Survey to Gather and Verify Information for Aid Measures to Improve Energy Security in the Pacific Region Power Sector

Final Report
Executive Summary

November 2015

Japan International Cooperation Agency (JICA)

Okinawa Enetech Co., Inc.

IL
JR
15-067

Table of contents

1. Survey Overview 1
1.1 Survey Background 1
1.2 Purpose of the survey 1
1.3 Survey area 2
1.4 Survey content 2
1.5 Member make-up 3
1.6 Survey Schedule 3
2. Overview of the Pacific Region 5
3. Systemization of Aid Measures for the Pacific Region Power Sector 6
3.1 Arrangement of an issue resolution policy for the improvement of energy self-sufficiency 6
3.1.1 Basic policy 6
3.1.2 Concept of a remote island microgrid 7
3.1.3 Method for restricting RE output 16
3.1.4 The merits and demerits of RE deployment 19
3.1.5 Summary of the remote island microgrid deployment method 19
3.1.6 Rough construction cost of a remote island microgrid configuration device 26
3.2 Arrangement of study steps for improving energy self-sufficiency 27
3.3 Arrangement of methods of application to each target country 28
4. Finalization of the aid measures road map for each target country 29
4.1 Fiji 31
4.2 Marshall Islands 33
4.3 Pohnpei (Micronesia) 35
4.4 Chuuk (Micronesia) 37
4.5 Yap (Micronesia) 39
4.6 Kosrae (Micronesia) 41
4.7 Tonga 43
4.8 Port Vila (Vanuatu) 45
4.9 Santo (Vanuatu) 47
4.10 Solomon Islands 49
4.11 Palau 51
4.12 Kiribati 53
4.13 Samoa 55
4.14 Tuvalu 57
4.15 Cook 59
4.16 Nauru 61
4.17 Niue 63
5. Summary 65

5.1 Summary of the policy for implementing aid measures for each target country 65
5.2 Closing Comments 65

Table of contents for tables and figures

Figure 3-1 Power supply-demand balance (small-scale PV deployment) 10
Figure 3-22 Power supply-demand balance (medium-scale PV deployment) 11
Figure 3-33 Power supply-demand balance (large-scale PV deployment) 12
Figure 3-4 Conceptual diagram of a remote island microgrid 15
Figure 3-5 Solar radiation and cumulative frequency in Okinawa 16
Figure 3-6 WT example 18
Figure 3-7 Wind speed and cumulative frequency in Hateruma Island, Okinawa 18
Figure 3-8 Aggregate monthly generation of various solar cells and solar radiation 20
Figure 3-9 Area efficiency comparison of 20°and 5°tilt angles 20
Figure 3-10 Concrete slab foundation 21
Figure 3-11 Spiral steel pipe pile 21
Figure 3-12 Super-Dyma PV frame 21
Figure 3-13 FRP PV frame (Cosmo System website) 21
Figure 3-14 WT unit capacity trend (Mitsubishi Electric website) 23
Figure 3-15 Mid-size WT made in Japan 24
Figure 3-16 Aid measures study step 27
Figure 6-1 Aid measures road map for Fiji 32
Figure 6-2 Aid measures road map for Fiji 34
Figure 6-3 Aid measures road map for Pohnpei (Micronesia) 36
Figure 6-4 Aid measures road map for Chuuk (Micronesia) 39
Figure 6-5 Aid measures road map for Yap (Micronesia) 40
Figure 6-6 Aid measures road map for Kosrae (Micronesia) 43
Figure 6-7 Aid measures road map for Tonga 44
Figure 6-8 Aid measures road map for Port Vila (Vanuatu) 46
Figure 6-9 Aid measures road map for Santo (Vanuatu) 48
Figure 6-10 Aid measures road map for the Solomon Islands 50
Figure 6-11 Aid measures road map for Palau 52
Figure 6-12 Aid measures road map for Kiribati 54
Figure 6-13 Aid measures road map for Samoa 56
Figure 6-14 Aid measures road map for Tuvalu 58
Figure 6-15 Aid measures road map for the Cook Islands 60
Figure 6-16 Aid measures road map for Nauru 62
Figure 6-17 Aid measures road map for Niue 64
Figure 7-1 Aid policy organizing method 65

Table 6-1 Comparison of the current status and the effects of implementing aid measures

for each target country.. 30
Table 7-1 Classification of the target countries based on their current status 65

1. Survey Overview

1.1 Survey Background

Many small and often scattered Pacific island countries have a small power demand per power system and scarce energy resources, and they rely heavily on imported fuel (diesel) for their main electric energy source. In addition, they are very far and isolated from major supply sources and were greatly impacted by soaring oil prices in the mid-2000s which remained at high levels, so reducing power generation costs has become one of their greatest issues.

Incurring these circumstances, in addition to receiving assistance from international organizations for improving energy security, these countries are actively aiming to promote the deployment of renewable energy (hereinafter RE). However, in deploying RE which has unstable output, it is indispensable to take into consideration the stability of the power system to which it will be integrated, the fuel consumption of diesel generators which are the main power source that will respond to output fluctuations, and the financial status of power utilities to ensure a stable energy supply and a sustainable implementation structure, and moreover, lead to reduced fuel consumption.

To date, in addition to improving diesel power plants and small hydroelectric power plants, solar generation equipment, and micro-grids, JICA has provided a wide range of assistance to the Pacific region power sector including assisting in establishing development plans and human resources development through training in Japan. As specific aid projects in recent years, in the remote islands of Tonga where solar (PV) power output is about 20% of diesel power output, JICA introduced energy storage technology (capacitor, etc.) aimed at stabilizing output to the power system. In the Marshall Islands, JICA assisted in developing plans for the integration of RE in both financial and technical terms while carrying out a survey to propose the economical operation of existing diesel power generation. The power sectors of the countries in the same region have considerably similar characteristics, and the need to conduct a systematic study from the viewpoint of reducing fuel consumption based on the knowledge accumulated by JICA through these projects has arisen.

Amid these circumstances, for challenges that the power sector in Pacific region faces today, this basic survey to gather and verify information will be conducted in order to establish JICA's aid strategy which aims to reduce fuel consumption accompanied by a stable power supply and a sustainable implementation structure, or in other words, contributes to realizing energy security improvement.

1.2 Purpose of the survey

(1) Gathering and organizing basic information on the power sector of each Pacific country.

(2) A systematic analysis and proposal of fuel consumption reduction measures accompanied by a stable energy supply and sustainable implementation structure.
(3) Establish a roadmap for aid measures which contribute to improving energy security including the power sector of the Pacific region

1.3 Survey area

The target countries are the following 13 Pacific countries. However, only the power systems of the main islands will be subject to aid measures: Fiji, Vanuatu, Solomon Islands, Samoa, Tonga, Kiribati, Tuvalu, Micronesia, Palau, Marshall Islands, Cook Islands, Niue, and Nauru.

In addition, in conducting the survey, an analysis will be conducted in Japan based on reports on aid provided by JICA and other donors as well as research mainly through literature, the Internet, and visits to relevant organizations in Japan. Also, a field survey shall be conducted in four countries (Vanuatu, Kiribati, Palau, and Fiji) where collecting information on-site is particularly desirable in order to establish a roadmap.

1.4 Survey content

This survey will be conducted in two stages. In the first stage, existing information will be collected, organized, and analyzed (1st Work in Japan). In the second stage, the aid measures will be reviewed through a field survey and the road map will be finalized (Field work and 2nd Work in Japan). In this report, the results of the first stage are reported. Study items for each stage are described below.

<u>Stage 1: Gather, organize, and analyze existing information</u>

(1) Gather, organize, and analyze basic information on the power sector of each target country.
(2) Conduct a study on aid measures which contribute to improving the energy security of the target countries.
(3) Establish a roadmap for aid measures which contribute to improving the energy security including the power sector of the Pacific region and target countries.

<u>Stage 2: Review aid measures through a field survey and finalize the road map</u>

(1) Gather, organize, and analyze basic information on the power sector of each target country (field work)
(2) Conduct a study on aid measures which contribute to improving the energy security of the target countries.
(3) Establish a roadmap for aid measures which contribute to improving the energy security including the power sector of the Pacific region and target countries.

1.5 Member make-up

Figure 1-1 Member make-up

Name	In charge	Work content
Luis Kakefuku	Coordinator/diesel generation/RE deployment	・Survey team coordinator and work progress management and consultation ・Responsible for coordinating meetings and consultations with relevant institutions of the target country ・Advice and instruction for each member's survey and work ・Responsible for the compilation, submission, and explanation of various reports on the project ・Establishment of a comprehensive aid measures roadmap
Hirotune Gibo	Diesel generation (economical operation-A)	・Survey of the existing power plant, technology review ・Validation of the possibility of deploying economic load dispatch (EDC) ・Confirmation of operation method and condition and measurement of fuel consumption ・Study on improving energy efficiency ・Preparation of various reports in the assigned field ・Establishment of a comprehensive aid measures roadmap
Yasushi Mori	Diesel generation (operation and maintenance)-electrical	・Survey of the existing power plant, confirmation of operation and maintenance status ・Getting an understanding of the repair and replacement status of existing diesel generators and proposal of aid measures ・Preparation of various reports in the assigned field ・Establishment of a comprehensive aid measures roadmap
Yoritaka Nakamura	Diesel generation (operation and maintenance)-mechanical	・Survey of the existing power plant, confirmation of operation and maintenance status ・Getting an understanding of the repair and replacement status of existing diesel generators and proposal of aid measures ・Preparation of various reports in the assigned field ・Establishment of a comprehensive aid measures roadmap
Chihiro Tobaru	RE grid connection technology	・Gather, organize, and analyze basic information on the power sector of each target country ・Proposal technical aid to maximize the RE integration limit ・Study on reducing loss for transmission and distribution equipment ・Preparation of various reports in the assigned field ・Establishment of a comprehensive aid measures
Yuma Uezu	Diesel generation (economical operation)	・Survey of the existing power plant, technology review ・Validation of the possibility of deploying economic load dispatch (EDC) ・Confirmation of operation method and condition and measurement of fuel consumption ・Study on improving energy efficiency ・Preparation of various reports in the assigned field ・Establishment of a comprehensive aid measures roadmap

1.6 Survey Schedule

The field survey schedule is as follows.

Field survey schedule: February 20, 2015 - March 23, 2015

Table 1-1 Field survey schedule

Total Days	Month/ Date	Start	End	Time req.	Journey	Comments
1	2/20	11:55	13:50	2:55	Naha ⇒ Hong Kong	
	Fri	17:50			Hong Kong ⇒	[Overnight flight]
2	2/21		9:50	11:00	⇒ Auckland (New Zealand)	
	Sat	13:05	14:20	3:15	Auckland (New Zealand) ⇒ Port Vila (Vanuatu)	Vanuatu ①
3	2/22					
	Sun					Vanuatu ②
4	2/23				Vanuatu survey ①	
	Mon					Vanuatu ③
5	2/24				Vanuatu survey ②	
	Tue					Vanuatu ④
6	2/25				Vanuatu survey ③	
	Wed					Vanuatu ⑤
7	2/26				Vanuatu survey ④	
	Thu					Vanuatu ⑥
8	2/27				Vanuatu survey ⑤	
	Fri					Vanuatu ⑦
9	2/28					
	Sat					Vanuatu ⑧
10	3/1					
	Sun					Vanuatu ⑨
11	3/2				Vanuatu survey ⑥	Vanuatu ⑩
	Mon	17:00	20:15	2:15	Port Vila (Vanuatu) ⇒ Nadi (Fiji)	Fiji (Nadi)
12	3/3	7:30	8:00	0:30	Nadi (Fiji) ⇒ Suva (Fiji)	
	Tue				Visit JICA Fiji Office	Fiji (Suva)
13	3/4				Visit JICA Fiji Office	
	Wed	17:30	18:00	0:30	Suva (Fiji) ⇒ Nadi (Fiji)	Fiji (Nadi)
14	3/5	8:00	11:00	3:00	Nadi (Fiji) ⇒ Tarawa (Kiribati)	
	Thu				Kiribati survey (1)	Kiribati (1)
15	3/6				Kiribati survey (2)	
	Fri					Kiribati (2)
16	3/7					
	Sat					Kiribati (3)
17	3/8					
	Sun					Kiribati (4)
18	3/9				Kiribati survey (3)	
	Mon					Kiribati (5)
19	3/10				Kiribati survey (4)	
	Tue					Kiribati (6)
20	3/11				Kiribati survey (5)	
	Wed					Kiribati (7)
21	3/12					
	Thu					Kiribati (8)
22	3/13					
	Fri					Kiribati (9)
23	3/14	16:15	19:15	3:40	Tarawa (Kiribati) ⇒ Nandi (Fiji)	
	Sat					
24	3/15	8:15	10:15		Nandi(Fiji) ⇒ Brisbene	
	Sun					
25	3/16					
	Mon	23:45			Brisbene ⇒	
26	3/17		5:45		⇒ Singapore	
	Tue	9:35	13:10		Singapore ⇒ Manira	
		21:45			Manira ⇒	
27	3/18				⇒ Koror(Palau)	
	Wed				Palau survey (1)	Palau (1)
28	3/19				Palau survey (2)	
	Thu					Palau (2)
29	3/20				Palau survey (3)	
	Fri					Palau (3)
30	3/21					
	Sat					Palau (4)
31	3/22	19:25	22:05	3:40	Koror (Palau) ⇒ Taipei	
	Sun					Taipei
32	3/23	8:35	10:55	1:20	Taipei ⇒ Naha	
	Mon					

2. Overview of the Pacific Region

Countries in the Pacific region have the following vulnerabilities due to their geographical characteristics.

(1) Small and scattered

The domestic market is small because the population is small, and their land is spread across a vast area of sea.

(2) Far from international markets

Geographically distant from major international markets and high transportation costs

(3) Vulnerable to environmental changes such as natural disasters and climate change

Vulnerable to rise in sea level; natural disasters such as earthquakes and cyclone occur frequently

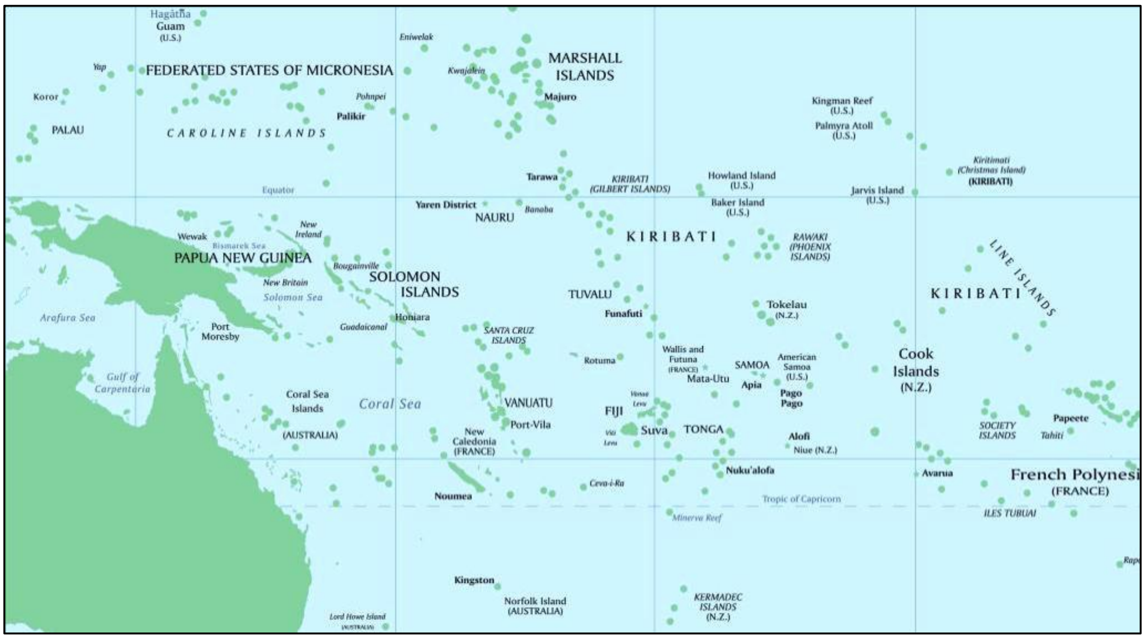


Figure 2-1 Location of Pacific Countries[1]

[1] The Pacific Power Association, Pacific Power Utilities Benchmarking Report 2012.

3. Systemization of Aid Measures for the Pacific Region Power Sector

3.1 Arrangement of an issue resolution policy for the improvement of energy self-sufficiency

3.1.1 Basic policy

With small power systems, since they are isolated and small, receiving backup power from other grids in case of emergencies is impossible. Also, regarding most equipment related to forming a microgrid[2], they must be procured from overseas. Even amid such circumstances, it is expected that the RE deployment rate will gradually or arbitrarily expanded since the need to increase energy self-sufficiency by reducing fossil fuel consumption is expected to increase.

With such a background, a simple system structure (control method) which can be easily understood by local stakeholders and sustainably operated by local engineers while at the same time securing effective power quality compensation is needed.

Based on Japan's achievements in deploying and operating solar power, wind power, hydropower, biomass power generation, energy storage devices (Pb, LiB, NaS, NH, EDLC and LiC, FWG), and various microgrid hybrid control systems in the domestic island region of Okinawa, the following three points are the basic policies for conducting this survey.

(1) Realization of a technology suitable to local conditions

Realize a sustainable "remote island microgrid system" suitable for island regions which can be practically operated and maintained while ensuring power quality.

(2) Transfer of technology developed in Japan

Aim to develop a system configuration which is highly convenient and feasible by implementing the most appropriate system study and structure design from among the various selections based on experience and technology established in the island regions of Japan and rural villages overseas.

(3) Securing independence and sustainability

Conduct a study on establishing a system where the equipment for the system configuration in this project constantly suits the regional energy supply system and can be independently advanced over its lifetime by aiming to enhance communication through gathering as much local information as possible.

[2] It is proposed by Japan Electrical Manufacturers' Association as a “versatile local power supply system,” and “by using renewable energy as a power source, it is ‘environmentally-friendly,’ and it is a ‘grid-friendly’ system as it does not impact the grid by absorbing local fluctuations with its integrated storage equipment.”

3.1.2 Concept of a remote island microgrid

(1) What is a microgrid?

The term "microgrid" was first coined in the "CERTS" project of the United States and is defined as follows. "A microgrid is a small grid with distributed power supplies and load, and multiple power supplies (and heat supplies) are collectively managed using IT technology, and it is an on-site power supply system that can be operated independently of the power company's existing grid and is normally operated with a connection at one point to the existing power grid." Therefore, from the existing power grid, a microgrid appears as one collective control unit, and is regarded as a "good citizen" as it does not cause disturbances such as voltage and frequency fluctuations to the existing power grid, and a "model citizen" as it may contribute to the operation of the existing power grid. This concept has been proposed not only by the United States, but in Europe and Japan as well. The Japan Electrical Manufacturers' Association has labeled it a "flexible regional power supply system," and proposed it as a system that is ‘environmentally friendly’ as it uses renewable energy as a power source, and ‘grid friendly’ as it absorbs the various fluctuations within the region with power and heat storage facilities.

Recently a new power system called a smart grid has been proposed, and the major difference is whether or not demand load is included for adjustability, and for a smart grid, demand load is controlled to control the grid supply-demand balance. Demand response (DR) and automated demand response (ADR), where users are requested to cooperate, or remote control are possible control methods. However, despite engaging in microgrids in various countries, a universal system concept for microgrids has yet to be established.

Therefore, in this lecture, we will only cover a microgrid which controls only the supply side.

(2)What is a remote island microgrid?

When deploying PV and WT or other renewable energy on a large-scale to a small grid, how each device and control method is constructed is critical. In addition, RE equipment utilization rate, power quality, integration and maintenance costs, etc. must all be balanced for sustainable facilities management.

When considering small power systems on remote islands, etc., since they are isolated and small, receiving backup power from other grids in abnormal times or emergencies is impossible, so they differ from the previously mentioned microgrid. For convenience, such small isolated power grids will be referred to here as "remote island microgrids."

With remote island microgrids, in addition to power flow and voltage fluctuations, frequency fluctuations also occur, so delicate management of power supply and demand balance is required. Also, since these grids are originally small, the capacity of the existing power lines are not suitable, and the use of dedicated power lines for connecting RE equipment should be given priority in meeting control performance requirements. In the case of dedicated power lines, since real-time measurements in the order of milliseconds for the power plant side with bus connections are possible, charge/discharge control from the stabilizing device (power storage device, etc.) in control periods of less than one second is possible.

Large scale power grids normally use a centralized control scheme where a single control device directly controls each generator control device. Even in small power grids in the island regions of Okinawa, we built wind hybrid systems with a centralized control scheme over 10 years ago, (deployed in Yonaguni Island, Tonaki Island, Aguni Island, Hateruma Island, Tarama Island, however excluding Yonaguni Island, they no longer exist) but if there are problems with the centralized control device and power storage devices, the WT cannot operate. On the other hand, when there were problems to the WT, and the batteries were left unattended leaving them fully discharged, many problems such as shortening battery life occurred repeatedly. The main cause is that with a centralized control scheme, when it has problems, each device is unable to operate, and since an infrastructure on the island with repair technicians, parts, tools, heavy machinery, etc. is not readily available, the failure is prolonged problems, damage tends to increase. Considering these experiences, even if an advanced control technology is realized, adequately maintaining it in island regions is often difficult.

Furthermore, with EMS (Energy Management System), an advanced centralized control device (deployed at the Miyako Island Mega Solar Demonstration Research Facility), realizing an efficient and economical base power operation plan is possible, but in addition to the function to predict demand a few days before, the function to correct previous/current day demand prediction, and economic load dispatch function, it is equipped with a weather forecasting function for RE equipment, generation prediction function, etc. for correctly formulating and executing operation plans for each generating device, and its deployment cost tends to be much more expensive (billions of yen). However, on small remote island grids where power demand can fluctuate drastically depending on rapid weather changes, which typical of tropical regions, and special events on the island, since it is very likely that the accuracy of the prediction function will worsen, trusting the operational plans of a power plant operator with years of experience for base power operation is considered the most practical approach with the current technology.

(3) Cooperative autonomous distributed control

Amidst such a background, autonomous distributed control based on a distributed control scheme, or "cooperative autonomous distributed control" so to speak is the recommended control method for remote island microgrids.

(In Okinawa Prefecture, it has been deployed as PV remote island microgrid on Tarama Island,

Kita-Daito Island, and Yonaguni Island)
(Retractable WT on Hateruma Island (245 kW × 2 units) and the same for the flywheel grid stabilizing device)

How the "cooperative autonomous distributed control" is incorporated will depend on whether the RE deployment scale is small, medium, or large, and whether or not batteries will be deployed for fluctuation measures.
Assuming a grid with a load trend as shown in the figure below, an overview of the "cooperative autonomous distributed control" is sorted out for each case.

Moreover, it should be noted that it is assumed that the main power supplies, such as diesel generators, always perform cooperative control such as governor free (GF)[4].

① For small-scale RE deployment
(Total RE capacity kW of roughly under 20% of grid capacity kW)
Total RE capacity kW is small relative to grid capacity kW (it depends on the responsiveness of the grid, but roughly under 20%), and we assume a deployment amount to the extent that there is no possibility of causing frequency fluctuations. For extremely large deployments, the output lower limit value of main power supplies, such as diesel generators, may be infringed. In this case, it is thought the adjusting capability of GF, etc. of main power supplies, such as diesel generators, can sufficiently absorb RE output fluctuations, so the deployment of batteries for fluctuation measures is not considered.

[4] Governor Free: One of the adjusting functions of a power generator. With Governor Free, the generator tries to maintain a constant RPM (frequency) to mitigate frequency fluctuations.

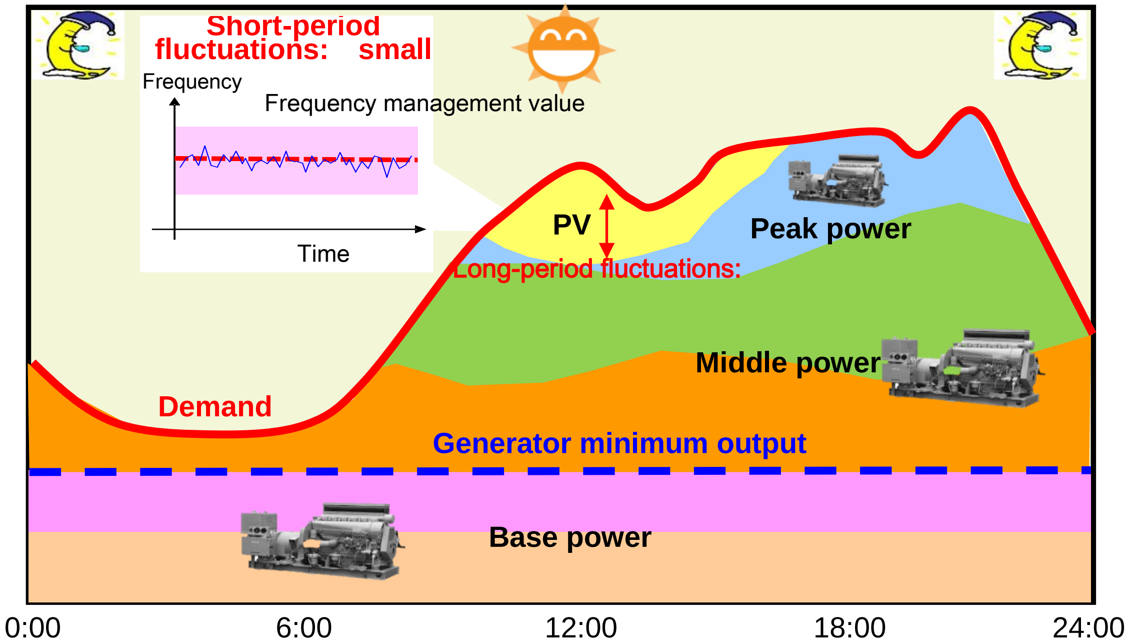


Figure 3-1 Power supply-demand balance (small-scale PV deployment)

<When batteries for fluctuation measures are not deployed>

Operation and control is performed to maximize the utilization rate of RE such as PV, WT, and hydroelectric power.

By performing autonomous distributed control such as output restriction control and quantity control in abnormal times such as when one of the devices is not working due to breakdown, even if the said failure is prolonged, each device can be operated and used independently.

When failure is prolonged, each device is suspended which invites condensation and in turn may give rise to new failures, so the ability to operate partially is important. Therefore, schemes such as equipping output restriction function to the extent that space, cost, etc. allows and making the system small and decentralized are needed.

Moreover, a scheme for an on-site control device which allows independent operation even if the remote control device or communication circuits from the power plant, etc. fails.

When deploying each RE, purchasing equipment equipped with such schemes should be considered.

In addition, RE deployment amount is only a standard, and depending on the responsiveness of main power supplies, such as diesel generators, measures such as batteries for suppressing short period RE fluctuations, which affects frequency fluctuation, may be required.

② For medium-scale RE deployment

(Total RE capacity kW of roughly over 20% and under 50% of grid capacity kW)

Total RE capacity kW is medium relative to grid capacity kW (it depends on the responsiveness of the grid, but roughly over 20% and under 50%), and we assume a deployment amount to the extent that there is a possibility of causing frequency fluctuations.

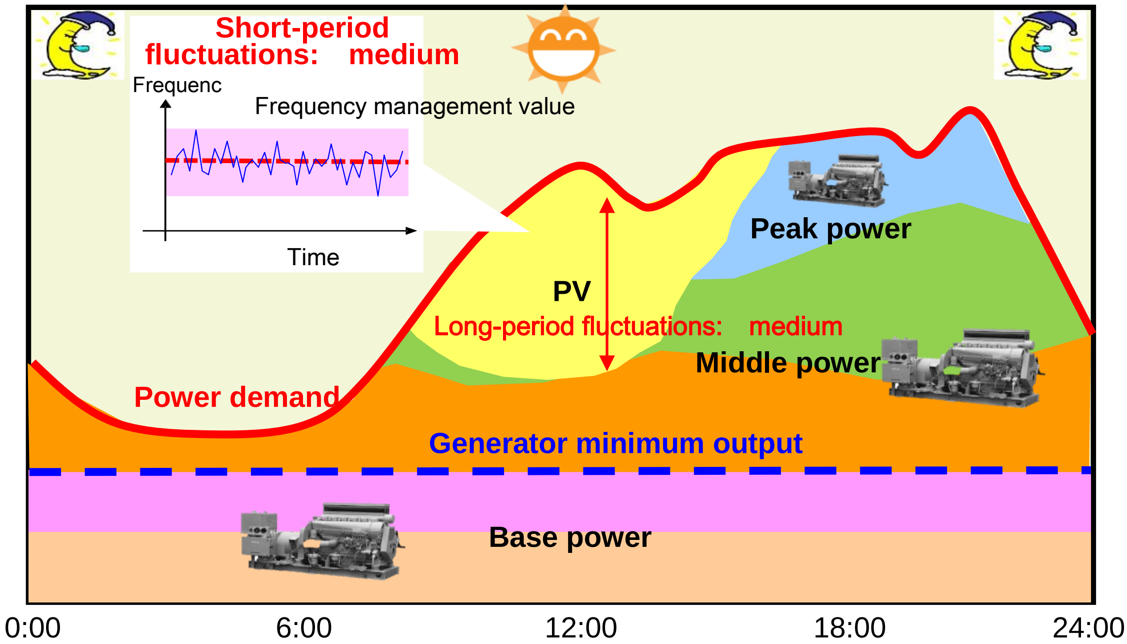


Figure 3-2 Power supply-demand balance (medium-scale PV deployment)

<When batteries for short period fluctuation measures are deployed>

Operation and control is performed to maximize the utilization rate of RE such as PV, WT, and hydroelectric power.

However, since RE fluctuation range grows according to deployment amount, main power supplies, such as diesel generators, are unable to keep up, which causes a short-period imbalance in supply and demand, and in turn may affect frequency fluctuations. Therefore, either a relatively high output battery must be deployed to directly suppress frequency (ΔF control), or short period RE output fluctuations must be suppressed (ΔP control).

Same as item ①for abnormal times such as during failures.

<When batteries for fluctuation measures are not deployed>

Batteries are convenient for adjusting as they are capable of responding to sharp charge/discharge commands, but they may not be deployed since they are expensive devices.

In such cases, the fluctuation range must be suppressed to the extent that main power supplies such as diesel generators are capable of keeping up. This is done by establishing output restrictions especially for PV and WT, which are derived from natural energy, to prevent high output. It will be explained again later, but the incidence of low output for PV and WT, which are derived from natural energy, is high, but the incidence of high output is low. Therefore, we believe that even with fixed settings for output restrictions throughout the year, there will not be a major impact to the annual power generation.

Same as item ①for abnormal times such as during failures.

③ For large-scale RE deployment

(Total RE capacity kW of roughly 50% or more of grid capacity kW)

For extremely large total RE deployments relative to grid capacity kW (depends on the responsiveness of the grid and operating range of the main power supplies, but roughly 50% or more), the output lower limit value of main power supplies, such as diesel generators, may be infringed. In this case, by suspending the main power supplies by unit, each unit's output is recovered, and infringing the output lower limit value of main power supplies can be avoided, but if total RE output drops in the next instance, the main power supply may not be able to restart in time and cause a blackout.

Therefore, surplus power from RE which infringes on the output lower limit of the main power supply must be eliminated.

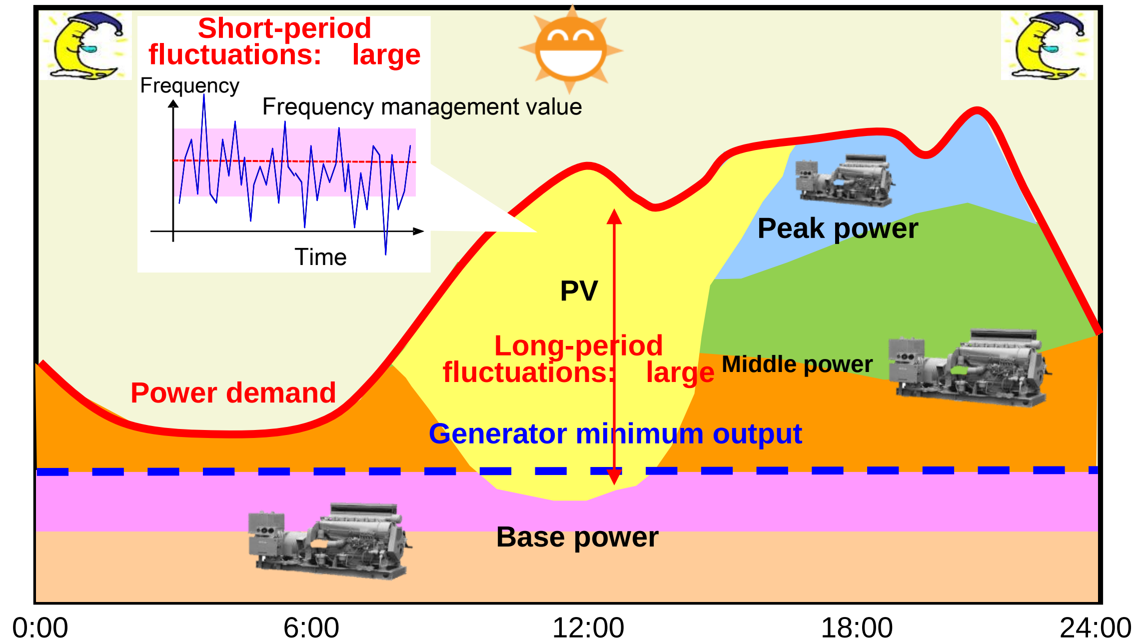


Figure 3-3 Power supply-demand balance (large-scale PV deployment)

<When batteries for long period fluctuation measures are deployed>

This is a method for adjusting supply/demand balance by charging relatively large capacity batteries for long-period fluctuation measures with the surplus power from RE, which infringes on the output lower limit of the main power supply. When deploying such batteries for long-period fluctuation measures, it is desirable to incorporate functions for short-period fluctuation measures and simultaneously execute them.

In this case, operation and control is performed to maximize the utilization rate of RE such as PV, WT, and hydroelectric power.

Same as item ①for abnormal times such as during failures.

<When batteries for short period fluctuation measures are deployed>

This is a method for adjusting long-period supply/demand balance by suppressing output to match the surplus power from RE, which infringes on the output lower limit of the main power supply.

In this case, since operation and control is performed to maximize the utilization rate of RE such as PV, WT, and hydroelectric power, RE fluctuation range becomes large, and main power supplies, such as diesel generators, are unable to keep up, which causes a short-period imbalance in supply and demand, and in turn may affect frequency fluctuations. Therefore, either a relatively high output battery must be deployed to directly suppress frequency (ΔF control), or short period RE output fluctuation must be suppressed (ΔP control).

Same as item ①for abnormal times such as during failures.

<When batteries for fluctuation measures are not deployed>

As with medium scale, this is done by establishing output restrictions especially for PV and WT, which are derived from natural energy, to the extent that main power supplies such as diesel generators are capable of keeping up to prevent high output. Although the utilization rate of single units of RE such as PV and WT will decline, but annual power generation can be secured to some extent at low output even with a simple system configuration.

Although close investigation and simulation are necessary, generally if PV penetration rate is high, it is often more beneficial in terms of cost to not install batteries for fluctuation measures.

Same as item ①for abnormal times such as during failures.

(4) Securing further adjustability

①Responsiveness of main power supplies such as diesel generators

Responsiveness of diesel generators, etc. is often determined by engine characteristics, but in some cases it is determined by slow governor settings. Therefore, it is essential to establish the best settings possible for responsiveness by consulting the engine manufacturer, etc. In addition, in this case, it is essential to connect all units to the grid at the same time. If only one unit is optimized for responsiveness, only this unit will absorb fluctuations, and in some cases, it may cause reverse power (motoring).

For a mechanical governor, responsiveness may be improved by replacing it with an electronic governor.

In addition, if additional installation or replacement of diesel generators is required, higher responsiveness can be secured by selecting engine models with high rpm and equipped with electronic governors.

Securing high responsiveness is effective as a measure for short-period RE fluctuations.

②Operating range of main power supplies such as diesel generators

Since the operating range of diesel generators may be limited if they are poorly maintained, it is essential to always keep them in good condition to secure an output range of 100%-50%.

Diesel engines for power generation are typically equipped with a supercharger, and at a low output range, intake and exhaust pressure are reversed, scavenging is not performed, and combustion gas is left in the cylinder, which would likely cause incomplete combustion. Therefore, if continuously operated at low power, soot will accumulate within the cylinder and may damage sliding parts.

However, depending on the characteristics of the unit, there are models capable of sufficiently responding even if output is reduced to around 30%, so it is essential to verify unit characteristics and usable output range in advance.

If a wide output range can be secured, it would be effective as a measure for long-period RE fluctuations.

③Variable speed control for hydroelectric power or quantity control

Hydroelectric power is one form of RE, but it is also a controllable and stable power supply. It is often used as a base power, but by installing multiple small units, quantity control is possible, and it can be used as a measure for long-period RE fluctuations.

Moreover, the latest models are equipped with a variable speed control function, and they are also capable of GF control, etc. By using such models, high responsiveness is secured, and it can be used as a measure for short-period RE fluctuations.

④Use of self-sufficient biodiesel, etc.

Others include the use of biodiesels such as coconut oil which can be produced and supplied on the island or within your country. It is a RE, and it can contribute to improving energy self-sufficiency. Problems do not arise for short-term use in diesel engines, but for long-term use, appropriate refining is required to prevent bad combustion and metal corrosion, and high importance needs to be placed on the refining cost.

(5) Schematic diagram of cooperative autonomous distributed control

Normal times of , The concept of cooperative control (remote island microgrid) of each target control device for small grids during normal, abnormal, emergency, and other times is as shown in the figure below.

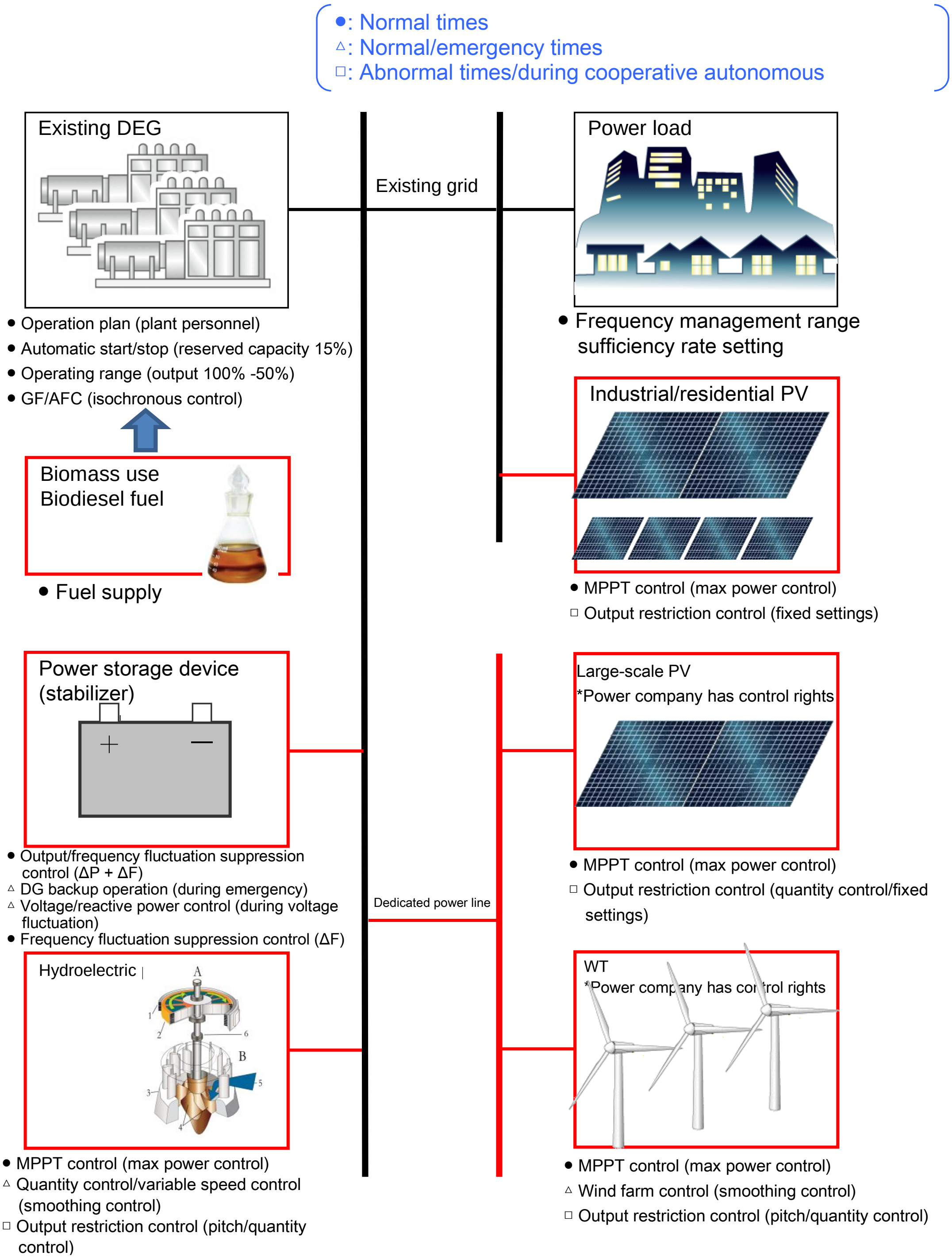


Figure 3-4 Conceptual diagram of a remote island microgrid (Cooperative autonomous distributed control scheme)[5]

[5] MPPT control: Maximum Power Point Tracking control. Control to maximize power generation by performing tracking control at the optimum operating point of power supplies such as PV which fluctuate due to weather conditions, etc.

3.1.3 Method for restricting RE output

①Basic approach

Among RE, the power output of PV and WT especially varies according to natural energy conditions. Therefore, the incidence of high output is low, and the incidence of low output is high. Output restriction is to prevent output higher than the fixed settings value, and low output up to this value occurs according to conditions without any restrictions. Therefore, we believe that even with fixed settings for output restrictions throughout the year, there will not be a major impact to the annual power generation.

By preventing high output through output restriction, the output fluctuation range becomes smaller and serves as a short-period fluctuation measure. In addition, the elimination of surplus power from RE which infringes on the output lower limit of the main power supply serves as a long-period fluctuation measure.

②PV output restriction

The diagram below is an example of solar radiation measurements in Okinawa. Solar radiation intensity equivalent to 50% of PV output is 0.625 kWh/m2 assuming the general system efficiency of 80%.

For example, if PV output is restricted to 50% throughout the year, annual power generation would be reduced by approximately 9.1%. Since the incidence of high output is low, you can see that there is not a major impact on annual power generation. Generation reduction rate for island regions through output restriction is also indicated in the following sections as cumulative frequency, and it is less than 17% at most. Output restriction methods are as follows.

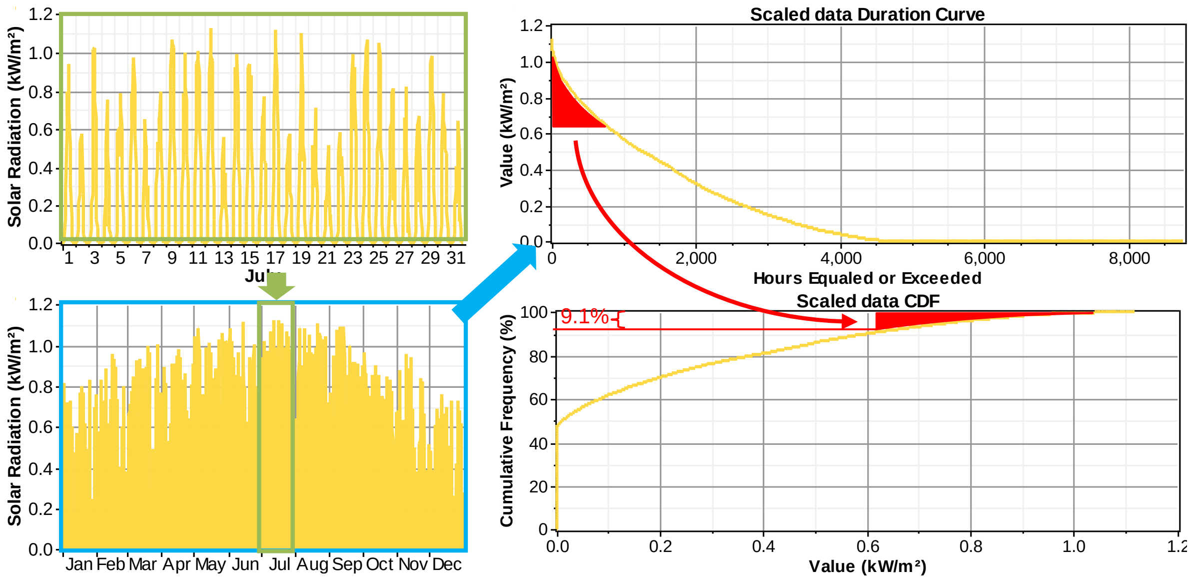


Figure 3-5 Solar radiation and cumulative frequency in Okinawa

Suppress output with the MPPT control function of the PCS

A method capable of real-time remote control of PCSs with communications capability is valid for the facilities of the power company or for facilities which the power company has control rights over. In Japan, preparations for application on private-sector deployed PV systems of 500 kW or more are underway. This can be done by scheduled operation instead of real-time operation. In Japan, preparations for application on PV systems of 10 kW or more are underway.

Connecting PCSs to PV panels at half the size

For example, output restriction can be fixed at 50% by connecting a 500 kW PCS to a 1,000 kW DC[6] PV panel. However, DC current only incurs the constraint of PCS maximum input current, but since DC voltage could damage the PCS, sufficient string design is required. In addition, when increasing PCS output in the future, adopting the DC common scheme in advance is recommended.

③WT output restriction

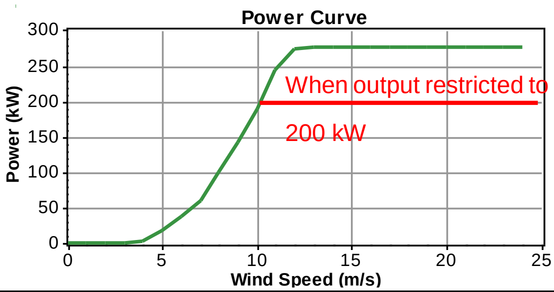
WT output restriction is conducted through pitch control which changes the blade angle according to wind speed. If there is wind speed to the extent rated output is produced, using pitch control to reduce output can cause excessive stress to the blades and other WT parts, so the minimum restricted output for each WT has been established.

For example, when restricting WT output throughout the year, considering future loads on the WT, it is recommended to stop at approximately 30% of the rated output. The table below shows a WT of approximately 300 kW, and in this case, an output restriction to 200 kW is recommended. Therefore, the WT deployment size is basically 1.5 times this.

When conducting a 200 kW output restriction, the wind speed for both is 10 m/s.

[6] DC：Abbreviation for Direct Current.

[Retractable WT MP 275]
- Rated output 275 kW
- Minimum restriction output 100 kW
- Rotor diameter 32 m
- Rated wind speed 12 m/s
- Cut-in wind speed 3.6 m/s
- Cut-out wind speed 20 m/s
- Wind resistance 70 m/s
- Power curve is as shown below



[Fixed WT KWT300]
- Rated output 300 kW
- Minimum restriction output 90 kW
- Rotor diameter 33 m
- Rated wind speed 11.5 m/s
- Cut-in wind speed 3.0 m/s
- Cut-out wind speed 25 m/s
- Wind resistance 70 m/s
- Power curve is as shown below

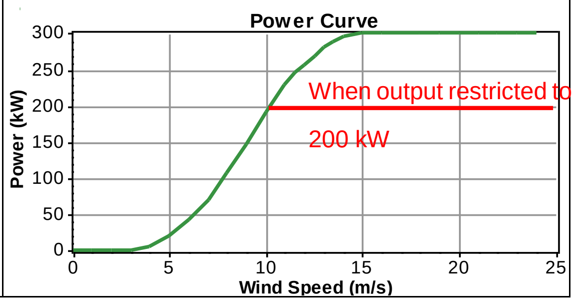


Figure 3-6 WT example[7]

When conducting a 200 kW output restriction using the retractable WT MP 275, the incidence of wind speeds of 10 m/s or higher is about 2.2%, which when converted results in approximately a 3.3% decrease in annual power generation. Since the incidence of high output is low, you can see that there is not a major impact on annual power generation.

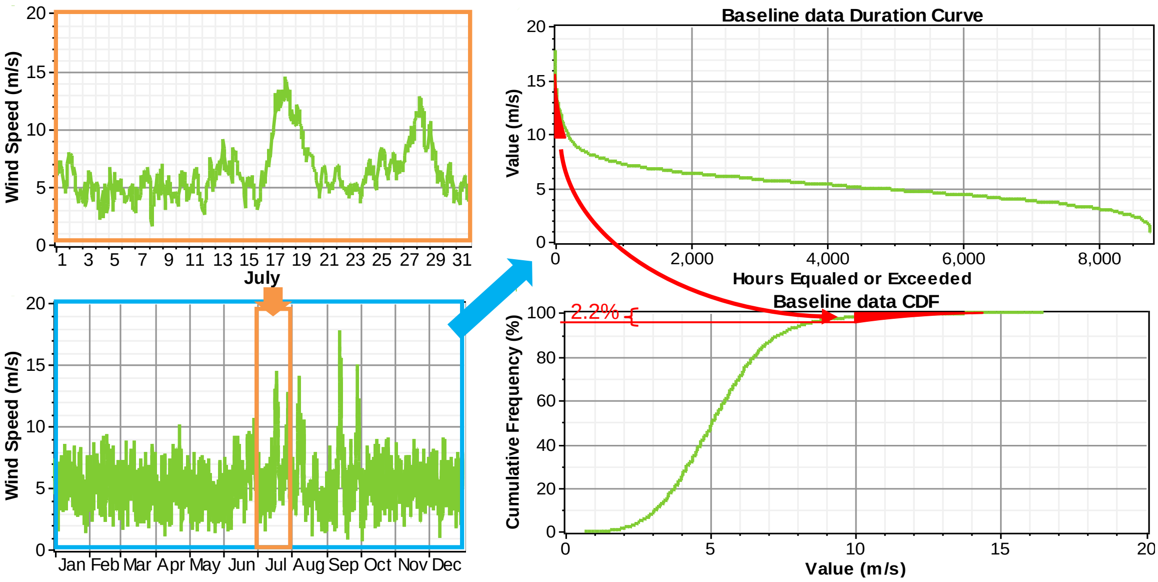


Figure 3-7 Wind speed and cumulative frequency in Hateruma Island, Okinawa

Output restriction through pitch control

[7] Cut-in wind speed: Wind speed at which wind turbines start generating power. Cut-out wind speed: Wind speed at which wind turbines stop generating power to ensure their safety during high winds.

The output restriction method is basically pitch control, but wind farm control is used for fixed settings, remote real-time control, and multiple unit settings.

3.1.4 The merits and demerits of RE deployment

Since many REs utilize natural energy, the greatest benefit is that there are very little costs for the energy integrated, and if the equipment is operated efficiently over its lifetime, power costs can be reduced. However, since there is a large risk of failure, and it may in some cases affect power costs, care should be heeded.

RE devices are often exposed to harsh natural environments, and storms such as cyclones, and sufficient measures against lightning, salt corrosion, etc. must be taken. Also, aside from regular maintenance, management of failures must also be considered, however in many cases, it is difficult to establish a system to immediately respond for restoration.

As mentioned above, for small power systems on remote islands, etc., since they are isolated and small, receiving backup power from other grids in abnormal times or emergencies is impossible, so RE devices used on remote island microgrids are effectively made small and decentralized. Therefore, even if one part fails, the other parts can continue to operate.

In addition, it is desirable to preserve as much of the existing main power supply such as diesel generators as possible, considering backup for RE equipment suspensions due to failure or exceeding their service life.

When deploying RE, the cost of such measures should be taken into account.

3.1.5 Summary of the remote island microgrid deployment method

Technical criteria for RE equipment which should take priority are sorted out as follows.

①PV

For solar panels, if it is expected that land can be adequately secured, priority should be given to amorphous (multijunction thin film) panels, which have little drop in efficiency due to a rise in panel temperature, or compound-based panels. However, if there are land constraints, polycrystalline silicon panels, which are relatively priced more competitively, will be given priority.

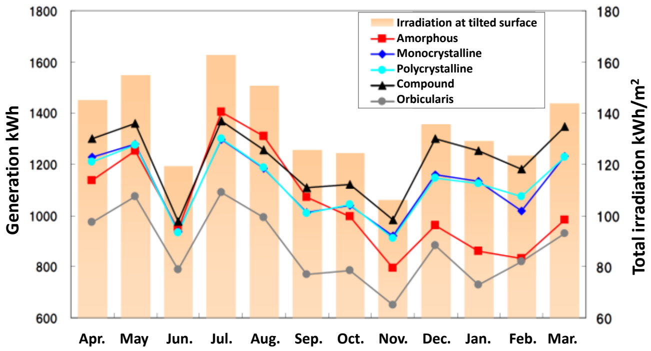


Figure 3-8 Aggregate monthly generation of various solar cells and solar radiation

(Source: NTT Facilities, Inc. "Demonstration Research at the NEDO Mega Solar Project Kitamura Site" 2010/11/9)

In addition, if it is expected that land can be adequately secured, the optimum tilt angle array for the site shall be given priority. However, if there are land constraints, 5°, the lowest tilt angle at which a natural cleaning effect can be secured, shall be considered as the minimum tilt angle. For large-scale PV facilities, using 5° over the optimum tilt angle will reduce annual power generation by a few percent (approx. 2%), but an economic effect of reducing the installation area and array mounting strength by approximately 20% each can be expected.

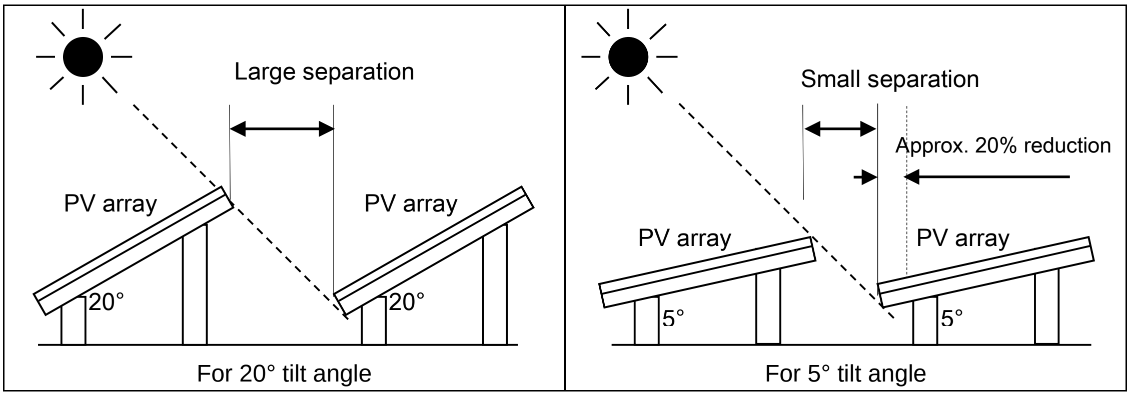


Figure 3-9 Area efficiency comparison of 20°and 5°tilt angles

For the PV array foundation, if a large volume of cement or concrete can be procured locally and from nearby island countries, a concrete slab foundation will be considered. Furthermore, in this case, priority will be given to unnecessary structure of ground excavation.

If procurement of cement or concrete is difficult in terms of amount or price, a spiral steel pipe pile can be brought from Japan and used as a foundation. With a spiral steel pipe pile, since highly precise land formation is not required, a comprehensive study including conditions and constraints is required.

Figure 3-10 Concrete slab foundation
(Miyako Island Mega Solar Experimental Study Facility PV foundation)

Figure 3-11 Spiral steel pipe pile
(Abe Mega Solar Demonstration Research Facility PV foundation)

For the PV array frames built on top of the foundation, maintenance shall be easy with its structural design, and they shall have a simple structure. To prevent salt corrosion, if galvanizing is available on-site, materials that have been corrosion-resistance treated equivalent to HDZ55 (highest grade galvanizing) shall be used to build the frame. If it is difficult to procure high corrosion-resistance treated products, products procured in Japan shall be used. In this case, using high corrosion resistance hot dip plated steel sheets (SuperDyma, ZAM, etc.), which have been adopted in the island regions of Japan and are half the weight of general steel, or FRP materials will be considered. Since rusting is prominent at joints and bolted parts, using an efficient cap-type caulking method will be considered. In any case, the materials and construction shall meet local construction standards (70 m/s wind resistance, etc.).

Figure 3-12 Super-Dyma PV frame

Figure 3-13 FRP PV frame (Cosmo System website)

Since the lifespan of the electrolytic capacitors inside the power conditioner (PV-PCS) is shorter than those of solar panels and will very likely have to be replaced before reaching the service life of the entire facility, the adoption of a 10 kW parallel scheme, which has less impact on control performance and on the entire facility even if equipment fails, shall take precedence.

For PV-PCS, the lowest unit at which 3-phase AC power can be obtained is 10 kW, and there are cases in which it is much cheaper than a single unit device of several hundred kW.

Concerning control performance, if a single unit device of several hundred kW is used, precise output control performance to the second through external signals is possible, but since the impact due to failure of one unit (utilization rate drop and recovery costs), maintenance is difficult for island regions. On the other hand, with a 10 kW device, output control through external signals is not capable of standard functions, but rather only start and stop functions. Output control alteration specifications are possible with Japanese technology, but since they are not universal, quantity control will basically be used for output control. For example, for a 1,000 kW PV facility, 100 units of 10 kW PV-PCS are installed in parallel, and if there is an external output limit command, the number of PCS commensurate with it are started/stopped to obey the output control. In addition, since it is often difficult for the already equipped islanding detection function (function to normally stop PCS during power outages) to perform for over 10 units installed in parallel (Due to communication link limits. There are some products in Japan that can handle up to several hundred units), a separate islanding detection device should be installed to operate collectively during emergencies. Furthermore, the said islanding detection device shall be equipped with an FRT function (unwanted operation protection due to instantaneous voltage fluctuation) if necessary.

Since by doing so, it can prevent the 10 kW-PV-PCS device from being subjected to special specification constraints, models not limited to Japanese products can be freely chosen when the device is deployed or replaced which also makes it economically effective.

②WT

Japanese WT are generally divided into models of either under 10 kW capacity per unit and 100 kW or more capacity per unit. Currently, there is basically no WT lineup with a capacity of 10 kW to 100 kW per unit. Models of less than 10 kW are mainly residential, and control and safety are often inadequate. On the other hand, models of 100 kW or more are equipped with control features similar to those of megawatt models and adequate wind resistance. WTs have become larger overall, and most Japanese WT manufacturers (Company M, F, J, etc.) have transitioned to MW class WT. Therefore, models with a capacity of 10 kW to 100 kW per unit are generally not produced.

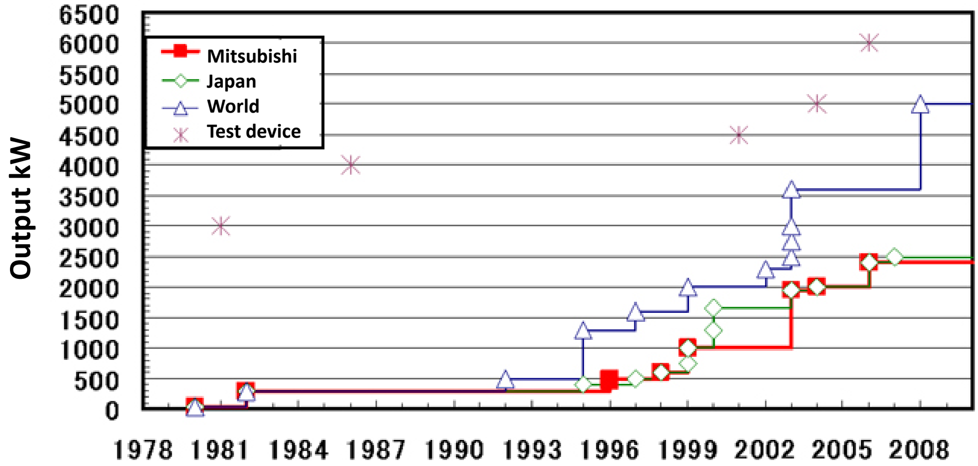


Figure 3-14 WT unit capacity trend (Mitsubishi Electric website)

When constructing a WT facility, large cranes are required to install the tower, nacelle, and blades. However, there are cases when large cranes are not available on island in island regions. Therefore, costs may increase during construction and repair. Therefore, in general it is desirable to deploy WT of a few 100 kW rather than WT of a few MW for a WT facility.

If a WT of several MW will be deployed, in addition to securing a large crane supplier, it is desirable to select a model capable of limiting output and output increase rate change control through pitch control.

A retractable WT is one model that does not require a large crane during construction or repair. There are also many deployments in the island regions of Japan. Its greatest feature is that the tower can be tilted from the base which allows construction and maintenance to be carried out on the ground. In the event of a cyclone invasion, it is possible to protect the WT from the storm by lowering it and fixing it to the ground.

Since the tower has a truss structure, if the blades are removed, the whole WT can be transported with a 20 ft container, and construction is relatively easy even in locations with poor geographical conditions.

The generator is an induction generator, and it has a two stages (low-speed mode and 46 min^{-1}) for blade revolution speed.

There are fixed WT of a few 100 kW that are manufactured and sold: a 300 kW WT by Company K and a 100 kW WT by Company T. The WT of both companies are equipped with synchronous generators, their allowable blade rotation speed range is wide, they are capable of frequency and voltage control through DC link (a power supply control technology which converts AC power from AC generators to DC power, and then coverts it back to AC power again) and output restriction and output change rate control through pitch control. In any case, the materials and construction shall meet local construction standards (70 m/s wind resistance, etc.).

		
・Rated output 275 kW ・Rotor diameter 32 m ・Rated wind speed 12 m/s ・Cut-in wind speed 3.6 m/s ・Cut-out wind speed 25 m/s ・Wind resistance 70 m/s	・Rated output 300 kW ・Rotor diameter 33 m ・Rated wind speed 11.5 m/s ・Cut-in wind speed 3.0 m/s ・Cut-out wind speed 25 m/s ・Wind resistance 70 m/s	・Rated output 100 kW ・Rotor diameter 21 m ・Rated wind speed 13 m/s ・Cut-in wind speed 3.0 m/s ・Cut-out wind speed 20 m/s ・Wind resistance 80 m/s

Figure 3-15 Mid-size WT made in Japan

However, it is essentially different from a maintenance-free PV system. WTs require daily and regular maintenance, so sufficient arrangements with the WT manufacturers for technical support and supply of parts must be made to consider whether their local deployment is possible. In addition, including the availability and development of local engineers, a comprehensive review is required to determine whether proper maintenance for the deployment of a WT facility is possible, so there are greater challenges for the deployment of WTs.

On the other hand, for annual power generation, a major factor for economic feasibility, close investigation of existing data on wind conditions is required.

③Hydroelectric power

It is also preferable to make hydroelectric power as small and decentralized as possible. For a duct line system, it is preferable to install multiple units using bypass ducts.

By making the system small and decentralized, quantity control is possible, configurations where long-period fluctuations can be suppressed in combination with PV, WT, and other RE, or configurations where scheduled operation (output reduction during the day in accordance to PV output) is possible is preferable.

In addition, variable speed hydroelectric power, which is Japanese technology, could be used as an alternative for batteries to suppress short-period fluctuations.

④Biomass

Biomass has the following 3 major uses, gaseous fuel, liquid fuel, and solid fuel.

For liquid fuel, vegetable oils such as coconut oil is used to refine biodiesel, and it may be used fuel for diesel generators. For solid fuels, waste wood such as tree thinnings, etc. is used to fire a boiler steam turbine for power generation or in a gasification furnace for power generation. For gaseous fuel, methane gas is extracted through methane fermentation, etc. for power generation. However, for methane fermentation power, the methane fermentation tank tends to be large, and maintenance is often difficult.

Since small-scale is required in small island regions, here, we will only examine biodiesel fuel as a method to use biomass.

⑤Power storage device

The power storage device shall be used to maximize RE utilization rate while combining ΔP control (suppression control corresponding to RE output fluctuations from dedicated power lines during normal times) and ΔF control (output fluctuation suppression control corresponding to grid frequency deviations) to efficiently maintain power quality. When doing so, in order to ensure fluctuation compensation capacity is never exhausted, the ability to perform SOC management at all times is required, and further, a function to ease compensation according to the amount of power stored is desirable.

In addition, since PV and WT (equipped with synchronous generators) generate AC power through power conditioners (PCS), instantaneous voltage fluctuations are rare. However, to avoid unnecessary behavior of PCS, etc. due to equipment start/stop, instantaneous voltage fluctuations caused by grid load factors, etc., the power storage device shall be equipped with voltage control (ΔV control) or reactive power control (ΔQ control).

It is desirable for frequency fluctuation suppression control (ΔF control) to not only handle RE, but also to have it prevent the frequency of the entire grid from deviating from the management range. In addition, since this function is required to rapidly detect → notify → calculate → command → operate, it is basically automatic terminal control (control where signals are acquired in the vicinity of the device), and charge/discharge compensation while connected to the power plant bus is desirable. Moreover, it is desirable for frequency fluctuation suppression control (ΔF) to be capable of autonomous distributed control independent of other devices.

For the power storage device, if RE is eventually deployed on a large scale, it cannot be covered by the current spinning reserve (load tracking capability of operating diesel generators), so the the next DEG unit would not be able to start which means all DEG units in operation would be overloaded and operated above rated output. This may result in a blackout (power outage) due to tripping, or in some cases, DEG engine damage. To avoid this, the output of the power storage device should be equivalent to the capacity of one existing DEG unit at minimum. In addition, the storage capacity in this case should be sufficient to cover the DG preparation time (from start command until synchronized parallel in).

Considering various conditions, the type of power storage device and its capacity will eventually require consideration.

When using variable power sources such as PV and WT to increase RE supply rate, it depends on the conditions of an existing power grid, but in general, with a supply rate of 30% or more, the capacity and type that is capable of long-period fluctuation suppression mainly for the charge/discharge of surplus power is required.

However, if the supply rate is less than 30%, or even 30% or more, if the output lowering margin were successfully increased by replacing the hydroelectric power mentioned above or the DEG mentioned later, using only short-period fluctuation suppression would suffice. However, even in this case, a capacity and type which would be beneficial must be chosen. For example, a flywheel power storage device differs from common batteries as it can store power as rotational energy of the machine, and have advantages such as easy maintenance and disposal.

In addition, when RE deployment plans are uncertain, in general, hybrid power storage devices which divide short-period and long-period fluctuation suppression is preferable.

⑥DEG replacement

For additional installation of diesel generators (DEG) or replacing old DEGs with new ones, in order to respond to the variability of PV, WT, etc., responsiveness is easier to obtain if a high-speed (approx. 1500-1800 min^{-1} rated rpm) diesel engine is chosen. Further, in this case, the proper generation efficiency can be maintained by equipping with an electronic governor.

Or if RE systems such as PV and WT generate power according to weather conditions, aiming to maximize the utilization rate of these generating devices is economically desirable, but in this case, it may infringe on the output lower limit (generally about 35% output) of the DEG, the main power supply. In such case, replacement with DEGs capable of low output operation (10-20% output) is recommended.

⑦Condition of existing DEGs

In order to ensure the proper output range and fuel consumption rate of existing DEGs can be maintained or restored, maintenance and appropriate replacement of expendable parts shall be implemented. Or the replacement of deteriorated parts is recommended.

3.1.6 Rough construction cost of a remote island microgrid configuration device

The rough construction costs and maintenance costs as a guide for the various remote island microgrid configuration devices mentioned in the preceding sections will be summarized through this survey.

3.2 Arrangement of study steps for improving energy self-sufficiency

The study shall be conducted centering on the aid measures study step shown in Figure 3-11 based on the arranged items above. In STEP 1, the possibility of applying EDC operation[8] and improving maintenance with the purpose of reducing fuel consumption by improving the operation of the existing DEGs. In STEP 2, preparation of the groundwork for RE integration will be examined by aiming to expand down reserve and improve output responsiveness through the replacement or additional installation of DEGs, which is the main power supply. In STEP 3, the effect of RE deployment for the power grid improved in the previous step will be examined. When doing so, the RE integration capacity at that time must be taken into consideration. In STEP 4, of the RE output fluctuations, regarding the short-period fluctuations component, which occurs at an early stage, in addition to output compensation by DEGs, the effect of deploying batteries for short-period fluctuation compensation for the purpose of expanding RE deployment and other effects will be examined. In STEP 5, assuming a stage of high RE deployment rate, the effect of deploying high-capacity batteries as a measure for surplus power in expanding RE deployment will be considered.

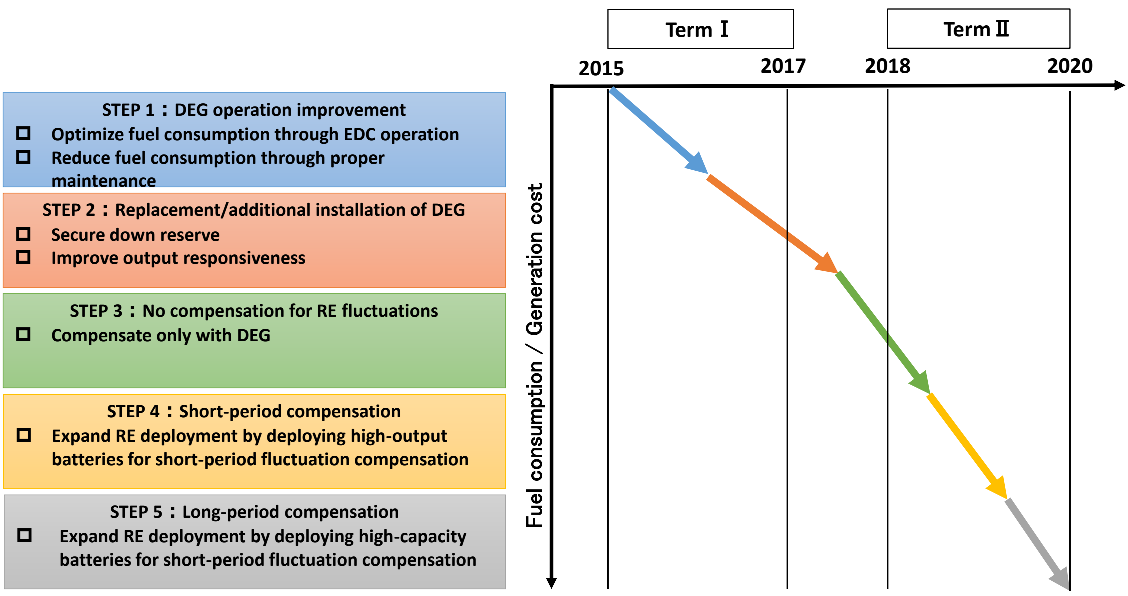


Figure 3-16 Aid measures study step[9]

---

8 The economic dispatch of the output of each generator with different efficiencies is calculated according to changes in power demand, and the generator output is controlled to maximize the efficiency of the entire power plant.

9 **If the target countries bear the initial costs and replacement costs on their own, these costs would be added to the cost of deploying renewable energy, so it may become higher than the present cost.**

3.3 Arrangement of methods of application to each target country

Regarding methods for applying the aid measures study steps to each country described in section 4, the necessity and possibility of each item shall be examined by comparing them to the criteria listed below.

STEP 1: DEG operation improvement

① EDC operation applicability

- ☐ At least three units are in operation at all times.
- ☐ Load sharing is not conducted through isochronous operation[10] or load sharing functions[11].
- ☐ EDC operation is not implemented.

② Improving maintenance

1) Education on structure and implementation method

- ☐ De-rated factor is at 80% or less.
- ☐ Fuel consumption rate is higher than the standard DEG stat of 0.25 L/kWh.
- ☐ Decision based on interview results.

2) Supply spare parts

- ☐ DEGs made in Japan are installed.

STEP 2: Replacement or additional installation of the main power supply

① DEG

1) Replacement

- ☐ More than 15 years has passed since installation.
- ☐ Has major operational issues.

2) Additional installation

- ☐ Reserved capacity (proportion of the maximum load in relation to the combined rated capacity all DEGs) of 80% or more.
- ☐ Number of DEG units (proportion of the total number of units in operation in relation to the total number of all units) is 50% or more.

---

[10] Governor control methods for generators. Droop control aims to lower the generator's target rpm as the engine load increases. Isochronous control aims to keep the generator's target rpm constant regardless of the engine load. The generator's rpm is synchronized with grid frequency. Since generally with isochronous control, the output of paralleled generators is often operated at a unique value, and the target group of generators to be controlled all have the same specifications, it is difficult to implement EDC operation, and it can be conceived that its impact would be small.

[11] Load-sharing function. With isochronous control, a control function is needed to distribute the output of each generator according to grid load. Since this control is automatic, using the manually controlled EDC operation in combination may cause hunting due to the timing of the of the two control signals.

STEP 3 - STEP 5

- ☐ The optimal RE deployment for each section will be examined by estimating the RE integration capacity. In doing so, the study will be conducted with the condition that power costs for each section do not exceed the current power costs.
- ☐ In addition, in the study, the following four items were examined by adding and subdividing the form of expense of the target countries to analyze the impact on power cost in those countries.

  A: Operation maintenance expenses are covered (initial costs, replacement costs not considered)

  Basically deployed with Japanese aid. Replacement costs are not considered.

  B: Initial costs, replacement costs and operation maintenance costs (price of Japanese products)

  If the target countries pay for the Japanese products at their own expense.

  C: Replacement cost and operating expenses (price of Japanese products) (initial costs not considered)

  If deployed with Japanese aid, but the target countries buy Japanese products for replacement at their own expense.

  D: Initial costs, replacement costs and operation maintenance costs (price of foreign products)

  If the target countries pay for the foreign products at their own expense.

4. Finalization of the aid measures road map for each target country

In this chapter, the energy security improvement aid measures road map for each target country is finalized. The current status and the effects of implementing aid measures for each target country are compared in Table 6-1. Considering the RE deployment rates in the table as energy self-sufficiency, Fiji and Santo, given their high water abundance, could achieve nearly 100%. In other regions, we estimated that an average of 35.7% energy self-sufficiency centering mostly on PV deployment could be secured. On the other hand power generation costs could be reduce by 3 US cents on average. However, it should be noted that it is assumed DEG improvement, installation of additional units, and the initial investments for the deployment of RE equipment will be conducted by donor aid, so they are not reflected in the power generation costs. Estimated expenses pertaining to aid are listed in the far right column of the table.

Table 4-1 Comparison of the current status and the effects of implementing aid measures for each target country

Country	Target region	RE deployment rate		Generation cost (USc/kWh)	
		Current status	At STEP 5	Current status	At STEP 5
Fiji	Viti Levu	50.9%	98.7%※	13.6	11.2※
Marshall Islands	Majuro	0.0%	24.0%	29.6	25.7
Micronesia	Pompeii	3.9%	26.9%	25.7	23.2
	Chuuk	5.5%	42.2%	26.6	23.8
	Yap	0.0%	30.8%	36.6	31.0
	Kosrae	0.0%	22.1%	28.9	26.3
Tonga	Tongatapu	6.8%	25.4%	32.2	30.2
Vanuatu	Port Vila	9.3%	24.6%	29.6	27.9
	Santo	82.1%	99.0%	17.5	13.7
Solomon Islands	Guadalcanal	0.1%	21.8%	40.8	34.0
Palau	Babeldaob	1.8%	11.0%	23.1	21.2
Kiribati	Tarawa	0.0%	19.0%	29.5	25.9
Samoa	Upolu	35.0%	53.6%	22.4	20.1
Tuvalu	Funafuti	0.0%	28.3%	32.0	28.2
Cook	Rarotonga	3.3%	21.8%	32.0	27.6
Nauru	Nauru	0.0%	5.1%※	11.2	10.8※
Niue	Niue	3.3%	30.5%	34.4	30.3
Target country average		12.1%	11.9%	34.4%	27.4

* Only Steps 1-3 implemented for Fiji and Nauru.

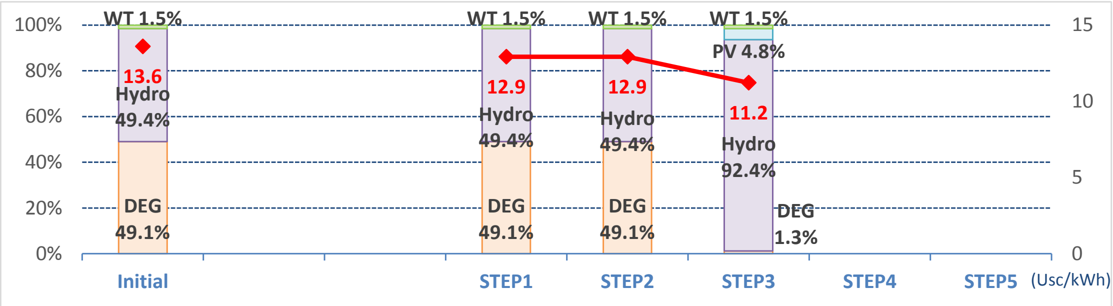
4.1 Fiji

Since hydroelectric power is the main power supply, the original generation costs are low, so reducing the amount of fuel burned and thereby reducing generation costs through RE deployment is limited. However, by optimizing the DEG operating range and adding 24 MW of PV and 32 MW of hydroelectric power, energy self-sufficiency can be raised to approximately 97.5%, and power generation cost could be reduced to 11.2 USc/kWh which would be the lowest in the Pacific region. Furthermore, this would allow the country to get closer to its goal of 100% RE without limitations.

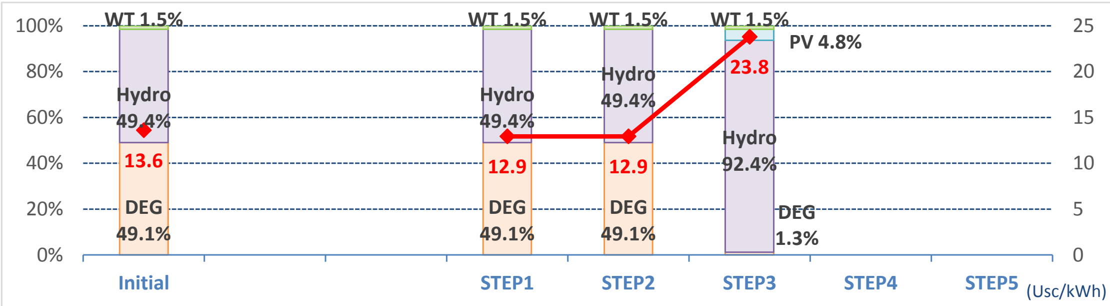
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	9,771 (5%)	0 (0%)	93,408 (48%)	95,775 (49%)	95,775 (49%)
Generation Cost (USc/kWh)	A	13.6	12.9	12.9	11.2	11.6	11.6
	B				23.8	34.3	34.3
	C				17.5	18.8	18.8
	D				22.1	32.2	32.2
RE Fraction		50.9%	50.9%	50.9%	98.7%	99.9%	99.9%
Initial Cost (mil. USD)	A,B,C	---	0.2	0	736	145	0
	D		0.2	0	608	113	0
Additional O&M Cost (mil. USD/yr)	A,B,C	---	----	----	41.3	42.6	42.6
	D				20.6	21.3	21.3
DEG			Operation Range 50-100%				
PV					PV 24MW		
WT							
Hydro					Hydro 32MW		
Controller							

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

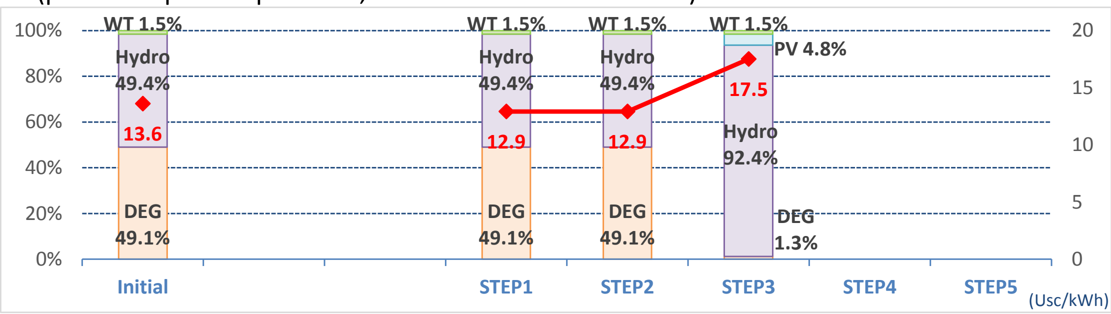


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

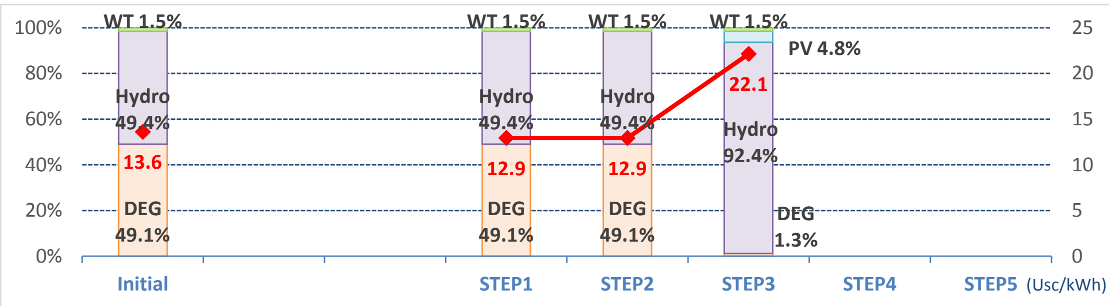


Figure 4-1 Aid measures road map for Fiji

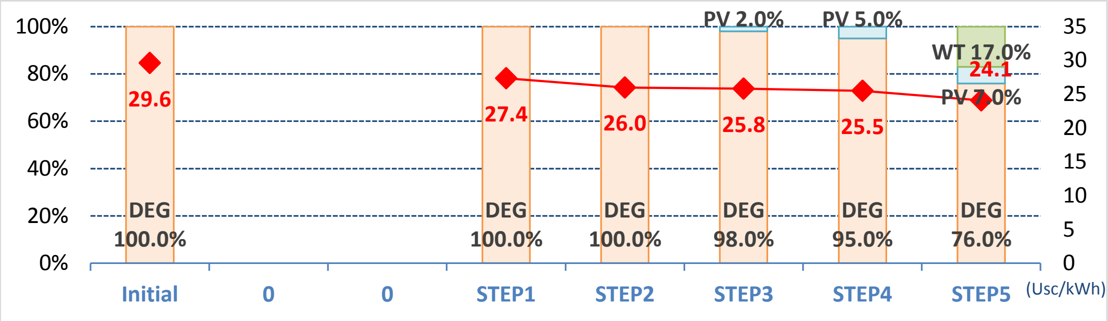
4.2 Marshall Islands

An expansion in RE deployment rate up to 24.0% can be expected by improving power plant operation flexibility by optimizing the operating range of existing DEGs and adding an additional 2 MW of DEGs, and deploying batteries for short-period and long-period measures, which would allow the deployment of approximately 5 MW of PV and 4.5 MW of WT. Generation costs could be reduced to 24.1 USc/kWh.

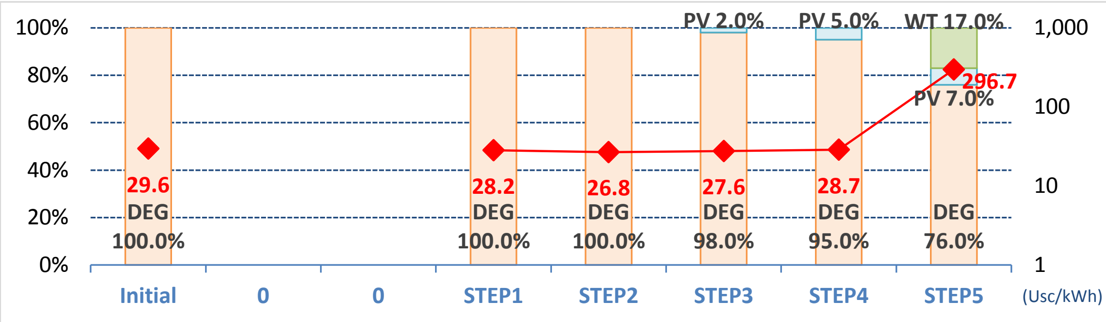
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	734 (5%)	147 (1%)	1,518 (10%)	950 (7%)	2,807 (19%)
Generation Cost (USc/kWh)	A	29.6	27.4	26.0	25.8	25.5	24.1
	B			26.8	27.6	28.7	269.7
	C			26.4	26.3	26.2	138.8
	D			26.8	27.0	27.2	291.9
RE Fraction		0.0%	0.0%	0.0%	2.0%	5.0%	24.0%
Initial Cost (mil. USD)	A,B,C	---	0.2	3.0	7.1	16	34.5
	D		0.2	3.6	3.6	8.0	24
O&M Cost (mil. USD/yr)	A,B,C	---	2.3	2.3	2.4	2.6	3.7
	D				2.4	2.5	2.9
DEG			Operation Range 50-100%	DEG 2.0MW			
PV					PV 890kW	PV 1MW	PV 3MW
WT							WT 4.5MW
Hydro							
Controller						Short Term Stabilizer	Long Term Stabilizer

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

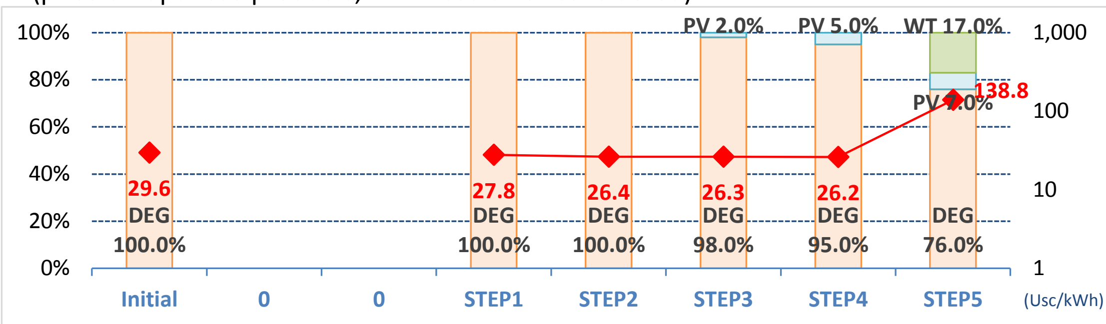


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

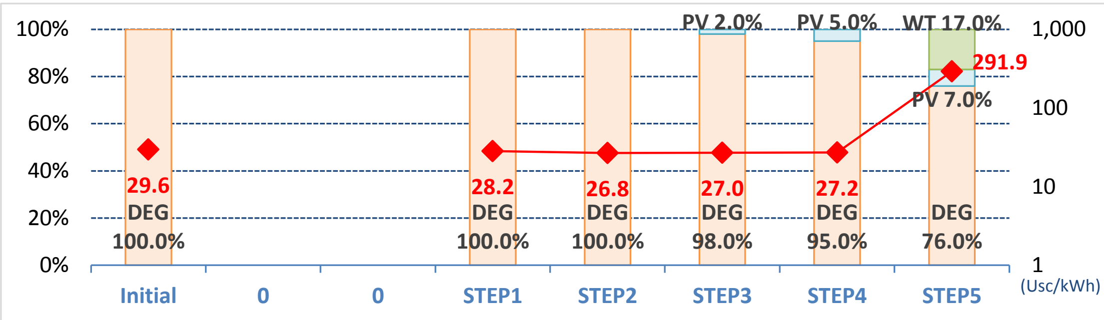


Figure 4-2 Aid measures road map for Marshall Island

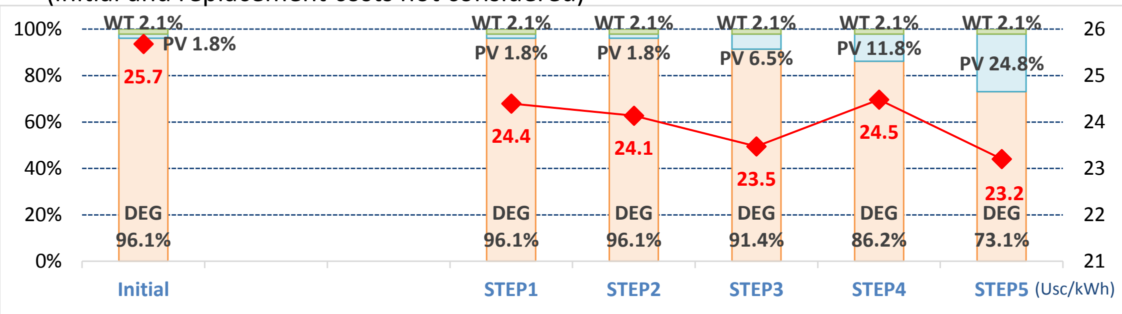
4.3 Pohnpei (Micronesia)

An expansion in RE deployment rate up to 26.9% can be expected by improving power plant operation flexibility by optimizing the operating range of existing DEGs and replacing 1.4 MW of existing DEGs, and deploying batteries for short-period measures, which would allow the deployment of approximately 6 MW of PV. However, the output of RE facilities must be suppressed as a long-period measure. Generation costs could be reduced to 23.2 USc/kWh.

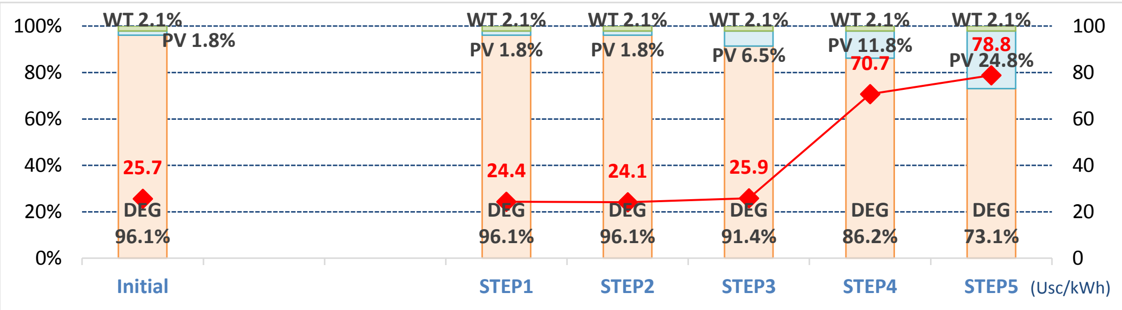
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	454 (5%)	91 (1%)	431 (5%)	905 (10%)	2,092 (23%)
Generation Cost (USc/kWh)	A	25.7	24.4	24.1	23.5	24.5	23.2
	B				25.9	70.7	78.8
	C				24.7	29.6	33.0
	D				24.4	67.7	70.1
RE Fraction		3.90%	3.9%	3.9%	8.6%	13.8%	26.9%
Initial Cost (mil. USD)	A,B,C	---	0.2	2.8	0	4.3	0
	D		0.2	2.8	0	4.3	0
Additional O&M Cost (mil. USD/yr)	A,B,C	---	----	----	0.16	0.34	0.96
	D				0.08	0.17	0.48
DEG			Operation Range 50-100%	DEG 1.4MW			
PV					PV 700kW	PV 1.4MW	PV 3.9MW
WT							
Hydro							
Controller						Short Term Stabilizer	RE output control

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

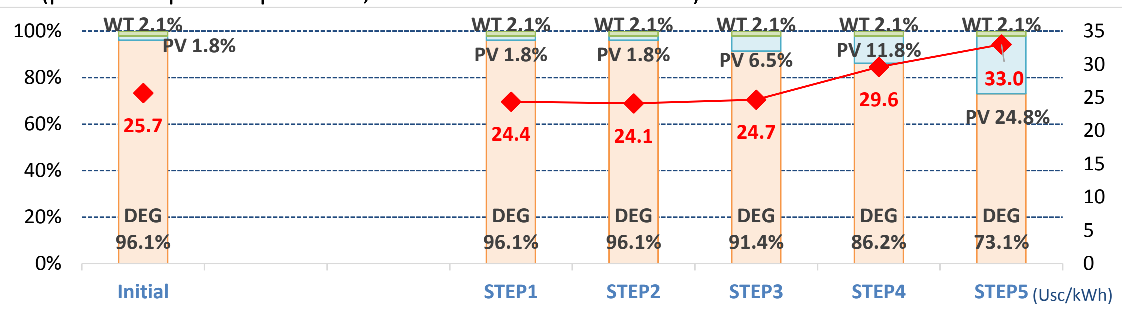


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

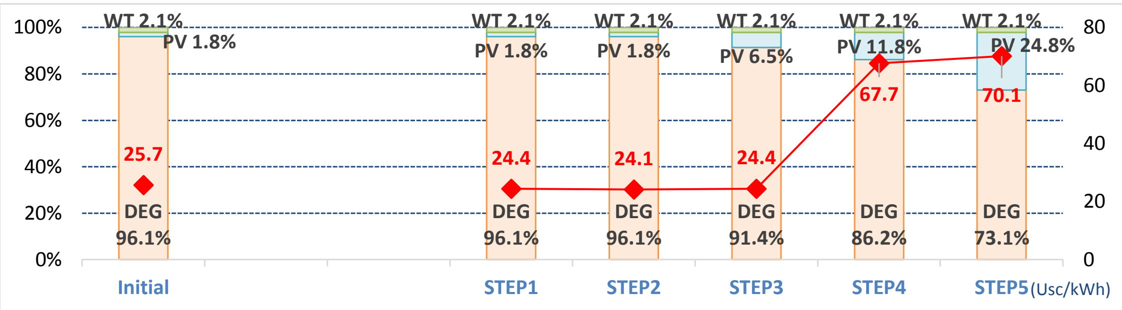


Figure 4-3 Aid measures road map for Pohnpei (Micronesia)

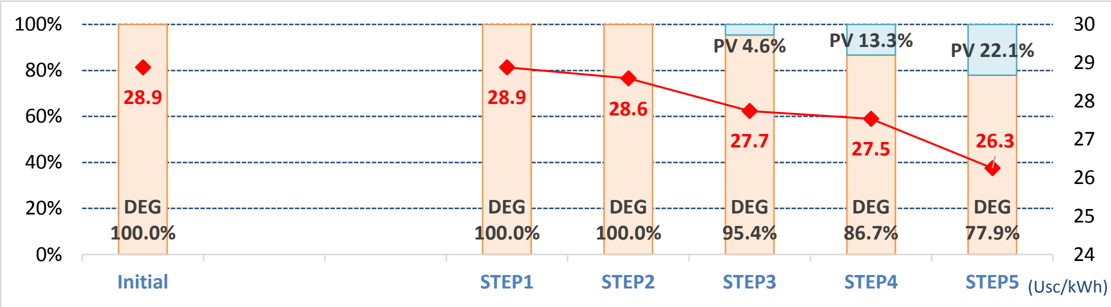
4.4 Kosrae (Micronesia)

An expansion in RE deployment rate up to 22.1% can be expected by improving power plant operation flexibility by replacing 300 kW of existing DEGs and deploying batteries for short-period measures, which would allow the deployment of approximately 1.1 MW of PV. However, the output of RE facilities must be suppressed as a long-period measure. Generation costs could be reduced to 26.3 USc/kWh.

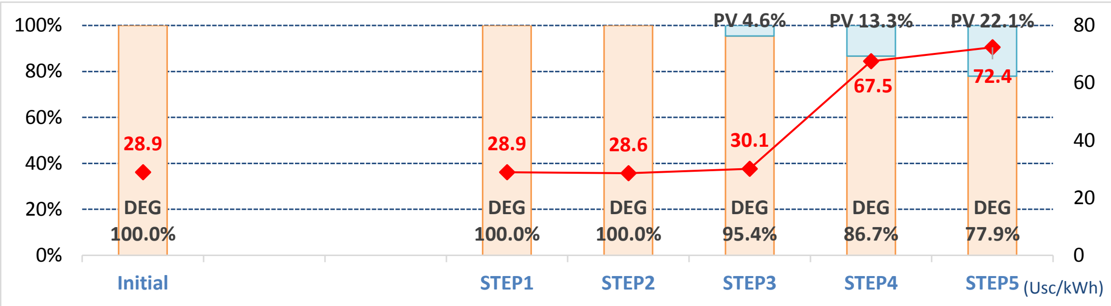
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	0 (0%)	18 (1%)	81 (5%)	236 (13%)	392 (22%)
Generation Cost (USc/kWh)	A	28.9	28.9	28.6	27.7	27.5	26.3
	B				30.1	67.5	72.4
	C				28.9	33.0	34.8
	D				28.7	63.5	64.6
RE Fraction		0.0%	0.0%	0.0%	4.6%	13.3%	22.1%
Initial Cost (mil. USD)	A,B,C	---	0	0.6	0.32	3.6	4.0
	D		0	0.6	0.16	2.1	2.0
Additional O&M Cost (mil. USD/yr)	A,B,C	---	----	----	0.0	0.09	0.17
	D				0.0	0.04	0.08
DEG				DEG 300kW			
PV					PV 190kW	PV 360kW	PV 500kW
WT							
Hydro							
Controller						Short Term Stabilizer	RE output control

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

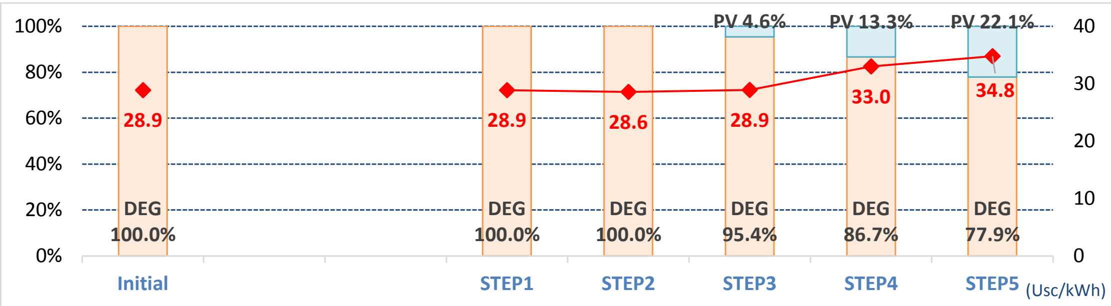


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

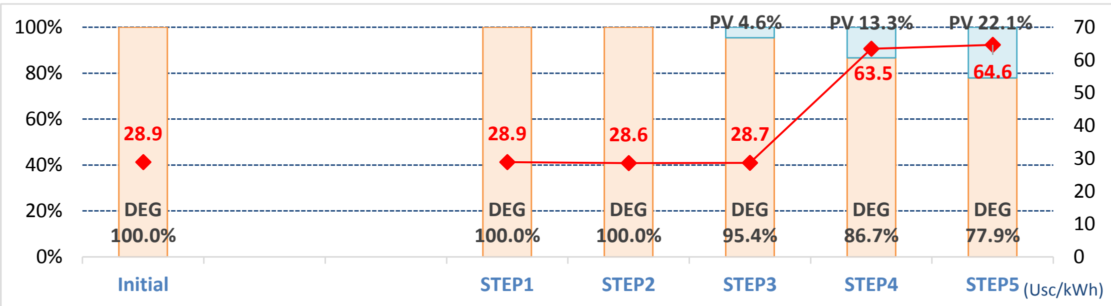


Figure 4-4 Aid measures road map for Kosrae (Micronesia)

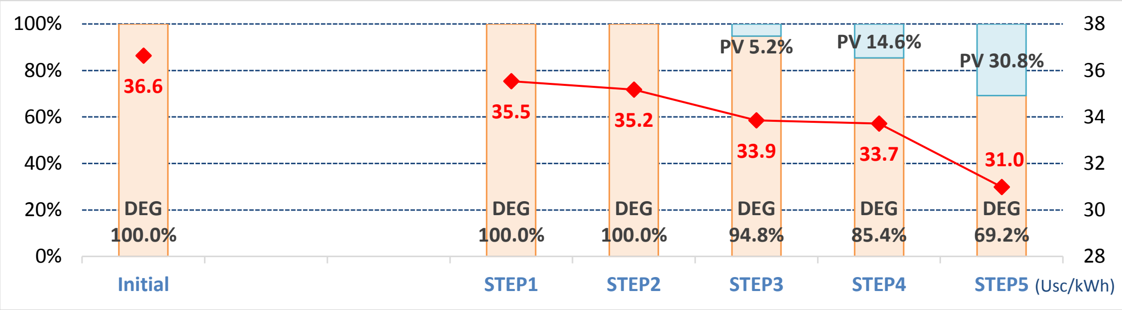
4.5 Yap (Micronesia)

An expansion in RE deployment rate up to 30.8% can be expected by improving power plant operation flexibility by optimizing the operating range of existing DEGs and replacing 500 kW of existing DEGs, and deploying batteries for short-period measures, which would allow the deployment of approximately 4.7 MW of PV. However, the output of RE facilities must be suppressed as a long-period measure. Generation costs could be reduced to 31.0USc/kWh.

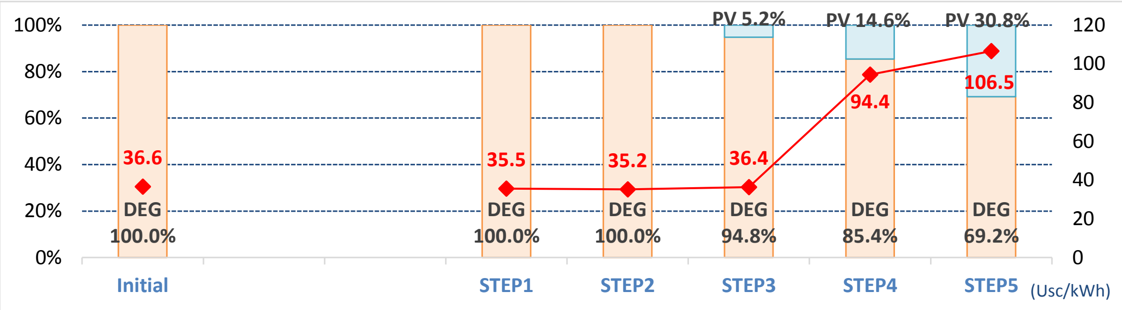
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	109 (3%)	36 (1%)	188 (5%)	529 (15%)	1,118 (31%)
Generation Cost (USc/kWh)	A	36.6	35.5	35.2	33.9	33.7	31.0
	B				36.4	94.4	106.5
	C				35.1	40.6	45.3
	D				34.9	90.1	93.3
RE Fraction		0.0%	0.0%	0.0%	5.2%	14.6%	30.8%
Initial Cost (mil. USD)	A,B,C	---	0.2	1.0	0.96	7.3	20
	D		0.2	1.0	0.5	4.2	10
Additional O&M Cost (mil. USD/yr)	A,B,C	---	---	---	0.07	0.19	0.59
	D				0.03	0.10	0.3
DEG			Operation Range 50-100%	DEG 500kW			
PV					PV 424kW	PV 770kW	PV 2.5MW
WT							
Hydro							
Controller						Short Term Stabilizer	RE output control

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

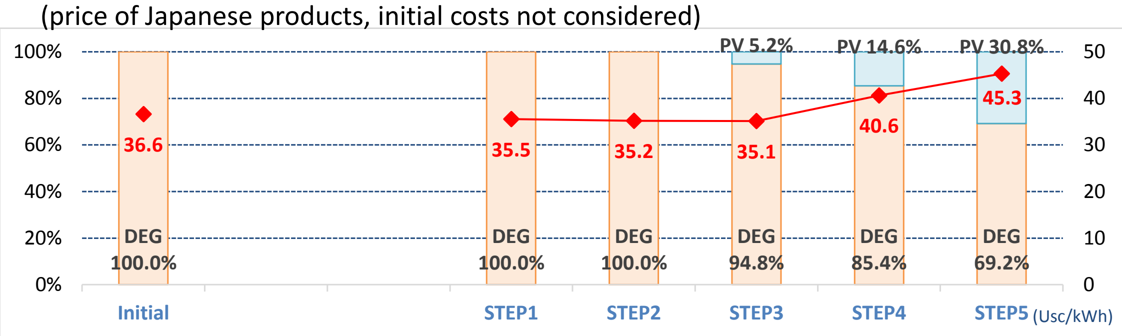


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

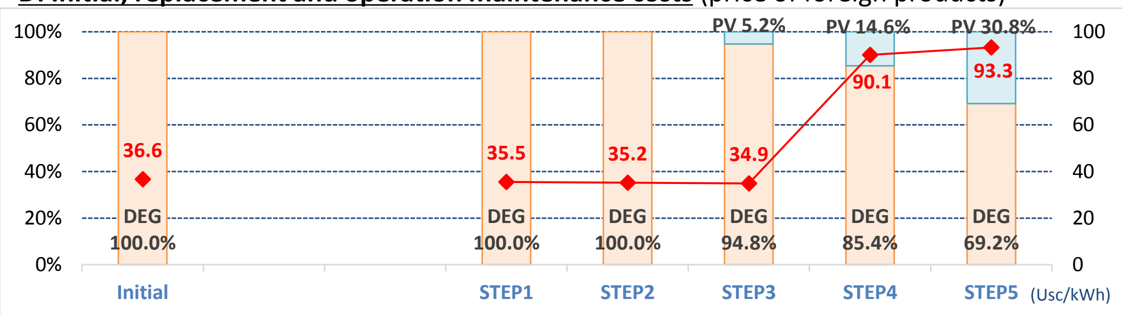


Figure 4-5 Aid measures road map for Yap (Micronesia)

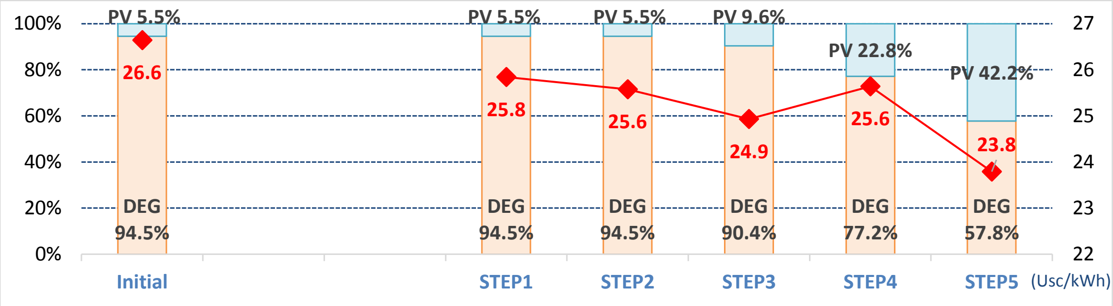
4.6 Chuuk (Micronesia)

An expansion in RE deployment rate up to 42.2% can be expected by improving power plant operation flexibility by optimizing the operating range of existing DEGs and replacing 500 kW of existing DEGs, and deploying batteries for short-period measures, which would allow the deployment of approximately 2.4 MW of PV. However, the output of RE facilities must be suppressed as a long-period measure. Generation costs could be reduced to 23.8 USc/kWh.

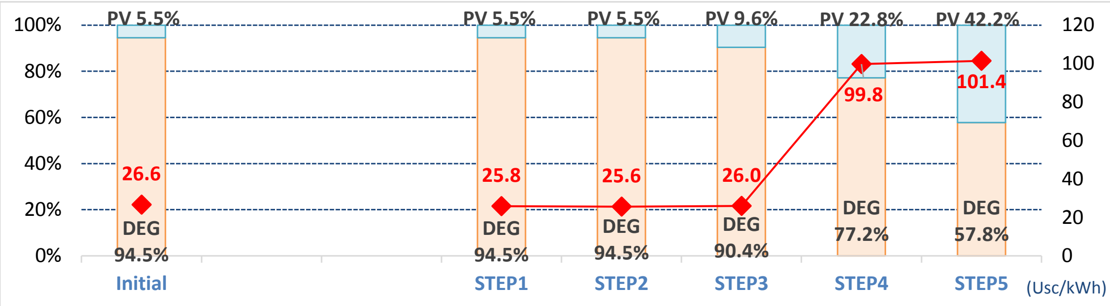
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	69 (3%)	23 (1%)	96 (4%)	401 (17%)	850 (37%)
Generation Cost (USc/kWh)	A	26.6	25.8	25.6	24.9	25.6	23.8
	B				26.0	99.8	101.4
	C				26.0	34.1	40.0
	D				25.2	94.6	92.9
RE Fraction		5.5%	5.5%	5.5%	9.6%	22.8%	42.2%
Initial Cost (mil. USD)	A,B,C	---	0.2	1.0	0.0	6.2	12.0
	D		0.2	1.0	0.0	3.7	6.0
Additional O&M Cost (mil. USD/yr)	A,B,C	---	---	---	0.03	0.13	0.37
	D				0.02	0.07	0.19
DEG			Operation Range 50-100%	DEG 500kW			
PV					PV 200kW	PV 635kW	PV 1.6MW
WT							
Hydro							
Controller						Short Term Stabilizer	RE output control

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

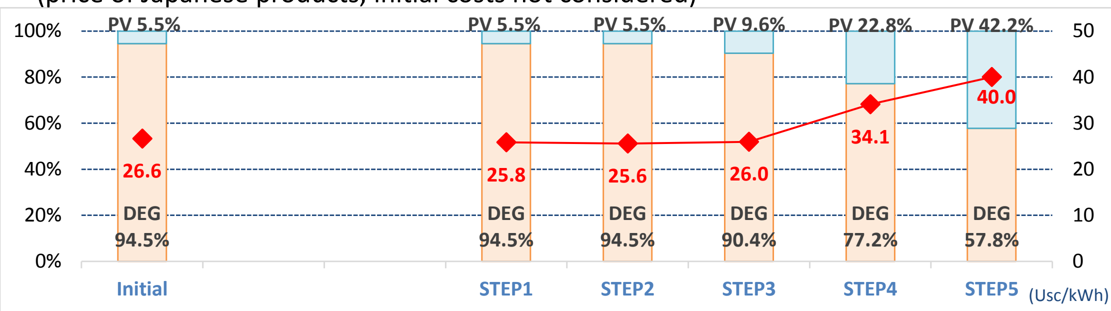


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

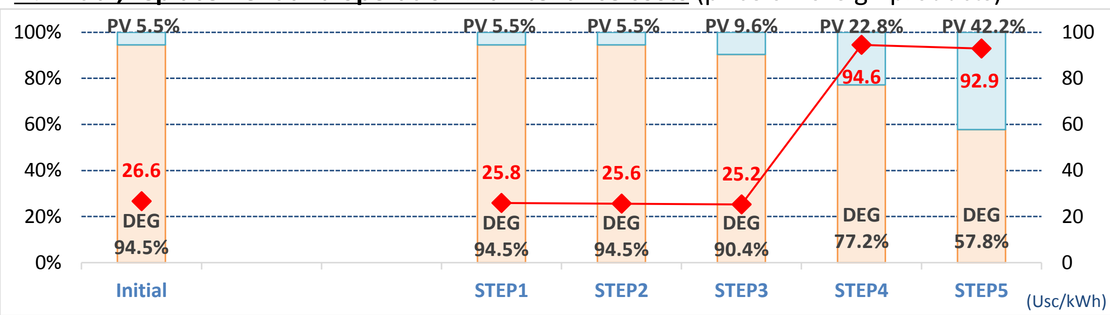


Figure 4-6 Aid measures road map for Chuuk (Micronesia)

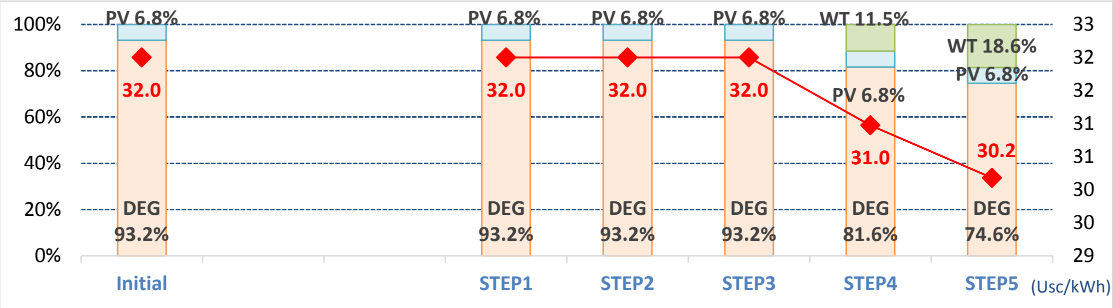
4.7 Tonga

The existing DEG power plant is in good condition, and the groundwork for RE integration is in place. An expansion in RE deployment rate up to 25.4% can be expected by deploying batteries for short-period measures, which would allow the deployment of approximately 4.2 MW of WT. However, the output of RE facilities must be suppressed as a long-period measure. Generation costs could be reduced to 30.2 USc/kWh.

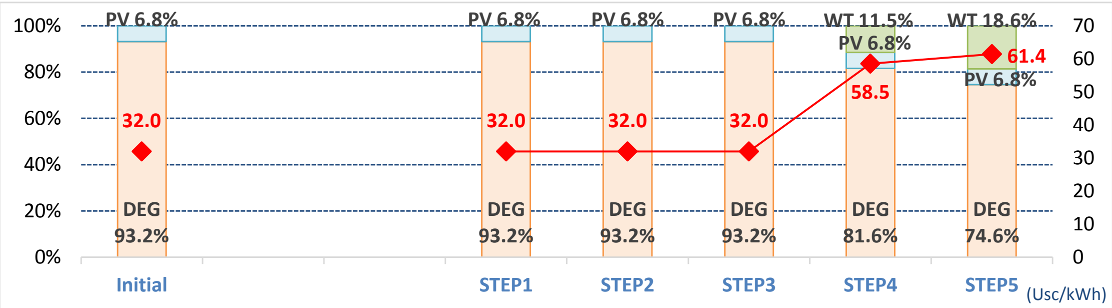
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	0 (0%)	0 (0%)	0 (0%)	1,510 (12%)	2,438 (19%)
Generation Cost (USc/kWh)	A	32.2	32.0	32.0	32.0	31.0	30.2
	B				32.0	58.5	61.4
	C				32.0	34.5	35.6
	D				32.0	55.6	55.9
RE Fraction		6.8%	6.8%	6.8%	6.8%	18.4%	25.4%
Initial Cost (mil. USD)	A,B,C	---	0	0	0	19.7	19.3
	D		0	0	0	15.6	9.6
Additional O&M Cost (mil. USD/yr)	A,B,C	---	---	---	0.0	0.88	1.65
	D				0.0	0.44	0.83
DEG							
PV							
WT						WT 2.2MW	WT 2MW
Hydro							
Controller						Short Term Stabilizer	RE output control

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

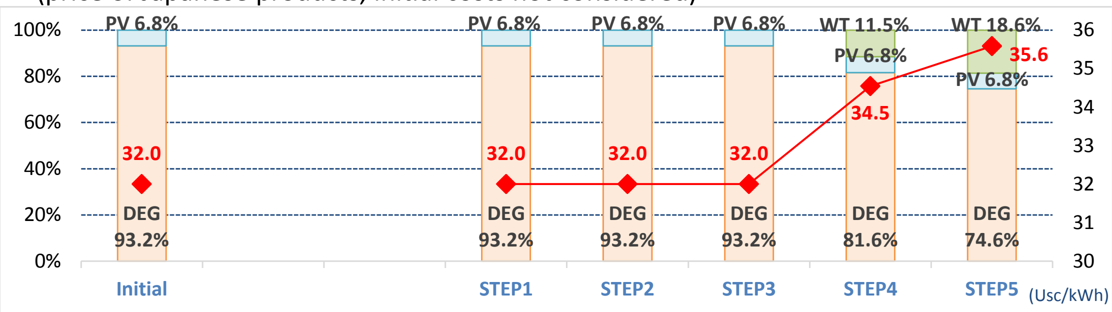


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

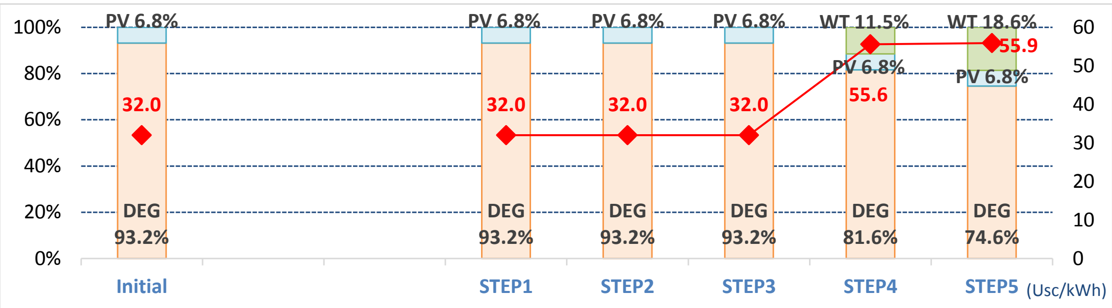


Figure 4-7 Aid measures road map for Tonga

4.8 Port Vila (Vanuatu)

The existing DEG power plant is operated by a private company, and no aid for improvements is needed. An expansion in RE deployment rate up to 24.6% can be expected by deploying batteries for short-period measures, which would allow the deployment of approximately 6.1 MW of PV. However, the output of RE facilities must be suppressed as a long-period measure. Generation costs could be reduced to 27.9 USc/kWh.

		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	0 (0%)	0 (0%)	0 (0%)	1,125 (7%)	2,404 (15%)
Generation Cost (USc/kWh)	A	29.6	29.6	29.6	29.6	29.4	27.9
	B				29.6	60.1	65.0
	C				29.6	33.0	33.8
	D				29.6	58.9	60.1
RE Fraction		9.3%	9.3%	9.3%	9.3%	16.4%	24.6%
Initial Cost (mil. USD)	A,B,C	---	0.0	0.0	0.0	8.8	28.0
	D		0.0	0.0	0.0	6.2	14.0
Additional O&M Cost (mil. USD/yr)	A,B,C	---	---	---	0.0	0.43	0.99
	D				0.0	0.21	0.49
DEG							
PV						PV 2.65MW	PV 3.5MW
WT							
Hydro							
Controller						Short Term Stabilizer	RE output control

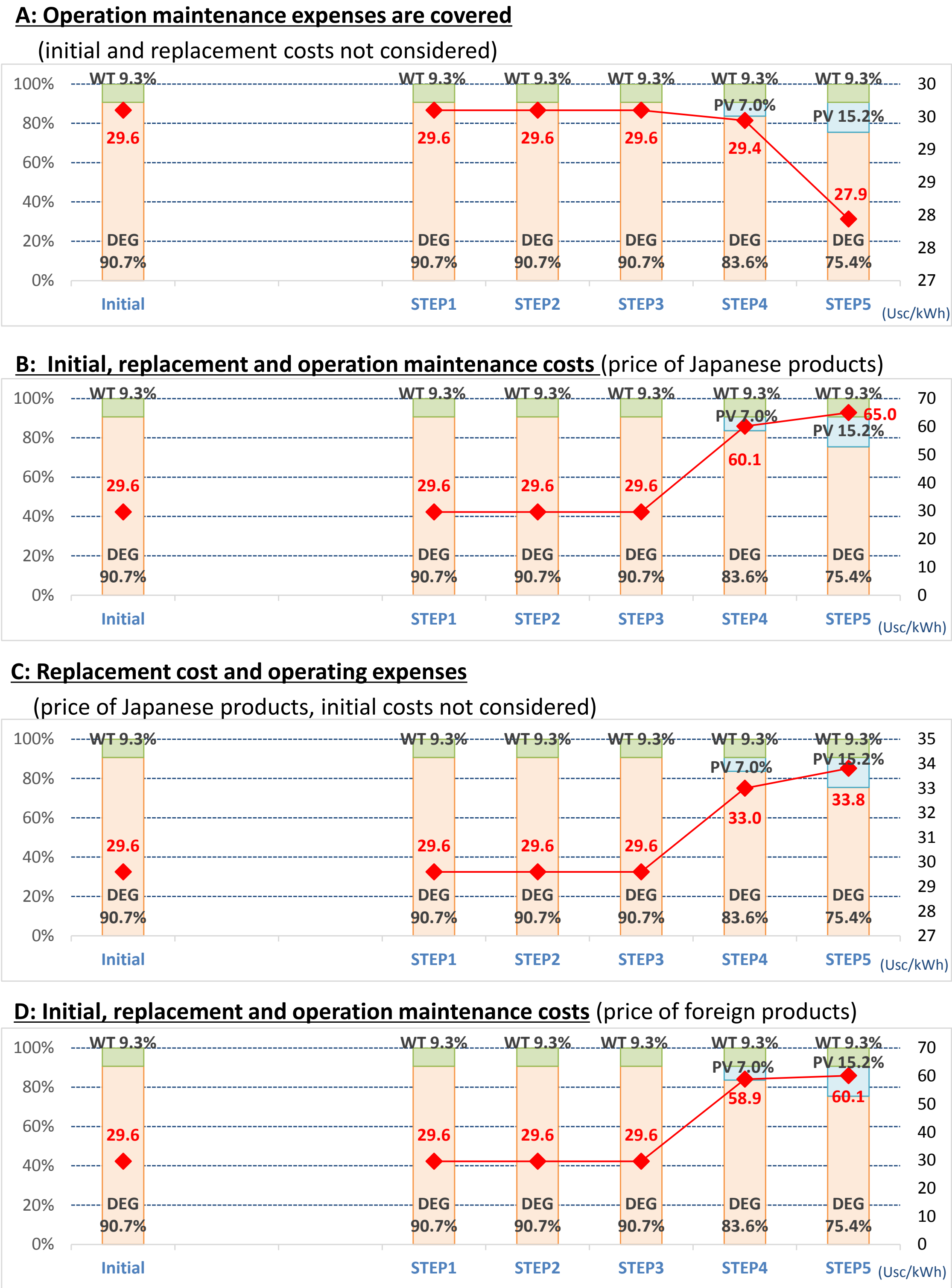


Figure 4-8 Aid measures road map for Port Vila (Vanuatu)

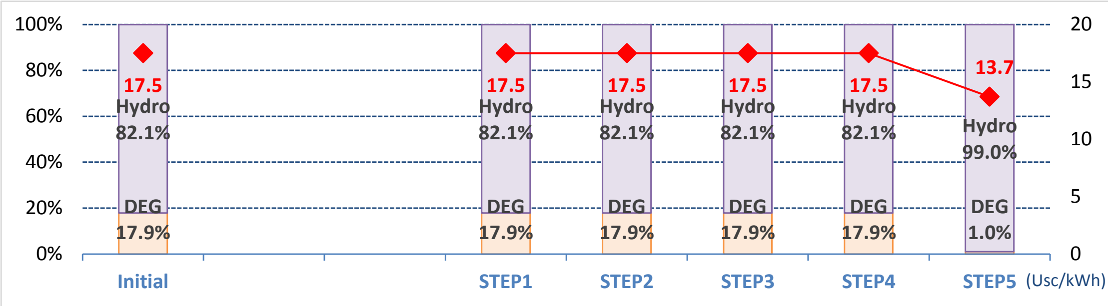
4.9 Santo (Vanuatu)

Since hydroelectric power is the main power supply, the original generation costs are low, so reducing the amount of fuel burned and thereby reducing generation costs through RE deployment is limited. However, by optimizing the DEG operating range and adding 600 kW of hydroelectric power, energy self-sufficiency can be raised to approximately 99%, and power generation cost could be reduced to 13.7 USc/kWh. Furthermore, this would allow the country to get closer to its goal of 100% RE without limitations.

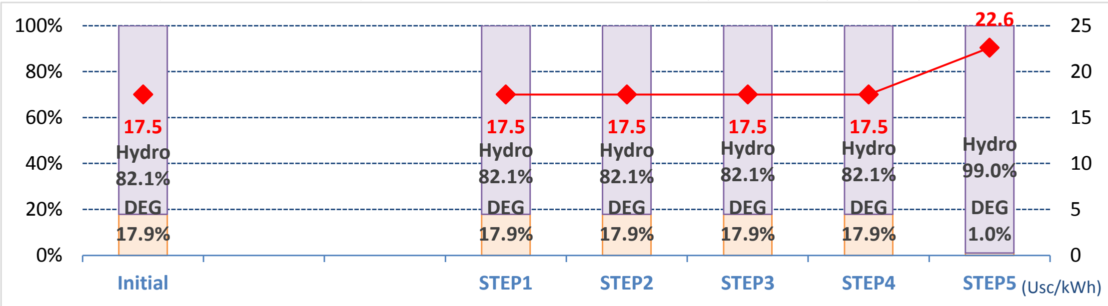
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	25 (5%)	0 (0%)	0 (0%)	0 (0%)	380 (77%)
Generation Cost (USc/kWh)	A	17.5	17.5	17.5	17.5	17.5	13.7
	B						22.6
	C						16.0
	D						22.6
RE Fraction		82.1%	82.1%	82.1%	82.1%	82.1%	99.0%
Initial Cost (mil. USD)	A,B,C	---	0.1	0.0	0.0	0.0	7.8
	D						
O&M Cost (mil. USD/yr)	A,B,C	---	1.0	1.0	1.0	1.0	1.0
	D						
DEG			Operation Range 50-100%				
PV							
WT							
Hydro							Hydro 600kW
Controller							

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

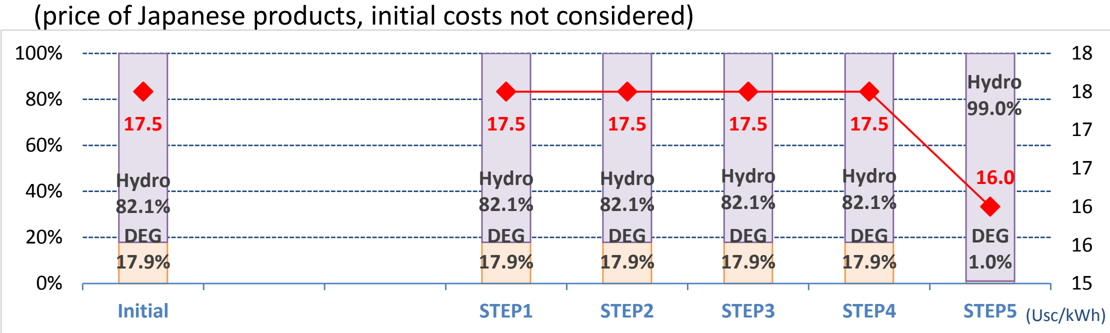


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

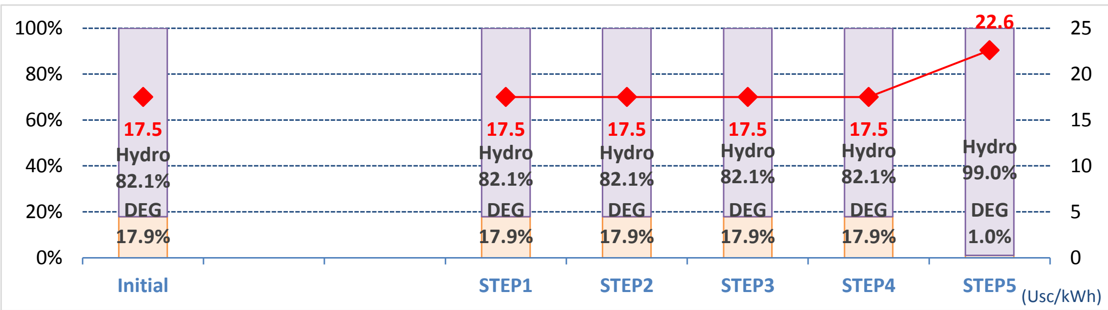


Figure 4-9 Aid measures road map for Santo (Vanuatu)

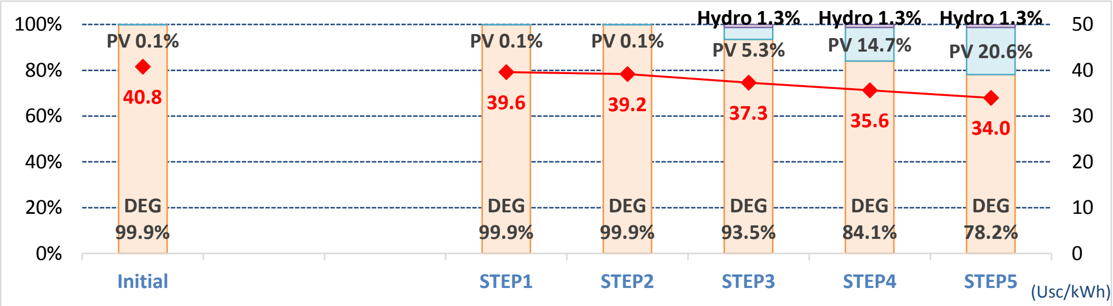
4.10 Solomon Islands

An expansion in RE deployment rate up to 21.8% can be expected by improving power plant operation flexibility by optimizing the operating range of existing DEGs, replacing 3.1 MW of existing DEGs, deploying batteries for short-period, which would allow the deployment of approximately 11 MW of PV, and adding an additional 300 kW of hydroelectric power. However, the output of RE facilities must be suppressed as a long-period measure. Generation costs could be reduced to 34.0 USc/kWh.

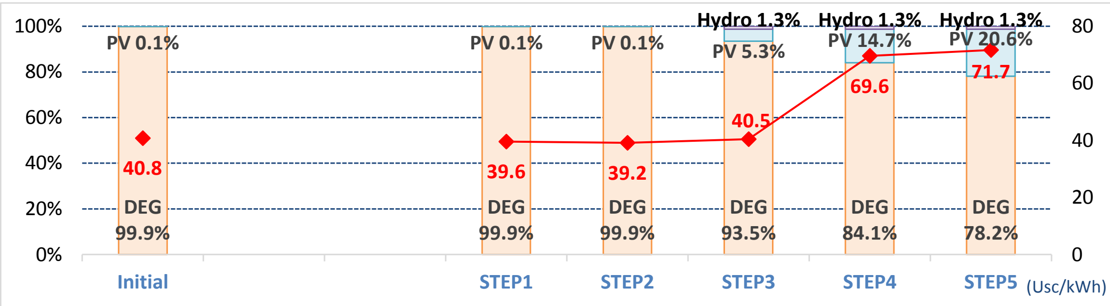
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	653 (3%)	218 (1%)	1,402 (6%)	3,447 (16%)	4,730 (22%)
Generation Cost (USc/kWh)	A	40.8	39.6	39.2	37.3	35.6	34.0
	B				40.5	69.6	71.7
	C				38.7	41.0	41.0
	D				38.7	64.7	64.7
RE Fraction		0.1%	0.1%	0.1%	6.5%	15.9%	21.8%
Initial Cost (mil. USD)	A,B,C	---	0.2	6.2	13.8	59.5	28.0
	D		0.2	6.2	6.9	39.7	14.0
Additional O&M Cost (mil. USD/yr)	A,B,C	---	---	---	0.53	1.32	1.88
	D				0.27	0.66	0.94
DEG			Operation Range 50-100%	DEG 3.1MW			
PV					PV 2.7MW	PV 5MW	PV 3.5MW
WT							
Hydro					Hydro 300kW		
Controller						Short Term Stabilizer	RE output control

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

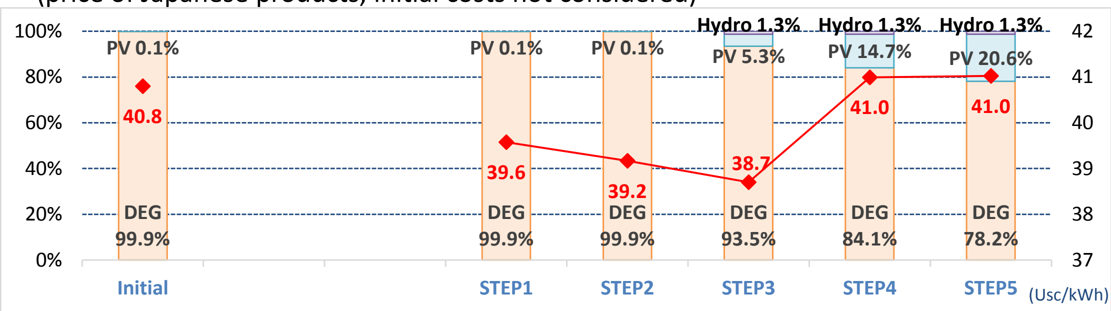


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

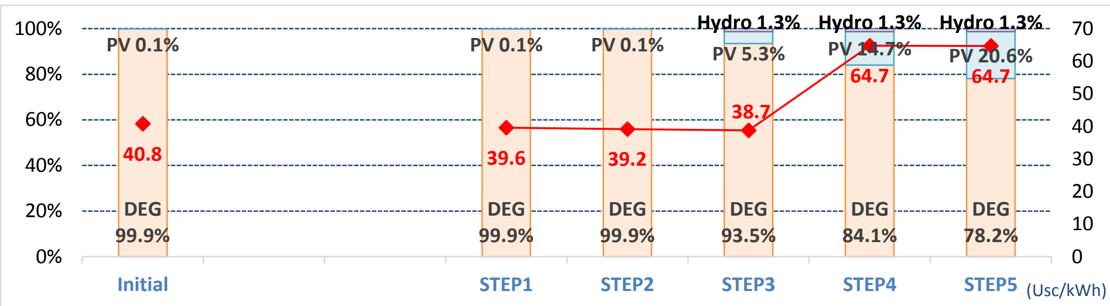


Figure 4-10 Aid measures road map for the Solomon Islands

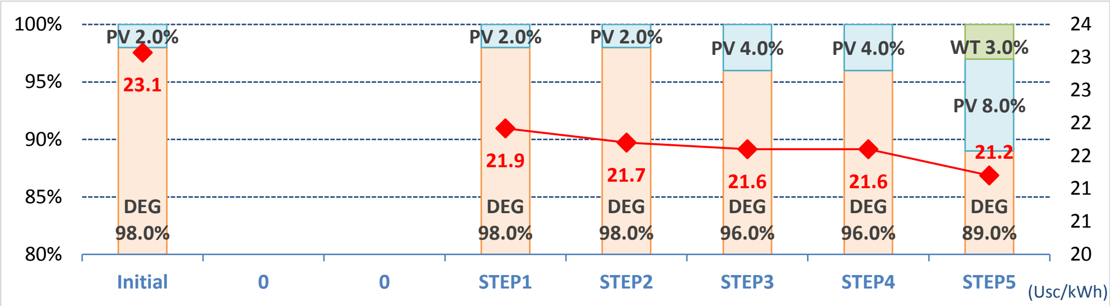
4.11 Palau

An expansion in RE deployment rate up to 11.0% can be expected by optimizing the operating range of existing DEGs, and deploying batteries for short-period measures, which would allow the deployment of 5 MW of PV. However, the output of RE facilities must be suppressed as a long-period measure. Generation costs could be reduced to 21.2 USc/kWh.

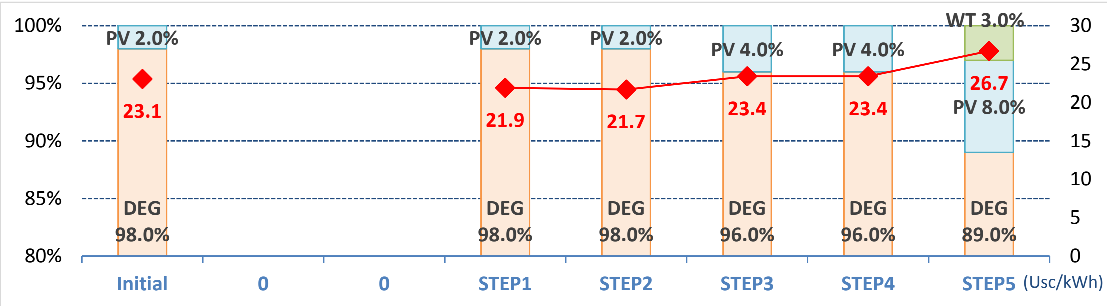
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	1,032 (5%)	0 (0%)	1,787 (9%)	0 (0%)	3,248 (22%)
Generation Cost (USc/kWh)	A	23.1	21.9	21.7	21.6	21.6	21.2
	B				23.4	23.4	26.7
	C				21.8	21.8	21.9
	D				22.3	22.3	23.3
RE Fraction		2.0%	2.0%	2.0%	4.0%	4.0%	11.0%
Initial Cost (mil. USD)	A,B,C	---	0.2	0	8	0	41
	D		0.2	0	4	0	25
O&M Cost (mil. USD/yr)	A,B,C	---	3.1	3.1	3.2	3.2	3.9
	D				3.1	3.1	3.4
DEG			Operation Range 50-100%				
PV					PV 1.0MW		PV 4.0MW
WT							
Hydro							
Controller						Short Term Stabilizer	RE output control

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

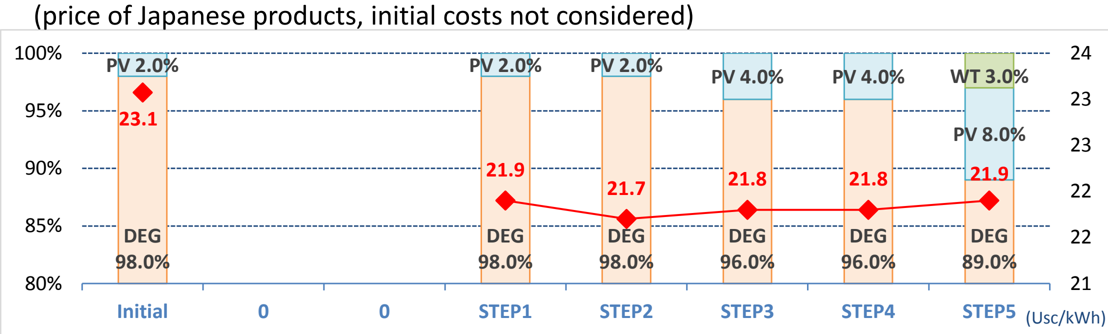


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

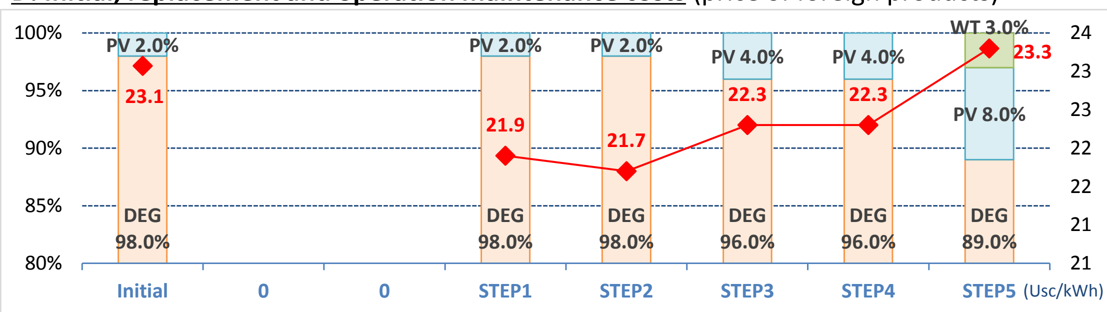


Figure 4-11 Aid measures road map for Palau

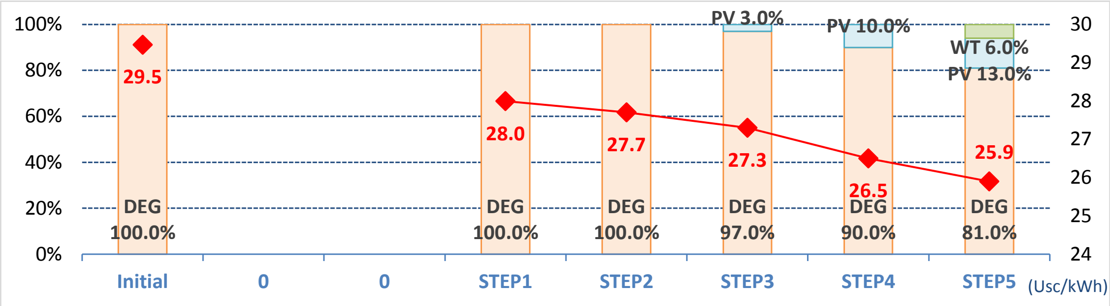
4.12 Kiribati

An expansion in RE deployment rate up to 19.0% can be expected by improving power plant operation flexibility by optimizing the operating range of existing DEGs and adding an additional 500kW of DEGs, and deploying batteries for short-period measures, which would allow the deployment of 2.5 MW of PV. However, the output of RE facilities must be suppressed as a long-period measure. Generation costs could be reduced to 25.9 USc/kWh.

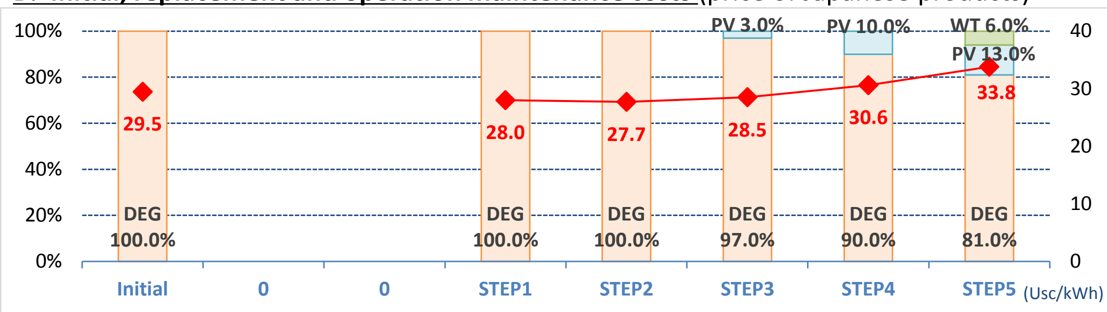
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	281 (5%)	0 (0%)	866 (15%)	531 (9%)	1,097 (20%)
Generation Cost (USc/kWh)	A	29.5	28.0	27.7	27.3	26.5	25.9
	B				28.5	30.6	33.8
	C				27.4	27.0	26.9
	D				27.8	28.1	29.0
RE Fraction		0.0%	0.0%	0.0%	3.0%	10.0%	19.0%
Initial Cost (mil. USD)	A,B,C	---	0.2	0.8	0.0	4.5	9.6
	D		0.2	0.8	0	4.5	4.8
O&M Cost (mil. USD/yr)	A,B,C	---	0.9	0.9	0.9	1.1	1.3
	D				0.9	1.1	1.3
DEG			Operation Range 50-100%	DEG 500kW			
PV					PV 400kW	PV 900kW	PV 1.2MW
WT							
Hydro							
Controller						Short Term Stabilizer	RE output control

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

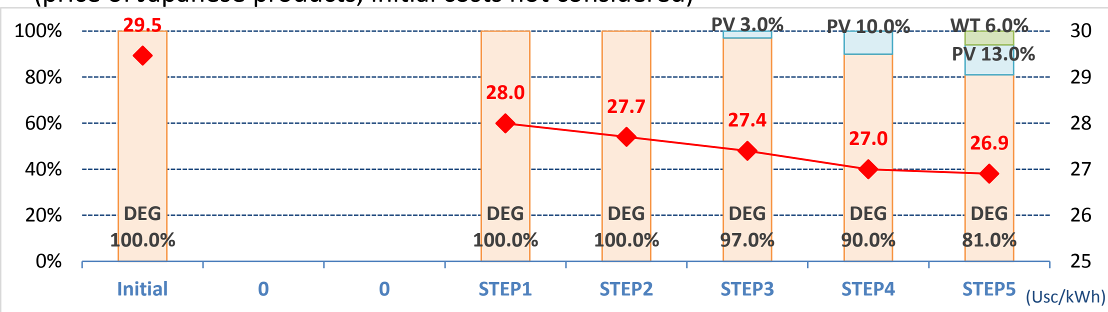


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

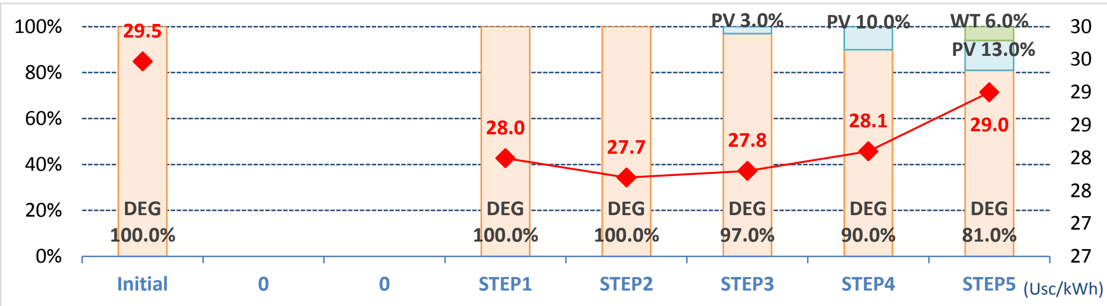


Figure 4-12 Aid measures road map for Kiribati

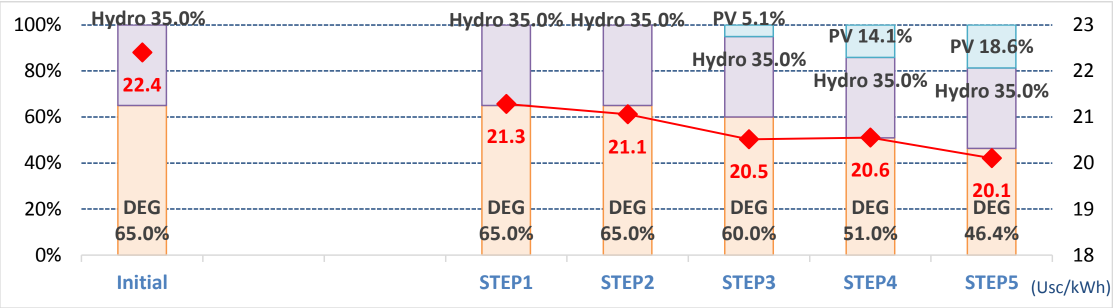
4.13 Samoa

An expansion in RE deployment rate up to 53.6% can be expected by improving power plant operation flexibility by optimizing the operating range of existing DEGs and adding an additional 4 MW of DEGs, and deploying batteries for short-period measures, which would allow the deployment of 13.5 MW of PV. However, the output of RE facilities must be suppressed as a long-period measure. Generation costs could be reduced to 20.1 USc/kWh.

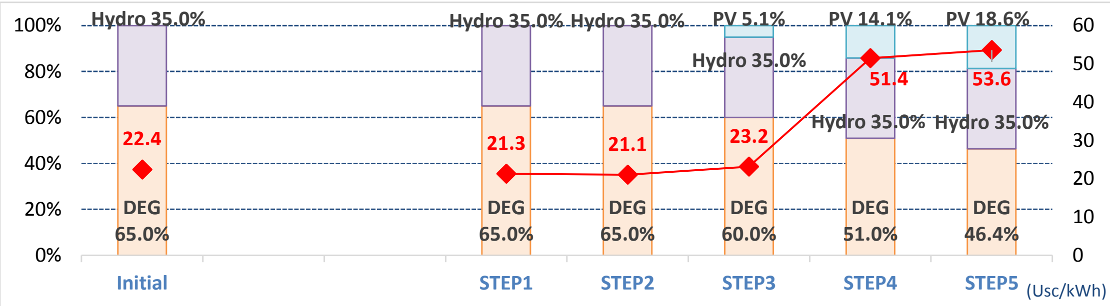
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	1,349 (5%)	270 (1%)	1,369 (5%)	3,802 (14%)	5,031 (19%)
Generation Cost (USc/kWh)	A	22.4	21.3	21.1	20.5	20.6	20.1
	B				23.2	51.4	53.6
	C				21.8	25.7	26.5
	D				21.6	47.0	47.6
RE Fraction		35.0%	35.0%	35.0%	40.0%	49.0%	53.6%
Initial Cost (mil. USD)	A,B,C	---	0.2	8.0	28.8	51.2	28.0
	D		0.2	8.0	14.4	25.6	14.0
Additional O&M Cost (mil. USD/yr)	A,B,C	---	---	---	0.58	1.61	2.17
	D				0.29	0.80	1.08
DEG			Operation Range 50-100%	DEG 4MW			
PV					PV 3.6MW	PV 6.4MW	PV 3.5MW
WT							
Hydro							
Controller						Short Term Stabilizer	RE output control

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

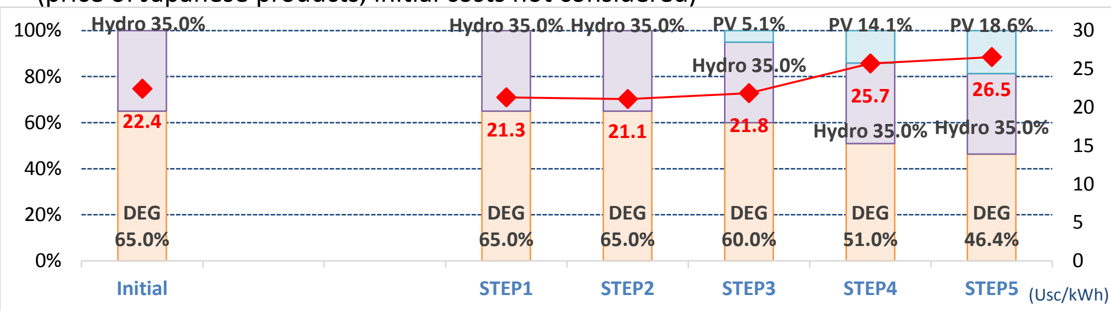


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

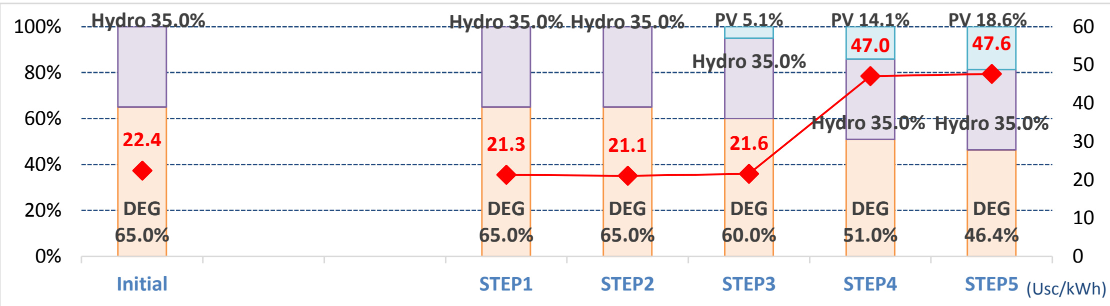


Figure 4-13 Aid measures road map for Samoa

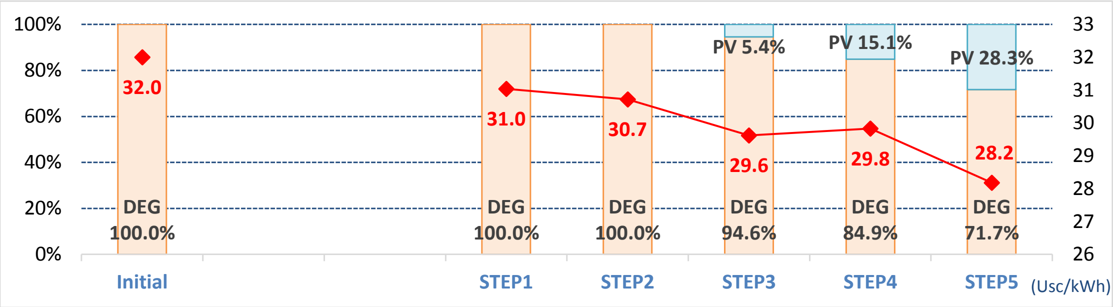
4.14 Tuvalu

An expansion in RE deployment rate up to 28.3% can be expected by improving power plant operation flexibility by improving the operating range of existing DEGs and replacing 300 kW of existing DEGs, and deploying batteries for short-period, which would allow the deployment of approximately 1.1MW of PV. However, the output of RE facilities must be suppressed as a long-period measure. Generation costs could be reduced to 28.2 USc/kWh.

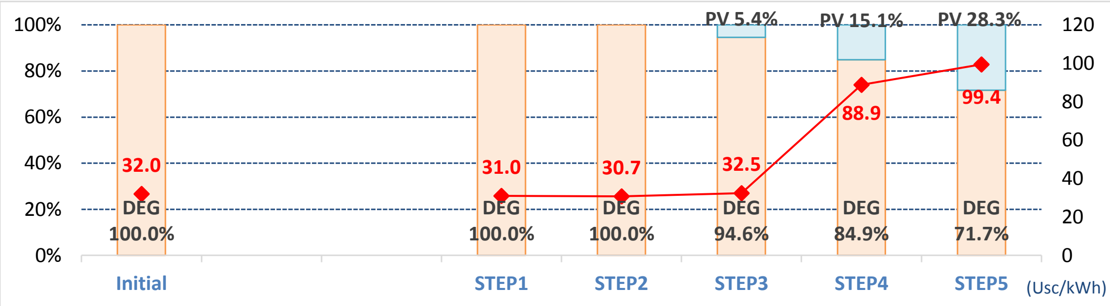
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	56 (3%)	19 (1%)	102 (5%)	283 (15%)	532 (28%)
Generation Cost (USc/kWh)	A	32.0	31.0	30.7	29.6	29.8	28.2
	B				32.5	88.9	99.4
	C				31.0	37.0	41.4
	D				30.8	84.1	87.4
RE Fraction		0.0%	0.0%	0.0%	5.4%	15.1%	28.3%
Initial Cost (mil. USD)	A,B,C	---	0.2	0.6	0.27	3.8	8.0
	D		0.2	0.6	0.14	2.1	4.0
Additional O&M Cost (mil. USD/yr)	A,B,C	---	---	---	0.04	0.10	0.26
	D				0.02	0.05	0.13
DEG			Operation Range 50-100%	DEG 300kW			
PV					PV 234kW	PV 416kW	PV 1MW
WT							
Hydro							
Controller						Short Term Stabilizer	RE output control

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

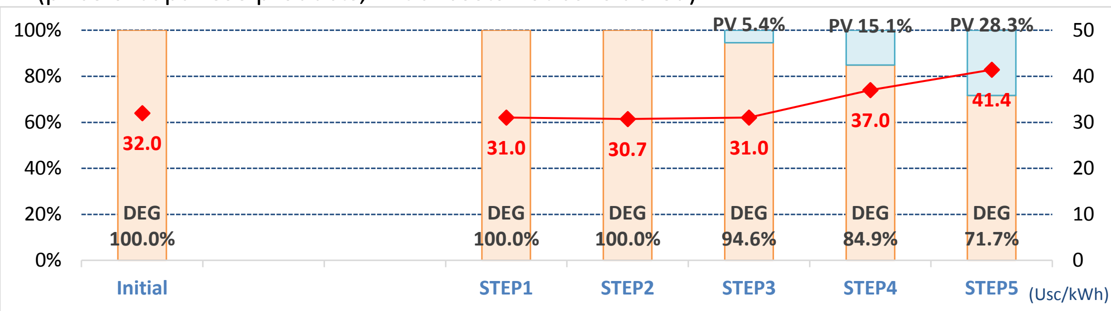


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

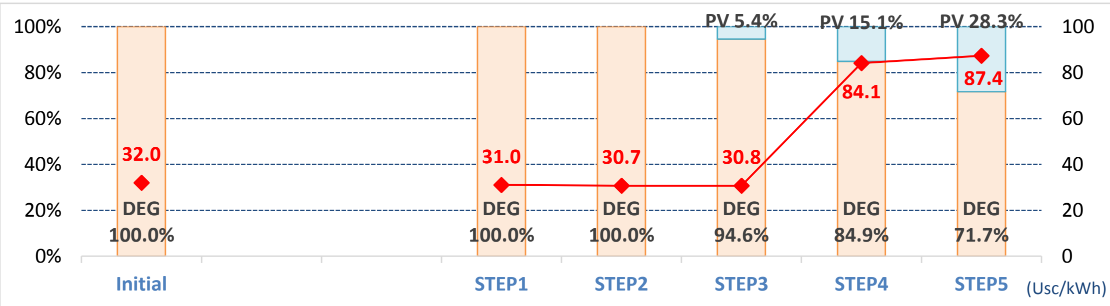


Figure 4-14 Aid measures road map for Tuvalu

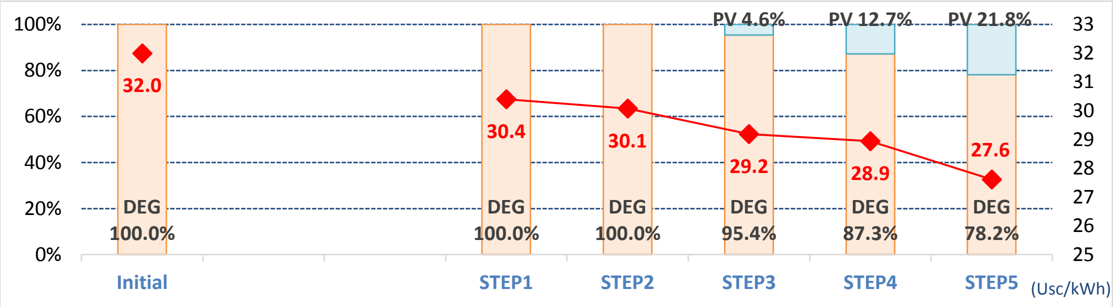
4.15 Cook

An expansion in RE deployment rate up to 21.8% can be expected by improving power plant operation flexibility by improving the operating range of existing DEGs and replacing 1 MW of existing DEGs, and deploying batteries for short-period, which would allow the deployment of approximately 5.8MW of PV. However, the output of RE facilities must be suppressed as a long-period measure. Generation costs could be reduced to 27.6 USc/kWh.

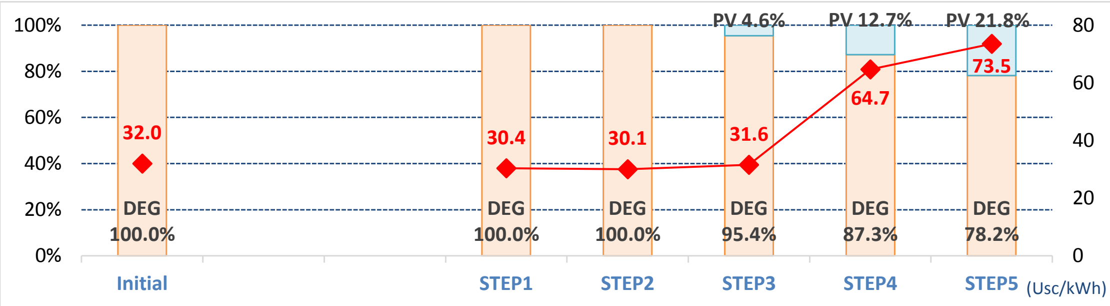
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	379 (5%)	76 (1%)	346 (5%)	966 (13%)	1,650 (22%)
Generation Cost (USc/kWh)	A	32.0	30.4	30.1	29.2	28.9	27.6
	B				31.6	64.7	73.5
	C				30.4	34.3	36.4
	D				30.1	62.4	65.4
RE Fraction		0.0%	0.0%	0.0%	4.6%	12.7%	21.8%
Initial Cost (mil. USD)	A,B,C	---	0.2	2.0	1.6	14.1	20.0
	D		0.2	2.0	0.78	7.9	10.0
Additional O&M Cost (mil. USD/yr)	A,B,C	---	---	---	0.14	0.39	0.79
	D				0.07	0.19	0.39
DEG			Operation Range 50-100%	DEG 1MW			
PV					PV 864kW	PV 1.5MW	PV 2.5MW
WT							
Hydro							
Controller						Short Term Stabilizer	RE output control

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

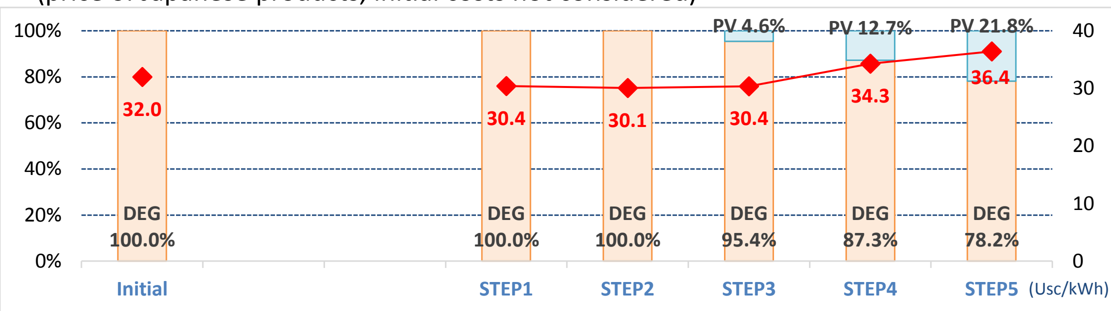


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

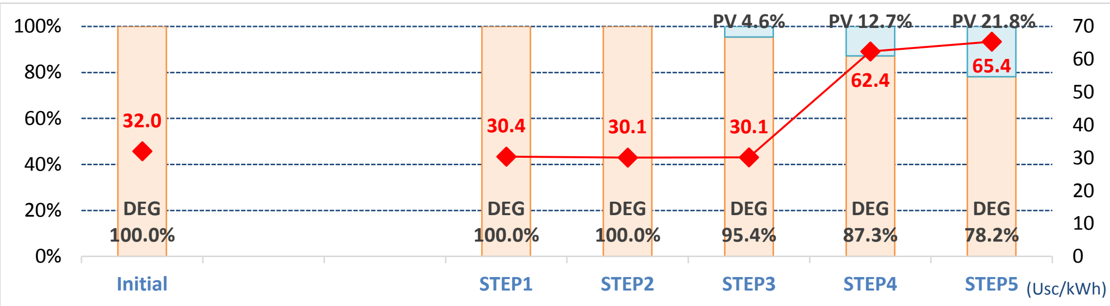


Figure 4-15 Aid measures road map for the Cook Islands

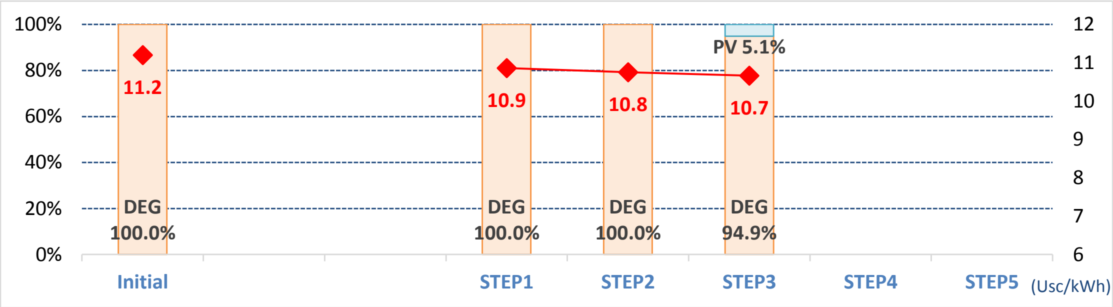
4.16 Nauru

Electric rates are the lowest in the region due to government subsidies, and generation costs are unknown. Reducing the amount of fuel burned and thereby reducing generation costs through RE deployment is limited. However, by improving power plant operation flexibility by optimizing the operating range of existing DEGs and adding an additional 700kW of DEGs, which would allow the deployment of 630 kW of PV, energy self-sufficiency can be raised to approximately 5.1% Generation costs could be reduced to 10.7 USc/kWh.

		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	265 (3%)	88 (1%)	447 (5%)	1,243 (14%)	1,583 (18%)
Generation Cost (USc/kWh)	A	11.2	10.9	10.8	10.7	11.3	11.3
	B				12.9	34.1	39.0
	C				11.8	15.7	16.6
	D				11.6	31.9	34.1
RE Fraction		0.0%	0.0%	0.0%	5.1%	14.1%	17.9%
Initial Cost (mil. USD)	A,B,C	---	0.2	1.4	5.0	10.5	4.0
	D		0.2	1.4	2.5	6.1	2.0
Additional O&M Cost (mil. USD/yr)	A,B,C	---	---	---	0.1	0.28	0.36
	D				0.05	0.14	0.18
DEG			Operation Range 50-100%	DEG 700kW			
PV					PV 630kW		
WT							
Hydro							
Controller							

A: Operation maintenance expenses are covered

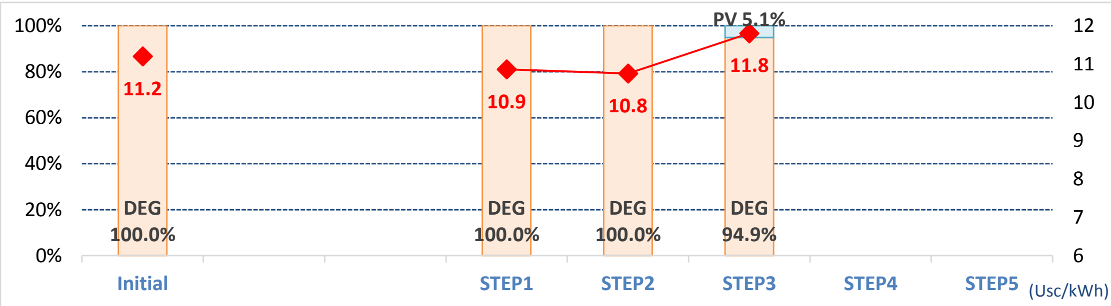
(initial and replacement costs not considered)



B: Initial, replacement and operation maintenance costs (price of Japanese products)

C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

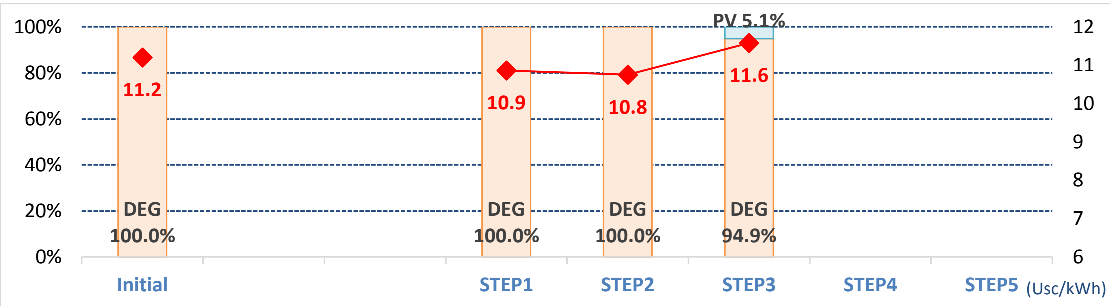


Figure 4-16 Aid measures road map for Nauru

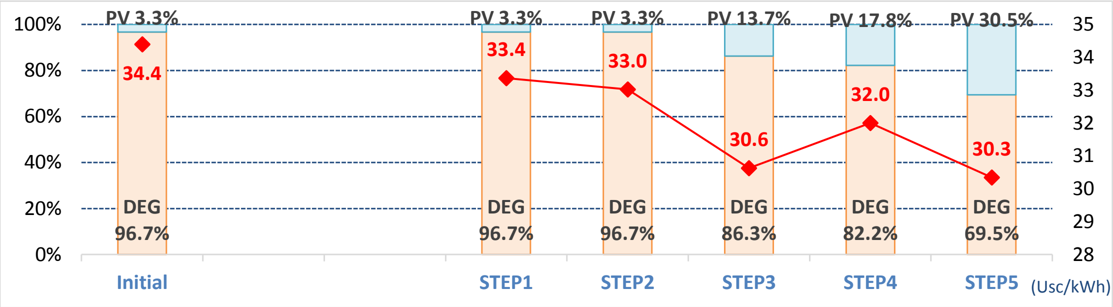
4.17 Niue

An expansion in RE deployment rate up to 30.5% can be expected by improving power plant operation flexibility by improving the operating range of existing DEGs and replacing 200 kW of existing DEGs, and deploying batteries for short-period, which would allow the deployment of approximately 600 kW of PV. However, the output of RE facilities must be suppressed as a long-period measure. Generation costs could be reduced to 30.3 USc/kWh.

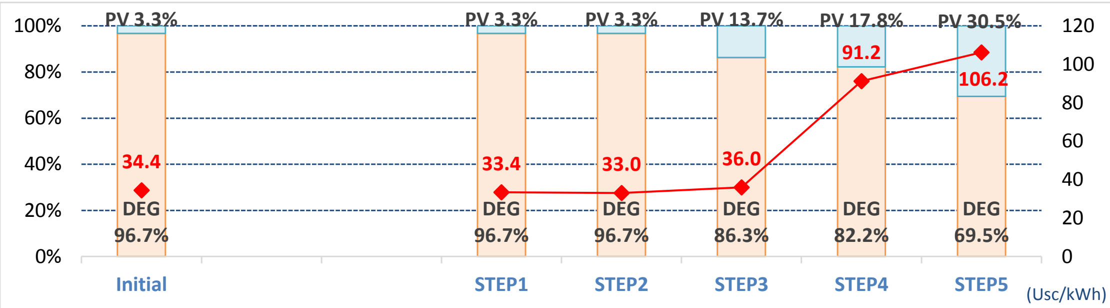
		Current Situation	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5
Fuel Reduction (kL/year)		---	22 (3%)	7 (1%)	78 (10%)	104 (14%)	202 (27%)
Generation Cost (USc/kWh)	A	34.4	33.4	33.0	30.6	32.0	30.3
	B				36.0	91.2	106.2
	C				33.3	38.7	43.8
	D				32.8	89.0	94.3
RE Fraction		3.3%	3.3%	3.3%	13.7%	17.8%	30.5%
Initial Cost (mil. USD)	A,B,C	---	0.2	0.4	0.0	0.5	4.0
	D		0.2	0.4	0.0	0.4	2.0
Additional O&M Cost (mil. USD/yr)	A,B,C	---	---	---	0.03	0.04	0.12
	D				0.02	0.02	0.06
DEG			Operation Range 50-100%	DEG 200kW			
PV					PV 200kW	PV 40kW	PV 500kW
WT							
Hydro							
Controller						Short Term Stabilizer	RE output control

A: Operation maintenance expenses are covered

(initial and replacement costs not considered)

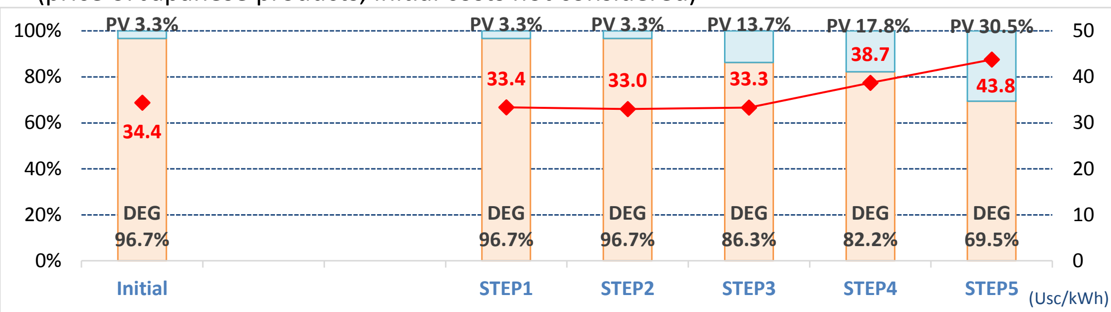


B: Initial, replacement and operation maintenance costs (price of Japanese products)



C: Replacement cost and operating expenses

(price of Japanese products, initial costs not considered)



D: Initial, replacement and operation maintenance costs (price of foreign products)

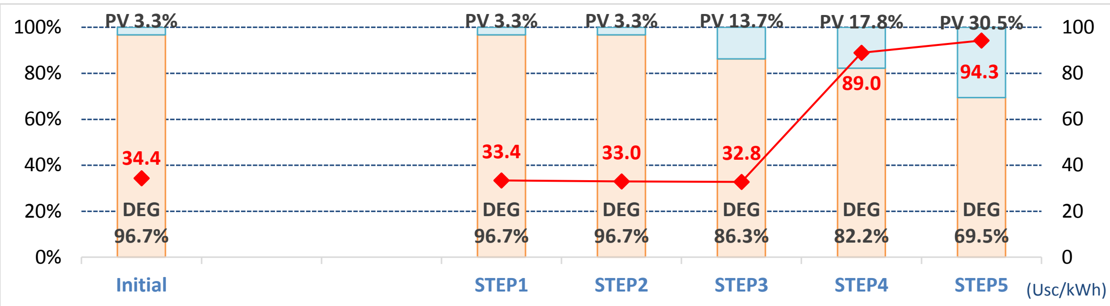


Figure 4-17 Aid measures road map for Niue

5. Summary

5.1 Summary of the policy for implementing aid measures for each target country

The RE deployment road map (draft) for aid measures for each target country mentioned in the preceding chapter is summarized in this chapter. Most of the target countries for the survey have already reached or will soon reach the integration capacity. However, as already mentioned in this report, PV and wind power are unstable power supplies, and considering the weather conditions in the Pacific countries which are susceptible to sudden changes, priority should be given to aid for improving the operational efficiency of DEGs, the main power supply, in order to realize a more stable supply of power. For example, grants for refurbishing and addition of DEGs and technical aid concerning the improvement of DEG operation and maintenance. After these, in order to realize an operation which brings about stability through the deployment of the appropriate amount of DEGs and renewable energy, it would be valid to consider grant aid and technical aid as aid for developing a microgrid system.

5.2 Closing Comments

When deploying PV and WT or other renewable energy on a large-scale to a small grid, how each device and control method is constructed is critical. In addition, RE equipment utilization rate, power quality, integration and maintenance costs, etc. must all be balanced for sustainable facilities management.

Since many RE utilize natural energy, the greatest benefit is that there are very little costs for the energy integrated, and if the equipment is operated efficiently over its lifetime, power costs can be reduced. However, since there is a large risk of failure, and it may in some cases affect power costs, care should be heeded.

RE devices are often exposed to harsh natural environments, and sufficient measures against storms such as cyclones, lightning, salt corrosion, etc. must be taken. Also, aside from regular maintenance, management of failures must also be considered, however in many cases, it is difficult to establish a system to immediately respond for restoration. For small power systems on remote islands, etc., since they are isolated and small, receiving backup power from other grids in abnormal times or emergencies is impossible, so it is ideal to effectively make RE devices used on remote island microgrids small and decentralized as splitting adjustability among various devices including DEGs is most effective for suppressing output fluctuations. By doing so, even if one part fails, the other parts can continue to operate.

Regarding main power supplies such as diesel generators, it is ideal to keep them in good condition in order to maintain an appropriate operating range and responsiveness to efficiently manage the short-period and long-period fluctuations derived from RE. In addition, it is desirable to preserve as much of the existing main power supply as possible, considering backup for RE equipment suspensions due to failure or exceeding their service life.

It is vital to consider maintenance costs, which provide for such measures, in order for people living in the scattered narrow lands in the Pacific region to break free from imported fuel (diesel) with erratically fluctuating prices and to improve the energy security of the power sector with the deployment of RE.