Republic of the Marshall Islands Energy Future

Electricity Roadmap

Technical Note 11: Pathway to 100% by 2020

Final version, December 2018

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Executive Summary

During the *Tile Til Eo* Committee meeting on 1 August 2018, Minister David Paul tabled a potential new GHG target for RMI's electricity sector of "100% by 2020", or by 2025 (interpreted here to mean zero emissions from RMI electricity generation by 2020 or 2025). The Minister requested the RMI Roadmap consultant team carry out analysis on this target to potentially include the target in the RMI Electricity Roadmap. The following short paper estimates the mix of technology, capital cost, annual costs and levelized cost of electricity (LCOE) to achieve this target. It presents a high-level workplan to achieve this target and identifies some of the considerable risks associated with such a workplan.

There are three critical findings from this analysis:

1. Moving to 100% renewables or net zero GHG electricity emissions in any near-term timeframe increases recurring annual costs, which would likely be passed on through increased tariffs to consumers, in addition to the very substantial capital investment that is intended to be met primarily through donor grants.
2. The cost of electricity between 80 and 100% renewables contribution rises sharply using only solar, wind and batteries, and more slowly with the use of biodiesel, as can be seen in Figure 1. This means that it is likely to be more cost effective to go to 80% and to seek emission reductions in other sectors.
3. Aiming for a target of 100% reduction of electricity GHG by 2020 is not considered a feasible timeframe. It does not allow usual lead times for procurement or recruitment of personnel, and it will not be possible to carry out due diligence on investments, including feasibility studies, which creates a very high risk of failure.

We have assessed two options to take the RMI to net zero emissions for electricity using currently available technologies: the first is to use solar, wind, batteries and enabling technologies; the second is to incorporate biodiesel, along with solar, wind, batteries and enabling technologies.[1] We have assumed for the sake of this expedited analysis that large numbers of wind turbine installations are feasible on Majuro.

The first option would cost around $600 million in upfront capital, with $43 million a year in recurring costs, which is $17 million per year more than baseline. The second option uses imported biodiesel for up to 25% of the energy mix and is far less expensive at $260 million upfront, with $30 million a year in recurring costs, or $4m per year more than baseline.

Table 1 presents a summary of the upfront capital and annual costs for these two options to have net zero electricity GHG emissions across the whole of the RMI. Figure 1 shows how the LCOE (i.e. the total cost per kWh of supplying electricity) rises sharply after 80% reduction in emissions, and how costs can be reduced by using biodiesel to achieve up to the last 25% of reduction in emissions.

[1] Note that even under the first option, biodiesel is recommended for backup on Majuro and Ebeye and to provide the last few percentage of energy for outer-island mini-grids.

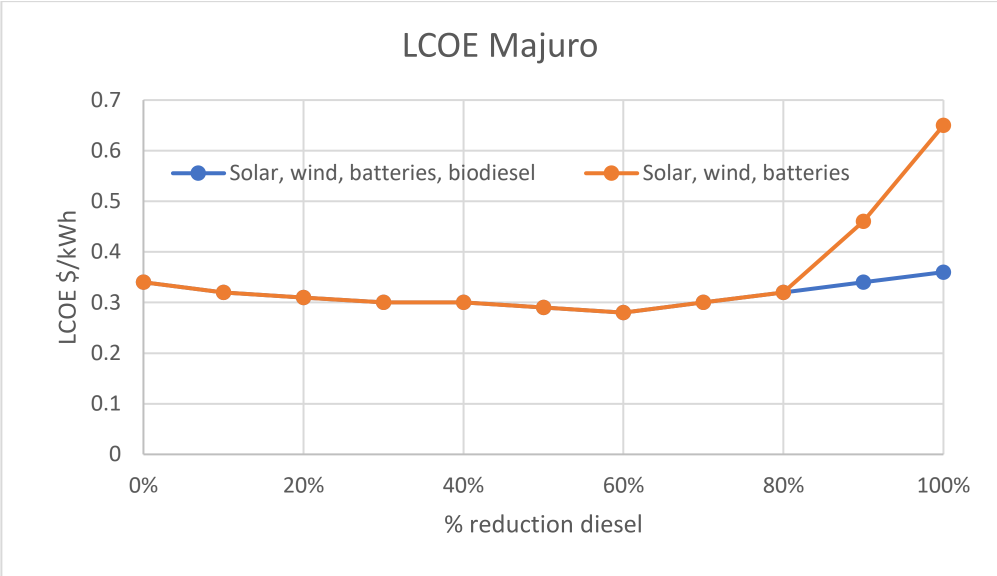

Figure 1: Majuro LCOE increases dramatically between 80 and 100% reduction in GHG for solar, wind and batteries, and can be significantly reduced if biodiesel is used.

	Initial Capital Cost (Donors)	Annual deposit in replacement reserve fund	Annual O&M	Annual fuel cost	**Total Annual costs faced by RMI**	LCOE (USD/kWh)
Baseline (existing planned projects)	$100m	$1.3m	$10m	$15m diesel	**$26m**	0.32 Majuro 0.37 Ebeye
Option 1: solar, wind and batteries	$600m	$19m	$24m	$0	**$43m**	0.65 Majuro 0.76 Ebeye
Option 2: solar, wind, batteries and biodiesel	$260m	$9m	$13m	$8m biodiesel	**$30m**	0.36 Majuro 0.46 Ebeye

Table 1: Costs faced by RMI for 100%/ net zero electricity nationwide 2020

It is assumed that four outer islands with sizeable communities will be converted to hybrid mini-grids with very high (90%+) levels of penetration of variable renewable energy, and the remaining few percent provided by imported biodiesel.

Waste-to-energy does not feature in a net zero emissions system for Majuro as the combustion of plastics and waste oil emits GHGs.

We would expect a dramatic effort to reduce the overall energy use in the Marshall Islands as part of a push to net zero emissions, to reduce the expense of investing in 100% renewables generation.

If diesel or waste-to-energy in any amount were part of the electricity energy mix, the RMI would need to purchase carbon offset units on the international market to achieve net zero emissions in electricity.

1 Background

During the *Tile Til Eo* Committee meeting on 1 August 2018, Minister David Paul tabled a potential new GHG target for RMI's electricity sector of "100% by 2020", or by 2025 (interpreted here to mean zero emissions from RMI electricity generation by 2020 or 2025). The Minister requested the RMI Roadmap consultant team carry out analysis on this target and include the target in the RMI Electricity Roadmap.

This paper estimates the mix of technology, capital cost, operating costs and levelized cost of electricity to achieve this target. It presents a view of what would need to be done to achieve this target and identifies the considerable technical and financial risks associated with such an approach.

This analysis comes after extensive analysis had previously been carried out by the Roadmap team and peer reviewed by experts, based on the RMI's NDC to achieve 32% reduction of 2010 GHG by 2025, 45% by 2030 and 100% by 2050, and is necessarily expedited and high-level as the resources available to complete detailed analysis under this project are exhausted.

We have set up a HOMER modelling scenario to reduce emissions/ diesel use to net zero with present day prices for equipment purchase. Net zero emissions were previously analysed by the Roadmap team for 2050 in line with the RMI's NDC. Replacement costs in that analysis assumed prices on equipment, especially batteries and PV panels continue to reduce with time.

2 Pathways to 100% for Majuro and Ebeye

2.1 Baseline 2022

For this baseline analysis, we assume that existing projects underway are completed; the World Bank and MFAT projects on Majuro and the JICA project on Ebeye. We also assume new diesel generators and significant investment in the degraded network.

2.2 Option 1: Solar, wind and batteries

The capital cost of equipment to build generation and enabling technologies is around $600 million. Annual costs faced by the RMI *in addition to that* would be around $43 million including deposits to a replacement reserve fund, or $17m/ year higher than the baseline scenario (current planned projects for Majuro and Ebeye+ grid investment). This is a 65% increase over the baseline cost to utilities to supply electricity.

The simple levelized cost of electricity (LCOE) would double from current costs to 65c/kWh on Majuro and 76c/kWh on Ebeye. Increased costs faced by utilities suggest that tariffs would likely need to increase.

2.2.1 Majuro

To achieve 100% renewable electricity (or zero emissions) on Majuro by 2020 without the use of biodiesel, would require:

- 74 MW solar PV ($210m, 180 acres of space)
- 30 MW wind ($92m, 30 - 60 turbines)
- 225 MWh batteries ($101m, 5 acres of space)
- Control and enabling technologies ($7m)
- Network investment ($53m).

In this case, we consider there is no need to replace the existing generators as they will only be used as backup in the case of a failure or prolonged period of low wind or solar resource.

Floating solar: There is very likely not sufficient space on Majuro for the required 180 acres (75ha) of PV and therefore floating PV would need to be used. Floating solar in marine environments is very much an emerging technology and a pilot study would be required, but in this timeframe solar would need to be deployed immediately. This means there is a high risk of failure for the floating solar, until we know how it performs in the corrosive environment and in adverse weather conditions in Majuro lagoon.

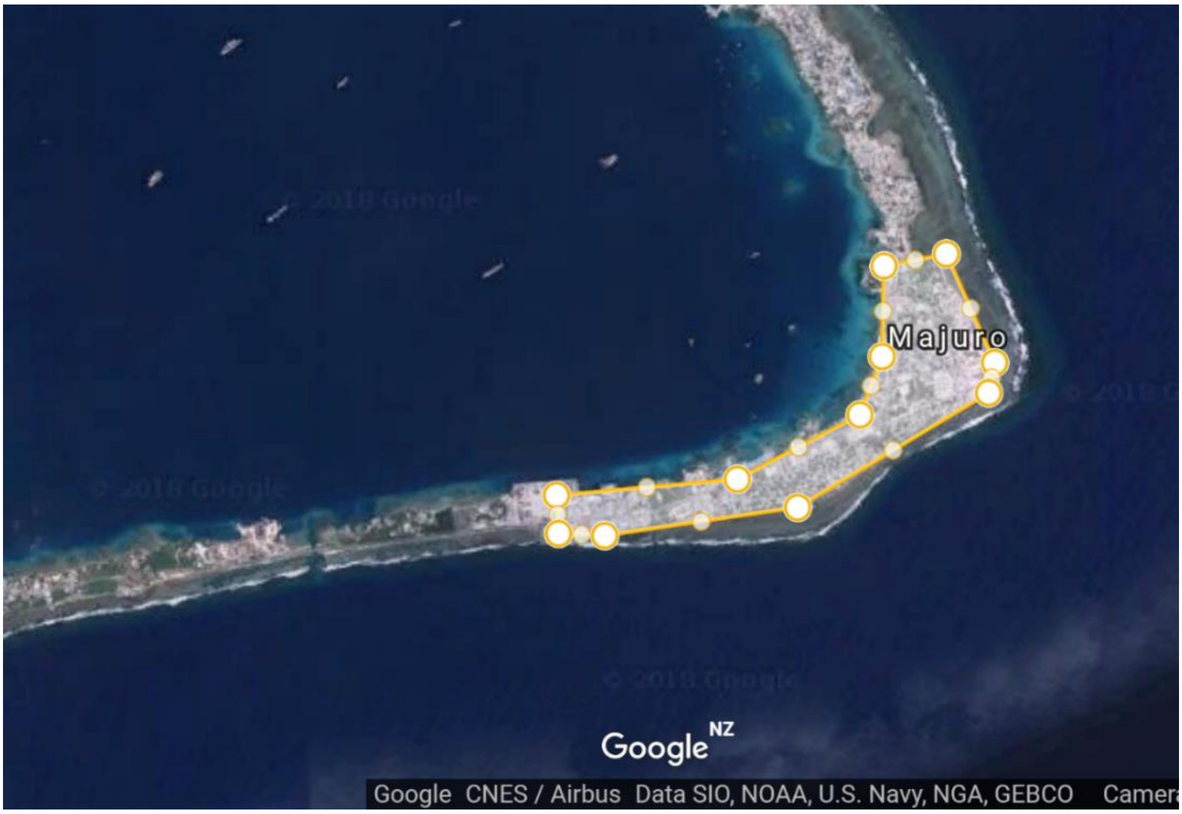

Figure 2: Illustration of the scale of solar panels required when compared to Delap on Majuro Atoll. The shape outlined is around 175 acres of land, or the area required by 70MW of solar panels.

Batteries: At 225MWh, batteries for this option are almost double the size of the “world’s largest Tesla battery” in Adelaide, Australia. The floor space required for this installation is around 5 acres (2 ha), which will need to be elevated and protected from storm surges. This would require most of the area currently used for Majuro’s port, for example.

Figure 3: Map showing required land area for batteries on Majuro (5 acres) near the power station

Wind: As has been detailed at length in the techno-economic analysis and supporting documents, preliminary analysis shows the potential for a good wind resource on Majuro, although this is not yet supported by the on-site wind monitoring usually required for a bankable project. To be able to build this by 2020, funders would need to be convinced to invest on this basis, which is highly unlikely. In addition manufacturer warranties for turbines in an uncharacterized resource are unlikely to be obtained. 30MW of wind turbines could be thirty 1MW turbines. It will need to be determined whether the reef flat identified as a possible site near Ajeltake is large enough to accommodate 30MW of turbines, or whether people will need to be relocated or alternatively islands on the north of Majuro utilised. The timeframe does not allow for proper environmental and social impact assessment.

Figure 4: Possible sites for 30MW wind turbines on Majuro

2.2.2 Ebeye

On Ebeye the requirements for net zero emissions using wind, solar, batteries and enabling technologies are:

- 11 MW solar PV ($40m, 27 acres of space)
- 7 MW wind ($21m, 7 - 14 turbines)
- 75 MWh batteries ($34m, 1.7 acres of space)
- Controls and enabling tech ($3m)
- Network investment ($5m).

There is likely enough suitable space for wind and solar along reef flats next to the causeway to Gugeegue. Around 2 acres of space would need to be found suitable for mounting batteries.

2.2.3 Mini-grids

Aside from Jaluit, Wotje and RongRong, other islands using diesel as their main supply (e.g. Kili, Santos) will need to be replaced with either SHS or with solar hybrid mini-grids. The last few percent of energy that cannot economically be provided by solar, wind and batteries will need to be provided by biodiesel, or an acceptance that there may be no power sometimes for days at a time.

It is assumed that Jaluit, Wotje, RongRong and Kili will be converted to hybrid mini-grids with very high levels of penetration of variable renewable generation and the remaining few percent to be met with imported biodiesel. It is assumed that Santos will have a similar system installed, however this would need to be designed and built from scratch. The combined cost to install these systems is assumed to be $20m, with combined running costs per year of $2.1m. All other outer islands are assumed to be serviced by solar household systems with $4m per year covering replacement and O&M costs. However, these costs are excluded from the analysis as they are the same as the baseline scenario.

2.3 Option 2: Solar, wind, batteries and biodiesel

The use of biodiesel significantly changes the economics by eliminating the need for ‘oversizing’ RE generation and storage to achieve these last few percent of diesel replacement. The options presented below for Majuro and Ebeye that include biodiesel are the “least cost” mix of wind, solar and biodiesel. We have made some assumptions about the costs of biodiesel – but the price of biodiesel is complex and influenced by many factors.

If biodiesel is used, the capital cost of equipment to build generation and enabling technologies to achieve 100% renewable electricity (or zero emissions) by 2020 is around $260 million. Annual costs faced by the RMI in addition to that would be around $30 million including biodiesel costs and deposits to replacement reserve fund, or around $4m/year higher than baseline, in other words a 15% increase in the cost to KAJUR and MEC.

The simple levelized cost of electricity would increase from around 32c/kWh on Majuro to 36c/kWh, and from 37c/kWh on Ebeye to around 46c/kWh.

In our understanding, the combustion of biodiesel does result in some greenhouse gases. In UNFCCC reporting, CO2 emissions from biofuels are not included in national emissions, however, N2O and CH4 and other products of combustion are included. Work will need to be done to estimate these emissions and to offset them via purchasing of international carbon credits or other means to achieve net zero emissions.

If using biodiesel, the RMI should also be aware of the reputational implications (as climate leadership is the reason for attempting to reduce emissions to zero). Life cycle analyses have been done on biofuels and while some have net zero or even negative emissions, others have high emissions, sometimes higher than fossil fuels over their life due to fertilisers, clearing of forests and other activities in growing the biomass to make biofuels. Typically, the “greener” biofuels will be more expensive.

2.4 Summary of Pathways to 100% by 2020 - costs

		Initial Capital Cost	Annual deposit in replacement reserve fund	Annual O&M	Annual fuel cost	Total Annual costs	LCOE (USD/kWh)
Majuro							
Baseline	Includes existing PV, WB and MFAT projects, new gensets and some network investment	$82m	$1.2m/year *2032 $10m, 2045 $8m*	$6.2m	$10.6m	**$18m**	0.32
Option 1:	74 MW solar PV ($210m), 30 MW wind ($92m), 225 MWh batteries ($101m), Controls and enabling tech ($7m), Network investment ($53m)	$486m	$14m/ year *2030 $73m, 2032 $15m, 2045 $148m*	$17m	$0	**$31m**	0.65
Option 2:	6 x 2MW generators ($9m), 10 MW solar PV ($30m), 20 MW wind ($63m), 23 MWh batteries ($10m), Biodiesel (24%) 1.3 million gallons/year, Controls and enabling tech ($7m), Network investment ($53m)	$192m	$4.2m/year *2030 $7m, 2032 $2.8m, 2040 $38m, 2045 $28m, 2053 $9m*	$8.6m	$6.3m biodiesel	**$19.1m**	0.36
Ebeye							
Baseline	Includes JICA 600kW +BESS, 2 new 1300kW generators	$17m	$.1m/year	$2.8m	$2.7m	**$5.6m**	0.37
Option 1:	11 MW solar PV ($40m), 7 MW wind ($21m), 75 MWh batteries ($34m), Controls and enabling tech ($3m), Network investment ($5m)	$102m	$4.3m/year *2030 $24m, 2032 $2.2m, 2040 $17m, 2045 $22m*	$5.3m	$0	**$9.6m**	0.76
Option 2:	2 x 1300kW generators ($1.9m), 3.6 MW solar PV ($19m), 4.5 MW wind ($14m), 6 MWh batteries ($2.7m), Biodiesel (23%) 0.26 million gallons/year, Controls and enabling tech ($3m), Network investment ($5m)	$47m	$3.8m/year *2020 $2m, 2030 $10m, 2032 $.7m, 2040 $9m, 2045 $7.2m*	$3.4m	$1.3m biodiesel	**$8.5m**	0.46
Mini-grids[2]							
Baseline	Jaluit, Wotje, Kili, Rongrong		DG replacement costs (excluded from this table)	$974k	$1.8m[3]	~$2.8m	
Hybrid minigrids (assume 90% VRE)	Jaluit, Wotje, Kili, Rongrong, and also establishing a minigrid on Santos	$20m	$.5m	$1.3m	$270k biodiesel	~$2.1m	-

[2] Kili and Santos costs are indicative/speculative given a lack of accurate data – see Techno Economic Analysis Report for further details
[3] Includes an additional $4.49/USG fuel delivery cost for Jaluit, Wotje and Kili (based on 2016 RepMar subsidy for Wotje and Jaluit)

2.5 Key assumptions:

- Annual total costs assume ALL CAPITAL is grant funded. If any capital is loan financed, additional loan repayments will be added to the above annual costs.
- Wind and solar resource as detailed in TN02 Inputs and Assumptions
- Upfront equipment prices are current assuming a 2020 timeframe, with replacement costs lower due to anticipated reductions in equipment costs.
    - Wind $5.1/W for one turbine installed falling to $3.0/W for ten turbines installed, remaining constant over time
    - Majuro wind transmission line $4.4m, Ebeye wind transmission line $540k
    - PV $3/W falling to $2/W for system replacement costs after 25 years, and inverter replacements at $0.2/W.
    - BESS $450/kWh falling to $325kW/h for replacement costs in 10 years
    - Majuro and Ebeye control systems $1m each
    - Majuro enabling technologies for grid stability $6m
    - Ebeye enabling technologies for grid stability $1.8m
- PV O&M costs $60/kW/yr
- BESS O&M costs $20/kWh capacity/yr
- Wind O&M costs $100/kW/yr for one turbine -> $77/kW/yr for ten turbines
- Diesel $2.45/gallon constant over time (oil price around $70/bbl)
- Biodiesel $4.92/gallon constant over time
- 0% real discount rate
- Prices are inexact and should be considered to have a range of at least +/- 25%.

See TN 03 for further key assumptions

3 Discussion

3.1 Costs faced by RMI increase substantially

It is sometimes mentioned that capital grant financing is "free money" and that moving to renewables will save the RMI money from lower diesel fuel use. At lower levels of renewables, by following a least-cost path we might expect some modest reduction in costs faced by RMI (as presented in the Technology Pathways/ Techno-economic analysis report).

However, as with other infrastructure investment, it is expected that replacement and maintenance costs need to be fully financed by the RMI, even if the initial capital expenditure is grant funded. The best way to plan for this is to 'save' capital replacement costs annually so that the finance is available when replacement is required.

In short, shifting to a capital-intensive electricity system places a heavy annual cost on the utilities to save for replacement, and if that does not happen, there is will be a very large financial obligation for capital replacement on the future governments of the RMI. If that obligation cannot be met, the RMI's electricity system will be at risk of collapse.

A good example of this is the current need to urgently replace generators on Majuro and Ebeye and the lack of readily available capital to finance that. If Option 1 in this analysis was adopted, the RMI would need to find around $100 million in capital for equipment replacement in 10 years' time, and a further $150m in 25 years' time.

This analysis assumes that:

- all upfront capital costs are grant financed. If upfront capital is loan financed, there would be additional loan repayments not included in this analysis.
- RMI bears the costs of operation, maintenance and replacement of equipment, as is the case for most donor-funded infrastructure programs.

3.2 Coconut oil as biodiesel

Although coconut oil has been mentioned in various documents as a potential indigenous renewable fuel for electricity generation in the Marshall Islands, there are several problems which make it unsuitable for inclusion in a short-term pathway to 100% by 2020 or 2025. The first is that technically it has not been shown to work consistently for any length of time in power generation, meaning we can consider it an early stage technology. What we do know about the technology is that it likely requires chemical processing (for example, trans-esterification) to convert coconut oil to a "drop-in" replacement for diesel, which adds to the cost and requires a whole new industrial facility to be established. It may also require modifications to conventional generators such as pre-heaters and filters, and likely increased maintenance due to the different properties it has from mineral diesel.

One of the reasons for the lack of development of coconut oil as a biofuel is the recent high world price of coconut oil based on its value in other uses for food and cosmetics. Which means that in general, it is more cost effective for the RMI to export coconut oil and to import cheaper biodiesel manufactured elsewhere. However, the current world price of biodiesel and coconut oil are both currently around $1,000 per metric tonne, so the option of manufacturing biodiesel from coconut oil could be further considered in the future to replace imported biodiesel.

3.3 Waste to energy

Waste to energy does not feature for either scenario for Majuro. A waste-to-energy plant would combust plastics and waste oil, emitting GHGs, and therefore does not form part of a net zero emissions system, unless the RMI wished to purchase international carbon credits to offset.

3.4 Carbon offsets

If diesel or waste-to-energy in any amount were part of the electricity energy mix, the RMI would need to purchase carbon offset units on the international market. Prices for these are difficult to forecast, but we could estimate between $30 and $100 USD per tonne of CO2-e.

3.5 Energy efficiency and demand side management

We would expect that, given the great expense of moving towards net zero emissions in the electricity sector, a dramatic effort should be made to reduce the overall energy use in the Marshall Islands. Active demand side management should also be considered to reduce the amount of. batteries and generation required- that is, asking businesses, homes and government offices to switch off power when renewables are low- that could reduce the amount of investment required and the overall cost. This would require significant behaviour change for government and businesses. We assume that fully automated “smart grid” demand side management would not be feasible to build and manage in the short- to medium-term. Although we have not costed it, we expect that a program to subsidise or to fund the replacement of appliances to energy efficient appliances would be a cost-effective alternative to building some portion of the renewables in this 100% scenario.

4 Workplan

4.1 100% by 2020

With a proposed date for bringing the RMI to net zero emissions in electricity by the end of 2020, the following activities would need to be expedited. The workplan below assumes that grant financing for capital is immediately available from development partners. It should be noted that we do not think this is a feasible workplan as it does not allow for due process, feasibility studies, wind monitoring, social and environmental impact assessment, or for appropriate and realistic procurement and contracting processes and creates unacceptably high risks for the RMI and its people.

2018

- Select the option of with or without biodiesel
- Confirm grant financing available for the required amount ($600m or $250m)
- Procurement of design engineers
- Commence procurement of biodiesel supplies and commence withdrawal from existing MEC fuel purchase contracts
- Commence procurement of mini-grids

2019

- Carry out technical design for entire Majuro grid, using proxy data from Kwajelein wind data for wind turbine specification
- Carry out technical design for Ebeye grid
- Write equipment specifications, tender documents, and select suitable tenderers.

2019- 2020

- Build and commission all plants
- Enter into long-term service contracts with suppliers
- Recruitment of in-house engineers and management for MEC and KAJUR
- Commence training of local staff.

4.2 Risks

Expediting and scaling up these large capital intensive projects comes with significant risks. These are briefly noted below.

Risk	Consequence	Likelihood rating	Impact rating	Risk rating
If wind turbines are built without proper wind monitoring data…	… wind power on Majuro may not meet expectations, resulting in greater need for batteries or solar.	Medium	High	High
If wind turbines are built without due process around noise and community perception…	… the quality of life of people on Majuro may be impacted by noise.	Low if turbines are located adequate distance away from homes and buildings.	Medium	Medium
If floating solar is installed without a good understanding of how it will survive in its environment…	…the floating solar may, corrode, be damaged or fail during a storm, with a resulting financial loss.	High	High	High
If floating solar is installed without a good understanding of how it will be maintained and operated	…the floating solar may, produce significantly less power than expected.	High	High	High
If the RMI takes significant capital assets onto its books…	… it may not be able to afford the replacement costs over time, resulting in a degraded or non-functioning electricity system.	High	High	High
If biodiesel or carbon credit prices go up under Option 2…	… operating expenses could go up.	Medium	Medium	Medium
If critical capacity in the RMI is not available….	… projects will not be successfully implemented and operated.	High	High	High

4.3 100% by 2025

This technical paper did not analyse this scenario, but due to very short timeframes between now and 2020, a scenario with more realistic, yet still ambitious, timeframe is considered.

Shifting the timeframe to 2025 would enable the required wind monitoring, feasibility and floating solar pilot studies to be done, thereby mitigating some of the risks presented above. However, there would not be any significant change in the high costs faced by the RMI in that timeframe.

5 Conclusions

In conclusion:

- moving to 100% renewables or net zero GHG electricity emissions in any near-term timeframe increases costs on the RMI Government very substantially, in addition to the very substantial capital investment that would be made through donor grants.
- this cost can be reduced significantly by using biodiesel for up to 25% of energy.
- the cost of electricity goes up dramatically between 80 and 100% GHG reductions.
- if the target is 100% reduction of GHG by 2020, it will not be possible to carry out due diligence on investments, including feasibility studies (due to the short timeframe), creating a very high risk of failure.