids. It is intended that a lead development partner will take on the role of major financier and coordinator for each of the main grids of Majuro and Ebeye. Other development partners can then contribute to the program of investment being coordinated by that lead development partner. The lead development partner will be responsible for coordinating all investments in these main grids and ensuring they work together as a cohesive whole. One development partner can similarly take responsibility for implementing all mini-grids.



- Lower transaction costs
- Whole-grid responsibility
- Smaller partners provide financing to lead partners to manage

Figure 16: A whole-grid approach to financing and implementation

Program-level governance arrangements

Governance for the implementation of the Roadmap will be an RMI-led process based on a strong, credible sector development plan in the form of this Roadmap. The Roadmap provides the strategic framework for decisions and investments, enabling both the RMI Government and development partners to work together towards a common vision.

The RMI recognizes the need to take the lead role in management, coordination, and implementation. A working group has been established comprised of senior management of the newly established National Energy Office, the utilities, and the Division of International Development Assistance (DIDA) in the Ministry of Finance. The role of this group is as a sector-wide task force to implement the Roadmap.

Typically, development partner projects would have separate steering committees set up on a project-by-project basis. Given the need to integrate these to reduce the burden on RMI key stakeholders, improve development partner coordination, and reduce transaction costs, steering committee structures will align with a program of investment based on the whole-grid approach to Majuro and Ebeye.

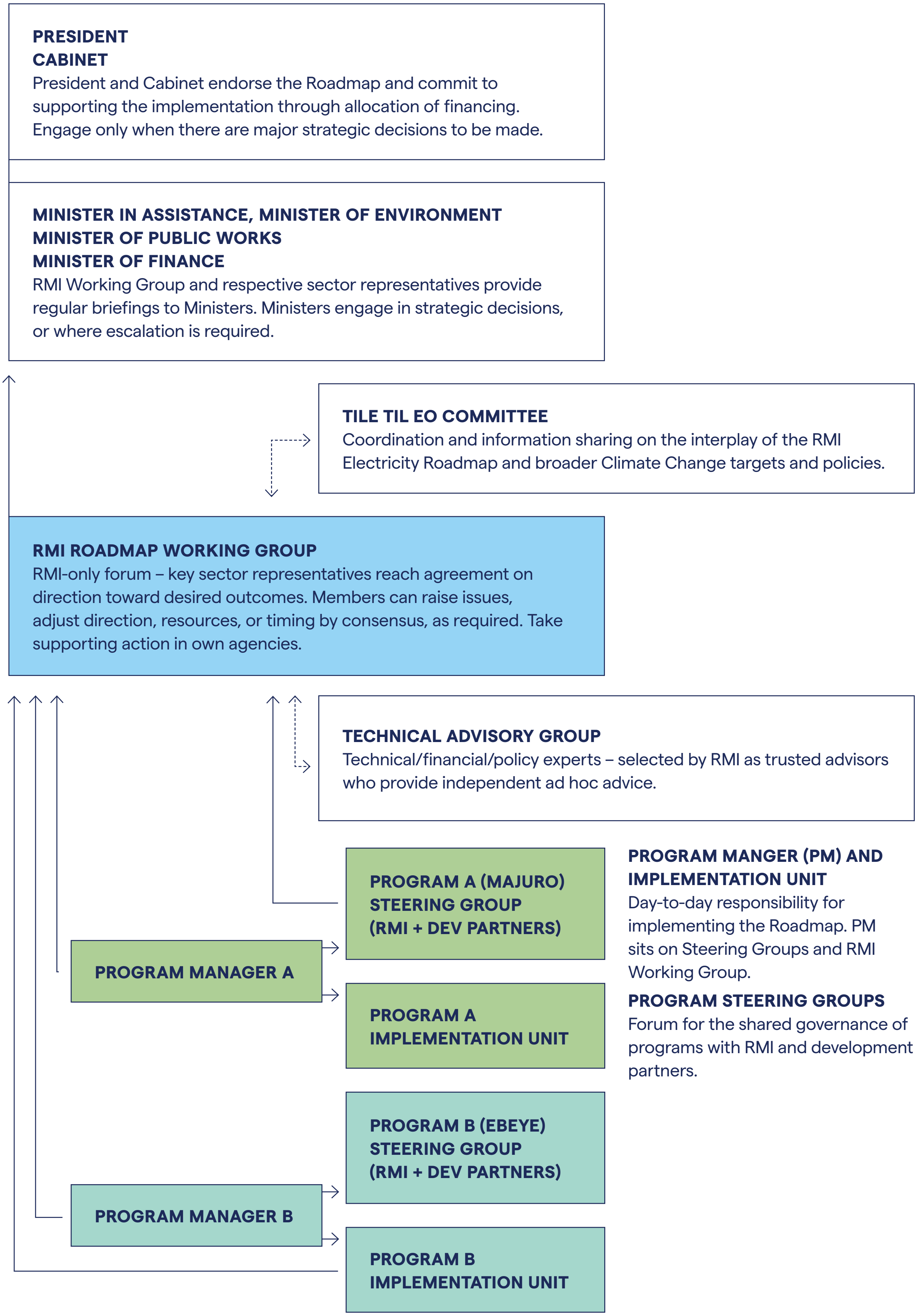


Figure 17: Implementation governance and coordination arrangements including the Roadmap Working Group and program steering groups based on the whole-grid approach

Program implementation units

Key to the successful implementation of our Roadmap will be expert resources to manage the rapid design and build of entire grid systems. Each program needs adequate resources to cover the following, although the resources may be shared between these or other programs of work, and can be provided by development partner in-house resources:

- Overall program management.
- Procurement.
- Financial management and disbursement.
- Environmental and social safeguards specialists.
- Communication and stakeholder management, communication strategy.
- Monitoring and reporting.
- Project managers.
- Engineers and technical specialists.

A key to developing the Roadmap's momentum will be to engage a program manager to oversee putting in place the above arrangements. An HR specialist will also need to be engaged in 2019 to ensure the development of a Marshallese workforce able to implement and manage the Roadmap following the initial investments up to 2025.

Strengthening MEC and KAJUR

In preparing this Roadmap, we recognize the important role to be played by the country's utilities, including the Marshalls Energy Corporation (MEC) and Kwajalein Atoll Joint Utilities Resources (KAJUR). In this regard, we reaffirm our commitment to pursue reforms designed to ensure progress towards financial and technical sustainability, as well as improved customer service levels. It is an underpinning of the Roadmap that the RMI has a robust utility sector able to:

- Integrate, operate, and maintain both new renewable energy systems, and diesel generation and network assets.
- Collect fees and tariffs for services provided.
- Develop a sound financial footing that allows for assets to be managed appropriately and replaced when necessary.

The ADB is carrying out a comprehensive review of MEC in 2018/19, which will then prescribe specific interventions for strengthening MEC. A similar review is required for KAJUR.

> ... we reaffirm our commitment to pursue reforms designed to ensure progress towards financial and technical sustainability, as well as improved customer service levels.

Strengthening the National Energy Office

The National Energy Office (NEO) was established by legislation in late 2018, elevating what was formerly a division of the Ministry of Natural Resources and Commerce, to a standalone office, reporting directly to the Minister of Environment. The expectation is that this new office will play a central role in the implementation of this Roadmap and other energy sector mitigation activities. Responsibilities for implementation, communication, coordination, monitoring and reporting of this Roadmap will largely fall to the NEO, working closely with the utilities and other government agencies. In order to carry out these responsibilities, the NEO will be properly resourced with adequate budget and personnel. This will include increasing staffing from two people up to around ten, and ensuring adequate expertise exists to support not only the Electricity Roadmap, but also similar efforts in transport and other energy-related areas.

09.

Policy roadmap

Policies to enable renewable energy

This section outlines the policy issues and recommended responses to enable the rollout of the technology pathways, in particular for Majuro and Ebeye. The policy approaches are devised specifically for the context of the Marshall Islands. It will be helpful for RMI stakeholders and development partners to have a shared view of the issues and why certain approaches may work better than others for the Marshall Islands.

Solar PV generation

> Grids are based on centrally planned and controlled generation, therefore household-scale solar will not be allowed to feed into the grid. A 'soft' approach will be taken to managing the other risks around private solar.

Solar PV can be defined by where it is installed, how big it is, who owns and maintains it, and whether the power is used on the grid or not. As described in the technology pathways of this document, solar PV generation feeding into the grid will be centrally planned and controlled, and utility-scale.

The approach to small- and household-scale PV systems is to take a 'soft' policy approach. That is, while it does not actively encourage household-scale solar, it allows for those who wish to install private solar PV generation at their homes or businesses. In order to protect the grid, it is necessary to not allow this small-scale solar to feed in.

IMPACT OF PRIVATE SOLAR PV ON TARIFFS AND GRID COSTS

When households or businesses on Majuro and Ebeye install private solar, they are most likely to also retain a connection to the grid, because sufficiently-sized storage to meet energy needs for more than a few hours is very expensive. This means that the utility needs to maintain enough generation capacity to meet load when all these users are on the grid (say, after a day of little sun), and also to maintain the distribution grid and connections. However, these users are also using less electricity from the grid and therefore they pay less. This has an impact on the financial sustainability of the utility, and, in the long-run, often shifts costs to those grid customers who can afford it less.

Some countries (e.g. New Zealand) are introducing higher tariffs for customers with rooftop solar to compensate for this. Another option is the introduction of a monthly fixed line charge to support the fixed costs of the grid.

If a large private solar installation is built, consideration will be given to requiring its users to have storage sufficient to cover overnight use, or to change the tariff structure for that customer to cover having the grid as a backup and for overnight use (e.g. have a flat rate line charge).

It will be important to be transparent and signal to the wider public the potential for a tariff review of fair pricing for partially self-sufficient users, so people can factor this into their investment decisions when thinking about private solar PV generation.

REASONS FOR PEOPLE WANTING PRIVATE SOLAR GENERATION

Anecdotally, private householders and businesses who wish to have small-scale PV systems seem to be motivated by the following:

- A desire to have backup power when the main grid goes down, or to go 'off grid' entirely and avoid being dependent on an unreliable grid.
- A desire to save money.
- The feeling that they are 'doing the right thing' and contributing to reducing GHGs.
- In some cases, customers may expect MEC to pay a feed-in tariff, based on what may have happened in other countries.

QUALITY CONTROL AND SAFETY ISSUES

Poor quality or mismatched components, poor installation, and inadequate maintenance can all lead to risk of fire or electrocution. Currently there are no standards or regulations governing the equipment or installation, or the qualifications of the installer. Some small-scale PV owners will be motivated and will have the means to ensure the maintenance of these systems, while other owners may not, particularly if they are lower-income and if the equipment was provided under a grant. Finally, the quality of the roof structures of many dwellings on Majuro and most dwellings on Ebeye make them unsuitable for the installation of PV panels.

EXISTING LOAN SCHEME FOR SOLAR PV ON MAJURO

A loan scheme is being introduced by the Marshall Islands Development Bank in late 2018, funded by the Taiwan International Cooperation and Development Fund, to provide householders with loans to purchase both energy efficient appliances and private rooftop solar. In line with the measures above, safeguards have been put in place in the loan program to ensure that private solar installations do not export energy to the grid and that both equipment and installation meet safety standards. In addition, units can only provide up to 50 percent of a household's consumption, so tha they do not affect the financial sustainability of the grid. If fully subscribed and if most of the available $4 million was used for solar PV, the program might contribute 1-3 percent reduction in diesel use on Majuro.

INTENDED MEASURES FOR PRIVATE SOLAR ON MAJURO AND EBEYE

Our intended measures for private solar PV are:

- Continue the MEC technical rule that rooftop solar cannot be connected to, or feed into the grid. Establish a similar rule for KAJUR.
- Signal that there will continue to be no net metering or feed-in tariff for Majuro and Ebeye, to inform the investment decisions of individuals and organizations.
- Signal that there could be a tariff review to ensure partially self-sufficient users are paying a fair price for being able to access the network, to better inform their future investment decisions.
- Increase reliability of the grid, and build public confidence in the grid, so people are less likely to seek alternatives as backup.
- Provide a statement to development partners that small rooftop solar systems in urban grid areas are outside RMI priorities (beyond the existing loan scheme noted above).
- Continue the import tax exemption for solar PV panels but do not actively promote it.
- Consider standards for imported equipment, and the licensing of installers.
- Include the integrity of roof structures in the revised Building Code, with a view to supporting PV installations, especially on larger roofs.

Rooftop and land access framework for solar PV

A standardized roof and land access framework for solar installations is urgently required as a prerequisite to the large-scale deployment of solar.

Solar PV generation requires large amounts of space. The technology pathways for Majuro show that under either the wind or no-wind pathways, between 13 MW and 34 MW of solar PV will likely be required before 2030, equating to between 32 acres (13 hectares) and 84 acres (34 hectares). This requirement will greatly exceed the amount of suitable government-owned rooftop space available, and will likely require the use of commercial and residential rooftop space, construction of new roof spaces, and ground-mounted solar, particularly if lagoon floating solar is not feasible.

The likely mix of government, commercial and residential rooftop space means that any rapid scale up of solar generation will require arrangements with multiple property owners to gain access to and use that space.

We need a framework to establish a sustainable and affordable compensation structure and reduce transaction costs by applying standardized terms. The framework will cover government buildings, commercial, and residential buildings and land area (where that is not already covered by existing arrangements).

Compensation will be developed in a manner that ensures any compensation in the form of power is fairly priced, incentivizes the efficient use of power, and is simple to administer over time. We wish to avoid the outcomes of previous schemes where landowners have been provided with Government-paid-for-power (see below), which have expanded over time and resulted in poor incentives for the efficient use of power.

Space will also be required for wind turbines and other components, such as batteries. However, these are expected to be large one-off projects and can be dealt with under the standard land-leasing framework.

Sector governance and coordination

The pool of people in the RMI electricity sector is very small and there is a need to work closely together. Frameworks and legislation are helpful, but sector coordination and governance will need to focus on relationships, information sharing and effective decision-making.

RMI Roadmap Working Group

An RMI working group has been established to oversee the development and implementation of the Roadmap, as discussed in Chapter 8. The details of this are discussed further in the Financing and Implementation Working Paper (forthcoming). Core members include the Chief Executive and Chief Technical Officer of both MEC and KAJUR, the National Energy Planner (NEO), a representative from the Division of International Development Assistance, and the Chief Secretary or representative.

Ministry for the Environment, Climate Change and Energy

There is a proposal to establish a Ministry for Environment, Climate Change and Energy, bringing together the RMI Environmental Protection Authority, the Office of Environmental Policy and Planning Coordination and the National Energy Office. A bill for an Act providing a framework for this Ministry is to be put to the Nitijela (RMI Parliament) in late 2018, or early 2019.

National Energy Policy

A National Energy Policy (NEP) was drafted in 2009 and updated in 2014/15. The RMI Electricity Roadmap builds on and updates the NEP in the area of electricity only. The update is required for two key reasons:

1. The RMI's GHG reduction targets declared in the NDC in 2015 supercede the previous targets of 20 percent renewable energy by 2020 and the associated energy efficiency target, which are the overarching goals of the NEP.
2. The very substantial amount of development partner investment in the electricity sector in recent years was not apparent when the NEP was developed in 2014/15.

Although many of the goals and actions contained in the NEP remain relevant, these two new conditions create a very different context for the development of our electricity sector, requiring significant scale-up of effort and coordination.

In addition, the NEP is due for renewal this year as the planning period ends in 2019. We also note that the NEP and the Roadmap have a different scope: the Roadmap addresses only parts of the energy sector related to the generation, transmission, and use of electricity, while the NEP is comprehensive across all energy in the RMI, including petroleum, transport, and energy for cooking.

In effect, the Electricity Roadmap will supercede the NEP in the areas of electricity generation, distribution, and use, and become the framework document for developing our electricity sector.

Energy Sector Management Act

The NEP identifies the need for an Energy Sector Management Act to better define the roles and responsibilities of actors across the sector. The EU is providing technical assistance to develop the Energy Sector Management Act in early 2019. Some issues that could be considered in that Act include processes and responsibilities for:

- Setting electricity tariffs and subsidies.
- Monitoring and controlling fuel prices.
- Collecting and collating energy data.
- Regulations/standards for equipment.
- Licensing electricians and other skilled personnel.

It will be important to consider capacity, resourcing, and planning to implement this legislation. Often in the RMI these issues are neglected, and legislation is not implemented in its intended form.

Policies for energy efficiency and demand side management

Free power to landowners on Majuro

Originally established around three decades ago as compensation for utility easements over land, there are currently allocations of free power to almost 1000 MEC customers on Majuro. These customers receive 1000 kW/h a month, paid for by the RMI Government. The number of recipients of the free power is many times higher than when the mechanism was established, resulting in a cost to the Government of over $3 million a year.

Analysis of electricity use shows that, in general, these customers use more power each month than customers who do not receive free power, as there is little incentive for them to conserve energy. We need to switch the compensation for easements from free electricity to some other form, such as a direct payment, to remove the disincentive to conserve power and to encourage energy efficiency.

Energy efficiency and conservation measures

There are many possible measures for energy efficiency and conservation – only some of these require consideration as policies:

- Ensure building code focus on energy efficiency.
- Whole-of-life costs and energy use included in Government procurement of major items.
- Mandate the purchase of Energy Star (or similar energy rated labelling) appliances for all government agencies ('soft' internal government policy).
- Minimum energy performance standard (MEPS) and appliance labelling scheme.
- A ban on incandescent lightbulbs.
- Prescribe air conditioning temperature set points for government agencies ('soft' internal government policy).

Regulatory processes

As noted above, there are several areas where transparent regulatory processes may be useful, including tariffs, and standards for equipment and personnel. It is expected that both the EU technical assistance to develop an Energy Sector Management Act, and MEC reform technical assistance managed by the ADB, will explore these issues in more detail.

If processes are sufficiently transparent, we may not need an independent regulator. Regulatory processes could include: electricity tariff setting; technical standards on equipment; and licensing skilled personnel.

Electricity tariff and subsidy setting

The combination of tariffs and subsidies should be set to provide for the long-term financial sustainability of MEC and KAJUR, including allocation of future capital needs, while at the same time ensuring affordability to users.

It would support the financial sustainability of the utilities and the Government to have tariffs and subsidies set against objectives that focused on the long-term interest of users.

Building code

A building code is being developed with technical assistance from the Italian Government. Important considerations for the Electricity Roadmap include:

- That building envelopes are designed with energy efficiency in mind – either allowing for orientation and air flow so the building is cool without air conditioning, or with insulation and minimizing leakage and drafts when using air conditioning.
- That roof structures, particularly those of larger buildings, are suitable for mounting solar panels.
- The integrated design of right-sized HVAC cooling systems in larger buildings.

10.

Workplan to 2027

The key projects to be carried out in implementing this Roadmap are summarized in Figure 18. A more detailed Workplan [16] has been developed as a living document, forming the basis for ongoing discussions with development partners.

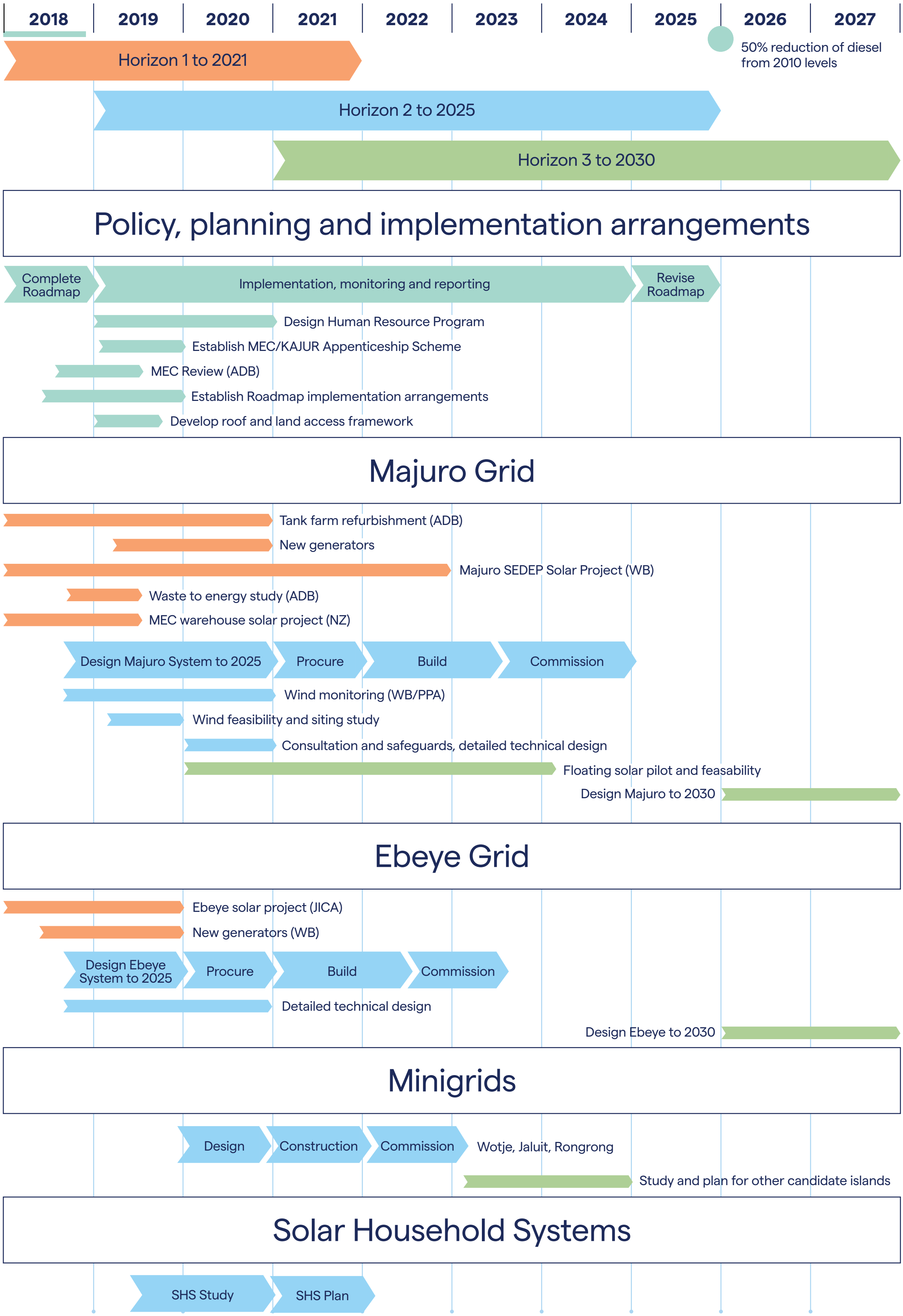


Figure 18: Summary of the workplan from 2018 to 2027

11.

Appendices

Summary of pathways and costs

		BASELINE	PATHWAY 1: WIND, SOLAR, AND BATTERY				PATHWAY 2: SOLAR AND BATTERY ONLY		
		2022	2025	2030	2050	2050	2025	2030	2050
					With biodiesel	Without biodiesel			
MAJURO	Diesel generation (MW)	12	–	–	12	12	–	–	12
	Solar PV (MW)	4	4	13	13	73	29	34	94
	Wind (MW)	–	12	12	12	42	–	–	–
	Battery (MWh)	1.5	20	20	20	300	38	75	1,050
	Annual OPEX ($M)	17.1	13.5	12.1	19.4	22.5	14.5	13.9	44.0
	Total CAPEX since 2018 ($M)	49.5	117.8	156.0	185.2	475.5	148.6	190.0	672.0
	Incremental CAPEX ($M)	49.5	68.3	38.2	29.2	319.5	99.1	41.4	482.0
	Diesel generation ($M)	9.0	–	–	9.0	9.0	–	–	9.0
	Solar PV ($M)	21.6	–	18.0	–	120.0	62.5	10.0	120.0
	Wind ($M)	–	39.2	–	–	164.6	–	–	–
	Battery ($M)	1.0	6.9	–	–	–	14.0	11.1	307.0
	Network and system ($M)	17.9	15.3	20.3	–	–	15.3	20.3	–
	Asset replacements ($M)	–	0.2	–	20.9	25.9	0.2	–	46.0
	Enabling technologies ($M)	–	6.0	–	–	–	6.0	–	–
	Simple LCOE ($/kWh)	0.29	0.29	0.29	0.35	0.55	0.32	0.34	0.93
	Renewable energy fraction (%)	9	54	68	100	100	51	67	100

		BASELINE	PATHWAY 1: WIND, SOLAR, AND BATTERY			
		2022	2025	2030	2050	2050
					With biodiesel	Without biodiesel
EBEYE	Diesel generation (MW)	2.6	–	–	2.5	2.5
	Installed solar PV (MW)	0.6	0.6	2.6	2.6	7.6
	Wind (MW)	–	3	3	3	7.5
	Battery (MWh)	0.6	6	6	6	150.6
	Annual OPEX ($M)	5.6	4.5	4.1	5.0	8.8
	Total CAPEX since 2018 ($M)	15.7	29.4	35.5	43.9	114.6
	Incremental CAPEX ($M)	–	13.7	6.1	8.4	79.1
	Diesel generation ($M)	1.9	–	–	1.5	1.5
	Solar PV ($M)	8.8	–	5.4	–	10.0
	Wind ($M)	–	9.4	–	–	13.4
	Battery ($M)	1.0	2.0	–	–	47.8
	Network and system ($M)	4.0	0.5	0.7	–	–
	Asset replacements ($M)	–	–	–	6.4	6.4
	Enabling technologies ($M)	–	1.8	–	–	–
	Simple LCOE ($/kWh)	0.37	0.36	0.38	0.44	0.90
	Renewable energy fraction (%)	5	51	68	100	100

Indicator framework

OUTCOME	INDICATOR	SYSTEM	TARGETS	COMMENTS
Reduced GHG economy-wide as per the RMI NDC	% reduction of GHG below 2010 levels	All RMI	As set out in the RMI's NDC 2025: 32% below 2010 levels 2030: 45% below 2010 levels 2050: net zero emissions	Measurement and reporting will be subject to guidelines for implementing the Paris Agreement.
Reduced GHG emissions from electricity	% reduction of GHG on 2010 levels in electricity sector	All RMI	2025: at least 50% below 2010 levels 2030: at least 65% below 2010 levels 2050: net zero emissions	As per RMI Electricity Roadmap TN-04 GHG Inventory and Targets, and assuming other sectors achieve the targets indicated in the RMI's NDC.
Reduced diesel use for electricity	Gallons per year diesel used for electricity generation	All RMI	2025: 2.91 million gallons 2030: 2.03 million gallons	As per RMI Electricity Roadmap TN-04 GHG Inventory and Targets.
		Majuro	2025: 2.34 million gallons 2030: 1.63 million gallons	As per RMI Electricity Roadmap TN-04 GHG Inventory and Targets.
		Ebeye	2025: 0.56 million gallons 2030: 0.39 million gallons	As per RMI Electricity Roadmap TN-04 GHG Inventory and Targets.
		Mini-grids	2025: TBD 2030: TBD	
	% reduction of diesel below 2010 levels	All RMI	2025: at least 50% below 2010 levels 2030: at least 65% below 2010 levels	As per RMI Electricity Roadmap TN-04 GHG Inventory and Targets.
		Majuro	2025: at least 48% below 2010 levels 2030: at least 64% below 2010 levels	As per RMI Electricity Roadmap TN-04 GHG Inventory and Targets.
		Ebeye	2025: at least 48% below 2010 levels 2030: at least 64% below 2010 levels	As per RMI Electricity Roadmap TN-04 GHG Inventory and Targets.
		Mini-grids	Greater than 90% reduction of diesel for each installed mini-grid.	
Appropriate service levels, improved reliability on Majuro and Ebeye	SAIDI (minutes)	Majuro	250	
		Ebeye	250	
	TBD	Mini-grids		
	TBD	SHS		
Improved supply side efficiency	Rate of generation losses %	Majuro		
		Ebeye		
	Rate of electricity transmission-distribution losses %	Majuro		
		Ebeye		

OUTCOME	INDICATOR	SYSTEM	TARGETS	COMMENTS
Improved energy use efficiency/ behavior change	Electricity consumption per unit GDP (MWh/$)	All RMI	2025: 10% reduction on 2018 levels 2030: 20% reduction on 2018 levels	Energy efficiency is very difficult to measure, particularly where there are trends for more air conditioning and appliances, meaning that people are seeking higher energy services.
	Average electricity consumption of households per capita (MWh/year)	Per grid	2025: 10% reduction on 2018 levels 2030: 20% reduction on 2018 levels	
	Average electricity consumption of households (MWh/ year)	Per grid	2025: 10% reduction on 2018 levels 2030: 20% reduction on 2018 levels	
	Energy use per government and commercial entity (MWh/year)	Per entity	2025: 10% reduction on 2018 levels 2030: 20% reduction on 2018 levels	Possibly want to set targets for the government sector much higher, as this can be influenced more strongly by 'soft' government policy and provides Government leadership messages.
Skilled Marshallese Workforce	# of enrolments in relevant engineering/ technical professional level qualifications (overseas) # of completions of relevant engineering/ technical professional level qualifications (overseas) # of professional qualified Marshallese technicians/ engineers working in the RMI # of professional qualified Marshallese technicians/ engineers working elsewhere			

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