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PNNL-36888

Power Supply Options for the Marpi Landfill, Saipan

Comprehensive Feasibility Study

November 2024

Malcolm P Moncheur de Rieudotte
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Christopher R Niebylski
Lindsay M Sheridan

U.S. DEPARTMENT OF ENERGY
Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99354

Executive Summary

The Marpi Landfill (“Marpi” or “the landfill”), located on the northern end of the island of Saipan in the Commonwealth of the Northern Mariana Islands (CNMI), is powered by a single on-site diesel generator that only operates when the landfill is open and staffed. The project team, composed of representatives of the Department of Public Works and the Office of Planning and Development (OPD), aspires to provide the Marpi Landfill with 24-hour power availability despite its remote location to increase the use of sustainable energy and to ensure environmentally compliant landfill operations. This is consistent with the sustainable development goals documented in the 2021–2030 Comprehensive Sustainable Development Plan (OPD 2021), including Goal #12 (ensure environmentally compliant waste management facilities) and Goal #7 (renewable energy deployment). Further, the CNMI has a 20% target for renewable energy consumption by 2030, as documented in the 2021–2030 Comprehensive Sustainable Development Plan (OPD 2021) and the renewable portfolio standard (Public Law 18-62). To accomplish these goals, the Federal Emergency Management Agency, through its Interagency Reimbursable Work Agreement with the U.S. Department of Energy, funded a feasibility study and follow-up study in 2023–2024 to assess and prioritize power supply options for the landfill. This report combines the results from both feasibility studies.

Marpi Landfill Loads

This feasibility study evaluated the power requirements for the Marpi Landfill under three conditions: (1) current conditions, (2) 24/7 operations, and (3) 24/7 operations with electric equipment. The loads for each of these scenarios are presented below.

Current Conditions: Marpi’s power requirements are driven primarily by pump loads; standard leachate and storm pumps operate the majority of the time when the landfill is open (Monday through Saturday from 7:30 a.m. to 4:30 p.m.) to keep the leachate below a certain level. Due to increased pump usage to control leachate levels during the rainy season (July through November), the facility’s load correspondingly increases. Based on the estimated loads for each of the site’s current and future end uses (through the end of the useful life of Cell 3), as characterized by the CNMI Department of Public Works team and the landfill operators, Marpi’s expected annual consumption is estimated to be 170 MWh, with a peak load of 112 kW. Figure ES-1 shows the hourly load profile for a typical week during both the dry and rainy seasons under current conditions.

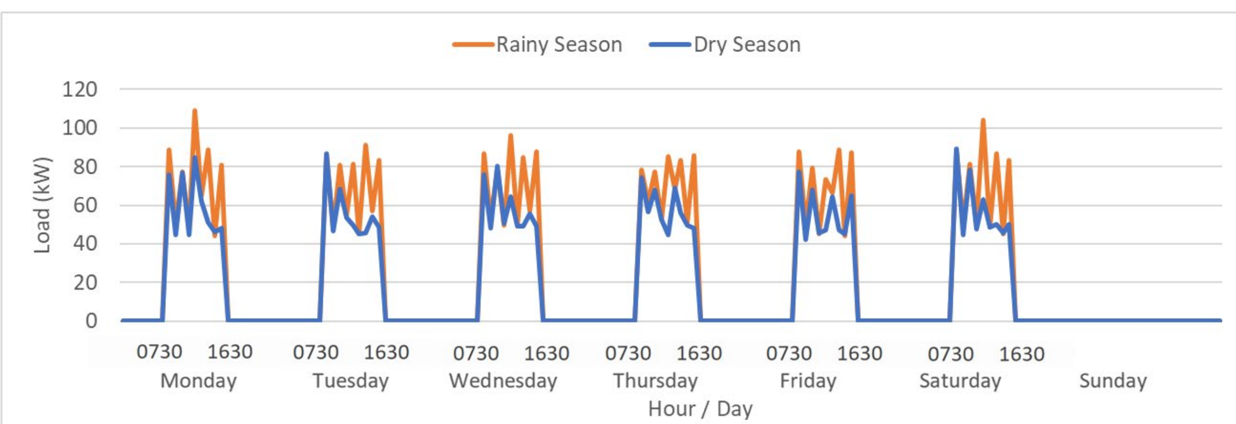

Figure ES-1. Estimated typical weekly Marpi Landfill load profile (current conditions).

24/7 Operations: This analysis assumes 24/7 operations for the Cell 2 and Cell 3 standard leachate and storm pumps to keep leachate levels below permit requirements.

Because of increased pump usage to control leachate levels during the rainy season (July through November), the facility's electric loads correspondingly increase. Based on the estimated loads for each of the site's current and future (through the end of the useful life of Cell 3) end uses under a 24/7 operational scenario, Marpi's expected annual consumption is estimated to be 182 MWh, with a peak electric demand of 109 kW. Figure ES-2 shows the "24/7 operations baseline" hourly load profile for a typical week during both the dry and rainy seasons.

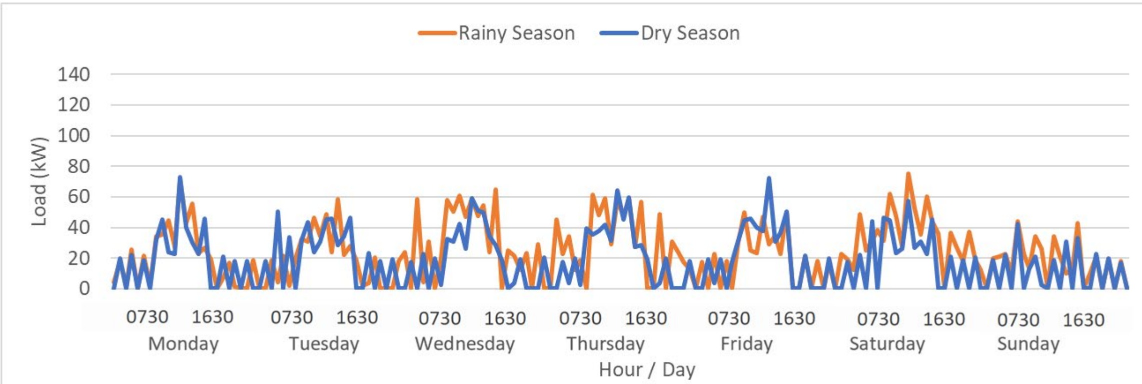

Figure ES-2. Estimated typical weekly Marpi Landfill load profile (24/7 operations baseline).

24/7 Operations with Electric Equipment: Further modifying landfill operations to include charging electric versions of existing landfill equipment would reduce the landfill's reliance on diesel fuel and reduce on-site air pollution and greenhouse gas emissions. Based on guidance from the Solid Waste Management Taskforce (SW Taskforce), the estimated 24/7 load profile was revised to account for charging electric versions of the existing dump truck, payloader, tanker truck, utility trucks, riding mower, and brush cutters.

This revised load profile assumes the chargers operate at a reduced rate throughout the night, rather than simultaneously at their maximum charge rate, to avoid significantly oversizing the power supply components. If simultaneous charging at their maximum rate is required, additional analysis will be needed. This will likely require increased generation and storage capacity beyond what is described in the power supply scenarios below.

Based on these additional loads, the landfill's expected annual electricity consumption with 24/7 operations and electric landfill equipment is estimated to be 458 MWh, with a peak load of 155 kW. Figure ES-3 shows the "24/7 operations & electric equipment" hourly load profile for a typical week during both the dry and rainy seasons. Since the electric equipment is only used when the landfill is open, the load goes down during the weekend.

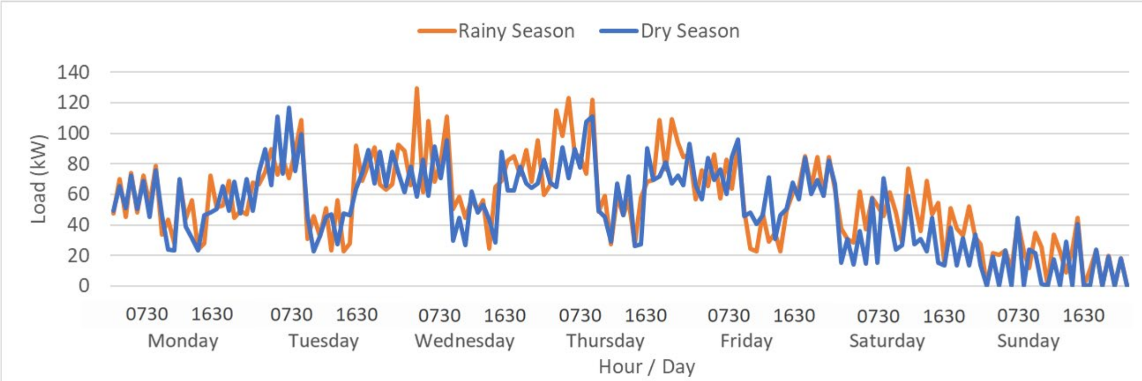

Figure ES-3. Estimated typical weekly Marpi Landfill load profile (24/7 operations & electric equipment).

Power Supply Scenarios

The 24/7 operations baseline and 24/7 operations & electric equipment load profiles were inputs to the technical and economic evaluation of several power supply scenarios. Each power supply scenario is a microgrid—a small power system that can operate independently from the larger grid. The scenarios evaluated were driven by the available energy resources for Marpi, which were determined through a resource screening. The screening identified solar photovoltaics (PV), wind turbines, battery energy storage systems (BESSs), and diesel generator technologies as viable options for inclusion in a power supply scenario located at the landfill.

The availability of solar and wind resources varies seasonally, as do the electric loads. A BESS can help to balance the mismatches between generation and load on short (hourly or daily) timescales but not across seasons. The microgrid scenarios evaluated for Marpi consider technology combinations that fully meet the load and utilize available resources. These scenarios face challenges due to the conjunction of higher loads and lower solar and wind availability during the rainy season. Figure ES-4 depicts these challenges for the current conditions load profile.

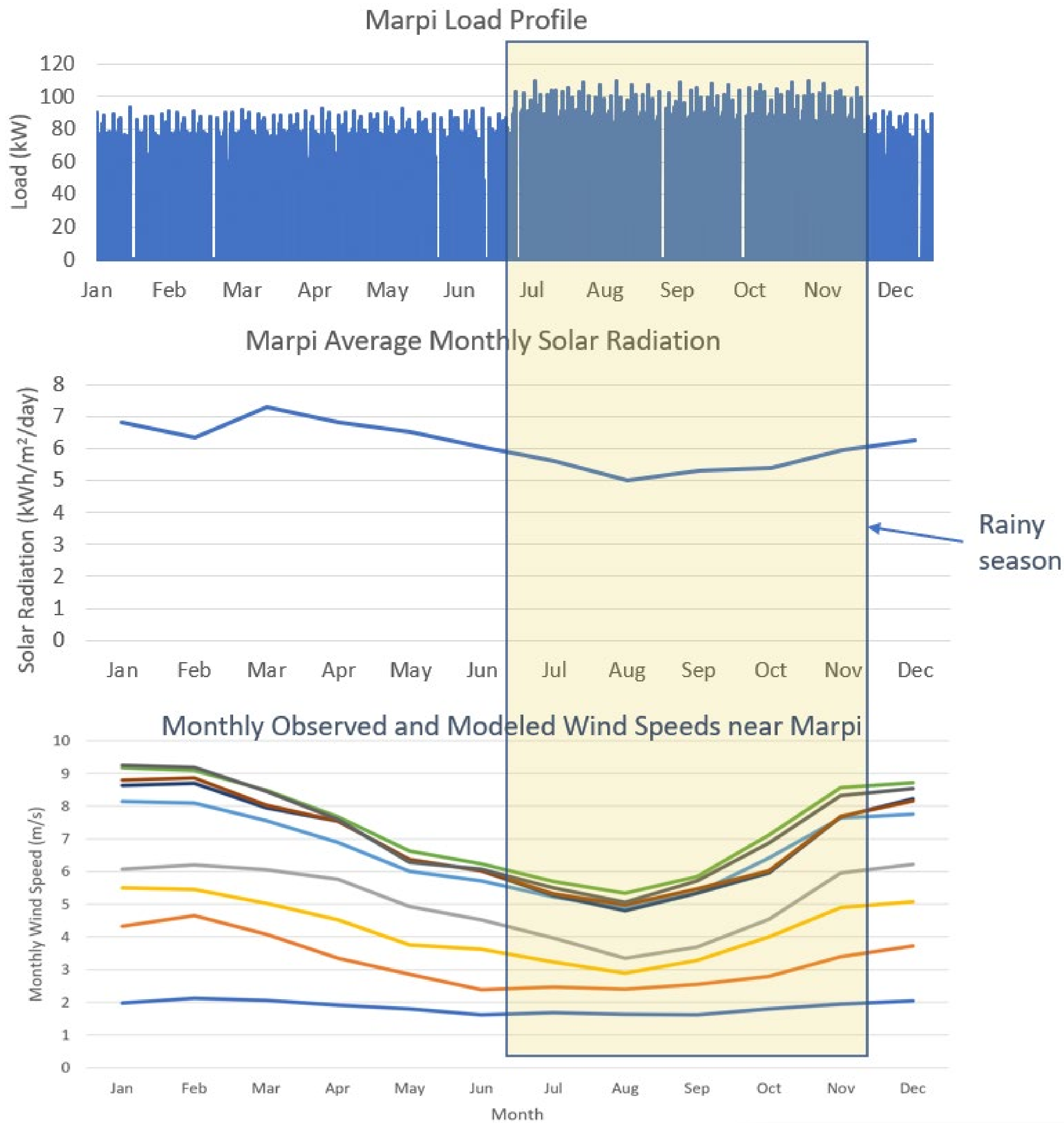

Figure ES-4. Rainy season impacts on the current conditions at the Marpi Landfill: load and solar and wind resources.

The seven power supply scenarios evaluated and presented in the tables below are as follows:

1. Solar PV + BESS
2. Wind + BESS
3. Solar PV + Wind + BESS
4. Solar PV + BESS + Diesel Generator
5. Wind + BESS + Diesel Generator

6. Solar PV + Wind + BESS + Diesel Generator
7. Diesel Generator Only[1].

Table ES-1 (24/7 operations baseline) and Table ES-2 (24/7 operations & electric equipment) summarize these scenarios as they apply to each load profile. Each scenario's configuration was optimized to include component capacities that reduce capital and operating costs, meet the load, and minimize carbon emissions, as feasible. The costs and levelized costs of energy (LCOEs) shown do not assume the use of any grant funding or incentives. The LCOE includes the cost of new distribution lines between new generation equipment and existing loads, the cost of replacing existing distribution lines at end of life (between loads and the existing diesel generator), and the social cost of carbon.

Most of the power supply scenarios require increased equipment capacity to provide uninterrupted power for the charging demands for electric landfill equipment. Because of the increased solar PV equipment capacity, some of the scenarios that include solar PV for the 24/7 operations & electric equipment load profile will not fit within the preferred project location's footprint and would require other areas of the landfill property or surrounding public land to provide additional space. Those scenarios are indicated in red font color and with an asterisk in Table ES-2.

Table ES-1. Summary of the evaluated scenarios (24/7 operations baseline).

Scenario	Solar PV (kW)	Wind Turbine (kW)	Diesel Generator (kW)	Battery (kW/kWh)	Capital Cost ($M)	Annual O&M Costs ($k/yr)	25-year LCOE ($/kWh)	Social Cost of Carbon ($k)	CO_2e Emissions Generated (tons/yr)	% Renewable Energy Curtailed Annually	% Load Not Met Annually
PV/BESS	200	0	0	250/1000	4.7	5	2.00	0	0	45%	0%
Wind/BESS	0	100	0	200/800	3.6	13	2.60	0	0	32%	33%
PV/Wind/BESS	150	100	0	150/600	4.0	14	1.85	0	0	58%	0%
PV/BESS/Gen	100	0	160	100/400	3.0	18	1.52	42	21	24%	0%
Wind/BESS/Gen	0	100	160	100/400	3.3	41	1.81	102	50	36%	0%
PV/Wind/BESS/Gen	100	100	160	60/120	3.2	19	1.58	24	12	52%	0%
Diesel Generator	0	0	160	0	0.8	75	1.2	270	132	0%	0%

[1] This scenario differs from current landfill operations in that the diesel generator is configured with the ability to operate 24/7 to meet permit requirements.

Table ES-2. Summary of the evaluated scenarios (24/7 operations & electric equipment).

Scenario	Solar PV (kW)	Wind Turbine (kW)	Diesel Generator (kW)	Battery (kW/kWh)	Capital Cost ($M)	Annual O&M Costs ($k/yr)	25-year LCOE ($/kWh)	Social Cost of Carbon ($k)	CO_2e Emissions Generated (tons/yr)	% Renewable Energy Curtailed Annually	% Load Not Met Annually
PV/BESS*	500	0	0	600/2400	8.7	12	1.47	0	0	45%	0%
Wind/BESS	0	100	0	300/1200	4.9	15	2.25	0	0	4%	62%
PV/Wind/BESS*	400	100	0	500/2000	10.4	21	1.71	0	0	46%	0%
PV/BESS/Gen*	300	0	300	300/1200	7.9	34	1.37	99	48	21%	0%
Wind/BESS/Gen	0	100	300	100/400	4.1	133	1.15	433	211	8%	0%
PV/Wind/BESS/Gen*	250	100	300	250/1000	7.9	44	1.41	97	48	34%	0%
Diesel Generator	0	0	300	0	1.5	190	0.97	680	332	0%	0%

For both load profiles, diesel generation alone (Scenario 7) has the lowest capital cost and the lowest LCOE without grants, but the highest annual operations and maintenance (O&M) costs and highest social cost of carbon. Solar PV, BESS, and diesel generation (Scenario 4) has the lowest LCOE of the scenarios that use renewable energy for the 24/7 operations baseline load profile, and the second-lowest for the 24/7 operations & electric equipment load profile. The three scenarios that do not use any diesel generation (Scenarios 1–3) have the highest capital costs and the highest LCOEs, but some of the lowest annual O&M costs, with Solar PV + BESS (Scenario 1) having the lowest O&M cost.

The costs of installing new distribution cable range between $29k and $483k, depending on the scenario and load profile. This is because different capacities of solar PV, wind, BESS, and diesel generators generate different amounts of current, which require cables rated for different ampacities, and cables with higher ampacity ratings are more expensive than those with lower ratings. The existing distribution cable, which connects loads to the existing generator, will need to be replaced within the lifetime of the project, with an estimated cost of approximately $802k. This value remains the same across scenarios because the replacement distribution cable is rated for the same ampacity no matter the power supply scenario.

The social cost of carbon for scenarios with diesel generators ranges from $24k to $270k for the 24/7 operations baseline load profile and from $97k to $680k for the 24/7 operations & electric equipment load profile. The higher costs for the latter are a result of the diesel generator operating more frequently to meet the greater loads resulting from the charging of electrified landfill equipment.

Potential Project Location

The potentially preferred location for a microgrid identified by the project team is in the southwest corner of the landfill property, near the location of the existing generator and electrical switchgear. A potential project layout that includes all considered microgrid components is presented in Figure ES-5, indicating potential component sizes that will fit within this space. New generators and batteries could be placed next to or at the current generator location. PV panels could be placed on a structural steel-framed roof structure shading the residential dropoff point, in addition to some ground-mounted panels.

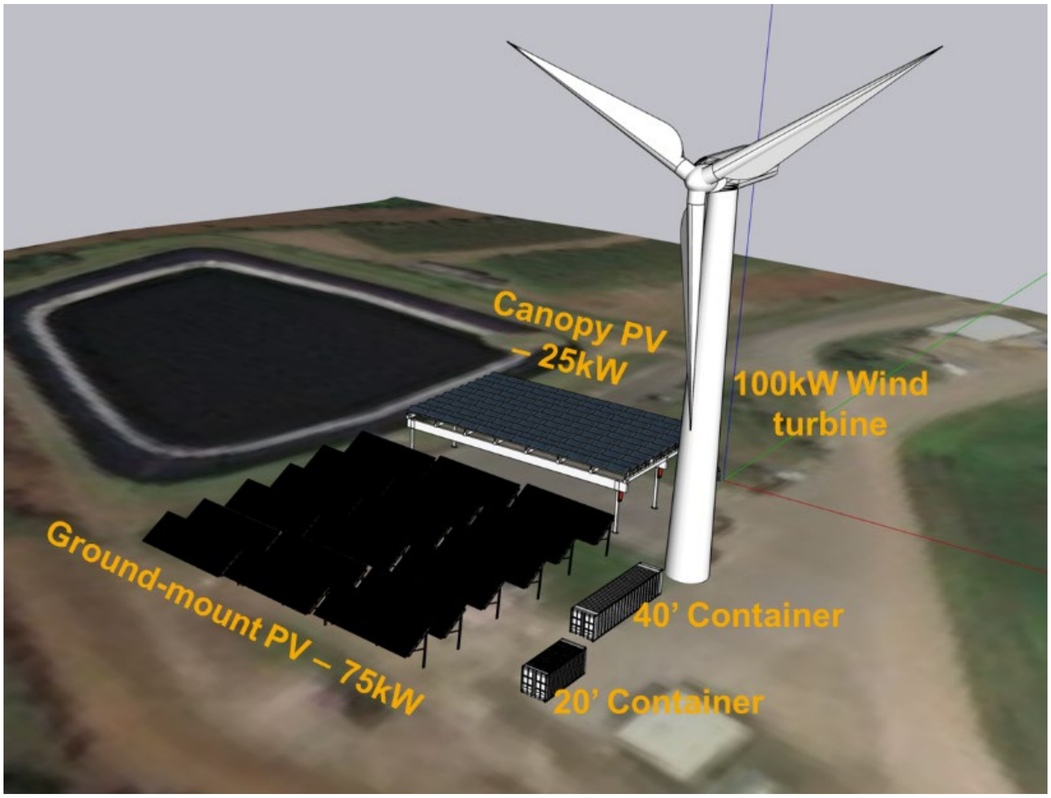

Figure ES-5. Potential layout for the microgrid components on the landfill property.

Hazards & Hardening Techniques

Several key hazards were identified for the Marpi microgrid; these hazards, as well as hardening techniques to reduce the risk of damage to the microgrid components from these hazards, are summarized in Table ES-3. Existing projects on Saipan were found to follow these techniques, such as the PV system at the Commonwealth Healthcare Corporation that is designed to withstand 200 mph winds.

Table ES-3. Hardening techniques for the microgrid components at the Marpi Landfill.

Technology	Typhoons	Aerosol Salt Deposition	Earthquakes
PV panels	Wind-load-rated racking to withstand ~200 mph winds and panel protection from flying debris (e.g., FEMA guidance, IEC 61730 and IEC 61215 certification)	Panels that comply with IEC 61215 standards for salt mist corrosion; UL 1703; NEMA 4X-6P-rated enclosures for ancillary equipment	Rack ratings for seismically active areas (ASCE 7-10 design categories)
Wind turbines	Tilt-up technology; rotor braking; ballast foundation	Similar standards for salt mist corrosion as PV	American Clean Power Standard 61400-1 includes seismic loading recommendations
Generator, BESS	Hardened enclosure with NEMA/IP ratings; structural fencing	NEMA-rated enclosure; CARC paint; MIL-STD 810G compliance;	Seismic retrofits and anchoring (e.g., for fuel tanks); adherence to Unified Facilities Criteria (UFC

	IEC 61427 and 62933 and IEEE 1679 (batteries, environmental conditions)	3-310-04); IEEE Recommended Practices for Seismic Design of Substations (IEEE 693-2005)

Scenario Prioritization

To assist with decision-making, two prioritization matrices (Table ES-4 and Table ES-5) were created to compare the power supply scenarios associated with the 24/7 operations baseline and 24/7 operations & electric equipment load profiles, respectively, according to various stakeholder priorities. The prioritization metrics were chosen based on discussions with OPD and were finalized through stakeholder feedback. The scenarios were given a score between 1 and 7 for how well they met each prioritization metric (the lower the score, the higher the priority), and total scores were calculated using assigned weights based on the relative priority of each metric. The total scores were then ranked to produce a prioritized list of microgrid scenarios based on the metrics most important to the project stakeholders.

These rankings show that a microgrid that includes a solar PV array, BESS, and diesel generator (Scenario 4) is the favored option for both load profiles. However, meeting the charging load for the 24/7 operations & electric equipment load profile with Scenario 4 requires more land than what was identified as available at the landfill. Table ES-6 shows the top three power supply scenarios for both load profiles. This table does not exclude scenarios that do not fit within the preferred project location's footprint and would require other areas of the landfill property or surrounding public land to provide additional space.

Funding Opportunities & Recommendations

Depending on the technology configuration, system ownership, and implementation timing of the microgrid for Marpi, there may be opportunities to defray some or all of the capital costs associated with purchasing and installing the equipment and infrastructure.

As of Spring 2024, several federal grants are available or announced that may be options for the Marpi microgrid project. Grant information, including funding amounts, key areas of interest, funding agency eligibility, lead agency responsibilities, and application deadlines, are described in Section 8.1. Table ES-7 highlights funding amounts and previous application windows for each opportunity.

Table ES-7. Funding opportunity, funding amount, and previous application window.

Funding Opportunity	Funding Amount	Previous Application Window
FEMA Building Resilient Infrastructure and Communities Program	Up to $2M per recipient in 2023	10/16/2023–02/29/2024
Department of Interior (DOI) Energizing Insular Communities (EIC) Program	Up to $4M per recipient in 2023	03/27/2023–06/15/2023
EPA Climate Pollution Reduction Planning Grant	Up to $500,000 per territory recipient in 2023	06/15/2023
EPA Climate Pollution Reduction Implementation Grant	$1–25M per recipient	04/01/2024

Funding Opportunity	Funding Amount	Previous Application Window
EPA Diesel Emission Reduction Act (DERA)	National Grants: Up to $4.5M per recipient (Region 9). State and Territory Grants: Guam and American Samoa received approximately $126,000 each. Tribal and Territorial Grants: Must not exceed $400,000.	National Grants: 12/01/2023 State and Territory Grants: 12/01/2023 Tribal and Territory Grants: 12/06/2024
DOI Office of Insular Affairs (OIA) Maintenance Assistance Program	In 2024, DOI will award $4.375M across 20 awards. In 2023, CNMI received $1.1M	03/17/2024
EPA Environmental Justice Grants (Community Change Grants)	$10–20M	Rolling applications accepted through 11/21/2024

One potential path forward is for OPD to evaluate and pursue funding opportunities in conjunction with a request for information or request for proposals from potential vendors. Suitable solutions may result from such a process, especially if a single-vendor microgrid is desired. The responses will need to be carefully evaluated in cases where the proposed solutions do not align with the scenarios presented here because there are still many undefined factors and other options may also be viable. These steps will assist the SW Taskforce in meeting their clean and resilient energy goals.

Table ES-4. Prioritization of Marpi power supply scenarios (24/7 operations baseline).

Relative Metric Priority	1	5	1	3	4	1	3	3	1	2	2		
Prioritization Metric	Capital Cost	Annual O&M Costs	25-Year Levelized Cost of Energy	% Load Not Met Annually	Meets Permit Req. for Backup Power	CO_2e Emissions Generated	Area Req.	Diversity of Resources (# of components)	Equipment Hardening Req.	Training Req.	Smart Safe Growth		
Scenario	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Total Score	Rank
PV/BESS	7	1	6	3	7	1	4	5	2	3	2	3.17	4
Wind/BESS	5	2	7	7	7	1	4	5	5	3	5	4.00	7
PV/Wind/BESS	6	3	5	3	7	1	4	2	6	5	5	3.60	6
PV/BESS/Gen	2	4	2	1	1	5	1	2	3	5	4	2.20	1
Wind/BESS/Gen	4	6	4	1	1	6	4	2	4	5	7	3.23	5
PV/Wind/BESS/Gen	3	5	3	1	1	4	4	1	7	7	6	3.00	2
Diesel Generator	1	7	1	1	1	7	1	7	1	2	5	3.00	2

Table ES-5. Prioritization of Marpi power supply scenarios (24/7 operations & electric equipment).

Relative Metric Priority	1	5	1	3	4	1	3	3	1	2	2		
Prioritization Metric	Capital Cost	Annual O&M Costs	25-Year Levelized Cost of Energy	% Load Not Met Annually	Meets Permit Req. for Backup Power	CO_2e Emissions Generated	Area Req.	Diversity of Resources (# of components)	Equipment Hardening Req.	Training Req.	Smart Safe Growth		
Scenario	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Total Score	Rank
PV/BESS	6	1	5	3	7	1	7	5	2	3	2	3.40	5
Wind/BESS	3	2	7	7	7	1	4	5	5	3	5	3.93	6
PV/Wind/BESS	7	3	6	3	7	1	7	2	6	5	5	3.97	7
PV/BESS/Gen	4	4	3	1	1	4	7	2	3	5	4	2.87	1
Wind/BESS/Gen	2	6	2	1	1	6	4	2	4	5	7	3.10	3
PV/Wind/BESS/Gen	4	5	4	1	1	4	7	1	7	7	6	3.37	4
Diesel Generator	1	7	1	1	1	7	1	7	1	2	5	3.00	2

* Please see Appendix F for a Smart Safe Growth analysis of the proposed options.

Table ES-6. Top three ranked power supply scenarios.

Ranking	24/7 Operations Baseline	24/7 Operations & Electric Equipment
1	Scenario 4: • 100 kW solar PV • 100 kW/400 kWh BESS • 160 kW diesel generator	Scenario 4: • 300 kW solar PV • 300 kW/1,200 kWh BESS • 300 kW diesel generator
2	*Tied:* Scenario 6: • 100 kW solar PV • 100 kW wind • 60 kW/120 kWh BESS • 160 kW diesel generator Scenario 7: • 160 kW diesel generator	Scenario 7: • 300 kW diesel generator
3	*Tied:* Scenario 6: • 100 kW solar PV • 100 kW wind • 60 kW/120 kWh BESS • 160 kW diesel generator Scenario 7: • 160 kW diesel generator	Scenario 5: • 100 kW wind • 500 kW/2,000 kWh BESS • 300 kW diesel generator

Acknowledgments

Pacific Northwest National Laboratory (PNNL) would like to acknowledge the Commonwealth of the Northern Mariana Islands (CMNI) Office of Planning and Development (OPD) team, specifically Erin Derrington, Michael Johnson, Matthew Nieswender, and Ricardo Miranda, for their support in the development of this report, especially coordinating with stakeholders and providing data. Other key stakeholders from CNMI who collaborated with the PNNL team include Secretary Ray Yumul, Solid Waste Division Director Blas Mafnas, and Solid Waste Accountant Lina Torres from the Department of Public Works; Director Zabrina Shai, Solid Waste Manager Greg Reyes, Administrator Eli Cabrera, and Safe Drinking Water Program Manager CDR Travis Spaeth from the Bureau of Environmental and Coastal Quality; Director Elizabeth Balajadia, Deputy Director Christopher Sablan, and previous Acting Director Chris Concepcion and Communications Specialist Joshua Santos from the Office of Planning and Development; and James Benavente and Mahesh Balakrishnan from MES, the landfill operator. Adam Klein from the Federal Emergency Management Agency and Pete Gingrass from the U.S. Department of Energy provided key direction and guidance throughout the process. From PNNL, Brittany Tarufelli and Mark Weimar provided economic analysis support, Bilal Faye provided grants research support, Michael Brown provided distribution system support, Pamela Jackson provided review support, and Isaiah Steinke provided technical editing support.

This feasibility study was funded by the Federal Emergency Management Agency through its Interagency Reimbursable Work Agreement with the U.S. Department of Energy.

Acronyms and Abbreviations

AC	alternating current
ACF	area cost factor
BECQ	Bureau of Environmental and Coastal Quality
BESS	battery energy storage systems
BNEF	Bloomberg New Energy Finance
BOP	balance of plant
BRIC	Building Resilient Infrastructure and Communities
CBO	community-based nonprofit organization
CHCC	Commonwealth Healthcare Corporation
CNMI	Commonwealth of the Northern Mariana Islands
CO_2e	carbon dioxide equivalent
CUC	Commonwealth Utilities Corporation
DC	direct current
DERA	Diesel Emission Reduction Act
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of Interior
DPW	Department of Public Works
ECMWF	European Centre for Medium-Range Weather Forecasts
EIC	Energizing Insular Communities
EPA	US Environmental Protection Agency
ERA5	ECMWF Reanalysis v5
FEMA	Federal Emergency Management Agency
GHG	greenhouse gas
GSA	General Services Administration
GWA3	Global Wind Atlas 3
HDPE	high-density polyethylene
IPP	independent power producer
IRA	Inflation Reduction Act
IRS	Internal Revenue Service
IRWA	Interagency Reimbursable Work Agreement
ITC	Investment Tax Credits
LCOE	levelized cost of energy
Li-ion	lithium-ion
MACRS	Modified Accelerated Cost Recovery System
MES	Micronesian Environment Services, LLC

NEMA	National Electrical Manufacturers Association
NREL	National Renewable Energy Laboratory
NSRDB	National Solar Radiation Database
O&M	operations and maintenance
OIA	Office of Insular Affairs
OMB	Office of Management and Budget
OPD	Office of Planning and Development
PCAP	Priority Climate Action Plan
PM	particulate matter
PNNL	Pacific Northwest National Laboratory
PV	photovoltaics
QA	quality assurance
QC	quality control
RICE	reciprocating internal combustion engine
SF	Standard Form
SoC	state of charge
SSG	Smart, Safe Growth
SW Taskforce	Solid Waste Taskforce
USACE	U.S. Army Corps of Engineers

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1.0 Introduction

The Marpi Landfill ("Marpi" or "the landfill") is located in a remote area on the northern end of the island of Saipan in the Commonwealth of the Northern Mariana Islands (CNMI). It is not served power by the local utility but rather by an on-site diesel generator that only operates when the landfill is open and staffed. Marpi is owned by the CNMI government and operated by a contractor, Micronesian Environment Services, LLC (MES), who also operates the generator. The current contract ends in July 2025.

The CNMI's Inter-island Solid Waste Management Taskforce (SW Taskforce) comprises representatives from the Department of Public Works (DPW), the Office of Planning and Development (OPD), the Bureau of Environmental and Coastal Quality (BECQ), representatives from offices of the Mayors, and the U.S. Environmental Protection Agency. The SW Taskforce was established in 2020 to support ongoing disaster response and recovery as it relates to solid waste and develop comprehensive and sustainable integrated solid waste management systems for the CNMI. It studies, makes recommendations, builds capacity, and implements projects to improve waste management across the islands, including landfill operations, recycling programs, and reuse initiatives. Members of the SW Taskforce representing DPW Saipan, BECQ, and OPD comprise the project team.

The project team aspires to provide Marpi with 24-hour power availability despite its remote location and to increase sustainable energy consumption within the CNMI. Accordingly, this feasibility study assesses and prioritizes power supply options to determine the optimal method for serving the landfill while meeting both reliability and sustainability goals.

1.1 Background

The need for a Backup Power Feasibility Study for the Marpi Landfill was first identified as a need to build capacity and resilience to natural disasters by the project team and the U.S. Environmental Protection Agency (EPA) Region 9 in early 2021. Because of its remote location on the north end of Saipan, Marpi has never been connected to the main power grid operated by the Commonwealth Utilities Corporation (CUC) and has instead been powered by diesel generators since it opened in 2003.

The project team solicited proposals in September 2021 for the development of a power supply feasibility assessment and cost benefit analysis for the leachate pump system and other operational loads serving the Marpi Landfill. Because of a lack of positive responses to the solicitation, the project team requested technical assistance from the U.S. Federal Emergency Management Agency (FEMA) and the Department of Energy (DOE) to conduct the analysis. FEMA provided funding allocated by its Interagency Reimbursable Work Agreement (IRWA) with DOE for energy recovery technical assistance in CNMI to fulfill this technical assistance request. This activity falls under deliverable 3 of the IRWA: technical and advisory assistance to the CNMI, and CNMI public entities, to support the federal investments made for the long-term resilient recovery of the CNMI's power system.

The members of the SW Taskforce have provided local insights and perspective on current and future power needs at the landfill and considerations for various power supply options. As the lead agency in solid waste infrastructure management, the DPW is the ultimate decision-maker regarding how the recommendations developed in this study will be incorporated into future Marpi Landfill operations and subsequent permit amendments and facility updates.

In response to the technical assistance request and in alignment with the SW Taskforce direction, this feasibility study explores alternative energy options that support the following local goals and strategic plans:

- Expand the use of residential and commercial rooftop solar photovoltaic (PV) systems to accomplish the CNMI Strategic Energy Plan's vision of creating a sustainable energy future for the CNMI (GHD 2022).
- Ensure access to affordable, reliable, sustainable, and modern energy for all, which is Sustainable Development Goal #7 in the Comprehensive Sustainable Development Plan and sets a target of 20% renewable energy portfolio for power needs by 2030 (OPD 2021).
- Support sustainable and environmentally compliant waste management systems in the CNMI, which is a component of Sustainable Development Goal #12 in the Comprehensive Sustainable Development Plan (OPD 2021).
- Achieve 20% of electricity sales from renewable resources by 2016, a target set by the CNMI renewable portfolio standard (Public Law 18-62).

Ensuring that Marpi can sustainably continue operations is a critical part of achieving these goals.

1.2 Scope

In 2023, Pacific Northwest National Laboratory (PNNL) conducted a feasibility study that evaluated alternative power supply options for Marpi. This feasibility study culminated in a report named "Power Supply Options for the Marpi Landfill, Saipan" (Solana et al. 2023). In 2023–2024, PNNL conducted a follow-up study assessing additional considerations regarding power supply options for Marpi. These included adjusting equipment dispatch in anticipation of 24/7 power supply availability, evaluating the impact of electrifying landfill equipment, and estimating the cost of new distribution lines between new generation equipment and loads (including the costs of replacing existing lines). This culminated in a report named "Power Supply Options for the Marpi Landfill, Saipan – Addendum to 2023 Feasibility Study" (Moncheur de Rieudotte et al. 2024). PNNL also researched specific funding opportunities available for Marpi and documented key information, including funding amounts, key areas of interest, funding agency eligibility, lead agency responsibilities, and application deadlines.

This report combines the original feasibility study, addendum report, and funding opportunities research into a single document.

This report presents each step of the feasibility analysis. Inputs to the analysis include a characterization of current and future landfill electric loads (Section 2.0) and an understanding of power supply options available for Marpi (Section 3.0). Using these inputs, a technical and economic evaluation of various power supply scenarios was conducted, as presented in Section 4.0. Additional factors for project feasibility include potential project siting options and considerations (Section 5.0) and natural hazard risks and mitigation (Section 6.0). Various stakeholders provided input on the prioritization of scenarios (Section 7.0). Implementation considerations including funding, procurement, ownership, and training options are discussed in Section 8.0. Overall project recommendations and next steps are presented in Section 9.0.

2.0 Landfill Operations and Estimated Loads

The Marpi Landfill typically operates Monday through Saturday from 7:30 a.m. to 4:30 p.m. It closes during severe-weather-related emergencies, and after it reopens, the operational hours can change from 6 a.m. to 6 p.m. as needed. During or after high rainfall conditions, the operating hours may also change from 6 a.m. to 6 p.m. Pumps are used to control leachate and stormwater levels when the landfill is open. Pumps are not used outside these hours because the generator is turned off when the landfill is unoccupied.

The landfill consists of an office building, a scale house, a maintenance building, a generator house, and several landfill cells (Figure 1). Cell 1 is the existing operational area, which is nearly full. Cell 2 is currently under rehabilitation, and Cell 3 is the future operational area, the design of which has been completed. This feasibility analysis included landfill operations up to the useful lives of Cell 2 and Cell 3. Cell 1 will receive waste intermittently until 2026-2027 in tandem with the ongoing Cell 2 operations. Cell 2 started operations in January of 2024. Cell 3 has not been constructed but is designed to have a service life of about 10 years.

Figure 1. Marpi Landfill cell layout; all structures are west of Cell 1.

From 2002 to 2014, a DPW-owned 200 kW diesel generator powered Marpi. In 2014, this generator became unserviceable, and the DPW rented a 175 kW diesel generator to provide power while awaiting the procurement of a 125 kW diesel backup generator. The 175 kW rental was used until the DPW procured the 125 kW backup generator in 2015. The DPW intended to use this backup generator to provide power to the landfill until the DPW repaired the 200 kW generator. However, the backup generator frequently broke down between 2015 and 2017 because of overuse and operation above its rated capacity.

Between 2017 and 2020, the DPW resorted to renting a 175 kW diesel generator to meet the power requirements of the landfill. This generator was the primary source of power for Marpi until a new operator/maintenance contractor began their contract in 2021. Since 2021, a 125 kW rental diesel generator has been the sole source of power for the landfill. This generator is not metered, and as such, no generation or hourly load data are available.

To characterize current and future loads, an hourly load profile for the landfill was generated based on information provided by the DPW and site operator. Marpi's power requirements are driven by pump loads; to keep the leachate below a certain level, pumps are running the majority of the time that the landfill is open. Within buildings, air conditioning and lighting are the main power draws. Because of increased pump usage to control leachate levels during the rainy season, the facility's load correspondingly increases. More information on how this load profile was generated is detailed in Appendix A.

Marpi's current annual consumption is estimated to be 170 MWh, with a peak load of 112 kW. Figure 2 shows the hourly load profile for a typical week during both the dry and rainy seasons under current conditions.

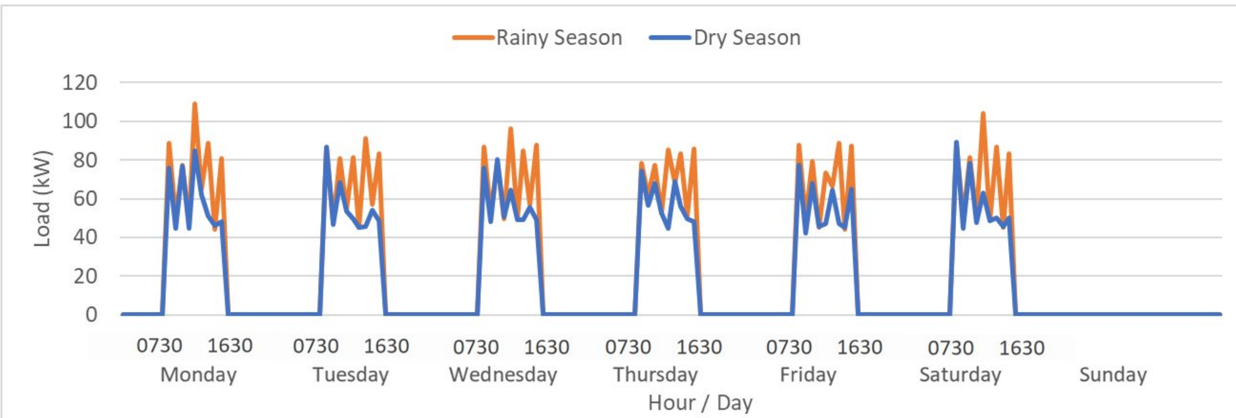

Figure 2. Estimated typical weekly Marpi Landfill load profile (current conditions).

However, a 24/7 power supply is necessary for leachate pumping operations to ensure that leachate accumulating above the high-density polyethylene (HDPE) liners is maintained at a level not to exceed 30 cm, as required by CNMI permit requirements[2].

A new load profile was generated, assuming 24/7 future operations can spread pump loads across hours when the landfill is closed (Sundays and evenings) since the power supply options investigated in this analysis can provide 24/7 power. The energy use of some equipment that is not currently functional is included in this profile, as well as that of some future loads such as the pumps for Cell 3. More information on the load descriptions, power draw, duty cycles, and assumptions used to generate the hourly load profile is detailed in Appendix C.

This analysis focuses on the need for 24/7 operations for the Cell 2 and Cell 3 standard leachate and storm pumps. Pump loads at Marpi are not metered, so reliable estimates of these loads do not exist. Operational logger data for Cell 2 standard and storm pumps (spanning

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[2] CNMI Solid Waste Management Facility Permit No. SWMF-S-LF-01-2021. This permit requires the manual operation of leachate pumps to make sure that the landfill leachate depth does not at any time exceed 30 cm over the liner.

August 14, 2023–September 18, 2023) provided by the landfill operator were analyzed to determine daily pump operation hours during the rainy season. The logger data show that the stormwater pump in Cell 2 is in operation 3 hours per day on average, with a maximum of 12 hours per day, and that the standard pump is in operation 5.4 hours per day, also with a maximum of 12 hours per day. The logger data indicate that both pumps are turned on and off multiple times throughout the day to control leachate levels. However, the logger data show that the leachate level exceeds the permitted levels for the full extent of time recorded. Through conversation with the DPW and OPD, it was assumed that the standard and storm pumps would need to operate 1.5 times as long during the rainy season to sufficiently lower leachate levels to meet permit requirements. As such, pump operation hours from the logger data were scaled by 1.5 and extrapolated to every month of the rainy season for both Cell 2 and Cell 3 standard and storm pumps, with pump loads randomly assigned throughout the day and night.

Based on the assumed 24/7 pump operations, the landfill's annual consumption is estimated to be 182 MWh, with a peak load of 109 kW. Figure 3 shows the estimated hourly load profile for a typical year, and Figure 4 shows the estimated hourly load profile for a typical week during both the dry and rainy seasons, respectively.

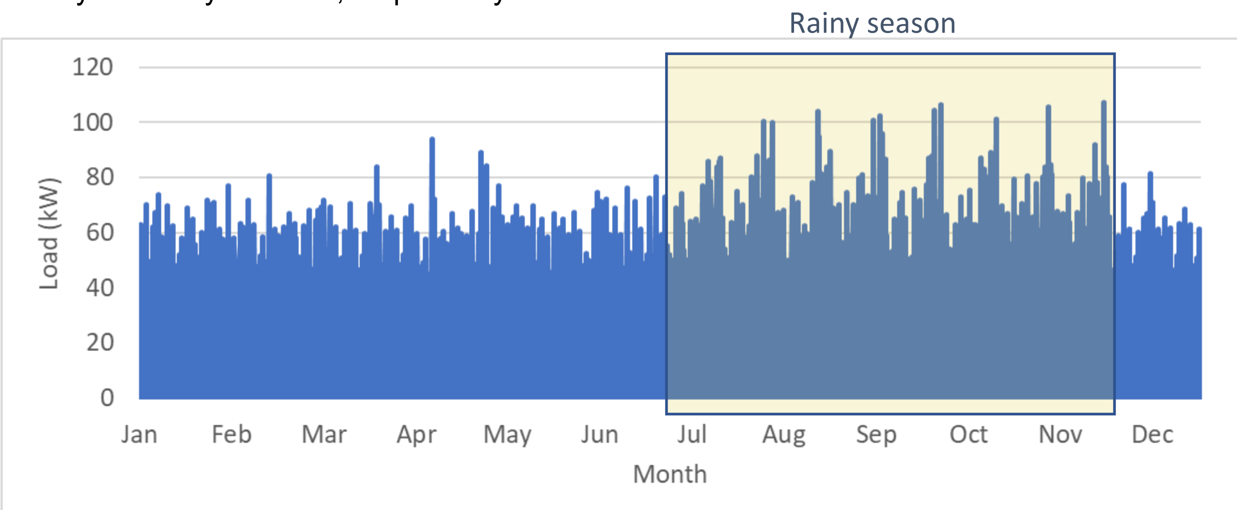

Figure 3. Estimated hourly Marpi Landfill load profile with 24/7 operations.

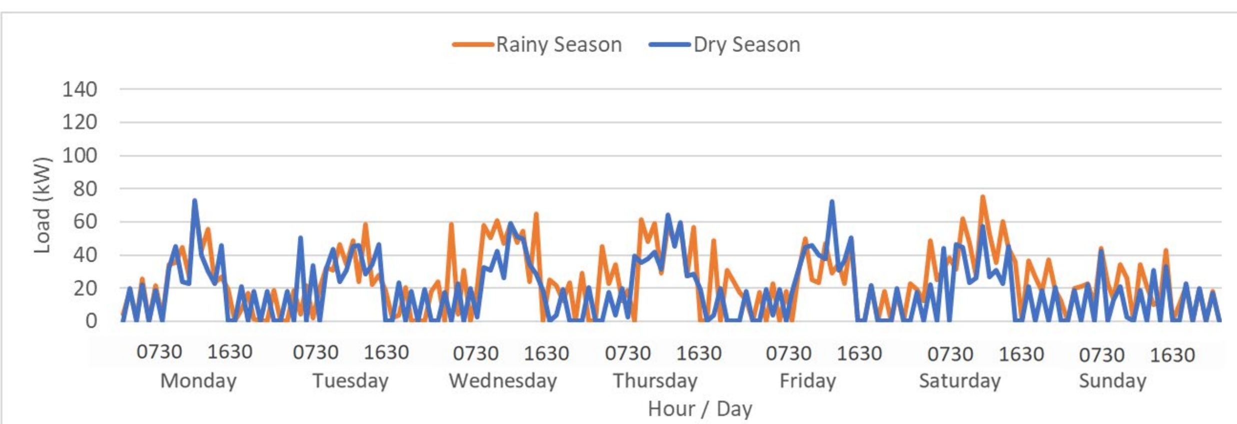

Figure 4. Estimated typical weekly Marpi Landfill load profile with 24/7 operations.

A second load profile was generated to account for the potential electrification of landfill equipment at Marpi. These two load profiles are referred to hereafter as the “24/7 operations baseline” and “24/7 operations & electric equipment” load profiles.

A variety of heavy equipment is required to operate Marpi, including a compactor, a dump truck, two bulldozers, a payloader, a tanker truck, two utility trucks, a riding mower, and three brush cutters. Equipment currently in use at Marpi, usage patterns, and fuel consumption were provided by the landfill operator. Figure 5 shows the existing equipment and usage in hours/day and days/week.

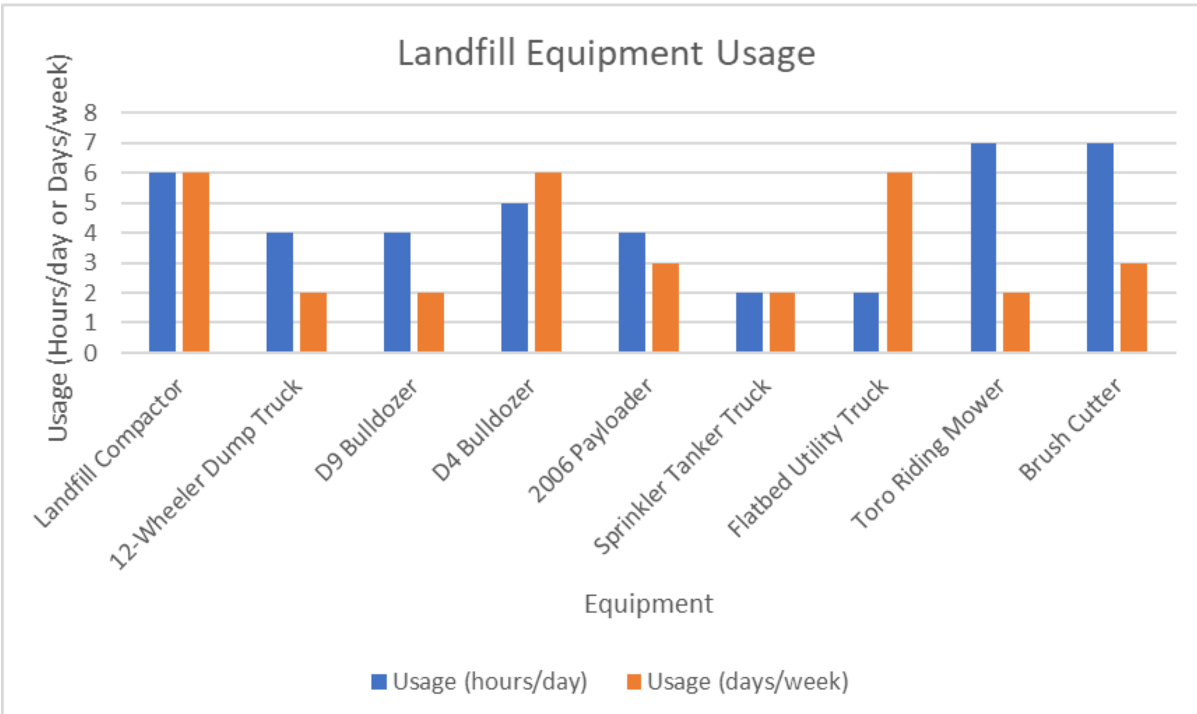

Figure 5. Marpi Landfill equipment and usage.

All landfill equipment currently operates on diesel or gasoline, furthering Marpi’s reliance on fossil fuels for daily operations. The SW Taskforce expressed interest in exploring alternatives to fossil-fueled heavy equipment at the landfill. As such, the project team evaluated the impact of converting the heavy-duty equipment used at Marpi to electric equivalents, including an assessment of the impact on the load profile and power supply scenarios.

OPD and the site operator recommended considering only electric alternatives that are currently available or projected to be available commercially in the near future. Based on this guidance, a subset of the existing equipment was considered for this analysis. Table 1 summarizes this equipment and the number of units in use, the daily energy storage of an electric equivalent, the estimated charge time based on charger type, and the commercial availability of the electric alternative.

It should be noted that electric heavy-duty landfill equipment is still an emerging technology, with few commercially available options. However, electrifying light- and mid-duty equipment, such as the flatbed utility trucks, riding mower, and brush cutters is more feasible utilizing current technology. At least one electric vehicle charging station exists on Saipan, indicating some amount of existing electric vehicle usage (Saipan Tribune 2023).

Table 1. Selected characteristics of electric alternative equipment.

Number of Units	Equipment	Estimated Daily Energy Storage Required per Unit (kWh)	Charge Time per Unit (hours)	Charger Type	Commercial Availability of Electric Alternative
1	12-Wheeler Dump Truck	586	3.9	DC[(a)]	No
1	2006 Payloader	654	4.4	DC	Yes
1	Sprinkler Tanker Truck	262	13.1	Level 2[(b)]	Yes
2	Flatbed Utility Truck	31	1.6	Level 2	Yes
1	Toro Riding Mower	229	11.5	Level 2	Yes
3	Brush Cutter	48	2.4	Level 2	Yes

(a) DC refers to a direct current fast charger, which requires 400–1000 V electrical service, provides 50–350 kW power output, and costs between $10,000 and $40,000 per charger, excluding installation.
(b) Refers to a Level 2 alternating current electric vehicle charger, which requires 208–240 V electrical service, provides 7–19 kW power output, and costs between $400 and $6,500 per charger, excluding installation.

This analysis assumed that the electric versions would have similar usage patterns and energy requirements as the fossil-fuel versions. Therefore, the daily fuel use was converted to kilowatt-hours to determine charging requirements for each piece of equipment. Daily energy storage requirements are driven by equipment use. For example, since the riding mower is used seven hours a day, the daily energy storage requirement is higher than for one of the flatbed utility trucks, which are used 2 hours a day. Charging was assumed to occur when the landfill is closed (4:30 p.m.–7:30 a.m.), requiring 24/7 power to meet charging requirements. Additionally, the chargers were assumed to operate at a reduced rate throughout the night, rather than at their maximum charge rate, to avoid oversizing the microgrid components. If simultaneous vehicle charging at their maximum rate is required, additional analysis will be needed. This will likely require increased generation and storage capacity beyond what is described in the power supply scenarios below.

Adding these charging loads, the landfill's annual consumption increases to 458 MWh with a peak load of 155 kW. The annual electricity consumption more than doubles because of the high energy needs of the landfill equipment, especially the payloader and dump truck. The peak load increases by a factor of 1.5x and occurs overnight rather than during the day.

Figure 6 shows the resulting hourly load profile for a typical year, and Figure 7 shows the hourly load profile for a typical week during both the dry and rainy seasons. The added overnight load from equipment charging is larger than the typical landfill daytime load, so the load profiles "flip." In other words, the loads are larger at night than they are throughout the day.

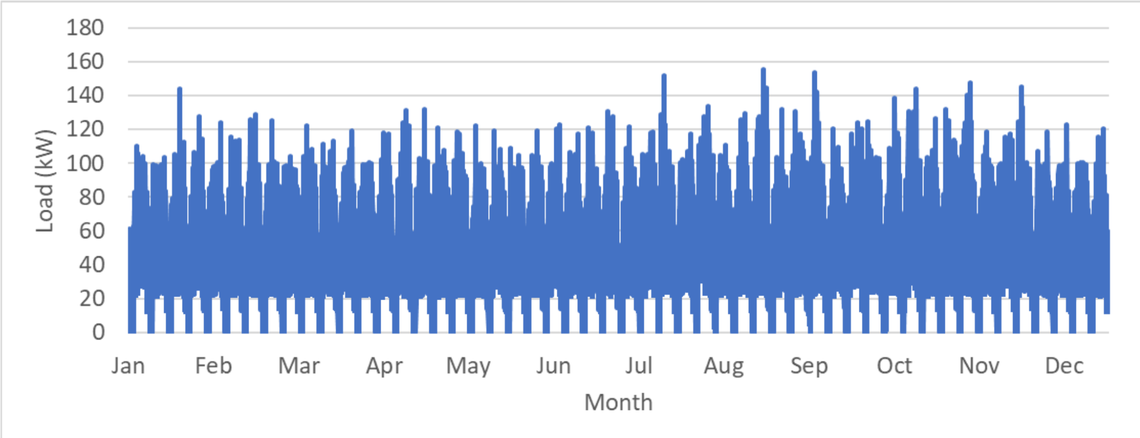

Figure 6. Estimated Hourly Marpi Landfill load profile with electric equipment charging.

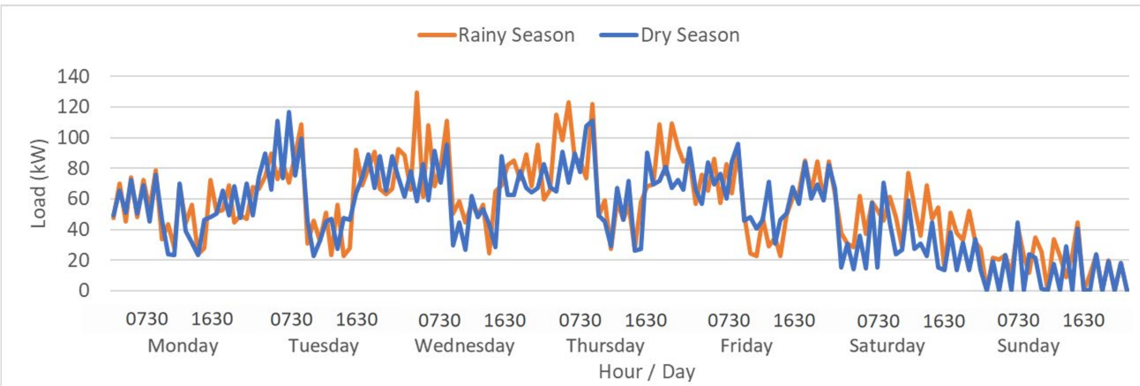

Figure 7. Estimated Typical weekly Marpi Landfill load profile with electric equipment charging.

The 24/7 operations baseline and 24/7 operations & electric equipment load profiles were used as input for the technical and economic evaluation of various power supply scenarios described in the following section.

3.0 Power Supply Options

Power for Marpi can be supplied via renewable energy and/or fuel-based generation. A resource screening was conducted to determine the best options to evaluate in more detail; then, the most promising options were characterized in terms of resource availability and technical feasibility.

3.1 Resource Screening

Several different renewable energy and other energy resources were initially considered for providing power to the landfill. Table 2 summarizes the various options and describes why or why not they are included in this feasibility study. These determinations also align with the Draft CNMI Strategic Energy Plan (GHD 2022).

Table 2. Summary of potential power supply sources for the Marpi Landfill.

Potential Power Sources to Consider	Include in Feasibility Study?	Justification
Solar photovoltaics (PV)	Yes	Solar energy is abundantly available on island.
Wind turbines	Yes	Small wind turbines have been installed on the island, and the wind resource appears to be strong.
Battery storage	Yes	Required with intermittent renewables to provide power when renewable resources are unavailable and for system stability.
Diesel generator	Yes	Previously used/proven.
CUC grid connection	No	Was previously investigated and determined to be cost-prohibitive and infeasible owing to local opposition (see below).
Biodiesel generator	No	Would require an existing supply of biodiesel in the region. Currently unavailable.
Landfill gas	No	No existing gas collection system. Landfill is too small for required scale of production.
Waste-to-energy	No	Marpi loads are much smaller than the potential output of a cost-effectively sized system, and there is insufficient waste on the island for it to be cost-effectively sized and operated.
Geothermal power	No	Load is too small. Also, geothermal resources may exist on Saipan, but exploration is high risk because of limited surface or subsurface evidence (Baring-Gould, et al. 2011).
Ocean thermal energy conversion	No	Technology is immature; insufficient loads at Marpi for ocean thermal energy conversion scale requirements.

Connection to the local CUC grid was previously investigated and resolved in court in 2012 (Casetext 2012). The landfill is located approximately 2 miles away from the nearest grid power line. The Marpi area is only sparsely populated by subsistence farmers who do not have connections to utility supplies of power or water. Previous attempts to provide the Marpi Landfill with reliable 24-hour grid power were met with prohibitive cost estimates and opposition by public interest groups. These groups do not support large infrastructure projects in the Marpi area to preserve the natural and historical environment. The feasibility of connecting Marpi to the CUC electrical grid was not investigated in this assessment. This is given the restrictions on the use of utility poles in the Marpi Conservation Area and the high cost of underground utility line deployment. However, changing conditions may justify revisiting this option in the future.

3.2 Resource and Technology Descriptions

Based on the outcome of the screening analysis documented in Table 2, solar PV, wind turbine, battery storage, and diesel generator technologies are evaluated and discussed below. For these systems to work together to provide power to the landfill, microgrid controls are also needed in addition to other balance-of-plant (BOP) equipment as described in Section 3.2.5.

3.2.1 Solar PV

Solar PV is a renewable energy technology commonly used around the world, especially in locations with high solar availability such as the CNMI. It is low maintenance, and the number of installations on Saipan continues to grow.

3.2.1.1 Technology

Solar PV arrays consist of panels installed in “strings” with inverters to convert direct current (DC) electricity to alternating current (AC). A transformer may be required to convert power to the appropriate voltage. The BOP includes the inverter, transformer, wires, mounts, racks to hold the panels, and other ancillary equipment that allows the produced power to be safely and effectively integrated into an electrical distribution system.

The method by which panels are mounted onto the ground or structures is determined by several factors including the availability of space, structural integrity, and cost. The mounting method influences power and energy production. Ground-mount arrays are generally the least expensive and have several options for securing the panels to the ground, including ballasts and drilled piles or piers. Roof-mounted arrays require assessments of the structure’s ability to handle both the weight of the system and the added wind loading. Penetrations may be required to secure the panels depending on the roof type and slope. Panels can also be placed on elevated structures, typically used for shading parking spaces. This is the most expensive mounting method because of the added cost of the structure but may be the most practical for many applications where available ground or roof areas are lacking.

All three mounting methods may use fixed-tilt panels; axis-tracking models are typically reserved for ground mounting only. Fixed-tilt panels are typically installed at an angle equal to the latitude of the installation location, facing south (in the Northern Hemisphere), and do not move. Axis-tracking racks allow the panels to follow the sun’s path across the sky throughout the day. Single-axis-tracking systems tilt the panels to face the sun as it travels from east to west, and the entire assembly is often tilted at an angle equal to the site latitude.

Solar PV arrays can be sized on an incremental basis to match the available area of a specific location or the load being served. Any number of PV panels can be installed to form an array. As more panels are installed together, more space is required beyond the size of the panel to allow for BOP equipment and spacing between panels. Proper spacing is required to avoid self-shading within the array and to allow access for cleaning and maintenance.

3.2.1.2 Resource Availability

Saipan has an abundant solar resource that averages 6.1 kWh/m²/day—comparable to Los Angeles, California. Solar resource estimates for the island of Saipan come from the National Renewable Energy Laboratory's (NREL's) National Solar Radiation Database (NSRDB), which contains decades of solar radiation data covering the United States and some international locations (Sengupta et al. 2018). Figure 8 shows the solar resource for the CNMI and Guam to be at the high end of the irradiance scale, based on the available 10 years of data.

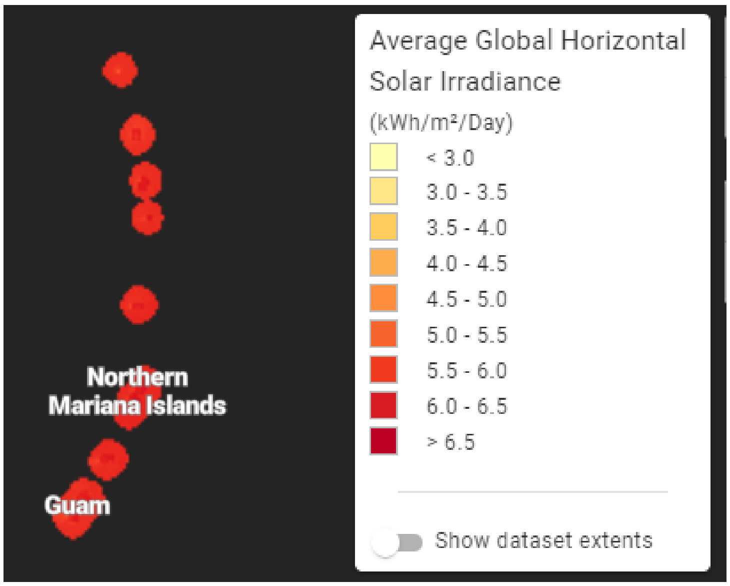

Figure 8. Solar resource for the CNMI and Guam (NSRDB).

This resource is seasonal; there is more solar energy available during the dry season (December–June) and less during the rainy season (July–November) when cloud cover is more frequent. Figure 9 displays the average monthly solar radiation available at Marpi (lat: 15.25°N, long: 145.78°E) based on NSRDB data.

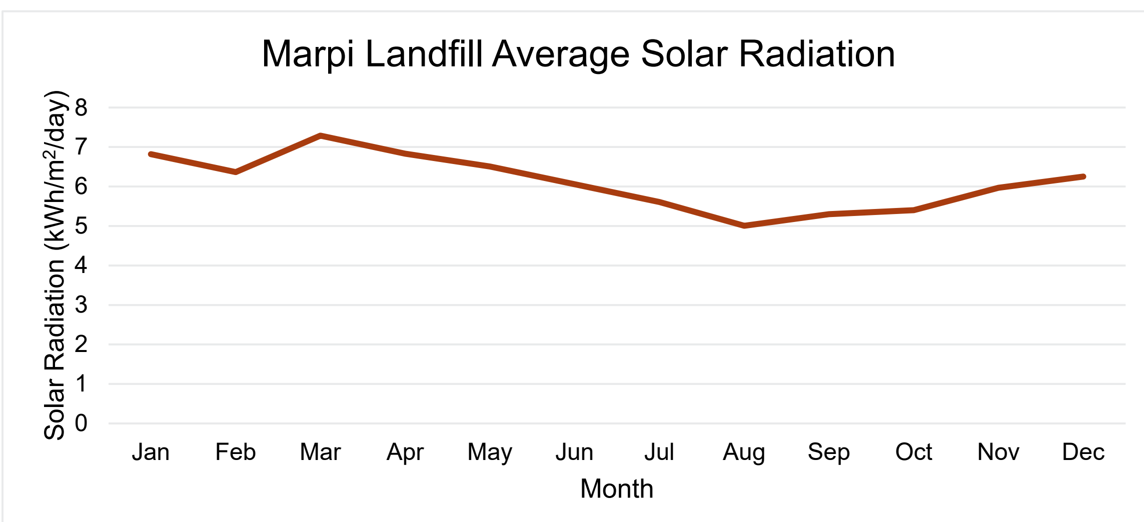

Figure 9. Monthly variation in solar radiation available at the Marpi Landfill.

The NSRDB distills many years of radiation data into a single typical meteorological year, which is a year of hourly data that represents median weather conditions over many years. The PVWatts® calculator[3] uses these data to estimate the energy production of user-defined solar PV systems (Dobos 2014). According to PVWatts, a 100 kW solar PV array at Marpi, facing due south, and tilted 15° will generate 170 MWh over a typical year, as shown in Figure 10. Systems tilted at an angle equal to their latitude maximize generation throughout the year.

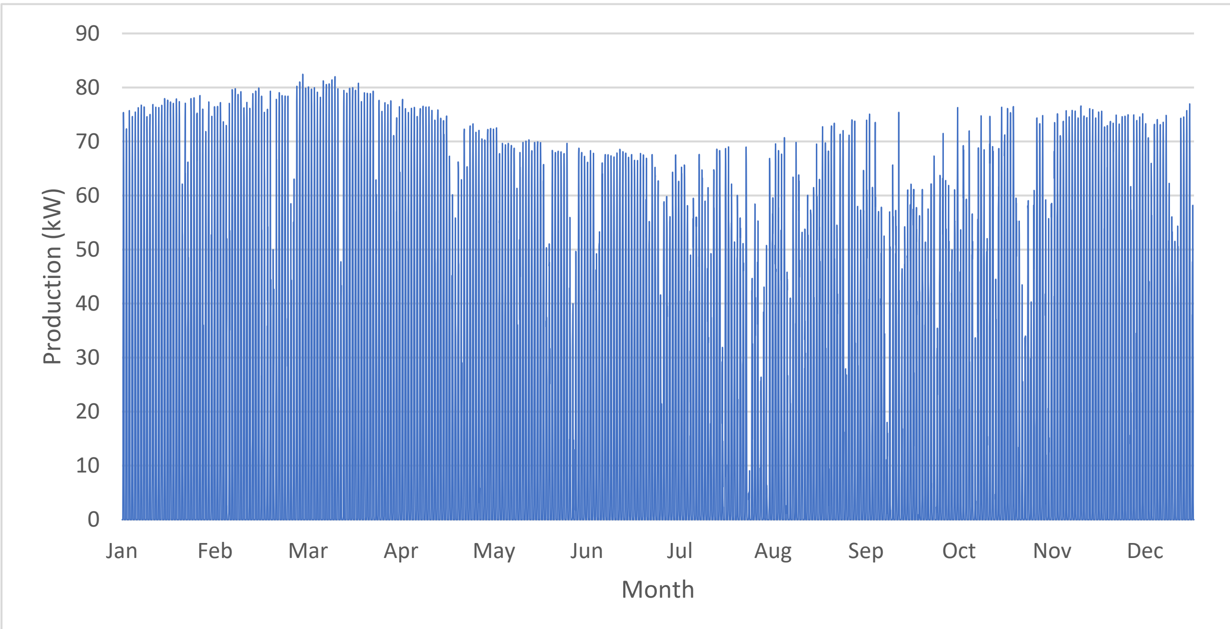

Figure 10. Hourly output from a 100 kW PV array facing due south and tilted 15°.

3.2.1.3 Operations and Maintenance

Operations and maintenance (O&M) for solar PV is relatively simple, especially for fixed-axis systems with no moving parts. The primary tasks that will help keep a system operational and optimize performance include module cleaning, vegetation and pest management, system inspection/monitoring, and replacement of minor component parts. On Saipan, the regular rainfall may be sufficient to keep panels clean, as demonstrated by other local PV projects. However, the presence of dust at the landfill and the site's proximity to the ocean (and resulting sea spray) may result in buildup on the panels and require additional cleaning to avoid reduction in output. See Section 8.4 for a discussion of O&M responsibilities and training needs.

3.2.1.4 Example Local Projects

There are several installed solar PV arrays on Saipan, ranging in age from over a decade in service to less than a year online to not yet operational. According to the CNMI Strategic Energy Plan (GHD 2023), there is over 5 MW of small-scale solar PV installed on residences, public buildings, and schools across Saipan. Micronesia Renewables is the primary solar installer in the region. A few example systems are discussed below.

[3] https://pvwatts.nrel.gov/

The largest PV system on Saipan is the 650 kW carport array at the Marianas Business Plaza (Figure 11), which was installed in 2015. It is net metered by CUC and shuts down if grid power is lost. The system is maintained by building maintenance personnel, who manually wash the panels with a mixture of rainwater and Polywater approximately four times per year. The system's monitoring software was purchased with ongoing monitoring and remote diagnostic services. Aside from replacing panels lost during the typhoons, the system has required minimal parts replacement over its life. Performance has degraded approximately 15% since 2015, which is higher at approximately 2% per year than expected for PV systems (0.5% per year).

Figure 11. Marianas Business Plaza solar PV system.

The roof of the DPW building supports a 2.86 kW PV system (Figure 12) that was installed in 2011. This system has sustained operations through two typhoons without degradation in performance over the years, and no O&M has been performed. Frequent rain keeps the panels clean. The original installer is no longer in business, so if the system does have an issue, it will likely be decommissioned rather than repaired, and the DPW building will make up for the loss of renewable energy by purchasing additional power from CUC.

Figure 12. Solar panels on the DPW roof.

Figure 13 shows the output of the system over four years, which demonstrates a fairly consistent monthly production peak of around 460 kWh and a similar production profile each year, peaking in spring and declining in fall/winter, corresponding to the seasonal variation with the dry and rainy seasons.

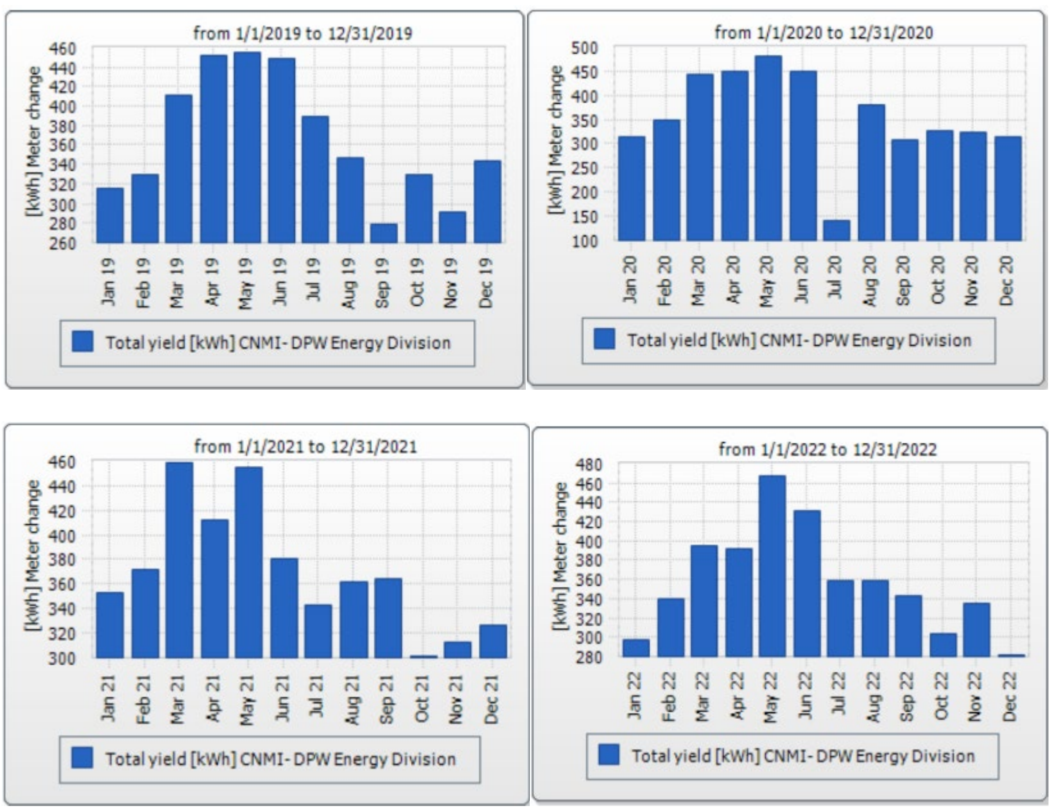

Figure 13. Electricity production of the DPW PV system for 2019–2022 (SunnyPortal 2023).

The Commonwealth Healthcare Corporation (CHCC) installed a 180 kW PV system (Figure 14) on its parking lot in 2019 and is planning to expand this by another 176 kW. The system saves

CHCC money on their CUC electricity bills, but no power is sent back to the grid; it is all consumed on site. The system was built to withstand 200 mph winds by using 14 ft deep structural piers to secure the carport structures to the ground. CHCC staff reported no issues with performance or O&M to date.

Figure 14. CHCC carport solar PV system.

The Public Schools System is installing solar PV panels across their facilities through a lease with Micronesia Renewables. Marianas High School has an older system that is no longer operational because of an inverter failure. Another system at the high school (Figure 15) was installed in March 2022 but has not yet been able to obtain CUC approval to begin operation.

Figure 15. Solar PV panels installed at a Marianas High School building.

3.2.2 Wind Turbines

Wind turbines are used to supply renewable energy for local loads around the world. For wind energy to be economical, the available wind resource at a site of interest must exceed certain thresholds, which is explored in Section 3.2.2.2. Operations costs for distributed wind turbines tend to be low; however, maintenance costs can be substantial in remote parts of the world. Tilt-up technology, which allows wind turbines to be lowered in advance of potentially damaging weather, is explored as an option to mitigate maintenance costs.

3.2.2.1 Technology

Wind turbines are machines that convert the kinetic energy of wind into electrical energy. They are composed of a tower, rotor (which includes the blades), and nacelle (which houses a generator and other power conversion components). Like solar energy, wind turbines can be sized according to energy need. One way to align energy supply and demand is by selecting an appropriate turbine generator and hub height. The hub height is the height of the tower where the rotor is mounted. Higher hub heights correspond to greater wind energy production since wind speed tends to increase with height above ground. The turbine tip height is the hub height plus the length of the blades, i.e., the total height of the wind turbine.

While most wind turbines remain vertical for their lifetimes, tilt-up technology is available for turbines deployed in areas subject to extreme weather. Tilt-up technology allows the entire wind turbine, including the tower, to be lowered in advance of extreme weather to mitigate potential damage to the system.

A variety of wind turbine designs are available, including horizontal- and vertical-axis turbines with different numbers of blades. Three-bladed horizontal-axis turbines are the most efficient design and are therefore the most widely used in the United States.

The 100 kW Northern Power Systems 100-28 3-bladed wind turbine is selected as the optimal turbine model to supply the load at Marpi (Table 3). Two tower and hub height options are considered: a standard tower option with a higher hub height of 37 m (121 ft) to maximize wind production and a tilt-up tower at a lower hub height of 23 m (75 ft) to reduce the potential turbine damage during severe weather, such as typhoons.

Table 3. Characteristics of a potentially suitable wind turbine for the Marpi Landfill.

Turbine Manufacturer/Model	Northern Power Systems 100-28 (Standard)	Northern Power Systems 100-28 (Tilt-up)
Nameplate Capacity	100 kW	100 kW
Hub Height	37 m (121 ft)	23 m (75 ft)
Tip Height	51 m (167 ft)	37 m (121 ft)
Land Area Required	8,171 m^2 (87,952 ft^2)	4,301 m^2 (46,296 ft^2)

3.2.2.2 Resource Availability

Saipan has a geographically diverse wind resource that is occasionally impacted by strong storms such as typhoons. Because of its remote location, the limitations of wind models and observations on Saipan urge the gathering of on-site measurements prior to reaching a decision on wind energy deployment. The specific location at Marpi evaluated for wind feasibility is shown in Figure 16.

Figure 16. Potential wind turbine location at the Marpi Landfill.

Since existing wind observations in the Northern Mariana Islands are far from the location of interest for wind development at Marpi and are not close to typical small wind turbine hub heights, models are employed to estimate the on-site hub height wind resource. The wind speed for Saipan from one model, Global Wind Atlas 3 (GWA3), is depicted in Figure 17.

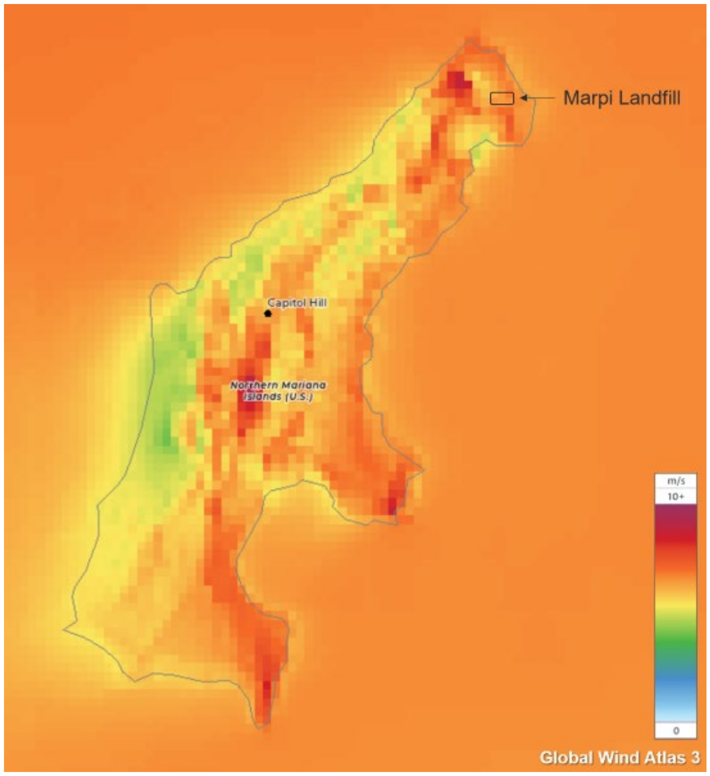

Figure 17. Wind speed map at 50 m from GWA3.

Using the models and methods described in Appendix E, the geolocated wind speed estimates for average, high, and low wind resource years are provided in Table 4. To put these values in context, the cut-in wind speed, typically around 3 m/s, is the lowest at which a wind turbine can generate power. Considering this constraint and wind energy investment costs, project developers typically advise that annual average wind speed minima of 4 m/s (8.9 mph) at 30 m (98 ft) (DOE 2012) and 6.5 m/s (14.5 mph) at 80 m (262 ft) (DOE 2011) are required for feasible wind energy project development. Extrapolating these rules of thumb to the hub heights of interest for Marpi means that the annual average wind resource needs to be at least 3.7 m/s (8.3 mph) or 4.4 m/s (9.8 mph) for a feasible project using a wind turbine with a hub height of 23 m (75 ft) or 37 m (121 ft), respectively. As shown, even the lowest wind speed estimates meet these criteria.

Table 4. Annual wind speed estimates based on model wind data.

Hub Height	Average Wind Resource Year	High Wind Resource Year	Low Wind Resource Year
37 m (121 ft)	5.1 m/s (11.4 mph)	6.4 m/s (14.3 mph)	4.4 m/s (9.8 mph)
23 m (75 ft)	4.3 m/s (9.6 mph)	5.5 m/s (12.3 mph)	3.7 m/s (8.3 mph)

While the annual speed estimates for an average wind resource year exceed the rule of thumb minima for both hub heights of consideration, it is important to consider that these are indeed estimates, and accordingly, the model wind speed error at nearby locations with observations must be examined. Figure 18 shows that the multiannual average 10 m (33 ft) wind speed errors for GWA3, at Saipan International Airport and two locations on Guam, range from −1.1 m/s (−2.5 mph) to +3.3 m/s (+7.4 mph). These errors are not necessarily indicative of the accuracy of wind speed estimates for Marpi but provide a range of error possibilities to consider.

As these errors are substantially greater than the difference between the Marpi estimates and the rule of thumb wind speed minima, on-site measurements are recommended to better inform decisions concerning the potential for wind energy development at Marpi.

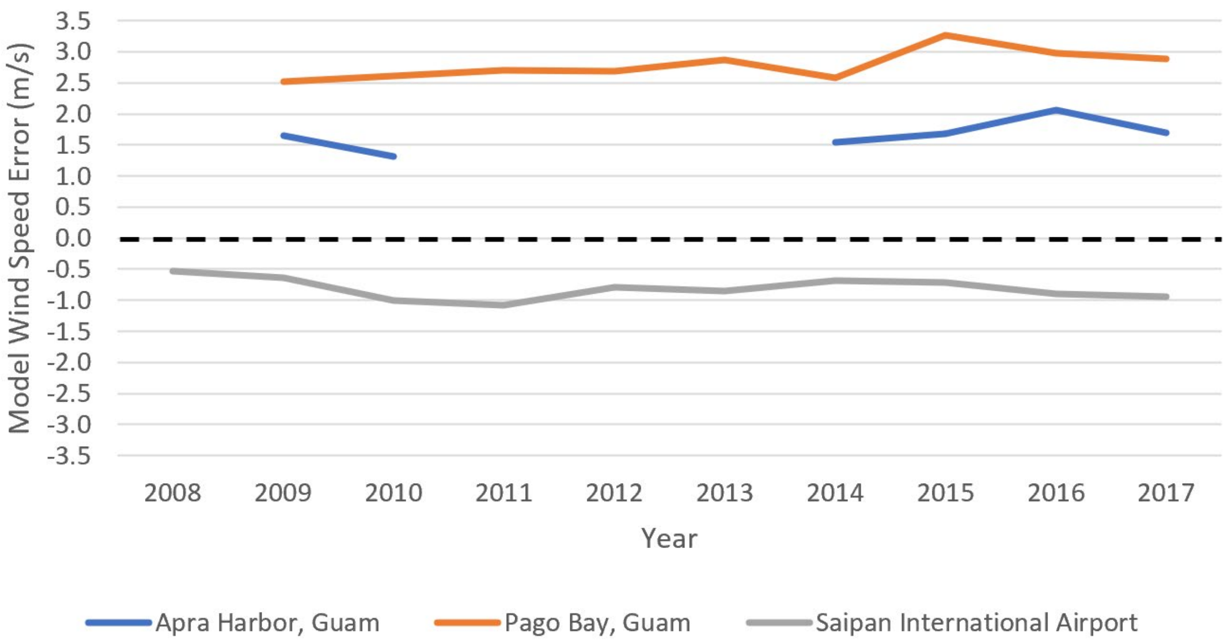

Figure 18. GWA3 errors at locations with wind speed observations on Saipan and Guam.

Wind turbines exhibit generation loss for a variety of reasons. Table 5 displays the custom loss assumptions created for a potential wind project at Marpi and assumes a higher loss for availability due to the length of travel likely required for personnel to perform maintenance and environmental impacts due to the relatively frequent occurrence of severe weather. Other loss categories are assumed to be low, such as wake loss since the desired location for wind deployment at Marpi allows for a single turbine and curtailment since the energy scenarios for Marpi feature battery energy storage systems (BESSs).

Table 5. Wind generation loss assumptions for the Marpi Landfill.

Loss Category	Typical Range	Notes	Marpi Assumption
Availability	4%–6%	Downtime for maintenance, assume higher end for lengthy travel likely required	6%
Wake (Array)	0%–15%	Not applicable for single turbine installations	0%
Turbine Performance	1%–3%	Assume high performance	1%
Electrical	2%–3%	Standard electrical losses	2%
Environmental	1%–10%	Assume weather, such as typhoons, may disrupt production	10%
Curtailment	0%–3%	All scenarios include a BESS	0%
Total	12%–25%		19%

Combining the wind speed estimates presented in Table 4, the Northern Power Systems 100-28 power curve, and the loss assumptions in Table 5 yields net generation estimates ranging from

121,050 kWh to 288,300 kWh for the 37 m (121 ft) hub height and 75,850 kWh to 208,150 kWh for the 23 m (75 ft) hub height, depending on the wind resource year (Table 6).

Table 6. Annual gross and net wind generation estimates based on model wind data and the Northern Power Systems 100-28 wind turbine.

	Gross Generation			Net Generation		
Wind resource year	Average	High	Low	Average	High	Low
37 m (121 ft) Hub Height	228,450	355,950	149,450	185,050	288,300	121,050
23 m (75 ft) Hub Height	153,450	256,950	93,600	124,300	208,150	75,850

The available wind resource varies throughout the time of day and year. At locations around Saipan and Guam, wind observations and models are in agreement that the lowest wind speeds of the year occur during the summer and early fall (Figure 19), which corresponds with the rainy season from July to November and is the period of greatest energy need at Marpi. The monthly energy estimates for an average wind resource year are displayed in Figure 20 to assess the impact of seasonal variation in the wind resource on expected wind production.

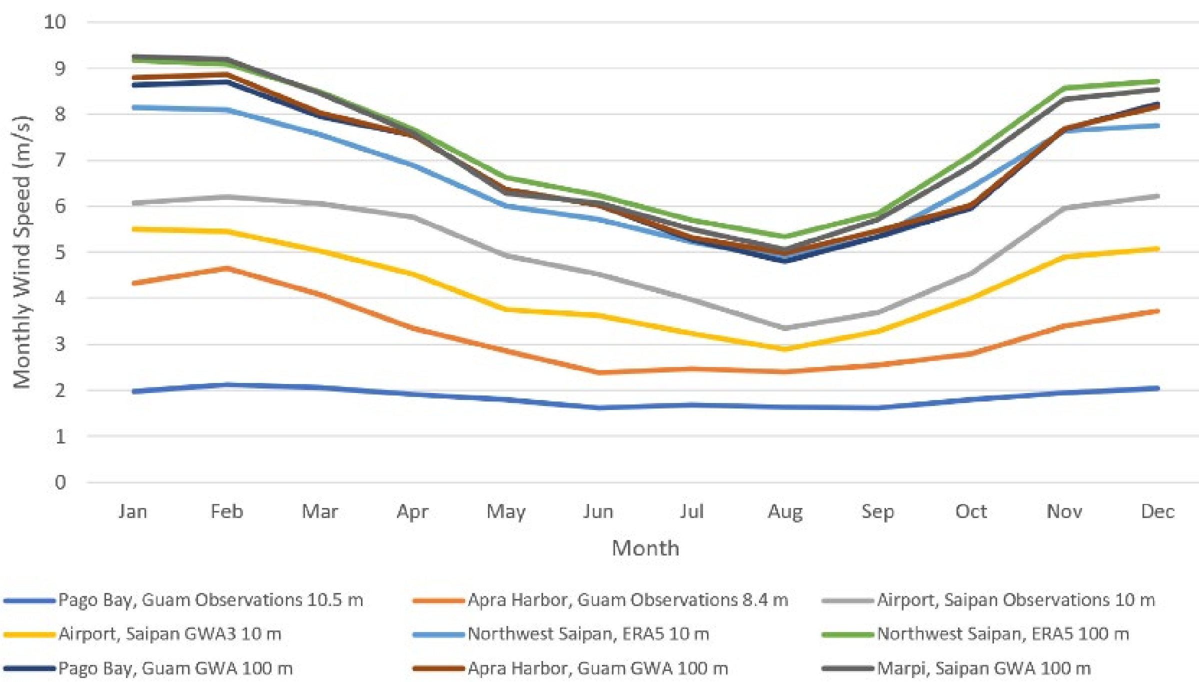

Figure 19. Monthly observed and modeled wind speeds near the Marpi Landfill.

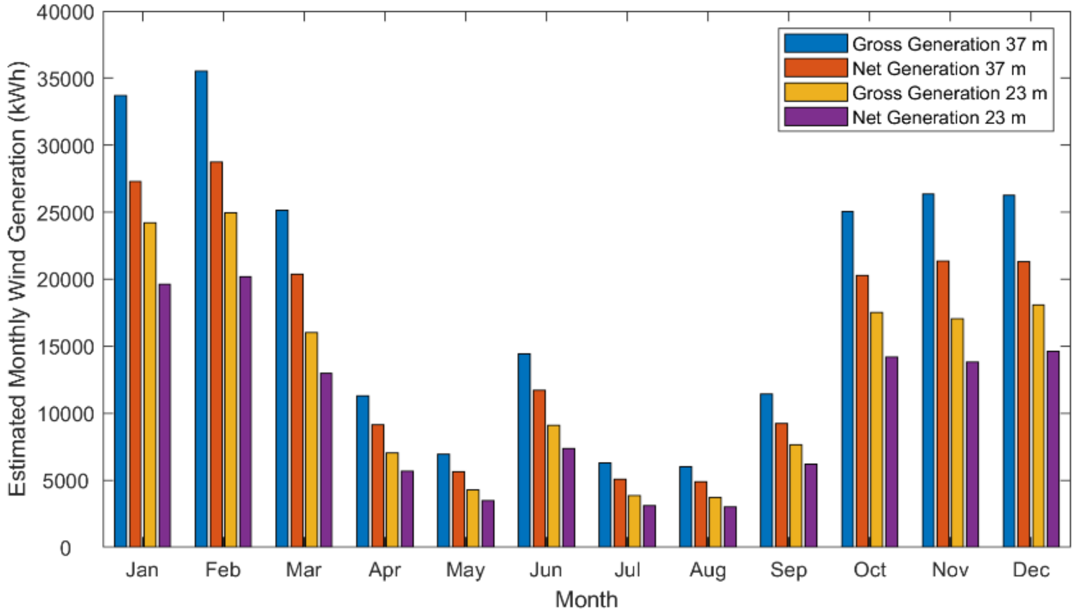

Figure 20. Estimated monthly gross and net wind generation for an average wind resource year.

The wind resource in the region of Marpi can also vary throughout the day and night. Figure 21 shows significant variation in local wind speeds throughout the day and night from observations near the surface, while the models show little to no variation with the time of day. Because of the lack of observations at heights above 10 m (33 ft), it is impossible to tell whether the discrepancy in observed and simulated diurnal wind profiles is due to model performance issues or is accurate, since the discrepancy in profiles with height above ground is normal and expected in many locations. On-site measurements would provide clarity on diurnal wind generation expectations in addition to annual expectations.

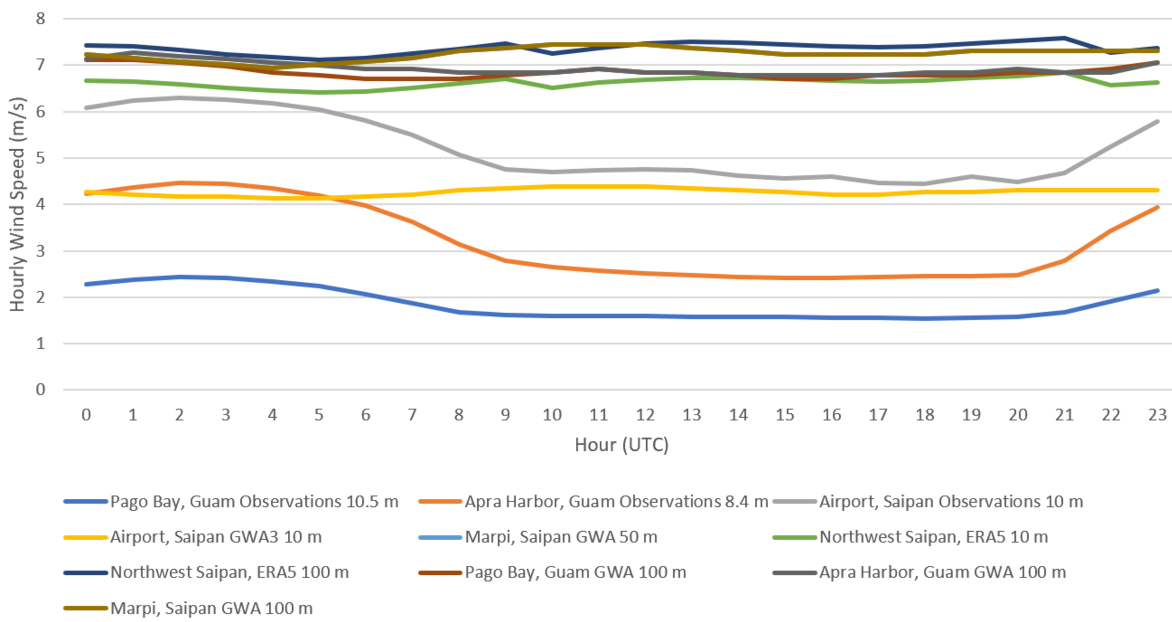

Figure 21. Hourly observed and modeled wind speeds near the Marpi Landfill.

In order to refine the wind energy estimates for Marpi, on-site measurements are necessary. Purchase and installation of a 60 m (197 ft) meteorological tower cost $25,000–$40,000 in the continental U.S. in 2018 (Dodd 2018). Using an area cost factor of 3.42, the cost for purchasing and installing a 60 m (197 ft) tower for Marpi is estimated to be $85,500–$136,800. The necessary meteorological tower would be shorter for Marpi (30–40 m or 98–131 ft), but the above cost estimate is anticipated to be representative due to (1) inflation since 2018 and (2) the shipment of anemometers and a monitoring system from the mainland. The cost estimate could increase depending on the availability of additional construction supplies on Saipan, along with personnel trained in installation and maintenance.

The timeline for meteorological tower purchase, transportation, installation, and at least 6 months of data gathering is estimated to be 9–12 months. The 6 months of data are recommended to refine wind speed estimates because model performance varies throughout the seasonal cycle. A full year of data observations would provide an even stronger analysis.

3.2.2.3 Operations and Maintenance

The operations costs for wind projects can include land lease payments, remote monitoring, operations contracts, insurance, and property taxes. The operations costs for a small distributed wind project are typically not substantial because the turbine owner and property owner are the same (Orrell et al. 2022). The operations costs at Marpi are anticipated to include remote monitoring and insurance.

The maintenance costs for a small wind project vary according to the maintenance provider's proximity to the project site (travel costs), the availability of spare parts, and the complexity of maintenance and repairs (Orrell et al. 2022). The average estimate for scheduled and unscheduled maintenance for a Northern Power Systems 100-28 turbine in the continental U.S. is $10,000 per year (Connor 2023). To minimize downtime and reduce cost, it would be critical to have some spare parts on Saipan at an estimated cost of $10,000–$20,000 and find or train local personnel to perform service activities (Connor 2023).

3.2.2.4 Example Local Projects

According to the draft CNMI Strategic Energy Plan (GHD 2022), there are only 144 kW of wind installed on Saipan. Small-scale turbines have been installed at facilities such as the Garapan Elementary School and the DPW building.

An operational 2.4 kW Skystream 3.7 wind turbine (pictured in Figure 22) is located at the DPW building. The turbine was deployed in 2011 and has survived two typhoons with no degradation in performance over the years and no O&M needed. Similar to the solar PV system at the same location, the installation company is now out of business, so if there was an issue, the system would likely be decommissioned instead of repaired. Sample output graphs for this turbine are shown in Figure 23 for an entire year (2012), in Figure 24 for a single month in the dry season (January), and in Figure 25 for the rainy season (June–July).

Figure 22. Skystream 2.4 kW wind turbine at the DPW building.

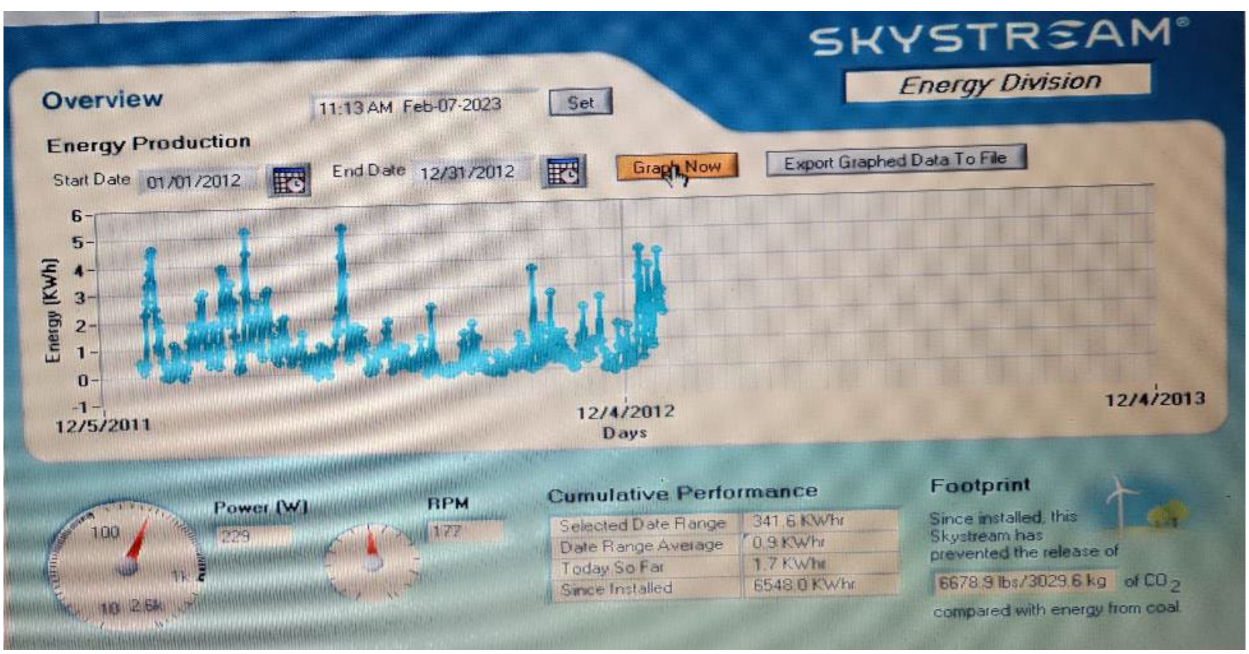

Figure 23. Power production profile for the DPW Skystream wind turbine for 2012.

Figure 24. Power production profile for the DPW Skystream wind turbine for January 2023.

Figure 25. Power production profile for the DPW Skystream wind turbine for June–July 2022.

There are no turbines of the scale being considered for Marpi currently installed on Saipan. In 2016, a 275 kW Vergnet GEV MP-C wind turbine with a 55 m (180 ft) hub height was deployed on Guam. This taller turbine experienced downtime and unplanned maintenance when one of the turbine blades was damaged during Typhoon Mangkut in 2018. The turbine returned to operations in 2019 (Losinio 2019).

3.2.3 Batteries

Batteries and the associated equipment for charge management, power conversion (from DC to AC), and other hardware are collectively known as a BESS. They are often paired with renewable energy technologies to store generation in excess of the load and to make that power available during times when the renewable resource is not. BESSs are key components in renewables-based microgrids, as has been shown in microgrid projects across the Pacific region. Various battery chemistries are available. O&M can mostly be automated through controllers.

3.2.3.1 Operation in a Microgrid

BESSs serve a critical function in enabling microgrids to include increased amounts of non-dispatchable[4] renewable energy sources (solar PV, wind, etc.) while reducing reliance on dispatchable fuel-fired generators. This support takes two primary forms: (1) the storage capacity associated with aligning the potentially mismatched output from renewable resources with loads that may not coincide with the availability of solar or wind power (often referred to as load shifting) and (2) the grid-forming and grid-stability functions associated with maintaining voltage and frequency levels within prescribed limits (e.g., 60 Hz, 480 V AC power). The first of these two functions takes place on timescales of minutes or hours, while the second happens at the sub-second timescales associated with AC power cycles.

Historically, grids and microgrids have relied on spinning generation (such as diesel generators) to stabilize the power supply and delivery to loads and to allow other resources such as solar and wind to contribute. Recent technology developments have enabled BESSs to perform these grid-forming functions traditionally associated with spinning generation; virtual inertia, frequency and voltage reference setting (grid forming), and fast frequency response are among the capabilities that enable BESSs to operate independently from a larger utility grid. This grid-forming ability is essential for microgrids that include renewable resources (such as solar PV) that use inverters dependent on a grid voltage and frequency reference to operate. There is ongoing work to further improve these capabilities, coupled with research into capability gaps; inverters lag behind spinning generators in their ability to source fault currents to adequately clear faults in protective devices. Despite remarkable advances in the BESS technology space, there is still a need for standardization and long-term performance data on existing systems.

When configured with inverters capable of independently forming an AC electric grid, batteries can maintain a microgrid using renewable resources without reliance on spinning generation (from diesel generators) for stability. The ability of BESSs to maintain stable grid operation is influenced in part by the battery's state of charge (SoC); when the battery SoC is very low (typically below 20%), then it may not be able to provide power to the microgrid if it is absorbing the output of the other energy resources. In these cases, the frequency may drop below acceptable thresholds. Likewise, when the battery is near full charge and unable to accept any additional input power, then system frequency can increase until other generation is curtailed.

3.2.3.2 Battery Chemistries

The BESSs used in microgrid applications for the power scales required for Marpi most often include lithium-ion (Li-ion) batteries. Several other battery configurations and chemistries exist,

[4] Resources that can only generate power when their input is available; see Appendix B for more explanation.

including lead–acid, sodium-metal, flow batteries (such as vanadium redox and zinc–air), and others. Of these other chemistries, lead-acid is the only one that may be suitable for a Marpi microgrid. The advantages and drawbacks to these common battery types are compared in Table 7. Other storage media used for stationary storage applications include ultracapacitors, flywheels, pumped hydro, or pumped air storage. None of these are considered an appropriate fit because the scale required is much larger than the Marpi loads.

Table 7. Comparison of battery chemistries.

	Advantages	Drawbacks
Li-ion	• Costs continue to fall • Multiple vendors • Fast response • Higher efficiencies	• High temperatures can result in electrolyte decomposition and flammable gas • Overcharging can lead to degradation and faults
Lead–acid	• Low cost • Ubiquitous	• Limited lifetime for older tech • Degradation from deep discharge • Low specific energy • Sulfation from prolonged storage
Sodium-metal	• Sodium is low cost • High energy density and specific power • High temp is OK	• Heaters needed when not in use • Charge/discharge limitations • Safety concerns
Redox flow	• Flexibility: separate power and energy • Multiple chemistries • Low fire hazard	• Low energy density and efficiency • Narrow temperature range • Pumped system susceptible to leaks

Li-ion batteries are the most widely deployed battery type in recent years, primarily for use in electric vehicles, which has led to decreasing costs for stationary power applications. There are numerous vendors on the market, driving performance and safety improvements. Li-ion batteries achieve a fast response necessary for grid stability and have higher efficiencies as compared to other battery chemistries.

Lead–acid batteries are another low-cost and ubiquitous offering. Older systems suffer from limited lifetimes and short cycle lives (~500–1,000 cycles), while newer lead–carbon systems can perform to ~5,000 cycles. Lead–acid batteries typically have a lower specific energy than that of Li-ion batteries and can suffer sulfation from prolonged storage.

3.2.3.3 Operations and Maintenance

BESS O&M consist of both ongoing operations of the battery in conjunction with the other microgrid components and periodic and long-term maintenance activities to ensure the sustained performance and safety of the equipment. The operations of the BESS require constant monitoring of the equipment’s performance including the power output of each individual battery cell, the system SoC, the battery temperatures, and other metrics. The data gathering and analysis for these performance metrics can be automated, with basic corrective actions being programmed into the BESS controllers. Errors or performance deviations beyond acceptable thresholds will require intervention by a trained operator.

The relatively small number and lack of long-term BESS projects in service mean that reference O&M costs vary widely and are dependent on project-specific characteristics. Unlike O&M for engine generators and other types of equipment that use consumables and have a significant variable component, BESS O&M costs are often calculated as a fixed annual cost.[5] This fixed cost typically consists of a service contract that includes labor for periodic system inspections and can include payments into an escrow account designed to levelize the higher costs associated with major component overhauls or replacements (battery cells, inverters, etc.). Whether or not long-term equipment replacement (which reduces performance degradation over the entire life of the battery) is included will have a significant impact on the O&M costs.

3.2.3.4 Example Projects

BESS projects (either as grid-facing utility resources or as part of microgrids intended for resilience purposes) are increasing rapidly throughout the Pacific, as battery costs continue to fall and the deployment of renewable power generation increases to meet emissions reduction and cost savings objectives. Representative projects on Pacific islands include the following:

- Tafuna, American Samoa – 500 kWh battery incorporated into a site microgrid at the Te'o U.S. Army Reserve Center
- an island-wide microgrid on Ta'u (American Samoa) including 60 Tesla Power Pack Li-ion batteries with an energy rating of 6 MWh, integrated with solar PV and diesel generators
- a 185 MW/565 MWh battery at the Port of Hawaii to provide grid services to Hawaiian Electric Company as coal generation is completely retired from service on Oahu
- Tonga Outer Islands (Asian Development Bank 2022)
  - 500 kW/660 kWh BESS on Ha'apai Island
  - multiple BESS projects ranging from 110 kW up to 295 kW on Niuafo'ou, Niuatopatapu, 'Uiha, Nomuka, Ha'ano, Ha'afeva, Kotu, Tugua, O'ua, and Mo'unga'one Islands
  - a 5 MW/2.5 MWh BESS and a separate 5 MW/17.4 MWh BESS on Tongatapu
  - multiple 0.4–0.9 MW BESS projects on Vava'u and 'Eua
- Cook Islands
  - 0.5 MW and 1.0 W BESS projects on Aitutaki Island
  - multiple BESS projects from 90–216 kW on Atiu, Mauke, Mangaia, and Mitiaro Islands.

The smaller systems on the Tonga outer islands and Cook Islands are all microgrids that do not have a larger utility grid as a voltage or frequency source; under most conditions, the batteries, their inverters, and their associated controls are operating in "islanded mode," autonomously forming the microgrid. This is a similar operating profile as what would be expected for a system operating at Marpi if no CUC utility service is provisioned for the site.

The Army Reserve microgrid is also similarly sized to the potential microgrid for Marpi and has demonstrated automated operation since March 2021, requiring minimal manpower for O&M once the system controls were optimized for cost savings and resilience. This battery allows seamless transition between the solar PV, grid, and diesel generation sources.

[5] Where BESS projects have a high number of charge/discharge cycles (e.g., more than one per day), the variable O&M will increase, reflecting a reduced lifetime of the battery.

3.2.4 Diesel Generators

Engines used for generating electricity are often referred to as “spinning generation” or reciprocating internal combustion engine (RICE) generators and can be configured for standby (backup) use or prime power (constant year-round use, serving as the primary generation resource) applications. They are often configured to use liquid fuels such as diesel, gasoline, or liquid propane. Because of its relatively low cost, high power density, widespread availability, and existing infrastructure for fuel transport and distribution, diesel is the most common liquid fuel for generators.

Today, a majority of standby power systems rely on diesel generators to provide backup power because they (1) can start and accept load very quickly (within seconds), (2) occupy a small footprint relative to their output, (3) can modulate their output (follow loads) reliably while maintaining the grid voltage and frequency, and (4) are relatively cheap to operate, maintain, and repair. The drawbacks associated with diesel engines include (1) ongoing operations costs for fuel and other consumables, (2) noisy operations that can require sound attenuation, and (3) significant emissions for both greenhouse gases (GHGs; e.g., CO_2, N_2O) and criteria pollutants (CO, NO_2, SO_2, particulate matter [PM]) that require expensive controls for compliance with regulations.

Whether in standby or prime power applications, diesel generators can be configured to operate in parallel with other generation resources (e.g., the utility grid or nearby solar PV) either as grid-following or grid-forming units, or they can operate entirely independently as the only source of power if no other resources are available or present.

3.2.4.1 Considerations for Marpi Application

Marpi has relied on diesel generators for power since it commenced operations; the site operators are familiar with the technology and are able to perform minor maintenance and repairs. As of February 2023, the DPW-owned generator at Marpi has been out of service for an extended period of time, requiring the use of a rental unit supplied by the site operator.

For prime power applications where there is no utility feed or where there are additional uptime requirements, microgrids should be configured with multiple generators to optimize fuel-use efficiency, meet contingency reserve needs, and provide generation redundancy. For Marpi, a microgrid configured with two identically sized generators, each sized to meet 50%–75% of the peak demand, would achieve those efficiency and redundancy objectives.

Electric loads at Marpi vary significantly throughout the day; for the 24/7 operations baseline load profile, frequently, the loads are at 30 kW or less, only peaking at 110 kW when there are coincident pumping requirements. A single generator, sized to meet the full peak demand, would often be running at less than 20% of its rated output for most of the time. At this output, the fuel efficiency of the generator can be as little as 50% of the efficiency when the unit is operating at its rated output. If the microgrid is configured with two smaller units, then either one can operate at lower loads (but higher relative to the generator’s nameplate rating), without the same fuel efficiency penalties. When loads increase beyond the capacity of a single unit, then either a battery can provide peak power, or the second generator can be brought online.

In addition to the optimization of fuel efficiency, multiple units provide redundancy to ensure some or all power needs can be met in the event of a failure of any single unit. In addition to mitigating the failure of a single generator, a second unit would also serve as contingency reserve for all generation sources in a microgrid, quickly responding to either the failure of output from the battery or a rapid decrease in output from the solar PV or wind. Diesel generators can come online from a cold start and ramp to full output very quickly (often within 10–20 seconds), minimizing the likelihood of a full system outage.

3.2.4.2 Diesel Fuel and Storage

Diesel fuel is widely available on Saipan as it is the primary source of fuel for power generation by CUC. For existing power plants, CUC procures between 3 and 5 million gallons of diesel each month, delivered to the Port of Saipan. Diesel is also used for vehicles and other standby generators on the island; the bulk price for diesel for 2022 and early 2023 averaged approximately $6.50 per gallon.

The landfill has a bulk diesel storage tank, intended for use by both the generator and heavy equipment at the site. The tank experienced leaks from corroded sections and was emptied and removed from service. A portable trailer-mounted tank with a 10,000-gallon capacity is currently in use by the site operator and parked adjacent to the bulk tank and generator building, shown in Figure 26.

Figure 26. Portable diesel tank at the Marpi Landfill.

3.2.4.3 Operations and Maintenance (O&M)

In order to ensure reliable performance over the life of the generator, there are several maintenance activities that should be performed at vendor-specified intervals:

- general inspections covering mechanical components, including the engine casing, spark plugs, exhaust, fuel, batteries (for black starting), and controls
- lubrication system maintenance covering oil and oil filters
- coolant system components: coolant levels, radiator inspection and cleaning, air filters, etc.
- fuel system inspections including tank draining and dewatering, fuel filter replacement, and general tank inspection for structural integrity
- battery testing to ensure charge to start the generator (adequate voltage and electrolyte levels).

O&M costs for diesel generators are typically expressed in variable costs, given the variability in their application (standby vs. prime power) and the impact on consumables and the lifetime of the engine. Typically for prime power applications, engines can range from 1–2¢/kWh to higher amounts (5¢/kWh or more) for units that are only used for standby applications.

3.2.5 Microgrid Controls and Balance of Plant

The DOE defines a microgrid as “a group of interconnected loads and distributed energy resources that acts as a single controllable entity with respect to the grid” (Ton & Smith, 2012). In simple terms, a microgrid is a small power system that can operate connected to the larger grid or by itself in stand-alone mode. A microgrid consists of the combination of power generation and storage resources (renewables, batteries, fuel-fired generators, etc.), distribution infrastructure (wires, switchgear, protective devices, transformers, etc.), and loads being supplied with electricity. Loads powered by a microgrid can range from several loads or buildings to a small town or large campus.

Microgrid technology emerged to address reliability concerns, ensuring that critical power infrastructure remained operational even during power grid failures. Consequently, the majority of early microgrids were primarily fueled by fossil fuels. However, the current definition of microgrids has emerged from a combination of these reliability needs as well as other goals, including reducing carbon emissions, lowering electricity costs, and increasing the deployment of renewable energy. This has resulted in renewable energy sources, such as solar PV or wind turbines, being added to traditional fuel-fired generation to power microgrids.

Typically, microgrids are configured to operate either in parallel with a utility grid or autonomously if there is a grid outage or if there is no utility feed available, such as at Marpi. The microgrid controller manages all aspects of the system’s operation to ensure stable, safe, and reliable delivery of power to the loads managing the system at very short (sub-second and second) and long (hourly and longer) timescales.

Other BOP pieces of equipment for the microgrid include (1) electric distribution system components to route power from generation sources to the loads; (2) cooling equipment to ensure that controllers, inverters, and related components are kept within tolerable temperature ranges; (3) human interface devices; and (4) communications equipment for remote monitoring and control. Distribution system components include cables, switchgear, and protective devices (circuit breakers, relays, fuses, etc.), voltage transformers, and other related equipment.

3.2.5.1 Purpose of the Microgrid Controller

A microgrid controller performs several functions, ranging from very high-speed controls (sub-second timescales) up to mode handling and transition (seconds, minutes) to resource scheduling and dispatch (minutes, hours).

- Grid forming through voltage and frequency regulation – the controller will work in conjunction with the individual system controllers (for the generator and BESS inverters) to provide voltage and frequency references for other resources on the microgrid.
- Real and reactive power provision to meet both real and reactive power requirements – as Marpi's electric loads are often dominated by single- and three-phase pumps with low power factors, the microgrid's ability to source adequate reactive power is important.
- System monitoring and controls for mode handling during steady-state and mode transitions (e.g., transition from the battery to the generator acting as the grid-forming device) – this function controls how to operate individual components (generation and storage resources, switchgear, and any load-control devices). During mode changes, it is especially important for the controller to properly and precisely sequence commands to ensure stable and smooth transitions.
- System protection and black start functions – for the system to respond to and isolate any faults or reenergize the system after an outage.
- Dispatch functions to determine when to start and stop certain components within the microgrid – this intelligence is programmed into the controller to ensure that loads are always met and to achieve other goals such as minimized diesel consumption or adequate contingency power reserves. Dispatch algorithms can use predictive intelligence to optimize the use of renewables (by utilizing near-term weather forecasting) or control the loads from historical usage trends or information to predict stormwater pumping needs based on recent rainfall amounts.

3.2.5.2 Operations and Maintenance

Operation of the system components can be largely automated by the microgrid controller and individual component controllers. Direct human operation of the system components and overriding automated functions or operations are possible and will require a trained operator or technician who is familiar with the controls software and power system operations. At least one operator will need to be trained in how to interact with the control software and be able to respond to faults or system alarms any time the system is operational and serving loads. During outage recovery or system black starts, it may be necessary to have multiple operators available to perform activities in parallel to restore power and/or resolve faults and bring the system online. For packaged microgrid systems (e.g., systems that come integrated and preconfigured from a single vendor), operator manuals and training materials will be provided to handle normal operations and troubleshooting. For systems integrated on site, this can be requested from the installer.

For microgrids, maintenance activities include maintenance of the individual system components (solar panels, batteries, inverters, generators, distribution system, etc.) and of the control platform itself. As the microgrid controller largely consists of computer hardware, maintenance requirements will largely consist of software and/or hardware updates to resolve any issues or implement new types of functionality. The *Installation, Operation, & Maintenance* *of Solar PV Microgrid - Handbook for Technicians* includes a comprehensive list of basic maintenance activities for the microgrid components (GSES 2015).

4.0 Power Supply Scenarios

The resources described above can be combined in various configurations to provide power to Marpi. The seven scenarios evaluated are as follows:

- 1: Solar PV + BESS (Section 4.1)
- 2: Wind + BESS (Section 4.2)
- 3: Solar PV + Wind + BESS (Section 4.3)
- 4: Solar PV + BESS + Diesel Generation (Section 4.4)
- 5: Wind + BESS + Diesel Generation (Section 4.5)
- 6: Solar PV + Wind + BESS + Diesel Generation (Section 4.6)
- 7: Diesel Generation Only (Section 4.7).

Each configuration provides certain benefits and challenges. For each scenario, the following are described in the sub-sections below. A side-by-side comparison of these scenarios is provided in Section 7.0.

- Technical configuration (equipment and sizing).
- Operating parameters (prioritization and availability of resources to meet the load).
- Project economics [capital costs[6]; O&M costs; social cost of carbon; and 25-year levelized cost of energy (LCOE),[7] which can be compared to the current CUC electricity rate of $0.41/kWh (CUC 2023); see Appendix D for economic analysis details].
- Equipment siting and space requirements.
- Environmental considerations, including quantification of annual air emissions.

The operating parameters vary for each scenario depending on the resources included and the system capacities. The estimated loads described in Section 2.0 increase during the rainy season and decrease during the dry season, but the expected solar and wind generation is the opposite, as shown in Figure 27. This results in the need for renewable energy systems to be sized too large to meet needs during most of the year and potentially not large enough for the rainy season, which in turn results in a seasonally varied dispatch of resources, including a BESS and generators. Specific microgrid dispatch considerations are described for each scenario.

[6] To compare scenarios, project economics were evaluated using full capital costs. However, grant funds may be available to cover renewable energy, BESS, or microgrid control capital costs. See Section 8.1 for some currently available grants.
[7] The LCOE is a measure of the present cost of electricity generation over the lifetime of a generation system. The LCOE is used to compare the cost of electricity generation between different generation options.

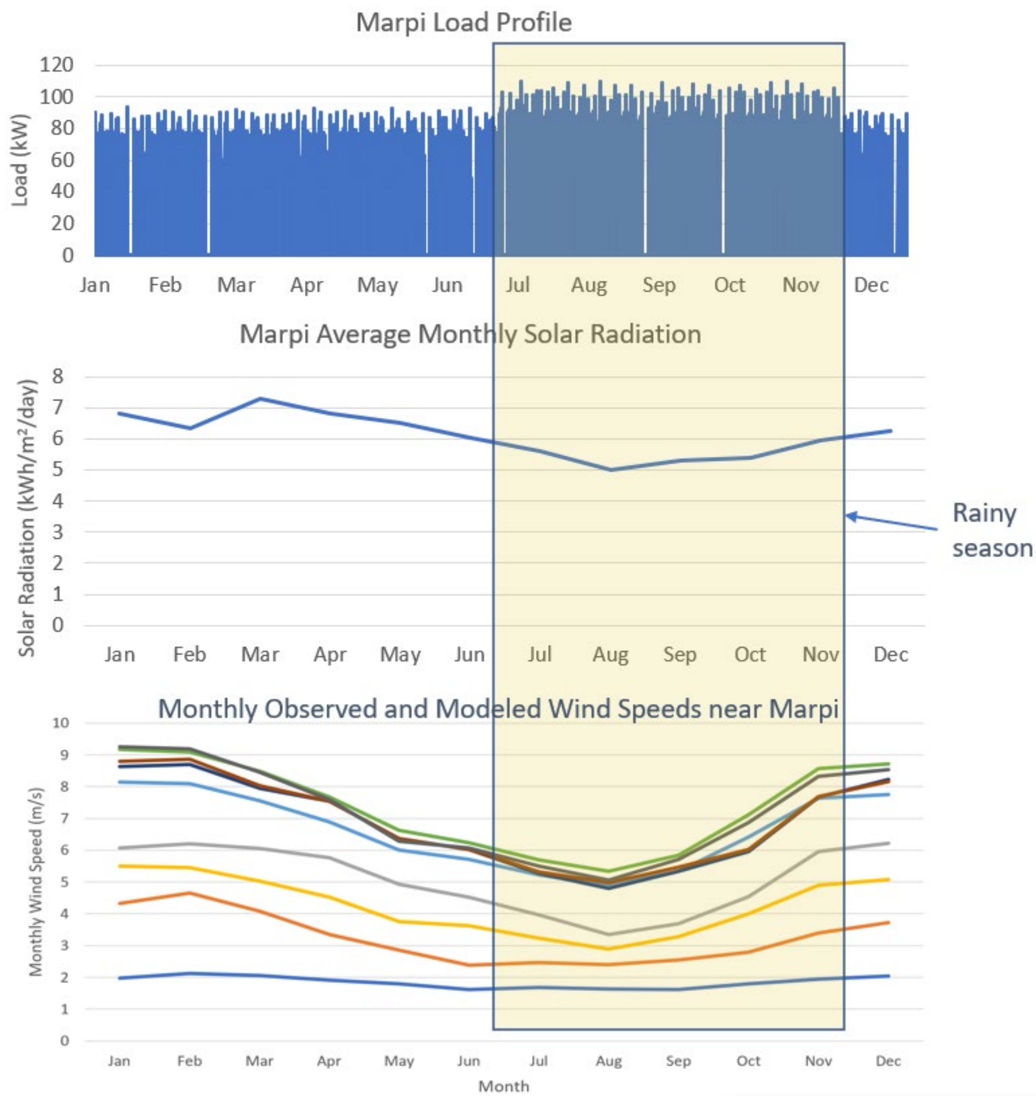

Figure 27. Rainy season impacts on Marpi Landfill loads and solar and wind resources.

4.1 Scenario 1: Solar PV + BESS

- Scenario 1 only includes a solar PV array and BESS. A solar PV array would generate power for the landfill, and a BESS would store excess energy for use at a time when renewable energy is not available. Table 8 shows the nameplate capacity (size), space requirement, and expected amount of the annual load served by each component for both estimated load profiles (24/7 operations baseline and 24/7 operations & electric equipment). Because of the increased capacity required to charge the electric landfill equipment, the solar PV array required for that load profile will not fit within the preferred project location's footprint. Using other areas of the landfill property or surrounding public lands would provide additional space, as described in Section 5.2. For both load profiles, 45% of the renewable energy generated by the solar PV array would be curtailed because generation exceeds the load when the BESS is full.

Table 8. Components, space requirements, and loads served for Scenario 1.

Load Profile	Component	Capacity	Space Requirement	Load Served
24/7 Operations Baseline	Solar PV	200 kW	~42,000 ft^2	100% (182 MWh)
24/7 Operations Baseline	BESS	250 kW/1,000 kWh	40 ft container	67 MWh charging/ 62.2 MWh discharging
24/7 Operations & Electric Equipment	Solar PV	500 kW	~105,000 ft^2	100% (458 MWh)
24/7 Operations & Electric Equipment	BESS	600 kW/2,400 kWh	40 ft container	309 MWh charging/ 292.2 MWh discharging

The Marpi load would be met first with any available generation from the PV array. When PV generation exceeds the load, the excess power would charge the BESS. Then, when the load exceeds the PV generation, the BESS would discharge to supply the difference. In addition, the BESS would operate all the time to keep the grid voltage and frequency stable. Figure 28 and Figure 29 show how the generation and BESS for the 24/7 operations baseline load profile are dispatched to meet the load during a representative month in the rainy and dry seasons, respectively. A dispatch plot shows how the various energy sources and the BESS are used (or dispatched) to meet the load.

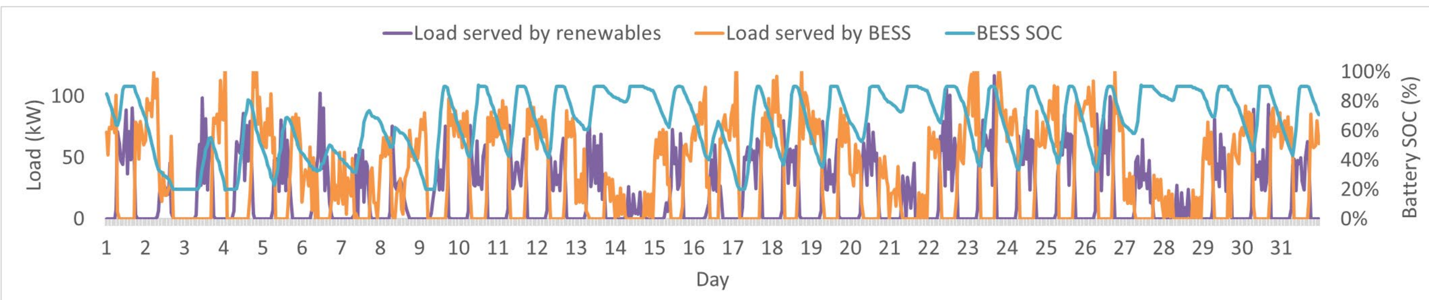

Figure 28. Scenario 1 dispatch plot for a typical month during the rainy season (24/7 operations baseline).

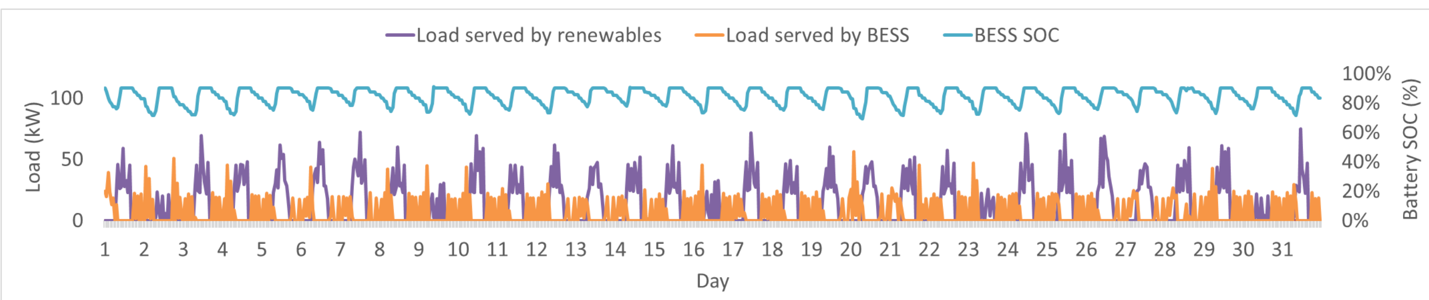

Figure 29. Scenario 1 dispatch plot for a typical month during the dry season (24/7 operations baseline).

As shown in Figure 28, during the rainy season, the solar generation (purple) is not always able to meet the load, resulting in some discharging and subsequent charging of the BESS. As shown in Figure 29, during the dry season, excess solar generation can be used to keep the BESS nearly fully charged.

Figure 30 and Figure 31 show how the generation and BESS for the 24/7 operations & electric equipment load profile are dispatched to meet the load during a representative month in the rainy and dry seasons, respectively. During both seasons, both the BESS and solar generation work together to meet the load.

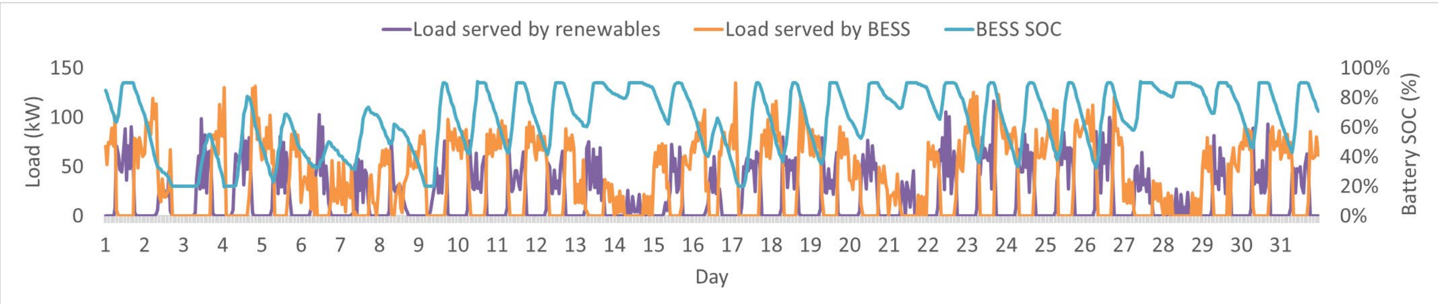

Figure 30. Scenario 1 dispatch plot for a typical month during the rainy season (24/7 operations & electric equipment).

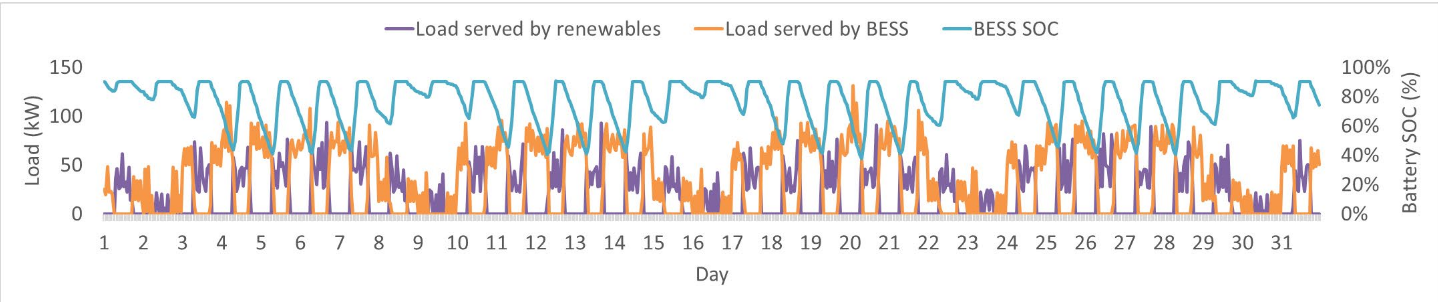

Figure 31. Scenario 1 dispatch plot for a typical month during the dry season (24/7 operations & electric equipment).

Table 9 shows the project economics for Scenario 1. Without grants, the LCOEs for both load profiles range between $1.47-2.00/kWh.

Table 9. Project economics for Scenario 1.

Economic Parameter	24/7 Operations Baseline	24/7 Operations & Electric Equipment
Capital Cost	$4.7M	$8.7M
Solar PV	$1.3M	$3.2M
BESS	$3.0M	$4.4M
Microgrid Controls	$0.4M	$1.1M
Annual O&M Costs	$5k/yr	$12k/yr
Social Cost of Carbon	$0k/yr	$0k/yr
25-year LCOE	$2.00/kWh	$1.47/kWh

Since this scenario only uses a solar PV array to power Marpi, there are no emissions or social cost of carbon associated with power generation.

This scenario prioritizes climate goals by avoiding diesel generation and the associated GHG emissions, but it does not have a diversity of resources to bolster resilience. It also has the second-highest LCOE of any scenario for the 24/7 operations baseline load profile. Additionally, the solar PV array for the 24/7 operations & electric equipment load profile would not fit within the footprint of the landfill.

4.2 Scenario 2: Wind + BESS

Scenario 2 only includes a wind turbine and BESS. A wind turbine (stationary, not tilt-up) would generate power for the landfill, and a BESS would store excess energy. Table 10 shows the nameplate capacity (size), space requirement, and expected amount of the annual load served by each component.

Table 10. Components, space requirements, and loads served for Scenario 2.

Load Profile	Component	Capacity	Space Requirement	Load Served
24/7 Operations Baseline	Wind Turbine	100 kW	~88,000 ft^2	66% (119 MWh)
24/7 Operations Baseline	BESS	200 kW/800 kWh	40 ft container	33.4 MWh charging/ 29.9 MWh discharging
24/7 Operations & Electric Equipment	Wind Turbine	100 kW	~88,000 ft^2	38% (175 MWh)
24/7 Operations & Electric Equipment	BESS	300 kW/1,200 kWh	40 ft container	25.2 MWh charging/ 23.1 MWh discharging

For the 24/7 operations baseline load profile, 32% of the renewable energy generated by the wind turbine would be curtailed because generation exceeds the load when the BESS is full. For the 24/7 operations & electric equipment load profile, 4% of the energy would be curtailed.

The load would be met first with any available generation from the wind turbine. Then, when wind generation exceeds the load, the excess power would charge the BESS. When the load exceeds the wind generation, the BESS would discharge to supply the difference. In addition, the BESS would operate all the time to keep the grid voltage and frequency stable. Figure 32 and Figure 33 show how the generation and BESS for the 24/7 operations baseline load profile are dispatched to meet the load during a representative month in the rainy and dry seasons, respectively.

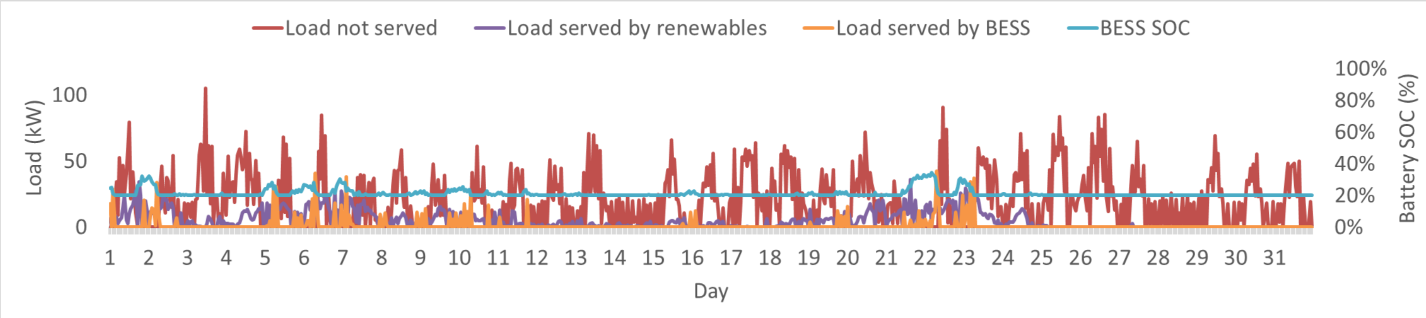

Figure 32. Scenario 2 dispatch plot for a typical month during the rainy season (24/7 operations baseline).

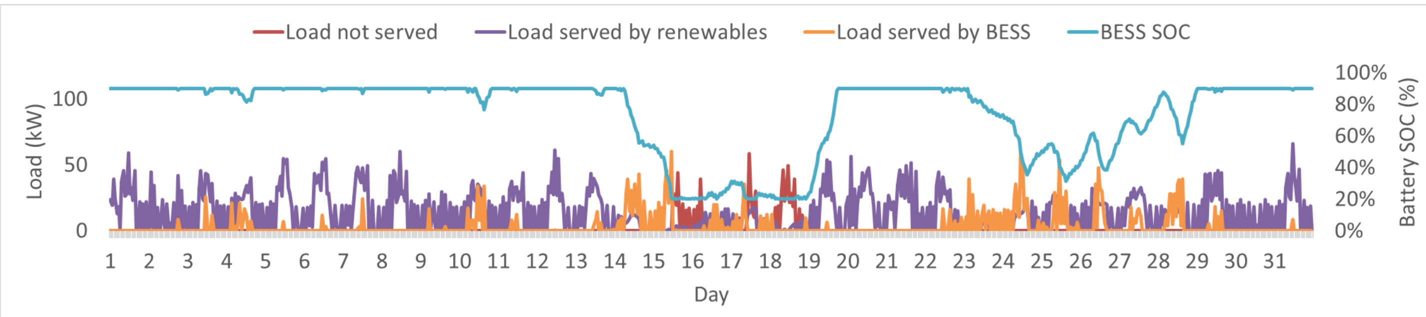

Figure 33. Scenario 2 dispatch plot for a typical month during the dry season (24/7 operations baseline).

As shown in Figure 32, during the rainy season, there is insufficient wind generation to meet the load (indicated by the red line showing load not being met) or keep the BESS charged (the blue line is at the minimum allowable SoC, 20%). As shown in Figure 33, however, during the dry season, the wind generation and BESS can meet the load, and the BESS stays close to fully charged most of the time. Over the course of the year, wind serves 66% of the load, leaving 34% of the load unmet.

Figure 34 and Figure 35 show how the generation and BESS for the 24/7 operations & electric equipment load profile are dispatched to meet the load during a representative month in the rainy and dry seasons, respectively. During both seasons, there is insufficient wind generation to meet the load or keep the BESS charged. Over the course of the year, wind serves 38% of the load, leaving 62% unmet.

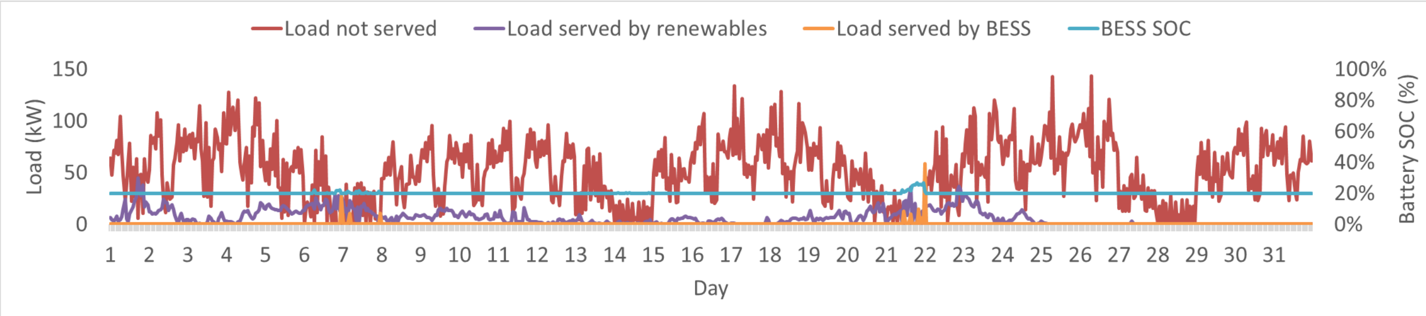

Figure 34. Scenario 2 dispatch plot for a typical month during the rainy season (24/7 operations & electric equipment).

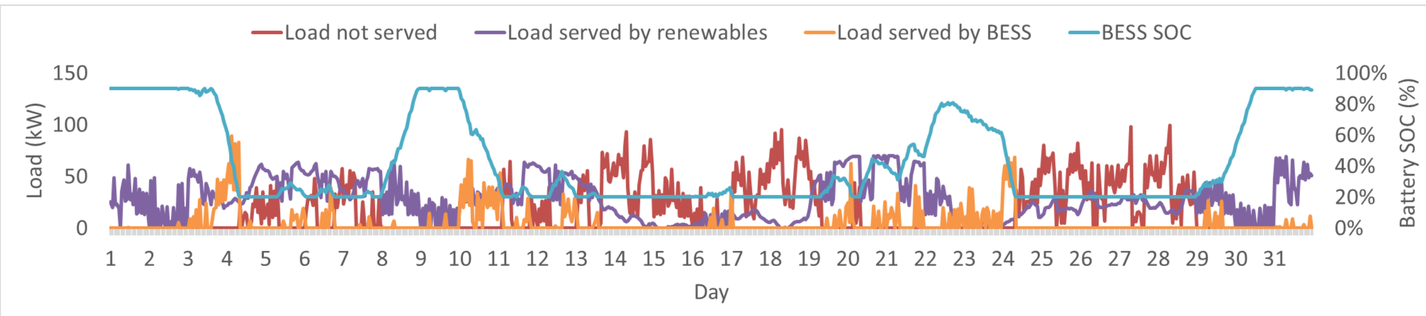

Figure 35. Scenario 2 dispatch plot for a typical month during the dry season (24/7 operations & electric equipment).

Table 11 shows the project economics for Scenario 2. Without grants, the LCOEs for both load profiles are in the range of $2.25–2.60/kWh.

Table 11. Project economics for Scenario 2.

Economic Parameter	24/7 Operations Baseline	24/7 Operations & Electric Equipment
Capital Cost	$3.6M	$4.9M
Wind Turbine	$0.9M	$0.9M
BESS	$2.4M	$3.6M
Microgrid Controls	$0.3M	$0.4M
Annual O&M Costs	$13k/yr	$15k/yr
Social Cost of Carbon	$0k/yr	$0k/yr
25-year LCOE	$2.60/kWh	$2.25/kWh

Since this scenario only uses wind to power Marpi, there are no emissions or social cost of carbon associated with power generation. However, wildlife impacts from the wind turbine would need to be studied.

This scenario prioritizes climate goals by avoiding diesel generation and the associated GHG emissions, but it does not meet the landfill's electricity demand a significant portion of the year. In addition, it has the highest LCOE of any scenario for both load profiles. Larger wind turbines could be considered to meet the load, but this would increase capital and O&M costs, increase the LCOEs, and increase the amount of wind energy needing to be curtailed.

4.3 Scenario 3: Solar PV + Wind + BESS

Scenario 3 includes a solar PV array, wind turbine, and BESS. A solar PV array and wind turbine (stationary, not tilt-up) would generate power for the landfill, and a BESS would store excess energy. Table 12 shows the nameplate capacity (size), space requirement, and expected amount of the annual load served by each component. Because of the increased capacity required to charge the electric landfill equipment, the solar PV required for that load profile will not fit within the preferred project location's footprint. Note that the amount of load served by the PV and wind generation can vary depending on how they are prioritized by the controller; in Table 12, PV is prioritized.

Table 12. Components, space requirements, and loads served for Scenario 3.

Load Profile	Component	Capacity	Space Requirement	Load Served
24/7 Operations Baseline	Solar PV	150 kW	~31,500 ft^2	73% (132 MWh)
24/7 Operations Baseline	Wind Turbine	100 kW	~88,000 ft^2	27% (50 MWh)
24/7 Operations Baseline	BESS	150 kW/600 kWh	40 ft container	30.3 MWh charging/ 27.8 MWh discharging
24/7 Operations & Electric Equipment	Solar PV	400 kW	~84,000 ft^2	76% (346 MWh)
24/7 Operations & Electric Equipment	Wind Turbine	100 kW	~88,000 ft^2	24% (112 MWh)
24/7 Operations & Electric Equipment	BESS	500 kW/2,000 kWh	40 ft container	216.3 MWh charging/ 204.9 MWh discharging

For the 24/7 operations baseline load profile, 58% of the renewable energy generated by the solar PV array and wind turbine would be curtailed because generation exceeds the load when the BESS is full. For the 24/7 operations & electric equipment load profile, 46% of the energy would be curtailed.

The load would be met first with any available generation from the PV array and wind turbine. When renewable generation exceeds the load, the excess power would charge the BESS. The microgrid controller would be programmed to direct the prioritization and curtailment of generation sources during times when both solar and wind are available, the generation potential exceeds the load, and the BESS is full. When the load exceeds the renewable generation, the BESS would discharge to supply the difference. In addition, the BESS would operate all the time to keep the grid voltage and frequency stable. Figure 36 and Figure 37 show how the solar and wind generation and BESS are dispatched to meet the load for the 24/7 operations baseline load profile during a representative month in the rainy and dry seasons, respectively.

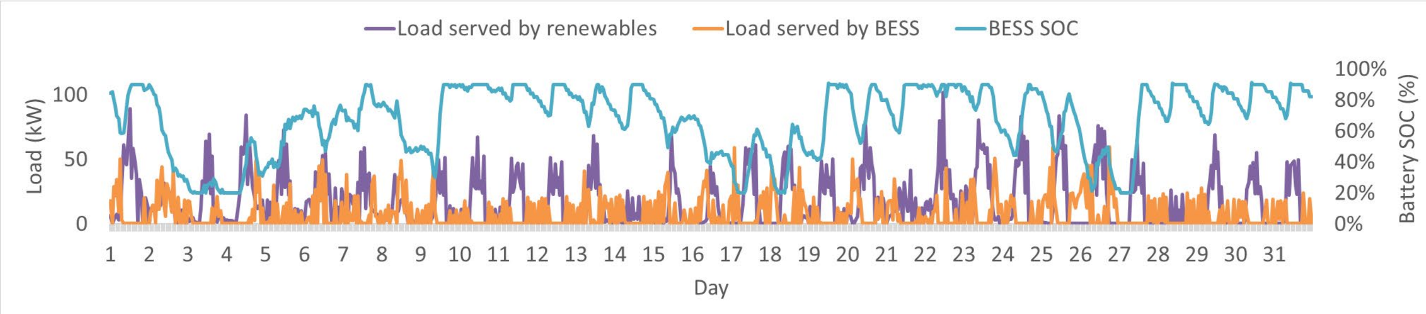

Figure 36. Scenario 3 dispatch plot for a typical month during the rainy season (24/7 operations baseline).

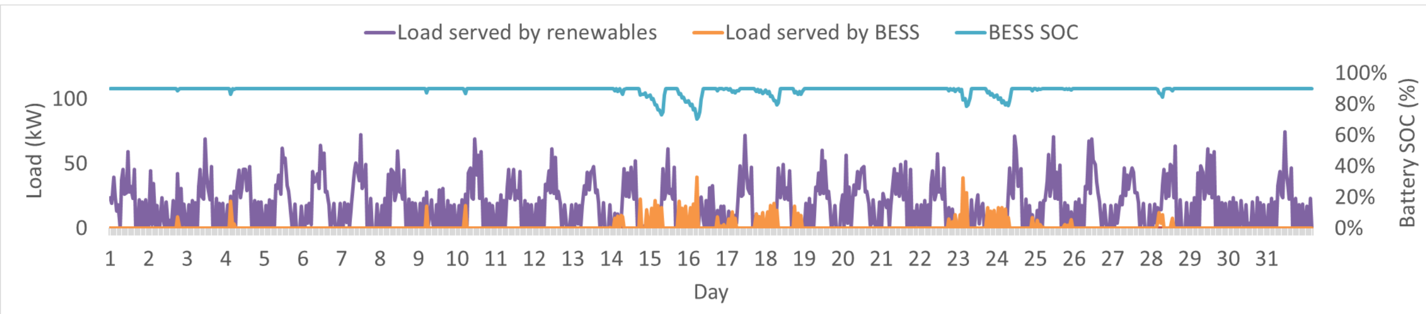

Figure 37. Scenario 3 dispatch plot for a typical month during the dry season (24/7 operations baseline).

As shown in Figure 36, during the rainy season, the solar and wind generation (shown in purple) and BESS (shown in orange) work together to meet the load, resulting in a fluctuating BESS SoC. As shown in Figure 37, during the dry season, lower loads mean that the excess solar and wind generation can be used to keep the BESS nearly fully charged.

Figure 38 and Figure 39 show how the generation and BESS for the 24/7 operations & electric equipment load profile are dispatched to meet the load during a representative month in the rainy and dry seasons, respectively. During both seasons, there is sufficient solar and wind generation to meet the load.

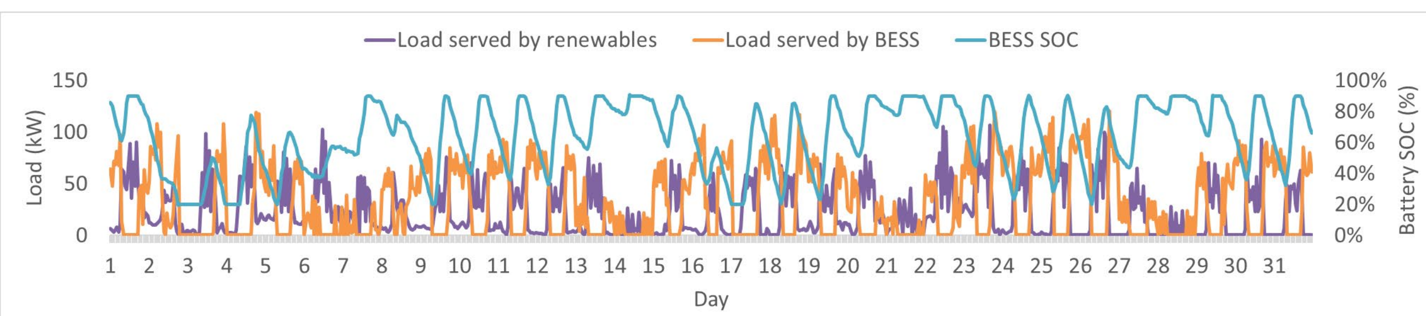

Figure 38. Scenario 3 dispatch plot for a typical month during the rainy season (24/7 operations & electric equipment).

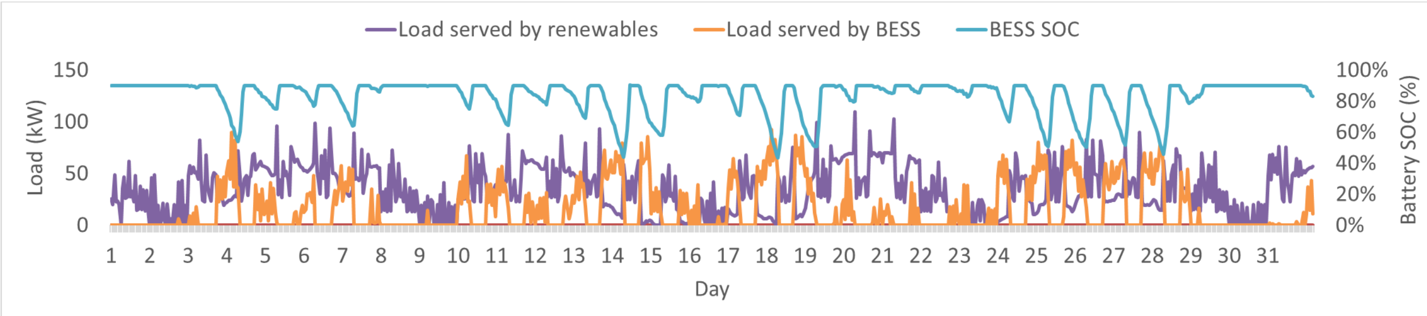

Figure 39. Scenario 3 dispatch plot for a typical month during the dry season (24/7 operations & electric equipment).

Table 13 shows the project economics for Scenario 3. Without grants, the LCOEs for both load profiles range between $1.71-1.85/kWh.

Table 13. Project economics for Scenario 3.

Economic Parameter	24/7 Operations Baseline	24/7 Operations & Electric Equipment
Capital Cost	$4.0M	$10.4M
Solar PV	$0.9M	$2.5M
Wind Turbine	$0.9M	$0.9M
BESS	$1.8M	$5.9M
Microgrid Controls	$0.4M	$1.1M
Annual O&M Costs	$14k/yr	$21k/yr
Social Cost of Carbon	$0k/yr	$0k/yr
25-year LCOE	$1.85/kWh	$1.71/kWh

Since this scenario only uses a solar PV array and wind turbine to power Marpi, there are no emissions or social cost of carbon associated with power generation. However, wildlife impacts from the wind turbine would need to be studied.

This scenario prioritizes climate goals by avoiding diesel generation and the associated GHG emissions. It also diversifies resources to bolster resilience but still completely relies on intermittent resources. Additionally, the solar PV array for the 24/7 operations & electric equipment load profile would not fit within the footprint of the landfill.

4.4 Scenario 4: Solar PV + BESS + Diesel Generation

Scenario 4 includes a solar PV array, BESS, and diesel generator. A solar PV array and diesel generator would provide power for the landfill, and a BESS would store excess energy from the PV array. Table 14 shows the nameplate capacity (size), space requirement, and expected amount of the annual load served by each component. Because of the increased capacity required to charge the electric landfill equipment, the solar PV array required for that load profile will not fit within the preferred project location's footprint.

Table 14. Components, space requirements, and loads served for Scenario 4.

Load Profile	Component	Capacity	Space Requirement	Load Served
24/7 Operations Baseline	Solar PV	100 kW	~21,500 ft^2	79% (143 MWh)
24/7 Operations Baseline	Diesel Generation	160 kW	15 ft container	21% (39 MWh)
24/7 Operations Baseline	BESS	100 kW/400 kWh	20 ft container	76.5 MWh charging/ 70.4 MWh discharging
24/7 Operations & Electric Equipment	Solar PV	300 kW	~63,000 ft^2	85% (391 MWh)
24/7 Operations & Electric Equipment	Diesel Generation	300 kW	20 ft container	15% (67 MWh)
24/7 Operations & Electric Equipment	BESS	300 kW/1,200 kWh	40 ft container	207.8 MWh charging/ 195.4 MWh discharging

For the 24/7 operations baseline load profile, 24% of the renewable energy generated by the solar PV array would be curtailed because generation exceeds the load when the BESS is full. For the 24/7 operations & electric equipment load profile, 21% of the energy would be curtailed.

The load would be met first with any available generation from the PV array. When solar generation exceeds the load, the excess power would charge the BESS. When the load exceeds the solar generation, the BESS would discharge to supply the difference, unless the BESS SoC is too low, at which point the diesel generators would meet the excess load. When no generator is running, the BESS would operate to keep the grid voltage and frequency stable. Figure 40 and Figure 41 show how the generation and BESS are dispatched to meet the load for the 24/7 operations baseline load profile during a representative month in the rainy and dry seasons, respectively.

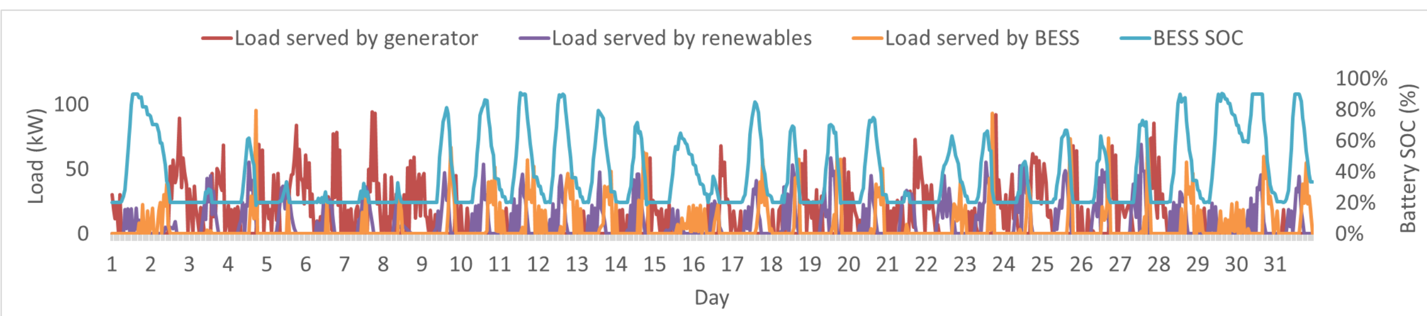

Figure 40. Scenario 4 dispatch plot for a typical month during the rainy season (24/7 operations baseline).

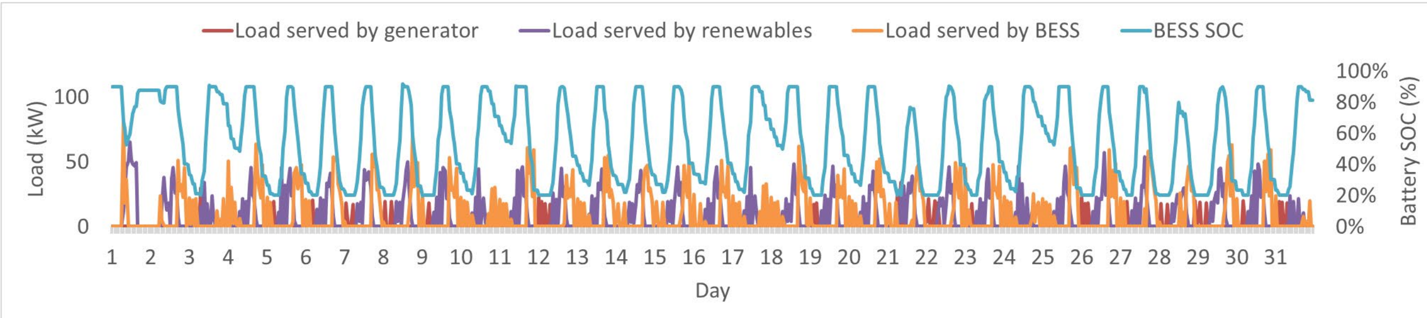

Figure 41. Scenario 4 dispatch plot for a typical month during the dry season (24/7 operations baseline).

As shown in Figure 40, during the rainy season, there is insufficient solar generation (purple) to meet the load, so the diesel generators (red) are dispatched to meet the shortfall. During the dry season, as shown in Figure 41, there is sufficient solar generation to meet the load and charge the BESS (orange), so the diesel generators are dispatched less often.

Figure 42 and Figure 43 show how the generation and BESS for the 24/7 operations & electric equipment load profile are dispatched to meet the load during a representative month in the rainy and dry seasons, respectively. During the rainy season, the solar generation (purple) is not always able to meet the load, resulting in the need to dispatch the diesel generation. During the dry season, the excess solar generation can be used to keep the BESS nearly fully charged, and the diesel generation is not required as often.

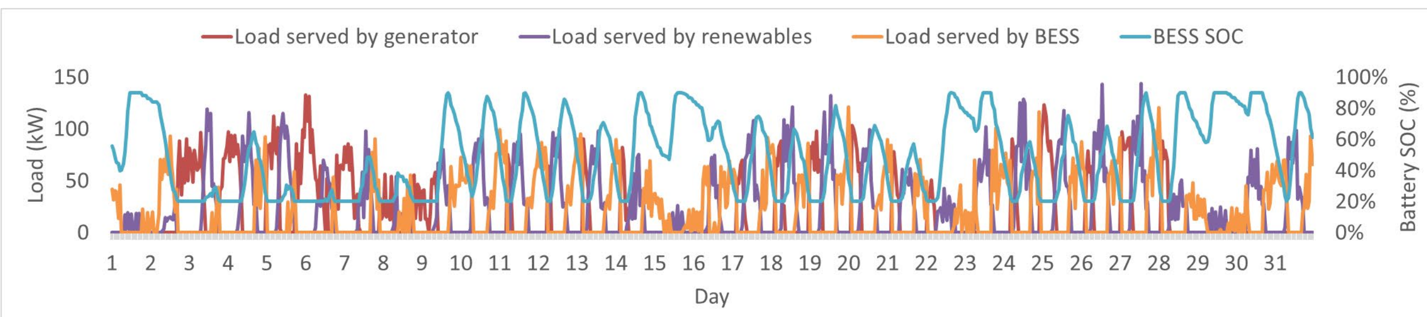

Figure 42. Scenario 4 dispatch plot for a typical month during the rainy season (24/7 operations & electric equipment).

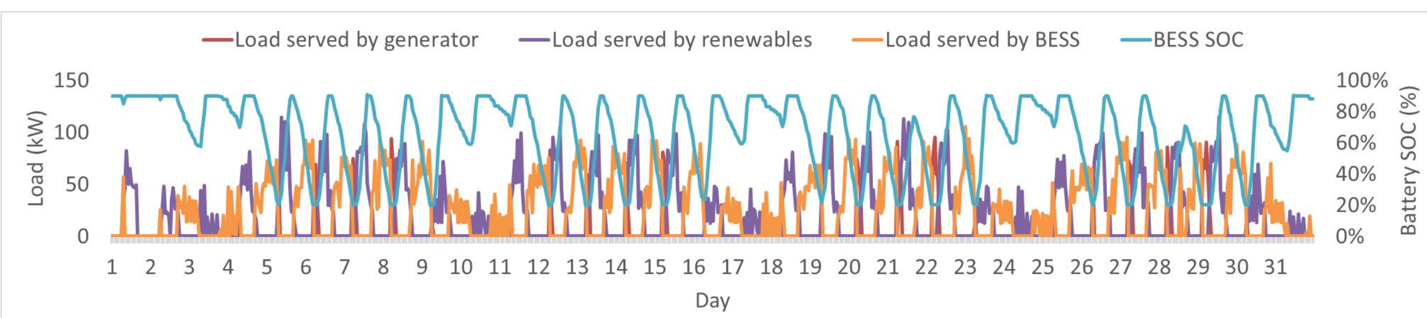

Figure 43. Scenario 4 dispatch plot for a typical month during the dry season (24/7 operations & electric equipment).

Table 15 shows the project economics for Scenario 4. Without grants, the LCOEs for both load profiles range between $1.37-1.52/kWh.

Table 15. Project economics for Scenario 4.

Economic Parameter	24/7 Operations Baseline	24/7 Operations & Electric Equipment
Capital Cost	$3.0M	$7.9M
Solar PV	$0.6M	$1.9M
Diesel Generator	$0.8M	$1.5M
BESS	$1.2M	$3.6M
Microgrid Controls	$0.4M	$0.9M
Annual O&M Costs	$18k/yr	$43k/yr
Social Cost of Carbon	$42k/yr	$99k/yr
25-year LCOE	$1.52/kWh	$1.37/kWh

Since this scenario uses diesel to power up to one fifth of Marpi's energy use depending on the load profile, there are emissions associated with power generation, as shown in Table 16. In addition, fuel spill containment, consumable disposal, and countermeasure considerations for diesel generation must be considered.

Table 16. Emissions associated with power generation for Scenario 4.

Load Profile	Pollutant	Emissions Generated (tons/year)
24/7 Operations Baseline	CO_2e	29
24/7 Operations Baseline	NO_X	0.01
24/7 Operations Baseline	PM	0.02
24/7 Operations & Electric Equipment	CO_2e	48
24/7 Operations & Electric Equipment	NO_X	0.02
24/7 Operations & Electric Equipment	PM	0.03

This scenario balances several goals: climate, reliability, and economics. It supports climate goals by primarily using solar energy to generate electricity, with diesel generation providing some of the landfill's electricity needs. This scenario uses both intermittent and dispatchable resources for added reliability and has the second lowest LCOE of any scenario for the 24/7 operations baseline load profile and third lowest LCOE of any scenario for the 24/7 operations & electric equipment load profile. However, the solar PV array for the 24/7 operations & electric equipment load profile would not fit within the footprint of the landfill.

4.5 Scenario 5: Wind + BESS + Diesel Generation

Scenario 5 includes a wind turbine, BESS, and diesel generator. A stationary wind turbine and diesel generator would provide power for the landfill, and a BESS would store excess energy. Table 17 shows the nameplate capacity (size), space requirement, and expected amount of the annual load served by each component.

Table 17. Components, space requirements, and loads served for Scenario 5.

Load Profile	Component	Capacity	Space Requirement	Load Served
24/7 Operations Baseline	Wind Turbine	100 kW	~88,000 ft^2	62% (113 MWh)
24/7 Operations Baseline	Diesel Generation	160 kW	15 ft container	38% (69 MWh)
24/7 Operations Baseline	BESS	100 kW/400 kWh	20 ft container	28.3 MWh charging/ 24.3 MWh discharging
24/7 Operations & Electric Equipment	Wind Turbine	100 kW	~88,000 ft^2	36% (166 MWh)
24/7 Operations & Electric Equipment	Diesel Generation	300 kW	20 ft container	64% (292 MWh)
24/7 Operations & Electric Equipment	BESS	100 kW/400 kWh	20 ft container	17.2 MWh charging/ 14.3 MWh discharging

For the 24/7 operations baseline load profile, 36% of the renewable energy generated by the wind turbine would be curtailed because generation exceeds the load when the BESS is full. For the 24/7 operations & electric equipment load profile, 8% of the energy would be curtailed.

The load would be met first with any available generation from the wind turbine. When wind generation exceeds the load, the excess power would charge the BESS. When the load exceeds the wind generation, the BESS would discharge to supply the difference, unless the BESS SoC is too low, at which point the diesel generators would meet the excess load. When no generator is running, the BESS would operate to keep the grid voltage and frequency stable. Figure 44 and Figure 45 show how the generation and BESS are dispatched to meet the load for the 24/7 operations baseline load profile during a representative month in the rainy and dry seasons, respectively.

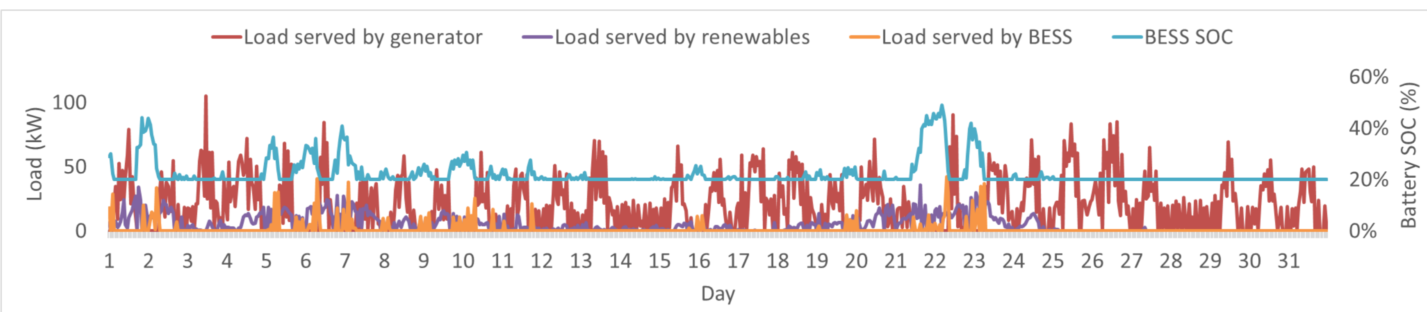

Figure 44. Scenario 5 dispatch plot for a typical month during the rainy season (24/7 operations baseline).

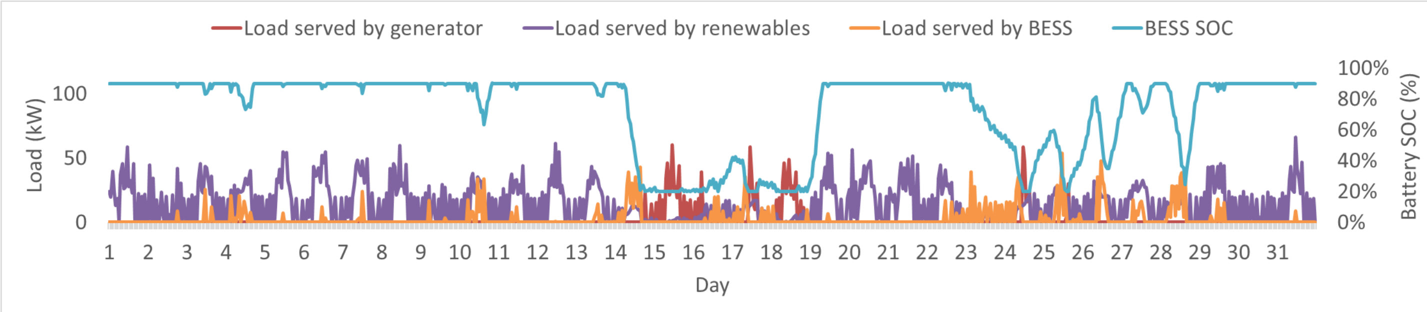

Figure 45. Scenario 5 dispatch plot for a typical month during the dry season (24/7 operations baseline).

As shown in Figure 44, during the rainy season, there is insufficient wind generation (purple) to meet the load so the diesel generators (red) meet the shortfall, and the BESS SoC (blue) remains at its minimum much of the time. During the dry season, as shown in Figure 45, there is sufficient wind generation to meet the load and charge the BESS the majority of the time, although the diesel generators must still occasionally be dispatched to meet the generation shortfall.

Figure 46 and Figure 47 show how the generation and BESS for the 24/7 operations & electric equipment load profile are dispatched to meet the load during a representative month in the rainy and dry seasons, respectively. During both seasons, there is insufficient wind generation to meet the load or charge the BESS, so the diesel generator is dispatched to meet the majority of the load.

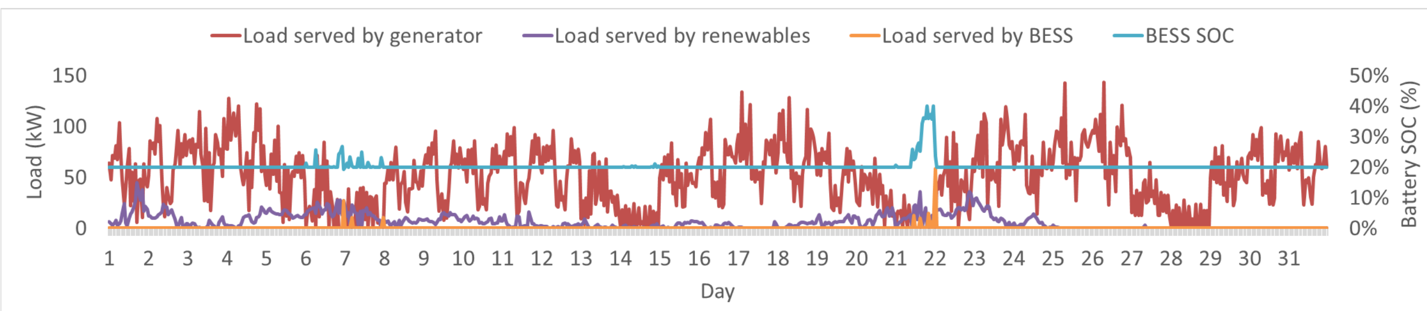

Figure 46. Scenario 5 dispatch plot for a typical month during the rainy season (24/7 operations & electric equipment).

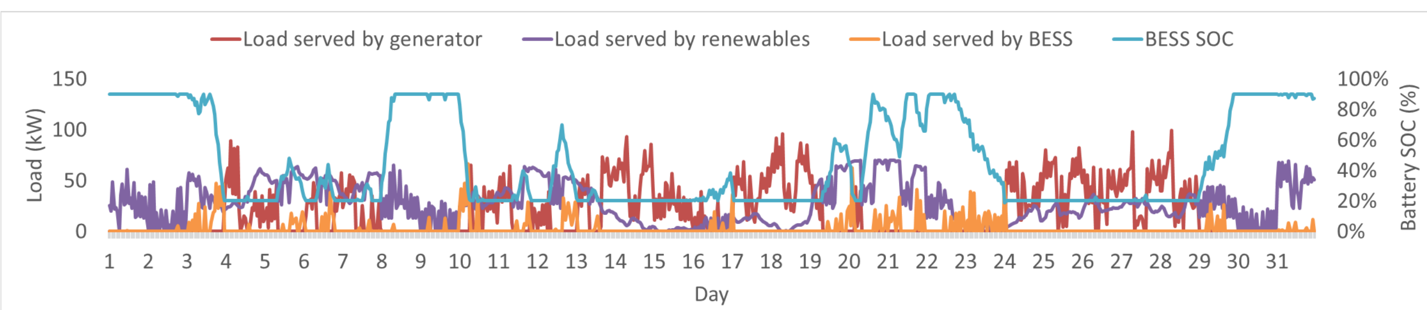

Figure 47. Scenario 5 dispatch plot for a typical month during the dry season (24/7 operations & electric equipment).

Table 18 shows the project economics for Scenario 5. Without grants, the LCOEs for both load profiles range between $1.15-1.81/kWh.

Table 18. Project economics for Scenario 5.

Economic Parameter	24/7 Operations Baseline	24/7 Operations & Electric Equipment
Capital Cost	$3.3M	$4.1M
Wind Turbine	$0.9M	$0.9M
Diesel Generator	$0.8M	$1.5M
BESS	$1.2M	$1.2M
Microgrid Controls	$0.4M	$0.5M
Annual O&M Costs	$41k/yr	$133k/yr
25-year LCOE	$1.81/kWh	$1.15/kWh
Social Cost of Carbon	$102k/yr	$433k/yr

Since this scenario uses diesel to meet 38%–64% of Marpi's annual load, there are emissions associated with power generation, as shown in Table 19. Additionally, there are other environmental impacts such as potential wildlife impacts from the wind turbine; and fuel spill containment, consumable disposal, and countermeasure considerations for diesel generation.

Table 19. Emissions associated with power generation for Scenario 5.

Load Profile	Pollutant	Emissions Generated (tons/year)
24/7 Operations Baseline	CO_2e	50
24/7 Operations Baseline	NO_X	0.03
24/7 Operations Baseline	PM	0.03
24/7 Operations & Electric Equipment	CO_2e	211
24/7 Operations & Electric Equipment	NO_X	0.11
24/7 Operations & Electric Equipment	PM	0.12

This scenario meets 36%–62% of the landfill's load using wind energy. However, diesel generation is required to meet the remainder of the load, resulting in high O&M costs, social cost of carbon, and GHG emissions.

4.6 Scenario 6: Solar PV + Wind + BESS + Diesel Generation

Scenario 6 includes a solar PV array, wind turbine, BESS, and diesel generator. The solar PV array, stationary wind turbine, and diesel generator would provide power for the landfill, and the BESS would store excess energy from the renewable generators. Table 20 shows the nameplate capacity (size), space requirement, and expected amount of the annual load served by each component. Because of the increased capacity required to charge the electric landfill equipment, the solar PV array required for that load profile will not fit within the preferred project location's footprint. Note that the amount of load served by PV and wind generation can vary depending on how they are prioritized by the controller; in Table 20, PV is prioritized.

Table 20. Components, space requirements, and load served for Scenario 6.

Load Profile	Component	Capacity	Space Requirement	Load Served
24/7 Operations Baseline	Solar PV	100 kW	~21,500 ft^2	62% (111 MWh)
24/7 Operations Baseline	Wind Turbine	100 kW	~88,000 ft^2	30% (55 MWh)
24/7 Operations Baseline	Diesel Generation	160 kW	15 ft container	9% (16 MWh)
24/7 Operations Baseline	BESS	60 kW/120 kWh	20 ft container	21.8 MWh charging/ 18.2 MWh discharging
24/7 Operations & Electric Equipment	Solar PV	250 kW	~52,500 ft^2	61% (275 MWh)
24/7 Operations & Electric Equipment	Wind Turbine	100 kW	~88,000 ft^2	27% (120 MWh)
24/7 Operations & Electric Equipment	Diesel Generation	300 kW	20 ft container	12% (63 MWh)
24/7 Operations & Electric Equipment	BESS	250 kW/1,000 kWh	40 ft container	165.3 MWh charging/ 152.9 MWh discharging

For the 24/7 operations baseline load profile, 52% of the renewable energy generated by the wind turbine would be curtailed because generation exceeds the load when the BESS is full. For the 24/7 operations & electric equipment load profile, 34% of the energy would be curtailed.

The load would be met first with any available generation from the PV array and wind turbine. When renewable generation exceeds the load, the excess power would charge the BESS. The microgrid controller would be programmed to direct the prioritization and curtailment of generation sources for times when both solar and wind are available, the generation potential exceeds the load, and the BESS is full. When the load exceeds the renewable generation, the BESS would discharge to supply the difference unless the BESS SoC is too low, at which point the diesel generators would meet the excess load. When no generator is running, the BESS would operate to keep the grid voltage and frequency stable. Figure 48 and Figure 49 show how the generation and BESS are dispatched to meet the load for the 24/7 operations baseline load profile during a representative month in the rainy and dry seasons, respectively

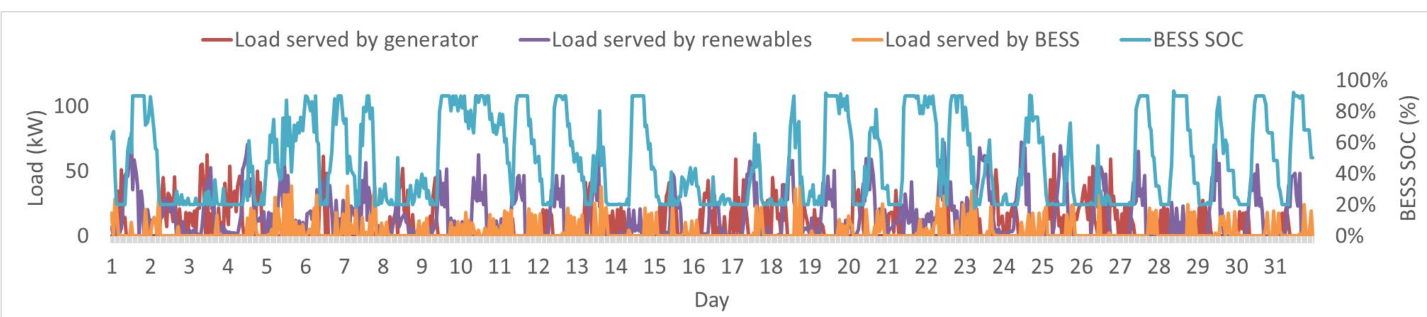

Figure 48. Scenario 6 dispatch plot for a typical month during the rainy season (24/7 operations baseline).

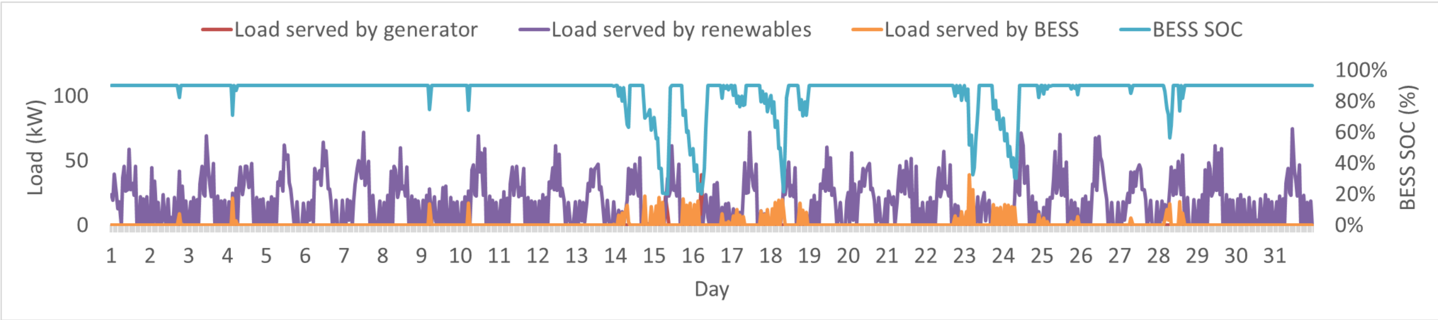

Figure 49. Scenario 6 dispatch plot for a typical month during the dry season (24/7 operations baseline).

As shown in Figure 48, during the rainy season, there is insufficient solar and wind generation (purple) to meet the load, so the diesel generators (red) are dispatched to meet the shortfall, and the BESS (blue) is cycled daily. During the dry season, as shown in Figure 49, there is sufficient solar and wind generation to meet the load and keep the BESS nearly fully charged.

Figure 50 and Figure 51 show how the generation and BESS for the 24/7 operations & electric equipment load profile are dispatched to meet the load during a representative month in the rainy and dry seasons, respectively. During the rainy season, there is insufficient solar and wind generation to meet the load, so the diesel generators are dispatched to meet the shortfall, and the BESS is cycled daily. During the dry season, there is sufficient solar and wind generation to meet the load and keep the BESS nearly fully charged.

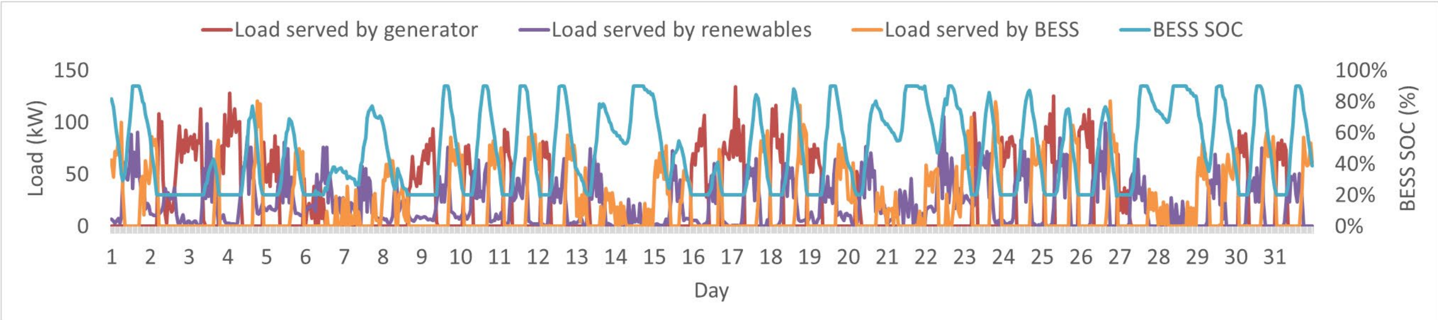

Figure 50. Scenario 6 dispatch plot for a typical month during the rainy season (24/7 operations & electric equipment).

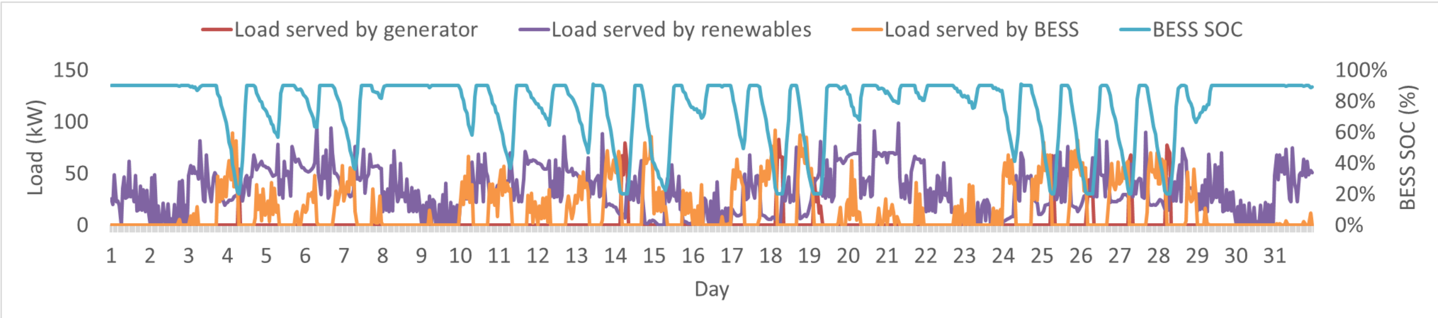

Figure 51. Scenario 6 dispatch plot for a typical month during the dry season (24/7 operations & electric equipment).

Table 21 shows the project economics for Scenario 6. Without grants, the LCOEs for both load profiles range between $1.41–1.58/kWh.

Table 21. Project economics for Scenario 6.

Economic Parameter	24/7 Operations Baseline	24/7 Operations & Electric Equipment
Capital Cost	$3.2M	$7.9M
Solar PV	$0.6M	$1.6M
Wind Turbine	$0.9M	$0.9M
Diesel Generator	$0.8M	$1.5M
BESS	$0.4M	$3.0M
Microgrid Controls	$0.5M	$0.9M
Annual O&M Costs	$19k/yr	$44k/yr
Social Cost of Carbon	$24k/yr	$97k/yr
25-year LCOE	$1.58/kWh	$1.41/kWh

Since this scenario uses some diesel to power Marpi, there are emissions associated with power generation, as shown in Table 22. Because the generator would only power 9%–14% of the load, the amount of emissions generated is less than that in other scenarios that include generators. Additionally, there are other environmental impacts associated with this scenario, such as potential wildlife impacts from the wind turbine; and fuel spill containment, consumable disposal, and countermeasure considerations for diesel generation.

Table 22. Emissions associated with power generation for Scenario 6.

Load Profile	Pollutant	Emissions Generated (tons/year)
24/7 Operations Baseline	CO_2e	12
24/7 Operations Baseline	NO_X	0.006
24/7 Operations Baseline	PM	0.007
24/7 Operations & Electric Equipment	CO_2e	48
24/7 Operations & Electric Equipment	NO_X	0.02
24/7 Operations & Electric Equipment	PM	0.03

This scenario prioritizes reliability by using a variety of resources and supports climate goals by primarily relying on wind and solar energy to generate electricity, with diesel generation providing only around 9%–14% of the landfill's electricity needs, depending on the load profile. This scenario also has the lowest GHG emissions of any scenario that includes a diesel generator. However, the solar PV array for the 24/7 operations & electric equipment load profile would not fit within the footprint of the landfill.

4.7 Scenario 7: Diesel Generation Only

This scenario uses 160 kW of diesel generation (supplied by a minimum of two 80 kW generators) to provide all the landfill's energy needs for the 24/7 operations baseline load profile and 300 kW of diesel generation (supplied by a minimum of three 100 kW generators) for the 24/7 operations & electric equipment load profile. This scenario is essentially a continuation of current practices but is sized for future loads and is intended to be a long-term solution that can provide power 24/7 rather than a temporary fix that must be turned on daily. Table 23 shows the project economics for Scenario 7. For this scenario, the LCOEs range between $0.97–1.20/kWh. It is assumed that grants will not be available for new generators.

Table 23. Project economics for Scenario 7.

Economic Parameter	24/7 Operations Baseline	24/7 Operations & Electric Equipment
Capital Cost	$0.8M	$1.5M
Diesel Generator	$0.8M	$1.5M
Annual O&M Costs	$75k/yr	$190k/yr
Social Cost of Carbon	$270k/yr	$680k/yr
25-year LCOE	$1.20/kWh	$0.97/kWh

Since this scenario solely uses diesel to power Marpi, there are more emissions associated with power generation than for any other scenario, as shown in Table 24. Additionally, there are other environmental impacts associated with this scenario, such as fuel spill containment, consumable disposal, and countermeasure considerations for the diesel generation.

Table 24. Emissions associated with power generation for Scenario 7.

Load Profile	Pollutant	Emissions Generated (tons/year)
24/7 Operations Baseline	CO_2e	132
24/7 Operations Baseline	NO_X	0.07
24/7 Operations Baseline	PM	0.08
24/7 Operations & Electric Equipment	CO_2e	332
24/7 Operations & Electric Equipment	NO_X	0.17
24/7 Operations & Electric Equipment	PM	0.2

This scenario uses diesel as a sole generation source for the landfill. As such, it does not support climate or sustainability goals, nor does it provide a diversity of resources to bolster resilience. It does, however, have the lowest LCOE of any scenario, assuming no grant funding.

5.0 Siting

The project team worked to identify a suitable location that is large enough for all system components, does not incur significant added cost, and is operationally feasible.

5.1 Space Requirements

The approximate amount of space required for each component being considered for Marpi is listed in Table 25.

Table 25. Space requirements for microgrid components.

Component	Footprint
Solar PV	~210 ft^2/kW_{AC} (ground-mount); ~100 ft^2/kW_{AC} (rooftop) (Gagnon et al. 2016)
Wind turbine	No habitable structures within a radius equal to the tip height (51 m for a 100 kW turbine with a 37 m tower height)
Batteries	Standard ISO 20–40 ft container (approximately 8′ × 8′ × 20′ or 40′), depending on battery size and vendor specifications
Generators	15-20 ft ISO-style enclosure for 160/300 kW generator or an equivalent space requirement for smaller units totaling 160/300 kW
Microgrid controls and BOP	10 ft ISO enclosure; can be collocated with generator or BESS

5.2 Potential System Locations

The primary location for a microgrid identified by the project team is in the southwest corner of the landfill property (Figure 52). The existing generator is located here (yellow rectangle), and power distribution lines already serve this site.

Figure 52. Satellite image of a potential location identified for a microgrid.

This area has several terrain changes, an elevated residential dropoff point, temporary piles of waste, and some landscaping (see Figure 53) that would need to be removed or accommodated in some way if this site were to be used for a solar PV array and/or wind turbine. New generators and batteries could be placed next to or at the current generator location. PV panels could be placed on a carport structure shading the residential dropoff point, in addition to some ground-mounted panels. A potential project layout that includes all microgrid components considered is presented in Figure 54, indicating potential component sizes that will fit within this space.

Figure 53. Overhead view of the potential location identified for a microgrid.

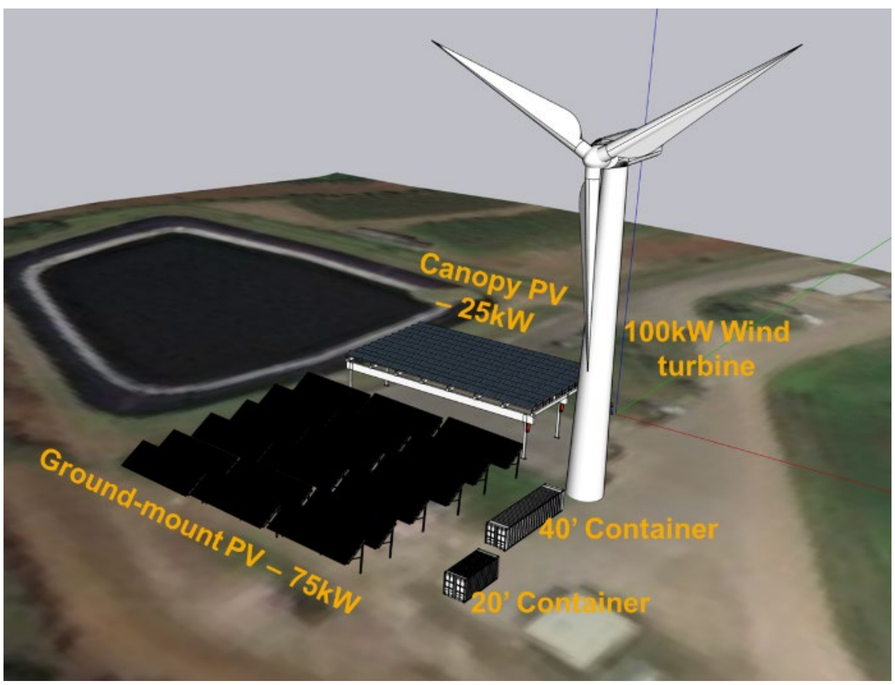

Figure 54. Potential layout for microgrid components on the landfill property.

The footprint of the new generator recommended for Marpi in several scenarios would be approximately the same as the current generator house (200–300 ft^2). The existing structure could be used, potentially keeping the existing electric switchgear in its current location and removing the existing generator to make room for two new units, each housed in dedicated enclosures. While the existing structure does provide some protection from rain and blown dust and other airborne debris, it provides minimal protection against corrosion from the marine environment. Further, the sheet-metal construction does not appear to be hardened to withstand any significant wind events or major storms.

New generators could also be delivered in a containerized format with enclosures rated to withstand adverse weather and corrosion. If this option were pursued, then additional consideration for the replacement of the existing panelboard and switchgear into dedicated metal-clad enclosures is warranted. For the new generator(s), an integrated day tank (configured as a belly tank underneath the generator enclosure) would minimize the footprint and reduce fuel pumping requirements. Installing the generator(s), either for this scenario or any of the others, in either a new building or new vendor-supplied enclosure also enables the DPW to relocate the generators to be more optimally located within the available footprint relative to any other system components that are installed (solar PV, BESS, controls, etc.).

Other locations were discussed for the solar PV array, as this is the component requiring the most land area.

- Installing the panels on capped Cell 1 is an option but would be challenging given the expected timeline for capping (possibly a decade or more down the road). In addition, mounting the panels to withstand typhoon winds requires structural piers buried approximately 14 feet deep, which is much deeper than the liner at just a few feet deep.
- Using other areas of the landfill property or surrounding public lands[8] would provide additional space but would require long electrical runs that would add cost and potential loss of voltage.

[8] Public land parcels surrounding the Marpi Landfill can be explored using the BECQ Public Permitting App (https://becq-dcrm.opendata.arcgis.com/apps/becq-public-permitting-app/explore).

6.0 Natural Hazard Risk and Mitigation

The risk of natural hazards must be considered for projects intended to provide a resilient source of power. Equipment can be hardened to reduce the risk of failure, but this adds cost to the project. Therefore, it is important to understand which hazard-hardening efforts should be targeted.

Figure 55 shows the most prevalent natural hazards in the South Pacific and the estimated annual damage for each hazard. This figure shows that tropical cyclones are the hazard of greatest concern, both in terms of frequency and damage, and earthquakes, floods, and drought are all significant hazards as well in the region. Note that drought was not included in the prevalence analysis shown on the left.

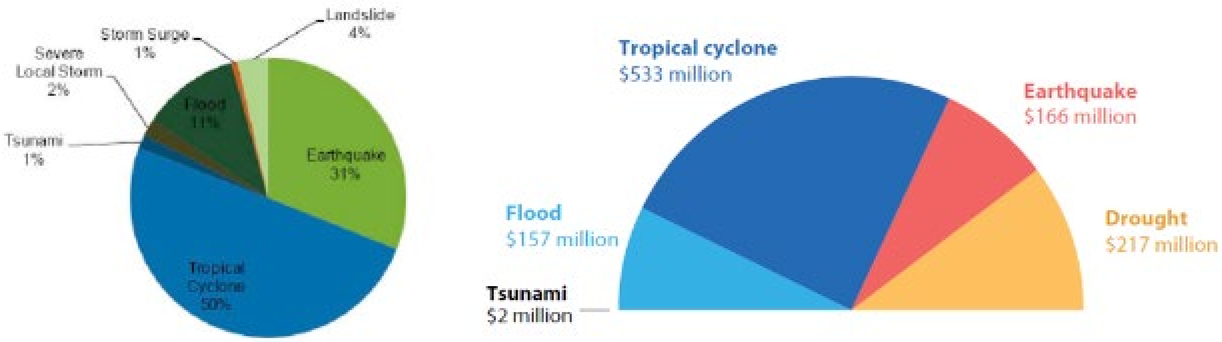

Figure 55. (Left) Natural hazard prevalence (World Bank 2013) and (Right) annual financial impact of natural hazards in South Pacific island nations (ESCAP 2020).

Table 26 summarizes the most prevalent hazards affecting Saipan and the CNMI. The table indicates the most common time of year when the hazard occurs, how susceptible electrical infrastructure is to the hazard, and whether the hazard has been demonstrated to be increasing over time. The infrastructure susceptibility is for general purposes and is not location specific. The risk level is assigned based on the information presented below.

Table 26. Summary of prevalent regional hazard risks and infrastructure susceptibility.

Hazard	Season	Risk	Electric Infrastructure Susceptibility to Damage	Increase in Future
Typhoon	Aug–Dec	High	High	Yes
Aerosol salt deposition	Year-round	High	High	No
Earthquake	Year-round	High	High	No
Flooding	Year-round	Low (landfill at 40 m elevation)	High	Yes
Drought	Dec–Apr	Mod	Low (does not impact electrical equipment)	Yes

6.1 Typhoons

Typhoons are storm systems that originate over tropical or subtropical water and are equivalent in the Pacific to a hurricane in the Caribbean or Atlantic. Their intensity and frequency are expected to increase in the future because of climate change (ESCAP 2020; Grecni et al. 2021; World Bank 2013).

Typhoons pose a significant threat to infrastructure through direct damage from wind and flying debris. Wind speeds and pressure differentials in air commonly destroy telephone poles, roof tiling, vehicles, antennae, and other smaller objects and structures, but the wind can also turn these objects into projectiles that can cause significant damage to larger, sturdy structures. Typhoons are often accompanied by torrential rainfall and sea water surges, which can cause coastal and inland flooding. Category 5 Super Typhoon Yutu hit the Northern Mariana Islands in 2018, leaving the region without electricity, and is the second strongest storm system to ever hit U.S.-owned land and the fifth strongest worldwide that has hit land, with sustained winds of 180 mph (Chiu et al. 2018). Widespread damage also delayed the restoration of utility services, but many solar PV systems were left intact and were fully operational once CUC service was restored (all are grid-connected and cannot operate without grid service), such as those at the DPW building and U.S. Army Reserve facility. Other systems were only partially damaged, such as that at the Business Plaza (Figure 56). Another event occurred in 2015, when Typhoon Souldelor struck, leaving the area without electric, water, or wastewater services for several months.

Figure 56. Damage from Typhoon Yutu to the solar PV system at the Marianas Business Plaza.

Figure 57 shows the historical paths of tropical cyclones in the Pacific. The Northern Mariana Islands are in an area with a heavy concentration of typhoons.

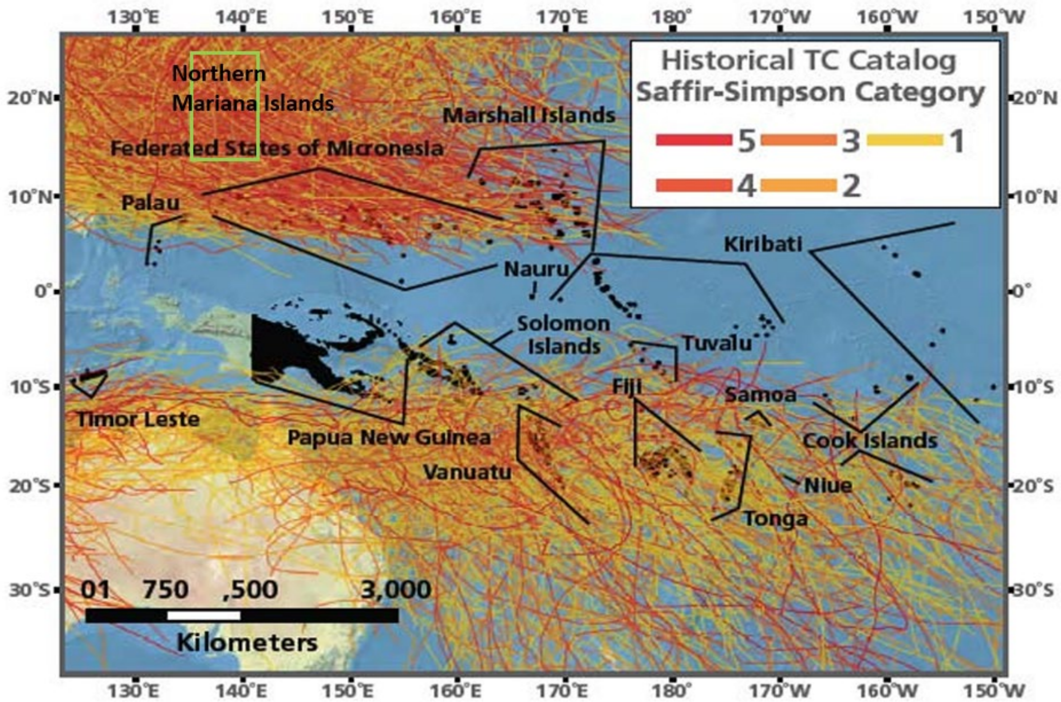

Figure 57. Map of tropical cyclone paths through the South Pacific (World Bank 2013).

6.2 Aerosol Sea Salt Deposition and Corrosion

Salt acts as a corrosion agent, deteriorating metal, paint, and finishes, and causes metals to oxidize. Several factors influence the corrosion rate of aerosolized salt air on metal, including wind speed and direction, coastal topography, humidity, and wave height. Each of these factors plays a role in determining the distance that salty air travels. The impact of salty air on metal materials is so extensive that it can affect structures up to 50 miles inland (Poma 2022). Sea salt deposition can significantly impact the longevity of exposed electrical infrastructure, accounting for as much as 40% of an asset's lifecycle cost (DoD n.d.), and cause utility disruptions if preventive maintenance is not taken.

Marpi is located within a mile of the Saipan coast on the windward side of the island. Figure 58 shows the corrosion of a metal pipe around a groundwater monitoring well. The rental generator is located in a shelter but is not fully enclosed; corrosion can be seen in Figure 59.

Figure 58. Corroded pipes surrounding water monitoring wells.

Figure 59. Rental generator in an enclosure with some corrosion.

6.3 Earthquakes

The earthquake zone that lines the perimeter of the Pacific Ocean is called the Ring of Fire or the Circum-Pacific Belt, and about 90% of the world's earthquakes occur in this area (National Geographic Society 2022). As a result, earthquakes are a significant risk across the Pacific. The Northern Mariana Islands are on the edge of the Philippine Sea Plate, where many strong earthquakes occur. There have been 11 earthquakes of magnitude 7.0 or greater (defined as major earthquake with serious damage) in the last century that have been in range of Saipan

(Earthquake Track n.d.). Figure 60 shows the prevalence of earthquakes in the Pacific. Saipan is in a high hazard area.

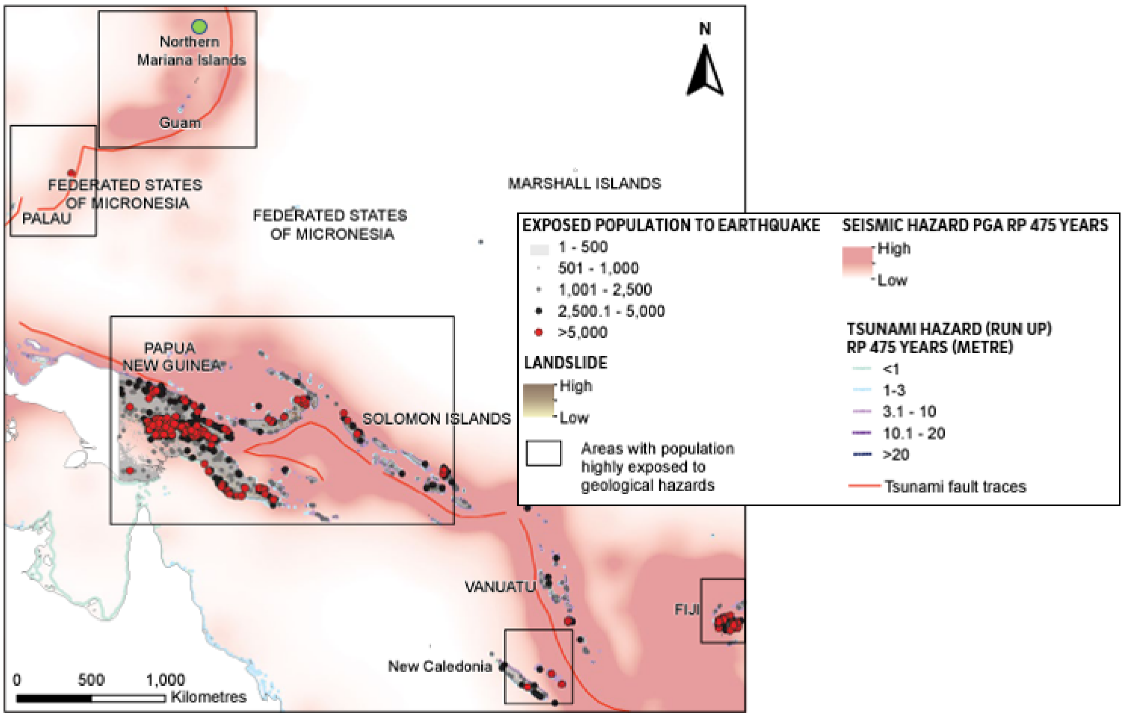

Figure 60. Earthquake hazard zones in the South Pacific (ESCAP 2020).

6.4 Other Hazards

There are additional hazards that are not high risk for power supply systems at Marpi and/or do not have distinct mitigation measures for power supply equipment. These are discussed below and outlined in the CNMI's 2014 Standard State Mitigation Plan (CNMI 2014). Climate change has also been identified as a threat that can interact with or exacerbate some of these hazards.

6.4.1 Flooding

Hydrologic hazards in the CNMI include coastal and inland floods, storm surge, coastal erosion, and droughts. Six areas on Saipan are prone to flooding and include Kanat Tabla, the San Roque village, the road at Tanapag, the lower base industrial area, Garapan/Putan Muchot, and the Chalan Kanoa–Lake Susupe area. However, Marpi is not located near any of those areas and is at an elevation of 40 m, so the risk of flooding and associated impacts to landfill power generation is low.

6.4.2 Drought

During the past 15 years, the driest years in the Mariana Islands have been associated with the El Niño phenomenon, which can change weather patterns within the Pacific. During the 1997–1998 El Niño, drought was so extensive as to cause widespread water rationing. However, drought does not impact electrical equipment, and as such, the risk to Marpi's power generation infrastructure is low.

6.4.3 Wildfire

There are hundreds of wildfires on the CNMI every year, especially during severe drought conditions. An uncontrolled wildfire near the landfill could damage power generation infrastructure.

6.4.4 Volcanic Activity

There are several active volcanic areas within the Mariana Islands, including Anatahan, Pagan, Alamagan, and Agrigan. While all areas exist on remote islands to the north, wind could cause ashfall on the southern islands. This ash could cause corrosion to metallic surfaces or lower PV array efficiency if allowed to settle.

6.4.5 Tsunami

There is no historical record of tsunamis in the CNMI; however, it is possible that an underwater volcanic eruption could cause one. Given the landfill's elevation, the hazard intensity rating is low.

6.5 Hardening Techniques

Hardening techniques to reduce the risk of damage from the key hazards identified for microgrid components at Marpi are summarized in Table 27, and additional details are provided below. The costs for hardening these technologies are included in the project costs throughout the report, with the exception of tilt-up wind turbines.

Table 27. Sample hardening techniques for microgrid components at the Marpi Landfill.

Technology	Typhoons	Aerosol Salt Deposition	Earthquakes
PV panels	Wind-load-rated racking to withstand ~200 mph winds and panel protection from flying debris (e.g., FEMA guidance, IEC 61730 and IEC 61215 certification)	Panels that comply with IEC 61215 standards for salt mist corrosion; UL 1703; NEMA 4X-6P rated enclosures for ancillary equipment	Rack ratings for seismically active areas (ASCE 7-10 design categories)
Wind turbine	Tilt-up technology; rotor braking; ballast foundation	Similar standards for salt mist corrosion as PV panels	American Clean Power Standard 61400-1 includes seismic loading recommendations
Generator, BESS	Hardened enclosure with NEMA/IP ratings; structural fencing	NEMA-rated enclosure; CARC paint; MIL-STD 810G compliance; IEC 61427 and 62933 and IEEE 1679 (batteries, environmental conditions)	Seismic retrofits and anchoring (e.g., for fuel tanks); adherence to UFC 3-310-04; IEEE 693-2005

Some measures can be implemented to reduce the risk of typhoon wind damage to power systems. PV panels should be designed and anchored sufficiently through the mounting systems to withstand 179–215 mph[9] wind speeds at Marpi, depending on the risk category chosen for solar PV (which is not specifically identified in the structure types listed by FEMA) (FEMA 2020). The carport PV system at CHCC was engineered to withstand 200+ mph winds using structural piers buried 14 ft deep and encased in concrete and rebar. The carport PV system at the Marianas Business Plaza is rated for 180 mph winds and has three rails and six clamps per panel, more than the recommended amount. Even so, more than a quarter of the system's panels were blown away by Typhoon Yutu. Several specific design and construction recommendations for PV survival in a typhoon are documented in the Rocky Mountain Institute's "Solar Under Storm" best practices report, which is based on lessons learned in the Caribbean from Hurricanes Irma and Maria. Recommendations include not only design for high wind loads but also methods such as through bolting and quality assurance (QA)/quality control (QC) of bolt torquing (Burgess and Goodman 2018). The cost premiums for several recommendations applicable to Marpi are summarized in Table 28 (Elsworth and Van Geet 2020). These costs are included in the overall project costs presented for solar PV options throughout this report.

Table 28. Solar PV system hardening cost premiums.

Measure	Base Case	Hardened Case	Ground Mount Premium	Roof/Carport Premium
Module Selection	Standard modules (2400 Pa uplift)	Highest rated modules (≥3600 Pa uplift)	\$100/kW	\$100/kW
Three-Framed Rail System	Two-rail racking	Three-rail racking	\$52/kW	\$57/kW
Two-Pier Mounting	One driven steel pier	Dual post piers	\$59/kW	N/A
Through Bolting	Top-down clamps	Through bolts	\$6/kW	\$7/kW
System Audit	No system audit	Torque-check fasteners (2% / 100% of fasteners)	\$0.50/kW / \$25/kW	\$0.50/kW / \$27/kW

Wind turbines should use tilt-up technology (including the hydraulic system to operate it) so that they can be lowered when a storm is coming to reduce damage to the system. A ballast foundation further improves resilience in high winds. Together, these cost approximately \$50k more than a turbine with a stationary tower and concrete foundation (Connor 2023).

Additional general construction and maintenance mitigation measures based on lessons learned from Super Typhoon Yutu are documented by FEMA (2021).

Measures to reduce the impact of salty air on the electrical infrastructure include burying, enclosing, or otherwise protecting generators, batteries, and inverters and using galvanized steel fasteners and frames/structures that do not corrode for PV panels and wind turbines. Although stainless steel, aluminum, copper, and galvanized steel have corrosion-resistant properties, they still react to salty air and oxygen unless a specialized metal finish that is designed for coastal areas with high levels of salty air is used (McCutcheon 2019). The Marianas Business Plaza uses synthetic rubber strips to separate PV panels from the aluminum

[9] According to FEMA's Special Wind Region Maps for CNMI, https://hazards.atcouncil.org/#/wind?lat=15.271285794690895&lng=145.8158297274414&address=.

rails to mitigate the effect of salty air and reduce rust. Equipment should be rated to National Electrical Manufacturers Association (NEMA) 4X and IP65 ratings for resistance to corrosion and water ingress. The use of marine-grade steel is common in island environments. As an example of how this impacts project costs on Saipan, fasteners for PV panels using marine-grade steel have a premium of approximately $11/kW over standard-grade steel fasteners (Elsworth and Van Geet 2020).

Earthquake-resistant (seismic) design and construction should be implemented for buildings and the nonstructural systems and components of the microgrid to minimize the risks associated with the earthquake seismic loading data for Saipan. This includes anchoring components, seismic restraints for floor-mounted or suspended equipment, and bracing for rigid and flexible pipes (including exhaust stacks) and electric conduit. The certification of components to meet earthquake hazard standards should strive to achieve the standards in the Unified Facilities Criteria 3-310-01, Table C-2 (DoD 2005).

7.0 Prioritization of Scenarios

To assist with decision-making, prioritization matrices were created to compare the power supply scenarios evaluated in this feasibility study according to various SW Taskforce priorities. The prioritization metrics (described below) were chosen based on discussions with OPD and were finalized through stakeholder feedback. The scenarios were given a score between 1 and 7 based on how they meet each prioritization metric (the lower the score, the higher the priority), and total scores were calculated using assigned weights based on the relative priority of each metric. The total scores were then ranked to produce a prioritized list of microgrid scenarios based on the metrics most important to the project stakeholders. This matrix (provided in a separate file) can be used to reprioritize if needs or scenarios change.

The prioritization metrics include the elements listed in the scenario descriptions as well as the factors described in other sections of this report. Scores were determined both quantitatively and qualitatively, and relative weights for each metric were assigned. The metrics are as follows:

- Capital cost – Scores were assigned by ranking each scenario: the lower the capital cost, the better the score. A low priority was assigned to this metric because of the potential for grants to reduce the cost in most scenarios.
- Annual O&M costs – Scores were assigned by ranking each scenario: the lower the O&M costs, the better the score. The highest priority was assigned to this metric because it impacts ongoing landfill responsibilities and is a concern for stakeholders.
- 25-year LCOE – Scores were assigned by ranking each scenario: the lower the LCOE, the better the score. Similar to capital cost, this metric was assigned a lower priority.
- Percent of load not met annually – Any scenario that could meet 100% of the load and includes diesel generation to cover unexpected renewable energy shortfalls was assigned a score of 1, any scenario that could meet 100% of the load and does not include diesel generation was assigned a score of 3, and any scenario that is not sized to meet 100% of the load was assigned a score of 7. This is a high priority metric because reliable, 24/7 power availability is a key goal for the landfill.
- Meets permit requirements for backup power – Any scenario with diesel generation was assumed to meet backup requirements and was assigned a score of 1; any scenario without diesel generation was assigned a score of 7. This was given a high priority because permit requirements must be met.
- Carbon dioxide equivalent (CO_2e) emissions generated per year – Scores were assigned by ranking each scenario: the lower the CO_2e emissions, the better the score. This was given a low priority but may be weighted more if certain grants requiring carbon reduction are pursued.
- Area requirement – If the scenario components are expected to fit within the identified location at the landfill, that scenario was assigned a score of 1. If it is unclear whether the components for a scenario will fit within the identified location, that scenario was assigned a score of 4. Scenarios with configurations that will not fit were assigned a score of 7. This metric was assigned a medium priority because other locations may be able to be used.
- Diversity of resources – Scores were assigned by ranking each scenario based on the number of microgrid components included: the higher the number of components, the lower

the score. This metric was assigned a medium priority because it helps to determine the reliability of the system but is not the sole determinant.

- Equipment hardening requirements – More equipment and larger capacities require more hardening. In general, wind turbines are the most difficult and expensive to harden, then PV, and then BESS and generators, which are housed in enclosures and therefore have some protection from certain hazards. Scores were assigned by ranking each scenario based on the types of equipment included and the hardening requirements for each equipment type. This metric was assigned a low priority because it does not significantly impact the feasibility of any scenario.
- Training requirements – All components (including diesel generators if O&M will not be contracted out) and microgrid equipment will require training dedicated operators. Scores were assigned by ranking each scenario based on the equipment and training requirements for each equipment type. This metric was assigned a lower priority because training is not expected to be a hindrance to project development.
- Smart, Safe Growth – Smart, Safe Growth (SSG) is a set of complementary development strategies and practices focused on improving the resiliency and recoverability of the built environment. This guidance and evaluation tool (available at opd.gov.mp) supports multiple sustainable growth objectives and is a foundational policy document incorporated into the CNMI's Comprehensive Sustainable Development Plan. SSG scores indicate consistency with SSG guiding principles. This metric was given a lower priority based on its less direct impact on the project. The SSG principles include the following:
  - climate change
  - retreat
  - retrofit
  - critical facilities location
  - development incentives
  - sustainable development best management practices
  - ecosystem services
  - green infrastructure
  - development decision process
  - early collaboration
  - knowledgeable SSG communities
  - adaptive management.

The scores for each metric and scenario and the overall scenario ranking scores are presented in Table 29 for the 24/7 operations baseline load profile and Table 30 for the 24/7 operations & electric equipment load profile.

These rankings show that a microgrid that includes solar PV generation, a BESS, and a diesel generator (Scenario 4) is the favored option for both load profiles. However, PV sized to meet the electric equipment charging load requires additional land than is available at the landfill. Diesel generators alone (Scenario 7) rank second under both sets of conditions, driven by lower capital costs and lower space requirements. However, Scenario 7 has the highest CO_2e emissions and the highest cost of carbon of any scenario. Scenarios without diesel generation

(Scenarios 1–3) are ranked lowest, primarily because of the unreliability of these scenarios in meeting load and permit requirements.

Table 29. Prioritization of Marpi power supply scenarios (24/7 operations baseline).

Relative Metric Priority	1	5	1	3	4	1	3	3	1	2	2		
Prioritization Metric	Capital Cost	Annual O&M Costs	25-Year Levelized Cost of Energy	% Load Not Met Annually	Meets Permit Req. for Backup Power	CO_2e Emissions Generated	Area Req.	Diversity of Resources (# of components)	Equipment Hardening Req.	Training Req.	Smart Safe Growth		
Scenario	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Total Score	Rank
PV/BESS	7	1	6	3	7	1	4	5	2	3	2	3.17	4
Wind/BESS	5	2	7	7	7	1	4	5	5	3	5	4.00	7
PV/Wind/BESS	6	3	5	3	7	1	4	2	6	5	5	3.60	6
PV/BESS/Gen	2	4	2	1	1	5	1	2	3	5	4	2.20	1
Wind/BESS/Gen	4	6	4	1	1	6	4	2	4	5	7	3.23	5
PV/Wind/BESS/Gen	3	5	3	1	1	4	4	1	7	7	6	3.00	2
Diesel Generator	1	7	1	1	1	7	1	7	1	2	5	3.00	2

Table 30. Prioritization of Marpi power supply scenarios (24/7 operations & electric equipment).

Relative Metric Priority	1	5	1	3	4	1	3	3	1	2	2		
Prioritization Metric	Capital Cost	Annual O&M Costs	25-Year Levelized Cost of Energy	% Load Not Met Annually	Meets Permit Req. for Backup Power	CO_2e Emissions Generated	Area Req.	Diversity of Resources (# of components)	Equipment Hardening Req.	Training Req.	Smart Safe Growth		
Scenario	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Total Score	Rank
PV/BESS	6	1	5	3	7	1	7	5	2	3	2	3.40	5
Wind/BESS	3	2	7	7	7	1	4	5	5	3	5	3.93	6
PV/Wind/BESS	7	3	6	3	7	1	7	2	6	5	5	3.97	7
PV/BESS/Gen	4	4	3	1	1	4	7	2	3	5	4	2.87	1
Wind/BESS/Gen	2	6	2	1	1	6	4	2	4	5	7	3.10	3
PV/Wind/BESS/Gen	4	5	4	1	1	4	7	1	7	7	6	3.37	4
Diesel Generator	1	7	1	1	1	7	1	7	1	2	5	3.00	2

8.0 Implementation Considerations

There are several aspects of implementing a microgrid that are important to consider once the equipment configuration and characteristics have been evaluated and prioritized. These include funding opportunities, procurement, ownership, and O&M training, among others.

8.1 Funding/Grant Opportunities

Depending on the technology configuration, system ownership, and implementation timing of the microgrid for Marpi, there may be opportunities to defray some or all of the capital costs associated with purchasing and installing the equipment and infrastructure. These funding opportunities can take the form of federal agency grants that directly offset (pay for) capital expenses (either directly or via a cost-share requirement) or tax benefits that can improve project financing terms.

The availability of federal grants is largely contingent on agency and administration priorities, which are currently focused on decarbonization and energy security/resilience. Some grant programs are available on a yearly basis (e.g., from the Office of Insular Affairs), while others may only occur as a single instance, driven by agency priorities or a precipitating event (e.g., American Recovery and Reinvestment Act or typhoon recovery funds). Tax credits, such as those associated with the Inflation Reduction Act (IRA), have a predetermined window of availability for projects to qualify.

PNNL researched specific funding opportunities available as of Spring 2024 for Marpi, and documented key information, including funding amounts, key areas of interest, funding agency eligibility, lead agency responsibilities, and application deadlines. Table 31 highlights funding amounts and previous application windows for each opportunity.

Table 31. Funding opportunity, funding amount, and previous application window.

Funding Opportunity	Funding Amount	Previous Application Window
FEMA Building Resilient Infrastructure and Communities Program	Up to $2M per recipient in 2023	10/16/2023–02/29/2024
Department of Interior (DOI) Energizing Insular Communities (EIC) Program	Up to $4M per recipient in 2023	03/27/2023–06/15/2023
EPA Climate Pollution Reduction Planning Grant	Up to $500,000 per territory recipient in 2023	06/15/2023
EPA Climate Pollution Reduction Implementation Grant	$1–25M per recipient	04/01/2024
EPA Diesel Emission Reduction Act (DERA)	National Grants: Up to $4.5M per recipient (Region 9). State and Territory Grants: Guam and American Samoa received approximately $126,000 each. Tribal and Territorial Grants: Must not exceed $400,000.	National Grants: 12/01/2023 State and Territory Grants: 12/01/2023 Tribal and Territory Grants: 12/06/2024

Funding Opportunity	Funding Amount	Previous Application Window
DOI Office of Insular Affairs (OIA) Maintenance Assistance Program	In 2024, DOI will award $4.375M across 20 awards. In 2023, CNMI received $1.1M	03/17/2024
EPA Environmental Justice Grants (Community Change Grants)	$10–20M	Rolling applications accepted through 11/21/2024

8.1.1 FEMA Building Resilient Infrastructure and Communities

Information on this opportunity can be found at https://www.fema.gov/grants/mitigation/building-resilient-infrastructure-communities. The FEMA Building Resilient Infrastructure and Communities (BRIC) program supports states, local communities, tribes, and territories as they undertake hazard mitigation projects, reducing the risks they face from disasters and natural hazards..

8.1.1.1 Eligible Activities

Eligible activities include the purchase and installation of secondary power sources and related equipment, such as generators, microgrids, solar PV systems, and battery back-up systems. CNMI/OPD could use this program to fund up to $2M or 66% of the cost of power supply Scenario 4 ($3M) for the 24/7 operations baseline load profile (100 kW solar PV, 100 kW/400 kWh battery storage, 160 kW diesel generation).

8.1.1.2 Eligibility

Per the funding opportunity website in Section 8.1.1, the eligibility requirements are as follows:

Applicant must be a state, U.S. territory, or federally recognized tribal government.

States or territories must have received a major disaster declaration under the Robert T. Stafford Disaster Relief and Emergency Assistance Act in the 7 years before the application period start date.

One agency must serve as applicant. Only one BRIC grant application can be submitted per applicant, and an application can be made up of an unlimited number of sub-applications.

Local governments, including cities, townships, counties, special district governments, and state agencies are considered sub-applicants. They must submit sub-applications to their state, territory, or tribal applicant agency.

8.1.1.3 Application Requirements

The application requirements according to the funding opportunity website in Section 8.1.1 are

> Applicants must have a FEMA-approved state Hazard Mitigation Plan by the application deadline. They must also have one at the time of obligation of grant funds.
>
> Sub-applicants must have a FEMA-approved local Hazard Mitigation Plan in accordance with Title 44 Code of Federal Regulations Part 201 by the application deadline. They must also have one at the time of obligation of grant funds for hazard mitigation projects and capability- and capacity-building activities.

8.1.1.4 Potential Award Amount

FEMA awarded up to $2M per recipient in 2023.

8.1.1.5 Previous Application Windows

- 10/16/2023–02/29/2024
- 09/30/21–01/29/2022
- 09/30/2020–01/29/2021

8.1.2 DOI Energizing Insular Communities

Information on this opportunity can be found at https://www.doi.gov/oia/energizing-Insular-communities. According to this website, “The Department of Interior Energizing Insular Communities (EIC) program provides grant funding to support U.S. territories in achieving sustainable energy strategies that mitigate climate change, reduce reliance and expenditures on imported fuels, develop and utilize domestic energy sources, and improve the performance of energy infrastructure and overall energy efficiency.”

8.1.2.1 Eligible Activities

Eligible activities include the deployment of renewable energy, power generation projects, and energy storage systems. CNMI/OPD could use this program to fund up to $4M or 100% of the cost of power supply Scenario 4 ($3M) for the 24/7 operations baseline load profile (100 kW solar PV, 100 kW/400 kWh battery storage, 160 kW diesel generation).

8.1.2.2 Eligibility

Per the funding opportunity website in Section 8.1.2, the eligibility requirements are as follows:

> Eligible applicants are local government entities, utilities, semi-autonomous agencies, and educational institutions located in the U.S. territories of Guam, American Samoa, the U.S. Virgin Islands, and the Commonwealth of the Northern Mariana Islands.
>
> The proposed project should be identified and supported in the territory’s Strategic Energy Plan and/or Energy Action Plan.

8.1.2.3 Application Requirements

The application requirements according to the funding opportunity website in Section 8.1.2 are

Applicants must provide a title, project abstract, detailed narrative description, and budget for each proposed project, as well as providing a complete timeline that demonstrates the project can be accomplished within 36 months (inclusive of required NEPA compliance).

Applicants must provide a copy of the territory's current energy plan, and describe the connection to the plan, impact on foreign fuel imports, and to the extent practicable, electricity costs.

8.1.2.4 Potential Award Amount

DOI awarded up to $4M per recipient in 2023.

8.1.2.5 Previous Application Windows

- 03/27/2023–06/15/2023
- 02/02/2022–06/15/2022
- 03/30/2021–06/03/2021
- 03/19/2020–06/15/2020

8.1.3 EPA Climate Pollution Reduction Planning Grant

Information on this opportunity can be found at https://www.epa.gov/inflation-reduction-act/about-cprg-planning-grant-information. According to this website, "EPA's Climate Pollution Reduction Planning Grant program provides $250 million for states, U.S. territories, municipalities, air pollution control agencies, tribes, and groups thereof to develop plans to reduce greenhouse gases."

Territory program guidance can be found at https://www.epa.gov/system/files/documents/2023-02/EPA%20CPRG%20Planning%20Grants%20Program%20Guidance%20for%20Tribes-Tribal%20Consortia-Territories%2003-01-2023.pdf.

8.1.3.1 Eligible Activities

Planning grant recipients can use funding to design Priority Climate Action Plans (PCAPs) that incorporate measures to reduce GHG emissions in six sectors (electricity generation, industry, transportation, buildings, agriculture/natural and working lands, and waste management). CNMI/OPD could use this program to update the current CNMI climate action plan, if necessary.

8.1.3.2 Eligibility

Eligible entities are states (includes CNMI), air pollution control agencies, municipalities, tribes, and groups of one or more of these entities.

8.1.3.3 Application Requirements

Applicants must provide a narrative workplan, including narrative and budget details. Other required documents include the following:

- Standard Form (SF) 424, Application for Federal Assistance

- SF 424A, Budget Information
- EPA Form 5700-54, Key Contacts Form
- Grants.gov Lobbying Form, Certification Regarding Lobbying
- EPA Form 4700-4, Pre-award Compliance Review
- Other Attachments Form – Optional Supporting Materials including Letters of Commitment and Resumes.

8.1.3.4 Potential Award Amount

EPA awarded up to $500,000 per territory recipient in 2023.

8.1.3.5 Most Recent Application Deadline

6/15/2023

8.1.3.6 CNMI Grant Submissions

The CNMI received a $500,000 Climate Pollution Reduction Planning Grant in 2023. In April 2024, the CNMI Office of the Governor's Climate & Policy Planning Program submitted a PCAP under the program, which included the following:

> Priority Action 1: Install solar photovoltaic or other renewable energy systems and energy storage where appropriate and feasible at water, wastewater, and solid waste management facilities.
>
> This action included the following:
>
> For Saipan's Marpi landfill, which currently operates leachate pumps on diesel generators for approximately 12 hours a day, six days a week, the Department of Public Works proposes to install a solar PV array or other renewable energy system with battery storage of sufficient capacity to expand to 24/7 operations, electrify its fleet and install charging infrastructure, and open a new landfill cell with an additional leachate pumping system. A feasibility study for DPW's project is in progress.
>
> Commonwealth of the Northern Mariana Islands Priority Climate Action Plan
> https://www.epa.gov/system/files/documents/2024-04/cnmi-pcap_0.pdf

The CNMI is working to develop a Comprehensive Climate Action Plan under this grant.

8.1.4 EPA Climate Pollution Reduction Implementation Grant (Tribes and Territories Only)

Information on this opportunity can be found at https://www.epa.gov/inflation-reduction-act/about-cprg-implementation-grants. According to this website, "EPA's Climate Pollution Reduction Implementation Grant program provides $4.6 billion for competitive grants to eligible applicants to implement GHG reduction programs, policies, projects, and measures identified in an applicable Priority Climate Action Plan."

8.1.4.1 Eligible Activities

Eligible activities include the development of distributed or community-scale renewable energy generation or microgrids in disadvantaged communities, including remote and rural regions. Based on funding awarded, CNMI/OPD could use this program to fund up to $25M or 100% of the cost of power supply Scenario 4 ($3M) for the 24/7 operations baseline load profile (100 kW solar PV, 100 kW/400 kWh battery storage, 160 kW diesel generation).

8.1.4.2 Eligibility

The eligibility requirements listed on the funding opportunity website in Section 8.1.4 include the following:

> Territories that directly received a CPRG planning grant (see previous grant description) are eligible to apply for an implementation grant. In addition, territorial municipal agencies, departments, or other municipal government offices in Guam, American Samoa, Northern Mariana Islands, and U.S. Virgin Islands that did not directly receive a planning grant but that seek funding to implement one or more GHG reduction measures that are included in an applicable Priority Climate Action Plan (PCAP) are eligible to apply. An applicable PCAP is one that geographically covers the entity and contains GHG reduction measures that can be implemented by the entity.

8.1.4.3 Application Requirements

Applicants must provide a project narrative, including a workplan and budget narrative. Other required documents include the following:

- SF 424, Application for Federal Assistance
- SF 424A, Budget Information for Non-Construction Programs
- EPA Form 4700-4, Pre-Award Compliance Review Report
- EPA Form 5700-54, Key Contacts Form
- Grants.gov Lobbying Form
- Standard Form LLL, Disclosure of Lobbying Activities (required if applicable)
- Project Narrative Attachment Form.

8.1.4.4 Potential Award Amount

EPA awards $1–25M per recipient.

8.1.4.5 Most Recent Application Deadline

04/01/2024

8.1.4.6 CNMI Grant Submissions

Based on the CNMI’s PCAP, the CNMI Office of the Governor’s Climate & Policy Planning Program submitted a Climate Pollution Reduction Implementation Grant competitive proposal, including a request for funding for renewable energy and battery storage at Marpi. That proposal is under EPA review.

8.1.5 EPA Diesel Emission Reduction Act

Information on DERA opportunities can be found at https://www.epa.gov/dera. According to this website, "The Diesel Emissions Reduction Act (DERA) Program offers funding assistance to accelerate the upgrade, retrofit, and turnover over the legacy diesel fleet."

National Grants: https://www.epa.gov/dera/national

State/Territory Grants: https://www.epa.gov/dera/state

Tribal and Territory Grants: https://www.epa.gov/dera/tribal-and-territory

8.1.5.1 Eligible Activities

National Grants

Per the National Grants website (https://www.epa.gov/dera/national),

> Eligible activities include the retrofit or replacement of existing diesel engines, vehicles and equipment with EPA and California Air Resources Board (CARB) certified engine configurations and verified retrofit and idle reduction technologies.
>
> Eligible diesel vehicles, engines and equipment include:
>
> - School buses
> - Class 5 – Class 8 heavy-duty highway vehicles
> - Locomotive engines
> - Marine engines
> - Nonroad engines, equipment or vehicles used in construction, handling of cargo (including at ports or airports), agriculture, mining or energy production (including stationary generators and pumps).
>
> Grant funds may be used for diesel emission reduction projects including:
>
> - EPA verified technologies or certified engine configurations
> - California Air Resources Board (CARB) verified technologies or certified engines
> - Idle-reduction technologies that are EPA verified
> - Aerodynamic technologies and low rolling resistance tires that are EPA verified
> - Early engine, vehicle, or equipment replacements with certified engine configurations

> Funds awarded under this program cannot be used to fund emission reductions mandated by federal law. Equipment for testing emissions or fueling infrastructure is not eligible for funding.

State and Territory Grants

Per the State Grants website (https://www.epa.gov/dera/state),

> Eligible activities include the retrofit or replacement of existing diesel engines, vehicles and equipment with EPA and California Air Resources Board (CARB) certified engine configurations and verified retrofit and idle reduction technologies.
>
> 1. Diesel Vehicles, Engines and Equipment: Projects may target in-use medium and heavy-duty diesel-powered highway vehicles and diesel powered nonroad vehicles and equipment
>   - School buses
>   - Transit buses
>   - Medium-duty or heavy-duty Class 5 – Class 8 highway vehicles
>   - Locomotives Marine engines
>   - Nonroad engines, equipment, or vehicles including, not limited to, those used in construction, handling of cargo (including at ports or airports), agriculture, mining, or energy production (including stationary generators and pumps).
> 2. Diesel Emission Reduction Solutions: Projects may upgrade existing diesel vehicles and equipment using the diesel emissions reduction solutions
>   - Certified vehicle and equipment replacements
>   - Certified engine replacement
>   - Certified remanufacture systems
>   - Verified idle reduction technologies
>   - Verified retrofit technologies
>   - Clean alternative fuel conversations
>   - Verified retrofit technologies
>   - Clean alternative fuel conversions
>   - Verified aerodynamic technologies and low rolling resistance tires

Tribal and Territory Grants

Per the Tribal and Territory Grants website (https://www.epa.gov/dera/tribal-and-territory),

> Eligible diesel emissions reduction solutions include verified retrofit technologies, verified idle reduction technologies, verified aerodynamic technologies, verified low rolling resistance tires, certified engine replacements and conversions, and certified vehicle or equipment replacement.

Eligible diesel vehicles, engines and equipment may include:

- Marine engines on fishing and other vessels
- Nonroad engines, equipment, or vehicles used in construction, handling of cargo (including at ports or airports), agriculture, mining, or energy production (including stationary generators and pumps)
- School buses
- Electrified parking spaces
- Heavy duty highway vehicles, such as dump trucks, water trucks, fire trucks
- Locomotive Engines

DERA grants require scrappage of the engines, vehicles, and equipment replaced.

CNMI/OPD may be able to use this program to replace some of the existing landfill equipment, such as the two existing bulldozers, or the diesel generator.

8.1.5.2 Eligibility

National Grants (https://www.epa.gov/dera/national): "In accordance with Assistance Listing 66.039, and EPA's Policy for Competition of Assistance Agreements (EPA Order § 5700.5A1), the following entities are eligible to apply:

1. A regional, state (including the District of Columbia), or local agency, Tribal government (or intertribal consortium) or Alaska Native Village, or port authority, which has jurisdiction over transportation or air quality. School districts, municipalities, metropolitan planning organizations (MPOs), cities, and counties are all generally eligible entities under this assistance agreement program to the extent that they fall within this definition.
2. A nonprofit organization or institution that:
   - represents or provides pollution reduction or educational services to persons or organizations that own or operate diesel fleets; or
   - has, as its principal purpose, the promotion of transportation or air quality."

State and Territory Grants (https://www.epa.gov/dera/state): "Eligibility to apply for and receive funds under the DERA State Grant Program is limited to the 50 states, the District of Columbia, Puerto Rico, and the territories: U.S. Virgin Islands, Guam, American Samoa, and the Northern Mariana Islands."

Tribal and Territory Grants (https://www.epa.gov/dera/tribal-and-territory): …"As defined in 48 U.S.C. §1469a, eligible territories include the U.S. Virgin Islands, Guam, American Samoa, and Commonwealth of the Northern Mariana Islands."

8.1.5.3 Application Requirements

Applicants must provide a project narrative. Other required documents include the following:

- SF 424, Application for Federal Assistance
- SF 424A, Budget Information for Non-Construction Programs

- EPA Form 4700-4, Pre-Award Compliance Review Report
- EPA Form 5700-54, Key Contacts Form.

8.1.5.4 Potential Award Amount

National Grants: Up to $4.5M per recipient (Region 9). Requires matching funds.

State and Territory Grants: CNMI did not participate in 2021; Guam and American Samoa received approximately $126,000 each.

Tribal and Territorial Grants: Must not exceed $400,000. Each applicant may submit up to two applications. No matching funds required.

8.1.5.5 Most Recent Application Deadlines

National Grants: 12/01/2023

State and Territory Grants: 12/01/2023

Tribal and Territory Grants: 12/06/2024

8.1.6 DOI-OIA Maintenance Assistance Program

Information on this opportunity can be found at https://www.grants.gov/search-results-detail/350743. According to this website, "The Maintenance Assistance Program funding supports, develops, improves, and institutionalizes infrastructure maintenance practices in the seven insular areas. Activities will support maintenance training to extend the life of island infrastructure, ensure the safety of maintenance technicians, and/or increase the capacity of infrastructure to withstand extreme events; this includes training of maintenance technicians that increases knowledge and awareness of measures to be taken to protect infrastructure from severe weather impacts."

8.1.6.1 Eligible Activities

- Temporary expertise (management and technical)
- Specialized vehicles, equipment, and tools
- Maintenance-related training
- Maintenance-related programs/systems
- Maintenance-related analysis/studies
- Minor renovations and critical repairs to infrastructure

CNMI/OPD could use this program to cover costs related to trainings for microgrid operation, such as bringing in experts to teach DPW staff how to run it.

8.1.6.2 Eligibility

Per the funding opportunity website in Section 8.1.6, "Eligible applicants are non-federal entities such as local government agencies (including utilities) in Guam, American Samoa, the U.S. Virgin Islands, the Commonwealth of the Northern Mariana Islands, the Federated States of

Micronesia, the Republic of the Marshall Islands, and the Republic of Palau; and hospitals/health centers, institutions of higher education and any non-profit organizations whose projects directly benefit the seven insular areas."

8.1.6.3 Application Requirements

Applicants must provide a project narrative, including a detailed project description, a detailed budget, a detailed timeline, a statement of need, project goals and objectives, a priority list (if applicable), a grant recipient, and a grant manager. Other required documents include the following:

- Core SF-424 Application for Federal Assistance form
- SF-424A Budget Information – Non-Construction Programs (or SF-424C)
- SF-424B Assurances – Non-Construction Programs (or SF-424D)
- Signed and dated cover letter
- Letters of support.

8.1.6.4 Potential Award Amount

In 2024, DOI will award $4.375M across 20 awards. In 2023, CNMI received $1.1M.

8.1.6.5 Previous Application Deadlines

- 03/17/2024
- 03/17/2023
- 04/01/2022
- 03/01/2017

8.1.7 EPA Environmental Justice Grants (Community Change Grants)

The EPA has multiple Environmental and Climate Justice grant programs. Information on all EPA Environmental Justice grants can be found here: https://www.epa.gov/environmentaljustice/environmental-justice-grants-funding-and-technical-assistance.

The Environmental and Climate Justice Grants (Community Change Grants) are highlighted at https://www.epa.gov/inflation-reduction-act/inflation-reduction-act-environmental-and-climate-justice-program.

The Environmental Justice Thriving Communities Grantmaking Program will provide simplified subaward pass-through cooperative agreements to advance environmental justice. U.S. territories are eligible, and application details are anticipated Fall 2024. https://www.epa.gov/environmentaljustice/environmental-justice-thriving-communities-grantmaking-program

8.1.7.1 Eligible Activities

- Community-led air and other pollution monitoring, prevention, and remediation, and investments in low and zero-emission and resilient technologies and related infrastructure and workforce development that help reduce greenhouse gas emissions and other air pollutants
- Climate resiliency and adaptation

A community-based organization, in partnership with a local government, could apply to use this program to cover costs of microgrid procurement and installation.

8.1.7.2 Eligibility

Eligible applicants for Community Change Grants include a partnership between two community-based nonprofit organizations (CBOs) or a partnership between a CBO and one of the following: a Federally recognized tribe, a local government, or an institution of higher education.

8.1.7.3 Application Requirements

Applicants must provide a project narrative. Other required documents include the following:

- Application for Federal Assistance (SF-424)
- Budget Information for Non-Construction Programs (SF-424A)
- EPA Key Contacts Form 5700-54
- EPA Preaward Compliance Review Report Form 4700-4
- Project Narrative Attachment Form.

8.1.7.4 Potential Award Amount

Implementation grant awards are expected to be $10–20M.

8.1.7.5 Application Deadline

Rolling applications are accepted through 11/21/2024.

8.1.8 Tax Benefits

In addition to federal agency grant funds, the IRA (GPO 2022) extends existing tax benefits and authorizes new tax benefits that can reduce the capital (and ongoing) costs for numerous types of clean energy projects. The following stipulations are potentially applicable to the Marpi microgrid project:

- Section 13102 of the IRA amends the tax code (26 U.S. Code § 48) to provide Investment Tax Credits (ITC) for Energy Property extended through 2023/2024 (construction before 1/1/2025). Beginning in 2025, the existing ITC will be replaced by the Clean Electricity

Investment Tax Credit, which will provide similar incentives and have similar requirements; the phase-out will begin in 2032.[10]

  - Solar PV, small wind, batteries (>5 kW), microgrid controllers (<20 MW)
  - Base credit amount is 6% of qualified investment (basis of the energy property)
  - Bonus credits (up to 30%) for prevailing wage, domestic content, and energy communities

- For the ITC, tax-exempt organizations (states and political subdivisions, tribal governments, and Alaska Native corporations) are eligible for direct pay of the benefit. Depending on the project ownership for the Marpi microgrid, the ITC benefit may go to a private (tax-paying) company or may be available as a direct payment to the CNMI government as the owner of the system, pending additional clarification by the Internal Revenue Service (IRS).
  - Eligibility of Territories is not explicitly stated in the IRS Sec 6417 language that defines ITC eligibility
  - Precedence set for ITC eligibility in Puerto Rico for U.S. corporation, citizen, or partnership owning the project (IRS private ruling)[11, 12]
  - Solar production tax credit eligibility for territories (especially mirror-code jurisdictions) in Internal Revenue Code Section 45[13]
- ITC eligibility for DPW/OPD (CNMI public entities) to take direct payment is unclear but may be possible; may require an IRS Private Letter Ruling.
- The IRA did not modify existing accelerated bonus depreciation provisions in the tax code. Accelerated bonus depreciation (Modified Accelerated Cost Recovery System [MACRS]) allows private businesses to write off a portion of an asset's cost in its first year of use; qualifying clean energy technologies have historically been eligible for accelerated schedules. The current bonus provisions will be phased out beginning in 2023 and ending in 2027. This tax benefit is only available to private taxpaying businesses (incorporated in the United States) and would not be available if the CNMI government procured the system directly.

8.2 System Procurement

The procurement of microgrid systems at the scale suitable for Marpi can largely fall into two approaches: (1) integrated solutions that specify the design, procurement, and construction of the distinct microgrid components into a customized solution or (2) single-vendor packaged systems that consist of components that have been designed and fabricated by the vendor to operate as a preconfigured system. The choice of procurement approach may impact which funding opportunities are available. The pros and cons of these options are summarized in Table 32 and detailed below.

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[10] Details on the various elements of the Inflation Reduction Act can be found in the accompanying Guidebook: https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf.
[11] Additional information on ITC eligibility for projects executed in Puerto Rico: http://dpny8pxabs9qx8.devcloud.acquia-sites.com/sites/default/files/2022-10/Reimagining%20Grid%20Solutions_Final%20SIPA%20REPORT_0.pdf.
[12] The IRS Private Letter Ruling establishing eligibility for a U.S. corporation to receive the ITC for a project built in Puerto Rico: https://www.irs.gov/pub/irs-wd/1324006.pdf.
[13] Clean Energy Production Tax Credit in Puerto Rico and U.S. territories: https://crsreports.congress.gov/product/pdf/R/R44651.

Table 32. Considerations for single vendors versus integrated microgrid systems.

	Pros	Cons
Single Vendor	• Minimizes site work for equipment integration • Should have single O&M offering	• Equipment sizing will be limited to vendor offerings and may not be optimal for site • Inherent design–build style contracts that can have higher costs and fewer vendor options
Integrator	• Allows for customization and selection of best-in-breed technologies optimal for Marpi project • Design–bid–build procurement can align with external requirements for competitive source selection by public agencies	• Longer installation and commissioning timelines • Multiple warranties and need for interoperability guarantees • May require multiple maintenance contracts

For integrated solutions, procurement may be design–build, where design and construction are bundled under the same contract, or design–bid–build, where elements are contracted separately. Each procurement approach has tradeoffs that impact the execution of the project.

Design–build projects may have accelerated timelines, better management of project risks, consistent and predictable budgets, and easier communication and project management. However, design–build projects are likely to be more expensive, as there are fewer opportunities to solicit competitive bids and therefore locked in with a single vendor.

Design–bid–build projects can offer more competitive bidding and pricing, more control over the design and construction elements of the project, and often align with procurement requirements for public agencies (like DPW or OPD). The adverse impacts of pursuing design–bid–build include longer execution timelines, a lack of product and logistics insight early in the process (design firms will not have the same knowledge about equipment options and availability as construction firms), increased conflicts and potential change orders, and late-stage definition of cost budgets. These factors should be considered when contemplating solutions that require significant system design and integration.

Integrated solutions will enable system designers and builders to identify a mix of technologies that are optimized for Marpi's energy needs and designed to meet the specifications set by the OPD and DPW. While this approach can result in a right-sized mix of generation and storage components, it will require a design and construction firm that is experienced in microgrid integration and operation.

The alternative approach to design–build integrated systems is to procure packaged microgrids from single vendors that deliver a microgrid solution where the components are preconfigured to operate together, eliminating many of the integration elements associated with design–build options. These systems reduce the risks and timelines associated with project execution but offer far less customization or opportunities for optimizing equipment sizing. Because the solution is provided by a single vendor, ongoing maintenance support and warranties can be simplified under a single contract.

8.3 System Ownership

As with procurement, there are multiple options for the ownership and operation of a Marpi microgrid. These broadly fall into two categories: (1) a government-owned system where ownership of the equipment resides with DPW and responsibility for O&M can fall on the government and/or support contractors or (2) third-party ownership of the system by a separate entity that retains any and all tax benefits and O&M responsibilities to provide power to the landfill. The ownership model may impact which funding opportunities are applicable. These options are summarized in Table 33 and detailed below.

Table 33. Comparison of ownership models.

	Pros	Cons
DPW-owned	• Less expensive capital • Better funding eligibility for certain programs • O&M can be performed in-house (DPW personnel) or included as part of a Marpi site operations contract	• Requires operator know-how for complex technology • Ability for CNMI government to qualify for the ITC is unclear
Third-party owned	• O&M responsibility with an entity that knows power generation • Tax credits (ITC, MACRS, etc.) are available for U.S.-based companies	• DPW is a customer for power output, may not have to cover the upfront capital costs of the system if a long-term power purchase agreement can be executed • Potential limitations on funding eligibility

Under a government-owned option, DPW would acquire and own the system and then either assign DPW personnel to operate and maintain the equipment (for O&M activities not within the scope of a vendor service contract) or contract the operation of the microgrid to the site operator or another entity. The operation of a government-owned system by a third party may reduce labor and other related costs, but performance risk may still reside with the government-owned equipment. Training DPW and contractor staff would be the responsibility of the government, and contract/staff turnover would complicate training efforts.

For third-party owned and operated systems, DPW would pay for energy services (electricity sales) from the third party. The risks and responsibility for system performance would reside with the system owner and would be managed via contractual obligations. System ownership would reside with an entity that knows power systems and how to optimize their operation and minimize risks. Typically, a utility company (such as CUC) or an energy services company has the expertise and is well-suited to fill this role.[14] In some ways, this could be a similar configuration to how DPW pays for and receives CUC electricity at other locations; in this case, CUC (or another third-party entity) would calculate a cost of power and the associated rate ($/kWh) to sell power to DPW, accounting for their requirements for recouping capital expenditures and returns on investment, as well as ongoing operating costs for the microgrid.

The ability of DPW to pursue and secure grant funding for the capital expenses for the project may be determined by (or may determine) the ownership model chosen; certain grants may only be available for projects where ownership is retained by the public entity, while tax credits, accelerated tax depreciation, and other grants may only be available to private entities. Considerations for funding opportunities are discussed in Section 8.1.

[14] For larger power plants in deregulated electricity markets, an independent power producer (IPP) can own and operate large-scale microgrids or power plants; the size of the Marpi project is well below the threshold of a typical IPP. As part of their large-scale solar PV and energy storage project for Saipan, CUC is evaluating options to have an IPP own and operate systems and sell power to CUC.

8.4 Operations and Maintenance Training

O&M requirements specific to individual technologies are discussed in the respective subsections of Section 3.2, with overall microgrid system O&M included in Section 3.2.5.2. As described in that section, trained operators will be required. Trained system operators help to avoid and quickly resolve system issues by monitoring the system and calling appropriate professional assistance as needed. Quick resolution and prevention of outages are important for Marpi because there is no grid power to rely on in case of equipment failure. DPW may use a maintenance contract to manage the system, but with or without a maintenance contract, DPW staff will need training for system familiarity at a minimum and ideally to troubleshoot and fix issues as well. The DOI-OIA Maintenance Assistance Program grant opportunity described in Section 8.1.6 could be used to cover costs related to trainings for microgrid operation and maintenance.

The microgrid equipment vendors (whether for individual components or for a single-vendor system, but usually the microgrid controls company) will provide manuals to guide operators on specific O&M tasks, including when to call vendors or other trained maintenance personnel. The project statement of work should include training for basic O&M as part of system commissioning, and some vendors also offer more detailed online or in-person training on their equipment. In addition, educational institutions (community colleges, universities, trade schools, etc.) offer a variety of in-person and online courses covering microgrids and renewable energy systems in varying amounts of detail. The following example training resources are available for microgrids and components being considered for Marpi:

- Microgrid: Online courses are available through organizations such as
  - Arizona State University (Microgrid Master Classes, https://leaps.asu.edu/trainings/)
  - IEEE (https://www.ieee.org/education/academy-index/smartgrid.html)
  - Tonex (https://www.tonex.com/training-courses/microgrid-certification-training/)
- Wind turbines:
  - https://windexchange.energy.gov/training-programs provides a list of training courses based on U.S. location and institution type (community college, university, or other education)
  - ENSA, a provider of “work at height” safety trainings for wind, telecom, and other industries, provides both basic and advanced tower climbing and safety trainings in person (https://www.ensa-northamerica.com/).

8.5 Additional Considerations

The CNMI DPW Solid Waste Management Facility’s BECQ permit requires, within two years of the effective date of the permit (June 24, 2021), the installation of an electrical source (either CUC grid interconnection or alternative energy such as solar or storage with a BESS) that can provide continuous power to perform 24-hour monitoring and automatic leachate pumping. While this permit is likely to be amended and this feasibility study evaluates alternative energy options, connection to CUC could also be considered. As described in Section 3.1, it has been considered in the past and was determined to be infeasible because of environmental concerns and cost. Conversations with Dr. Dallas Peavey at CUC in February 2023 indicated that the utility is building a solar PV and BESS project at the Marianas Country Club, which is closer to the Marpi Landfill and may provide an alternative route that is less expensive. A new route will require new archaeological and environmental studies, which can add significant cost to a project, along with Historic Preservation Office requirements. On the other hand, a CUC connection may impact the desired configuration for on-site power supply options, potentially resulting in smaller system requirements and the offset of those project costs. Even with a CUC connection, on-site generation is still important for the prevention of extended loss of power; any disruptions on the CUC grid that require repairs may take some time to fix, especially to serve the landfill's far northern location.

Another consideration is the need to plan for future growth or changes to power needs. The systems evaluated in this feasibility study are sized to power loads based on estimates of current and future operations. While limited data were available for current power requirements, the recommended microgrid sizing is expected to cover all loads considered. However, in the case that future loads (beyond the 5–10-year projections included here) exceed estimates and the output of the selected microgrid systems, expansion of the power generation technologies is possible. For instance, additional PV panels could be considered for other locations in the future, or space could be reserved in the project footprint for additional PV panels, batteries, wind turbines, or generators. Reservation of space would need to be included in the project statement of work and design.

9.0 Recommendations and Next Steps

The details and results presented in this report are for consideration by the SW Taskforce. Of the power supply options presented here, a microgrid that includes solar PV generation, a BESS, and diesel generation was shown to best meet Marpi, OPD, DPW, and SW Taskforce requirements and goals. Based on landfill operator and DPW inputs, the evaluation found that approximately 100 kW of solar PV generation, a 100 kW/400 kWh BESS, and 160 kW of diesel generation (2, 80 kW units) will provide the necessary power requirements for 24/7 continuous landfill operations. Additionally, the capacities of the solar PV array and BESS could be expanded as needed to meet additional new loads at Marpi. Equipment capacities must be increased to 300 kW of solar PV generation, a 300 kW/1200 kWh BESS, and 300 kW of diesel generation (3, 100 kW units) if electric landfill equipment charging is included, with the caveat that the larger solar PV array will not fit within the preferred project location’s footprint and would require other areas of the landfill property or surrounding public land to provide additional space.

One potential path forward is for OPD to evaluate and pursue funding opportunities in conjunction with a request for information or request for proposals from potential vendors. Suitable solutions may result from such a process, especially if a single-vendor microgrid is desired. The responses will need to be carefully evaluated in cases where the proposed solutions do not align with the scenarios presented here because there are still many undefined factors and other options may also be viable. These steps will assist the SW Taskforce in meeting their clean and resilient energy goals.

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Appendix A – Current Conditions Load Profile

As described in Section 2.0, Marpi is not connected to the Commonwealth Utilities Corporation (CUC) electric distribution grid; instead, it is powered by an on-site diesel generator. The landfill's operating hours are 7:30 a.m.–4:30 p.m. Monday to Saturday (6 a.m.–6 p.m. during or after high rainfall conditions). During operating hours, pumps are used to control leachate and stormwater levels. Pumps are not used outside these hours because the generator is turned off when the landfill is unoccupied.

The power supply options from the original feasibility study (Solana et al. 2023) were all configured to be capable of providing power 24/7, despite all loads occurring during landfill operating hours. It was important to the Solid Waste Management Taskforce (SW Taskforce) to understand how adapting future operations to 24/7 power availability, spreading pumping loads across hours when the landfill is closed (Sundays and evenings), could impact power supply equipment sizing. As such, an addendum to the feasibility study focused on developing a revised load profile and modeling the impact on power supply scenarios (Moncheur de Rieudotte et al. 2024). This revised load profile, presented in Section 2.0 of this report, is preferred and has superseded the load profile from the original feasibility study. The results related to the original load profile based on current conditions are provided in this section.

Marpi's expected annual consumption based on the original load profile was estimated to be 170 MWh, with a peak load of 112 kW. Figure A-1 shows the hourly load profile for a typical week during both the dry and rainy seasons.

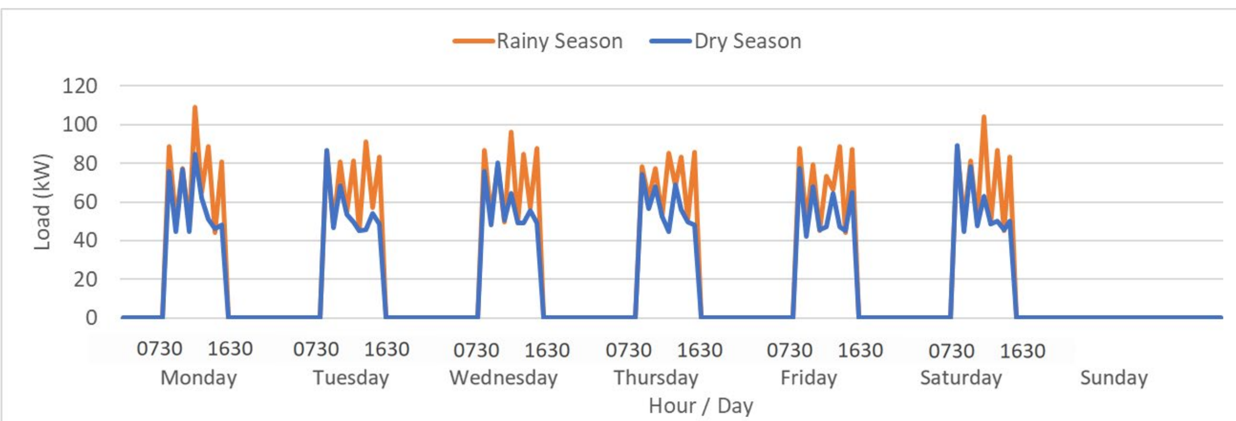

Figure A-1. Estimated typical weekly Marpi Landfill load profile (current conditions).

This load profile was used to evaluate the same scenarios presented in Section 4.0. The seven scenarios evaluated are summarized in Table A-1. The costs and levelized costs of energy (LCOEs) shown do not assume the use of any grant funding or incentives.

Table A-1. Summary of the evaluated scenarios (current conditions).

Scenario	Solar PV (kW)	Wind Turbine (kW)	Diesel Generator (kW)	Battery (kW/kWh)	Capital Cost ($M)	Annual O&M Costs ($k/yr)	25-year LCOE ($/kWh)	Social Cost of Carbon ($k)	CO_2e Emissions Generated (tons/yr)	% Renewable Energy Curtailed Annually	% Load Not Met Annually
PV/BESS	200	0	0	350/1400	6.0	6	2.56	0	0	50%	0%

Scenario	Solar PV (kW)	Wind Turbine (kW)	Diesel Generator (kW)	Battery (kW/kWh)	Capital Cost ($M)	Annual O&M Costs ($k/yr)	25-year LCOE ($/kWh)	Social Cost of Carbon ($k)	CO_2e Emissions Generated (tons/yr)	% Renewable Energy Curtailed Annually	% Load Not Met Annually
Wind/BESS	0	100	0	300/1200	4.9	15	3.66	0	0	37%	34%
PV/Wind/BESS	150	100	0	260/1040	5.5	16	2.47	0	0	61%	0%
PV/BESS/Gen	100	0	160	75/300	2.7	14	1.43	44	22	15%	0%
Wind/BESS/Gen	0	100	160	100/400	3.3	43	1.97	110	54	46%	0%
PV/Wind/BESS/Gen	100	100	160	60/120	3.2	19	1.68	24	12	56%	0%
Diesel Generator	0	0	160	0	0.8	70	1.25	250	122	0%	0%

Without grants, diesel generation alone (Scenario 7) has the lowest capital cost and the lowest LCOE, but the highest annual operations and maintenance (O&M) costs. Scenario 4, with solar PV, BESS, and diesel generation, has the lowest LCOE of the scenarios that use renewable energy. The three scenarios that do not use any diesel generation (Scenarios 1–3) have the highest capital costs and the highest LCOEs, but some of the lowest annual O&M costs, with solar PV and BESS (Scenario 1) having the lowest O&M costs.

The costs for the direct burial of new distribution cable range between $131k and $220k for Scenarios 1–6. The direct burial cost of new distribution cable for Scenario 7 (diesel only) is $38k. The existing distribution cable, which connects loads to the existing generator, will need to be replaced within the lifetime of the project, with an estimated cost of approximately $802k. The social cost of carbon for scenarios with diesel generators ranges from $24k to $250k, based on the social cost of carbon described in Appendix D.5.

To assist with decision-making, a prioritization matrix was created to compare the power supply scenarios associated with these updated results (Table A-2). As shown, Scenario 4 (100 kW of solar PV, a 75 kW/300 kWh BESS, and 160 kW of diesel generation) ranks highest.

Table A-2. Prioritization of Marpi power supply scenarios (current conditions).

Relative Metric Priority	1	5	1	3	4	1	3	3	1	2	2		
Prioritization Metric	Capital Cost	Annual O&M Costs	25-Year Levelized Cost of Energy	% Load Not Met Annually	Meets Permit Req. for Backup Power	CO_2e Emissions Generated	Area Req.	Diversity of Resources (# of components)	Equipment Hardening Req.	Training Req.	Smart Safe Growth		
Scenario	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Total Score	Rank
PV/BESS	7	1	6	3	7	1	4	5	2	3	2	3.17	4
Wind/BESS	5	3	7	7	7	1	4	5	5	3	5	4.17	7
PV/Wind/BESS	6	4	5	3	7	1	4	2	6	5	5	3.77	6
PV/BESS/Gen	2	2	2	1	1	5	1	2	3	5	4	1.87	1
Wind/BESS/Gen	4	6	4	1	1	6	4	2	4	5	7	3.23	5
PV/Wind/BESS/Gen	3	5	3	1	1	4	4	1	7	7	6	3.00	2
Diesel Generator	1	7	1	1	1	7	1	7	1	2	5	3.00	2

Appendix B – Terms and Definitions

Battery State of Charge (SoC) – The amount of energy stored in the battery relative to its capacity. A minimum SoC is typically around 20%, and a maximum is typically around 90% for lithium-ion (Li-ion) batteries.

Curtailment – Shutting down the generation of a system during times when the potential output cannot be used, resulting in a reduction in the output and therefore capacity factor and financial gains for the project.

Dispatchable/Nondispatchable – Energy resources are often characterized by whether they can be turned on and off and produce power whenever the operator or system requires it or whether they depend on a natural resource that may be available intermittently. Dispatchable generation includes resources like engines, turbines, fuel cells, and batteries, which can supply power on command. Nondispatchable resources include solar photovoltaics (PV), wind, and some hydropower resources that can only generate power when their input (sunlight, wind, flowing water) is available.

Levelized Cost of Energy (LCOE) – A measure of the present cost of electricity generation over the lifetime of a generation system. The LCOE calculation accounted for capital, fixed operations and maintenance (O&M), variable O&M, fuel, major maintenance, and insurance costs. The LCOE is used to compare the cost of electricity generation between different generation options.

$$\text{LCOE} = \frac{\text{Net Present Value of Costs}}{\text{Net Present Value of Output}} \tag{B-1}$$

Microgrid – A small power system that can operate connected to the larger grid or by itself in stand-alone mode. A microgrid consists of the combination of power generation and storage resources (renewables, batteries, fuel-fired generators, etc.), distribution infrastructure (wires, switchgear, protective devices, transformers, etc.), and loads being supplied with electricity. Loads powered by a microgrid can range from several loads or buildings to a small town or large campus.

Social Cost of Greenhouse Gasses – defined as “the monetary value of the net harm to society associated with adding a small amount of that greenhouse gas to the atmosphere in a given year” (Interagency Working Group on Social Cost of Greenhouse Gases 2021).

Appendix C – Marpi Landfill Load Assumptions

Operations at the landfill were characterized based on the assumptions in the following table, with information provided by Office of Planning and Development (OPD) and Micronesian Environment Services, LLC (MES) staff.

Equipment	Load (VA)	Dry Season Duty Cycle (h/day)	Dry Season Wh/day	Rainy Season Duty Cycle (h/day)	Rainy Season Wh/day	Load %	Assumptions/Notes
Existing Office Building							
General illumination @ 3.5 VA/SF	3,885	9	34,965	9	34,965	100%	Assumed used at full capacity.
General use receptacles @ 1 VA/SF	1,110	9	2,497.5	9	9,990	50%	Assumed only used at partial capacity.
Miscellaneous outlets @ 1 VA/SF	1,110	9	2,497.5	9	9,990	50%	Assumed only used at partial capacity.
Air conditioning	4,050	9	36,450	9	36,450	75%	Assumed to turn on above 62°F. Assumed 75% of load to account for building area that is not cooled.
Supply pump	2,400	9	21,600	9	21,600	100%	Assumed 9 h/day when facility is open.
Dryer	5,000	1	5,000	2	10,000	100%	Per DPW, should be provided as regulators require it.
Washer	1,100	1	1,100	2	2,200	100%	Per DPW, should be provided as regulators require it.
Electric Water Heater	4,500	3	13,500	5	22,500	100%	Per DPW, should be provided as regulators require it.
Scale House							
General illumination @ 3.5 VA/SF	875	9	7,875	9	7,875	100%	Assumed used at full capacity.
General use receptacles @ 1 VA/SF	250	9	1,125	9	1,125	50%	Assumed only used at partial capacity.
Miscellaneous outlets @ 1 VA/SF	250	9	1,125	9	1,125	50%	Assumed only used at partial capacity.
Air conditioning	1,958	9	17,622	9	17,622	100%	Per MES, operator has cooling on for 9 h during both dry and rainy seasons instead of 4 h only for dry season.
Maintenance Building							
General illumination @ 2.5 VA/SF	3,620	9	16,290	9	16,290	50%	Assumed only half the lights are in use.
General use receptacles @ 1 VA/SF	1,810	9	8,145	9	8,145	50%	Assumed used at partial capacity.
Miscellaneous outlets @ 1 VA/SF	1,810	9	8,145	9	8,145	50%	Assumed only used at partial capacity.
Ventilation	3,620	0	0	0	0		Per MES, not currently in use.

Equipment	Load (VA)	Dry Season Duty Cycle (h/day)	Dry Season Wh/day	Rainy Season Duty Cycle (h/day)	Rainy Season Wh/day	Load %	Assumptions/Notes
Air compressor	16,800	1	16,800	1	16,800	100%	Assumed 1 h/day, 3 days/week
Welding machine	18,013	1	18,013	1	18,013	100%	Assumed 1 h/day, 2 days/week
Pump, 1/2 hp	2,400	9	21,600	9	21,600	100%	A 1/2 hp water pump is presently used for Maintenance bldg. No other pumps are being used.
Roll-up doors, 3 each 1 hp	4,500	2	9,000	2	9,000	100%	DPW suggests to provide for this item to power up when funds are available. Assumed 1 h of use in morning and evening.
Generator Building							
General illumination @ 3.5 VA/SF	1,575	9	14,175	9	14,175	100%	DPW suggests including these loads for future rehabilitation plans.
General use receptacles @ 1 VA/SF	450	9	2,025	9	2,025	50%	DPW suggests including these loads for future rehabilitation plans.
Miscellaneous outlets @ 1 VA/SF	450	9	2,025	9	2,025	50%	DPW suggests including these loads for future rehabilitation plans.
Fuel pump	1,100	4	4,400	4	4,400	100%	DPW suggests including these loads for future rehabilitation plans.
Cell 1							
Storm pump	11,190	0	0	0	0	100%	Per MES, Cell 1 stormwater pump is no longer used.
Standard pump	3,730	4	14,920	4	14,920	100%	Per MES, operator runs pump 4 h/day.
Leak detection pump	1,120	1	1,120	1	1,120	100%	Assumed 1 h/day when facility is open.
Cell 2							
Storm pump				See Section 2.0			
Standard pump				See Section 2.0			
Leak detection pump	1,120	1	1,120	1	1,120	100%	Assumed 1 h/day when facility is open.
Leachate pond	1,490	9	13,410	9	13,410	100%	Per MES, operator runs 2 hp pump 9 h/day all year.
Blower/aeration pump	14,920	9	134,280	9	134,280	100%	Per MES, blowers run alternately. Operator is supposed to run blowers 9 h/day all year as part of treatment cycle

Equipment	Load (VA)	Dry Season Duty Cycle (h/day)	Dry Season Wh/day	Rainy Season Duty Cycle (h/day)	Rainy Season Wh/day	Load %	Assumptions/Notes
							under normal conditions.
Vegetative submerged beds effluent sump force main pump	2,240	9	20,160	9	20,160	100%	
Cell 3							
Storm pump	22,380	2	44,760	5	111,900	100%	Per MES, operator runs this pump approximately 2 h/day during dry season and 5 h/day during rainy season.
Standard pump	2,240	5	11,200	5	11,200	100%	Assumed to operate every other hour when facility is open.
Leak detection pump	400	1	400	1	400	100%	Assumed 1 h/day when facility is open.

DPW: Department of Public Works; SF: square foot (feet).

Appendix D – Economic Assumptions and References

The financial analysis calculated the levelized cost of energy (LCOE) as the net present value of costs divided by the net present value of the output. This approach was used to account for degradation in the generation output, battery energy storage system (BESS) efficiency losses, and major maintenance at different intervals for each component. The costs and production for each asset were discounted back to the present using the real discount rate of 0.45%. The rate was based on the interpolation of 20-year and 30-year real interest rates as specified in Appendix C of OMB Circular No. A-94.

Capital costs occurred in Year 0. Major maintenance occurred in years 8 and 16 for solar, 10 and 20 for wind, 8 and 24 for the BESS, and 15 for microgrids, which was a major asset replacement. The remaining value of the assets at the end of the 25-year project was added back in year 25 using straight-line depreciation. These costs as well as annual operations and maintenance (O&M) and fuel costs were discounted to present. The total present values of the costs for all assets were summed and divided by the total present value of production in kilowatt-hours, resulting in the LCOE of each scenario.

Table D-1 lists the parameters used in the economic analysis, along with references for each. Lists of example projects and other reference costs used to determine cost assumptions for each technology are included in the subsections below.

Table D-1. Economic parameters and assumptions.

Parameter	Value	Source
PV capital cost	$4,250/kW	Research on equivalent local projects
PV O&M cost	$12/kW-year	Various
Wind capital cost	$6,000/kW	Manufacturer
Wind O&M cost	$140/kW	Manufacturer
Battery capital cost	$490/kW of power capacity plus $1,226/kWh of energy capacity (~$1,347/kWh total)	Viswanathan et al. “2022 Grid Energy Storage Technology Cost and Performance Assessment” + ACF
Battery O&M cost	$15.5/kW-year	Viswanathan et al. “2022 Grid Energy Storage Technology Cost and Performance Assessment” + ACF
Generator capital cost	$3,424/kW	GSA costs for marine-rated generators, estimated costs for installation and NEMA enclosures, + ACF
Generator O&M cost	Variable: $0.0333/kWh	Lazard’s Levelized Cost of Energy Analysis, v11.0, + ACF
Microgrid capital cost	$450/kW	
Diesel fuel cost	$6/gallon	Current local price
Economic life	25 years; BESS and microgrids are reinvested in during this time	Per scope of work
Real discount rate	0.45%	OMB (https://www.wbdg.org/FFC/FED/OMB/OMB-Circular-A94.pdf)
Insurance rate	0.5%	Speer et al. “Insuring Solar Photovoltaics: Challenges and Possible Solutions”
ACF	3.42 (capital), 3.33 (O&M); included in above costs	USACE (https://www.usace.army.mil/Cost-Engineering/Area-Cost-Factors/)

Parameter	Value	Source
Battery round-trip efficiency	85%	Viswanathan et al. “2022 Grid Energy Storage Technology Cost and Performance Assessment”
ACF: area cost factor; GSA: General Services Administration; NEMA: National Electrical Manufacturers Association; OMB: Office of Management and Budget; PV: photovoltaic; USACE: U.S. Army Corps of Engineers.		

D.1 Solar PV

Table D-2 lists several relevant capital cost references for solar photovoltaics (PVs).

Table D-2. Solar PV capital cost references.

Source	Mounting Type	System Size	Year of Cost	PV Cost ($/kW)
Installed Systems				
Rota Aquaponics (https://www.saipantribune.com/index.php/solar-power-system-for-rota-aquaponics-underway/)	Rooftop	36 kW_{DC}	2022	4,250
U.S. Army Reserve in American Samoa; costs incl. microgrid design	Rooftop	325 kW	2017	5,880
USDA grant for 82 homes, 3 kW each (https://sablan.house.gov/press-release/17-million-awarded-solar-energy-efficiency)	Rooftop	246 kW	2015	5,526
Marianas Business Plaza (https://www.mbjguam.com/2015/01/26/saipan-center-completes-solar-project/)	Carport	650 kW	2015	3,538
Commonwealth Healthcare Corporation (per conversation with Warren Villagomez on 7 Feb 2023)	Carport	178 kW	Planned: ~2024	7,955
Estimated Costs				
CNMI Strategic Energy Plan	Rooftop Ground	>10 kW >10 kW	2022 2022	2,664 3,056
BNEF cost for system in Hawaii	Ground	Commercial (~1 MW)	2023	1,150
BNEF cost above, with area cost factor	Ground	Commercial (~1 MW)	2023	3,933
“U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2022” (NREL report) - modeled market price, (https://www.nrel.gov/docs/fy22osti/83586.pdf)	Ground	Commercial (200–500 kW)	2022	2,139
NREL report cost above, with area cost factor	Ground	Commercial (200–500 kW)	2022	7,315

BNEF: Bloomberg New Energy Finance; CNMI: Commonwealth of the Northern Mariana Islands; NREL: National Renewable Energy Laboratory; USDA: U.S. Department of Agriculture.

O&M costs for solar PV systems were estimated from Bloomberg New Energy Finance (BNEF) and National Renewable Energy Laboratory (NREL) and include module cleaning, vegetation/pest management, system inspection/monitoring, and the replacement of minor component parts. The CNMI Strategic Energy Plan quotes $11.70/kW for PV O&M (GHD 2022).

D.2 Wind

Capital and O&M costs for a wind turbine were based on conversations with the vendor of a suitable 100 kW wind turbine, Northern Power Systems (Connor 2023). The capital cost includes a 50% markup for shipping and construction in Saipan over U.S. mainland costs. O&M costs include the cost for skilled laborers to travel to Saipan from the U.S. mainland once per year for annual inspections. These costs are in line with the cost of the 275 kW wind turbine installed in 2016 in Guam ($2.1M, a 40% premium over U.S. mainland prices at the time).

D.3 BESS

Table D-3 lists several relevant capital cost references for the BESS.

Table D-3. BESS capital cost references.

Source	Year of Cost	Cost per kWh
Installed Systems		
Ta'u added battery capacity (1.5 MWh)	2016	$618
American Samoa added battery capacity (345 kWh)	2021	$966
Estimated Costs		
CNMI Strategic Energy Plan	2022	$1,000
2022 Grid Energy Storage Technology Cost and Performance Assessment	2021	$448
Cost above, with area cost factor	2021	$1,532
2022 Grid Energy Storage Technology Cost and Performance Assessment	2030	$340
Cost above, with area cost factor	2030	$1,162
U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2022	2022	$672
Cost above, with area cost factor	2022	$2,298

In surveys of system performance and O&M costs by NREL, DNV GL, Pacific Northwest National Laboratory (PNNL), and others, a representative annual cost is about 2.5% of the installed capital cost of the battery; this produces a range of $8/kW to $25/kW for the surveyed systems (Cole and Frazier 2020). Several factors will influence the O&M costs: size and type (chemistry) of the batteries used, location and climate of the system (and associated cooling requirements), system utilization and dispatch (frequency of cycling the battery), and others.

D.4 Cost of Distribution

The project team estimated the cost of new distribution lines between new generation equipment and existing loads, as well as the costs associated with replacing existing distribution lines (between loads and the existing diesel generator), if required in the future. This latter cost will occur if the existing distribution to be replaced during the project lifetime. These costs are incorporated into the life cycle cost analysis of each scenario.

The assumptions outlined for this task are related to installation and cost considerations. In terms of installation, it is assumed that all new conduit is required, supported by the observation that no extra empty conduit exists from images of manholes shared by the Department of Public Works (DPW). The layout of the new conduit avoided paved areas, assuming open trench direct burial of conductor whenever possible (as opposed to directional boring). A typical rocky ground profile is assumed. Regarding materials, copper conductors are used for ampacity calculations. Conductor costs were taken from the U.S. Army Corps of Engineers (USACE 2022a), the Department of Defense (DoD 2023), and the Phase I analysis (Solana et al. 2023) and are listed in Table D-4. The values in this table were further multiplied by an area cost factor (ACF)[15] of 3.6 based on USACE assumptions for Saipan (USACE 2022b), with the caveat that this factor may not be entirely accurate for common materials like power cable. A 50% contingency factor was also applied to account for uncertainty.

Table D-4. Conductor unit costs.

Description	Rated Ampacity (A)	USACE ($/ft)	DoD ($/ft)	Phase I Analysis ($/ft)
4 conductor set of 1/0	130	$49.8	$51.8	$40.6
8 conductor set of 1/0	260	$75.6	$77.7	$61.3
4 conductor set of 4/0	195	$60.2	$64.9	$50.0
8 conductor set of 4/0	390	$93.5	$107.5	$80.0
12 conductor set of 4/0	585	$129.7	$146.4	$110.0
20 conductor set of 4/0	780	$201.9	$224.3	$170.0

Figure D-1 shows an overview of the site, including the confirmed and assumed paths of existing conductor and the path of the required new conductor.

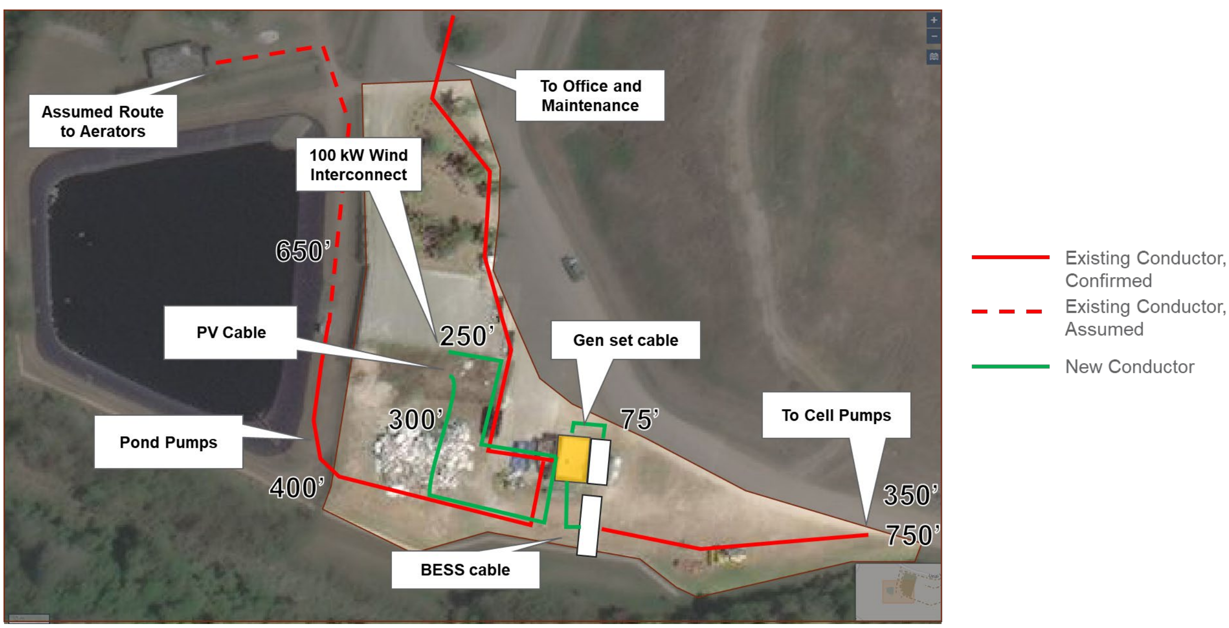

Figure D-1. Overview of existing and new electric distribution cable.

[15] USACE area cost factors are a DoD mechanism to adjust U.S.-based construction costs based on location.

The costs for the direct burial of new distribution lines and the replacement of existing distribution lines were calculated for the 24/7 operations baseline and 24/7 operations & electric equipment load profiles. Both the average and highest estimated costs of the three data sources are presented.

As discussed in Section 2.0, electric landfill equipment charging requires larger solar PV, diesel generator, and BESS capacities. These generate more current, requiring more expensive conductors with higher ampacity ratings, increasing the cost of the new generation cable. The cost of the replacement of existing cable remains the same.

Table D-5 and Table D-6 list the average and highest estimated costs for the direct burial of new generation cable for the 24/7 operations baseline and electrified equipment load profiles, respectively. Table D-7 lists the average and highest estimated costs for the replacement of cable for existing facilities, which is the same for both load profiles This cost will occur if the existing distribution between the loads and breaker box needs to be replaced during the project lifetime.

Table D-5. Cost summary for the installation of new distribution cable (24/7 operations baseline).

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
Direct Burial, Average	$192k	$122k	$206k	$144k	$131k	$208k	$29k
Direct Burial, High	$213k	$133k	$228k	$157k	$143k	$227k	$31k
Cost Difference	$21k	$11k	$22k	$13k	$12k	$19k	$2k

Table D-6. Cost summary for the installation of new distribution cable (24/7 operations & electric equipment).

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
Direct Burial, Average	$483k	$140k	$433k	$257k	$131k	$321k	$29k
Direct Burial, High	$545k	$157k	$489k	$293k	$143k	$363k	$31k
Cost Difference	$62k	$17k	$56k	$36k	$12k	$42k	$2k

Table D-7. Cost summary for the replacement of existing distribution cable.

	Cell #1 Pumps	Cell #2 Pumps	Office and Maintenance	Leachate Pond Pumps	Leachate Pond Aerators
Direct Burial, Average	$90k	$192k	$252k	$102k	$166k
Direct Burial, High	$98k	$210k	$280k	$112k	$182k
Cost Difference	$8k	$18k	$28k	$10k	$16k

The costs for the direct burial of new distribution cable for the 24/7 operations baseline load profile are less than those for the 24/7 operations & electric equipment load profile for Scenarios 1–6 because smaller BESS capacities require less expensive cable. Adding electric equipment more than doubles the cost for scenarios with larger equipment capacities. This is because electric landfill equipment charging requires larger solar PV, diesel generator, and BESS capacities. These generate more current, requiring more expensive conductors with higher ampacity ratings, increasing the cost of the new generation cable. For both load profiles, the direct burial cost of new distribution cable for Scenario 7 (diesel only) is $38k. The direct burial cost of replacing existing cable at end of life for both load profiles and power supply scenarios is expected to be $802k.

The average direct burial costs of new and replacement cable were used to inform the life cycle cost analysis for each power supply scenario, as discussed in Section 4.0.

D.5 Social Cost of Carbon

The Solid Waste Management Taskforce (SW Taskforce) prioritized scenarios using ranked qualitative criteria related to climate and environmental justice considerations; these considerations may also be represented quantitatively by the social cost of carbon. As such, this project team calculated the social cost of carbon for each power supply scenario and incorporated it into the life cycle cost analysis.

The social cost of carbon used for this analysis comes from the Interagency Working Group on Social Cost of Greenhouse Gases. The Working Group defines the social cost of carbon in 2020 dollars per metric ton of CO_2 equivalent (CO_2e), which was projected to future dollars using a 2.5% discount rate for this analysis (Table D-8).

Table D-8. Social cost of carbon.

Year	Social Cost of Carbon (2022$/Ton CO_2e emitted)
2022	89
2023	90
2024	91
2025	93
2026	94
2027	96
2028	98
2029	99
2030	100
2031	102
2032	103
2033	105
2034	107
2035	108
2036	109
2037	111
2038	112
2039	114
2040	116
2041	117
2042	118
2043	120
2044	121
2045	123
2046	125

To calculate the social cost of carbon, the CO_2e emissions associated with each scenario were calculated using a U.S. Environmental Protection Agency (EPA) emissions factor of 0.07421 tons of CO_2e per million British thermal units of fuel consumed by the diesel generator (EPA 2022). The tons of CO_2e were then multiplied by the social cost of carbon and incorporated into the life cycle cost analysis for each power supply scenario in Section 4.0.

Appendix E – Wind Assessment Details

The wind models that provide coverage in the Commonwealth of the Northern Mariana Islands (CNMI) region fall into two categories: (1) high spatial resolution but low temporal resolution or (2) high temporal resolution but low spatial resolution. A high spatial resolution is needed to represent the wind resource as it follows the local terrain, which is especially important for islands. A high temporal resolution is needed to understand the wind resource as it changes seasonally, diurnally, and on other timescales to facilitate the assessment of the wind resource relative to the load. The wind resource assessment for Marpi employed the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5 (ERA5) model (ECMWF 2023) to provide the long-term hourly trends in wind speed and direction and the GWA3 model (DTU 2023) to provide more localized wind information for the site of interest (Table E-1).

Table E-1. Characteristics of the models that provided wind resource data for this study.

Model	ERA5	GWA3
Developer	ECMWF	DTU Wind Energy, World Bank Group
Temporal Coverage (years)	1950–present	2008–2017
Temporal Output Frequency	1 h	Annual
Horizontal Spatial Coverage	Global	Global
Horizontal Grid Spacing	0.25° (~25 km)	0.25 km
Wind Speed Output Heights	10 m, 100 m	10 m, 50 m, 100 m, 150 m, 200 m

Wind speed data at 10 m and 100 m above ground level at the nearest neighbor ERA5 grid point (15.25°N, 145.75°E) were extracted from 2008–2017 (the overlapping temporal period with GWA3). In order to produce wind speed time series at hub heights of interest z_{HH}, the power law in Eq. (E-1), in conjunction with a dynamic shear exponent (α), as shown in Eq. (E-2), was used to calculate the simulated wind speeds v_{10} and v_{100} from the two surrounding model heights of 10 m and 100 m. This vertical interpolation scheme for the simulation of the wind speed at the measurement height was selected because it considers multiple levels in the wind speed profile and does not rely on static stability assumptions (Olauson and Bergkvist 2015).

$$v_{\mathrm{ERA5,HH}} = v_{10}\left(\frac{z_{\mathrm{HH}}}{10}\right)^{\alpha} \tag{E-1}$$

$$\alpha = \ln\left(\frac{v_{100}}{v_{10}}\right)\Big/\ln\left(\frac{100}{10}\right) \tag{E-2}$$

Using the overlapping grid cell to the site from the high-resolution GWA3 model (Figure 17) (DTU 2023), the ERA5 wind speed time series $v_{\mathrm{ERA5,HH}}$ was geolocated to the potential turbine location in Figure 16 for two hub heights available for a Northern Power Systems 100-28 wind turbine (37 m for a standard tower and 23 m for a tilt-up tower) using the following equation:

$$v_{\mathrm{Site,HH}} = v_{\mathrm{ERA5,HH}} \cdot \frac{\overline{v_{\mathrm{GWA3,50}}} \cdot \overline{v_{\mathrm{GWA3,50,norm}}}}{\overline{v_{\mathrm{ERA5,50}}}} \tag{E-3}$$

where $\overline{v_{\mathrm{GWA3,50}}}$ is the mean GWA3 50 m wind speed for a year of interest, $\overline{v_{\mathrm{ERA5,50}}}$ is the mean ERA5 50 m wind speed for a year of interest, and $\overline{v_{\mathrm{GWA3,50,norm}}}$ is the mean GWA3 50 m wind speed for a year of interest normalized by the mean GWA3 50 m wind speed for all years.

Because power curves are typically developed at an air density of 1.225 kg/m^3 before converting wind speeds to power, the hub height wind speed estimates were adjusted for the local and temporally varying density using the following calculation:

$$v_{\text{Adjusted}} = v_{\text{Site,HH}} \cdot \left(\frac{\text{density}}{1.225\ \text{kg/m}^3}\right)^{1/3} \qquad \text{(E-4)}$$

Appendix F – Smart Safe Growth Analysis

Smart, safe growth (SSG) is a set of complementary development strategies and practices focused on improving the resiliency and recoverability of the built environment. As reflected in the SSG Guidance Manual and Assessment Tool for the Commonwealth of the Northern Mariana Islands (CNMI) (Nimbus Environmental Services 2018) and as incorporated into the 2021-2030 Comprehensive Sustainable Development Plan (OPD 2021), SSG principles (listed in Figure F-1) support project scoping and an analysis of alternatives. The SSG Guidance Manual and evaluation tool supports multiple sustainable growth objectives and is a foundational policy document incorporated into CNMI's Comprehensive Sustainable Development Plan.

	Principle	Definition
1	Climate Change	Consider long-term climate change impacts of sea level rise, coastal inundation, increased storm intensity, variabilities in precipitation, and drought in planning, design, and cost determination for infrastructure and development projects as well as natural area preservation and enhancement planning.
2	Retreat	Plan to retreat from the areas of highest risk by discouraging or regulating development in these areas and promoting alternative uses of high-risk land, such as walkable public waterfront parks and recreation areas.
3	Retrofit	Retrofit existing structures and infrastructure located in hazard-prone areas to reduce vulnerabilities.
4	Critical Facilities Location	Locate new critical facilities (e.g., water and sewer systems, roads, hospitals, power plants, transmission and communication lines, and public safety facilities) outside of high-risk zones.
5	Development Incentives	Utilize regulatory and financial incentives to locate new development away from high risk areas into lower risk areas or to areas where risk can be reduced through management measures.
6	Sustainable Development BMPs	Establish regulatory policies that recommend/require the use of "*CNMI Sustainable Development Manual: Best Management Practices*" for commercial/public/multifamily developments.
7	Ecosystem Services	Maintain sufficient key natural resource areas (e.g., coral reefs, wetlands, mangroves, riparian zones, and vegetated slopes) that support and enhance ecosystem services, to protect infrastructure investments and developed areas.
8	Green Infrastructure	Encourage green infrastructure, soft stabilization measures and living shoreline alternatives at development sites, island open spaces and infrastructure deployment.
9	Development Decision Process	Ensure that development decision processes are predictable, fair, and transparent.
10	Early Collaboration	Encourage early-stage government agency collaboration and stakeholder engagement in development planning and decision making.
11	Knowledgeable SSG Communities	Promote a community of leaders and networks knowledgeable in the principles of smart, safe growth.
12	Adaptive Management	Integrate adaptive management approaches to smart, safe growth development and incorporate lessons learned into future planning and development efforts. Periodic assessments and updates to be scheduled and funded.

Figure F-1. Smart, Safe Growth principles.

The project team scored each power supply scenario according to each of eight principles that would be impacted by a power supply project at Marpi. Then, the scores were averaged over the eight principles, assuming that they all have the same relative weight. Scores ranged from 1 to 9, with 1 indicating a beneficial impact on the SSG principle and 9 indicating a detrimental impact. (The climate change principle was scored based on additional factors, as shown in Figure F-2.) The result was a total score for each scenario, representing a high-level analysis of its consistency with SSG guiding principles. The results of this analysis are shown in Figure F-3 and used in the prioritization of scenarios. The full SSG analysis tool is available at https://opd.gov.mp/assets/SSG%20Project%20Evaluation%20Tool_Blank.xlsx.

		1	2	3	4	5	6	7	8	9	10	
Scenario	Climate Change factors - considered for energy mix below:	Impacts sea level rise (causes global warming i.e. emissions)*	Impacts coastal inundation (indirectly from sea level rise)	Increased storm intensity (indirectly from dispersed , warming climate that changes weather patterns)	Affects variabilities in precipitation	Drought	Planning	Design	Cost	Natural area preservation	Enhancement planning (towards conservation)	**Score**
1	PV, BESS	1	CF	CF	CF	CF	CF	CF	CF	CF	1	**1**
2	Wind Turbine, BESS	1									5	**1**
3	PV, Wind Turbine, BESS	1									5	**1**
4	PV, BESS, Generator	7									1	**6**
5	Wind Turbine, BESS, Generator	7									5	**7**
6	PV, Wind Turbine, BESS, Generator	5									5	**5**
7	Generator	9									1	**8**

Notes:

1. * assumes that diesel generators have CO2 emissions known to cause global warming
2. The choice of energy mix scenarios assumes that the contribution of the Climate Change factors 1 (Impacts sea level rise) and 10 (Enhancement planning) are 90% and 10%, respectively
3. CF - confounding variable. As such, the choice of energy mix is only one confounding variable of the many that has impacts on Climate Change

Figure F-2. Climate change scores.

Smart , Safe Growth Principles

Scenario	Infrastructure Mix	Climate Change	Retreat	Retrofit (discourages or regulates high risk development)	Facilities Location (at high risk zones, rank 1- 9)	Incentives (risk can be reduced through management	Sustainable Development BMPs	Ecosystem Services	Green Infrastructure	Development Decision Processes	Early Collaboration	SSG Knowledgeable Communities	Adaptive Management	Score*
	SSG Principles	1	2	3	4	5	6	7	8	9	10	11	12	
1	PV, BESS	1	1	1	6	1	1	1	1	No Effect	No Effect	No Effect	No Effect	2
2	Wind Turbine, BESS	1	9	9	6	5	1	7	5	""	""	""	""	5
3	PV, Wind Turbine, BESS	1	9	9	6	5	1	5	6	""	""	""	""	5
4	PV, BESS, Generator	6	1	5	6	1	1	9	3	""	""	""	""	4
5	Wind Turbine, BESS, Generator	7	9	9	6	5	1	9	8	""	""	""	""	7
6	PV, Wind Turbine, BESS, Generator	5	9	9	6	5	1	9	7	""	""	""	""	6
7	Generator	8	1	5	6	1	1	9	9	""	""	""	""	5

* averaged over the 8 SSG principles assuming they have equal relative weights

Figure F-3. Smart, Safe Growth analysis.

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