Energy Audit
under the Initiative on Distributed Energy System for Phayam Island

Final Report

14 March , 2023

Tokyo Electric Power Services Company, Inc.

TEPSCO 東電設計株式会社

Background & Objectives

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- Background
  - Some islands and industrial areas in the ASEAN region **rely heavily on diesel power generation** for power supply, and the issue is how to reduce fuel costs and greenhouse gas emissions.
  - Japan proposed the **Distributed Energy System Initiative** at the 9th East Asia Summit (EAS) Energy Ministerial Meeting held in Malaysia in October 2015, and the agreement was reached. As part of this initiative, a request was made for a survey on the introduction of a distributed energy system in Thailand.
  - DEDE requested METI, GoJ to conduct Energy Audits on Koh Phayam Island.
  - METI entrusted TEPSCO to conduct the study in December 2022.
- Purpose of the Study
  - This project targets **Koh Phayam Island**, Thailand, and conducts literature research, field surveys, and exchanges of opinions with local stakeholders to understand the power supply, power system, power load, and other energy situations. After analyzing these issues, we will develop and propose a distributed energy system that combines cogeneration, renewable energy, energy conservation, smart grids, microgrids, energy management systems, storage batteries, etc., based on technology, economic efficiency, environmental and social aspects, etc.
- Study Period
  - Dec. 2022 to Feb. 2023

What is TEPSCO

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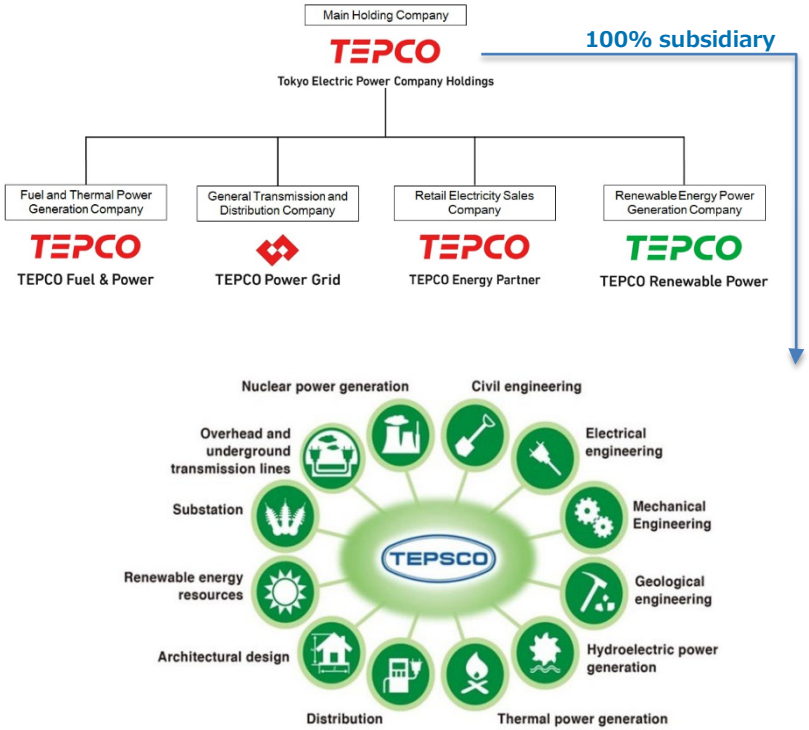
- Tokyo Electric Power Services Company, Inc. (**TEPSCO**) is a subsidiary of Tokyo Electric Power Company Holdings, Inc.(**TEPCO**).
- Established in December 1960 to provide consulting services in the power sector for electric power industries and others.
- TEPSCO has been entrusted with this study by the Ministry of Economy, Trade and Industry, Government of Japan.



Renewable Energy
TEPSCO is proactively advancing new technologies in the field of renewable energy sources like solar, wind, and hydropower to harmonize society with the natural environment and economic growth.

Thermal Power
We have been engaged in many thermal power projects worldwide, covering all stage of projects from feasibility studies to design/construction supervision.

Transmission and Distribution
Based on the latest technology, TEPSCO can propose a total energy solution for energy conservation, energy savings and harmonization of the surrounding area.

METI Study Team from Japan

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	Name / in charge of / e-mail		Name / in charge of / e-mail
	(TEPSCO) Project Manager Power Development Plan A		(TEPSCO) Project Planning / Financing
	(TEPSCO) Power Development Plan B Power System Analysis Computer Simulation		(TEPSCO) Economic and Financial Analysis Environmental and Social Considerations Coordinator
	(TEPSCO) Energy Management System Communication System		(TEPSCO) Energy Saving Technologies

Possible Solutions - Distributed Energy Systems -

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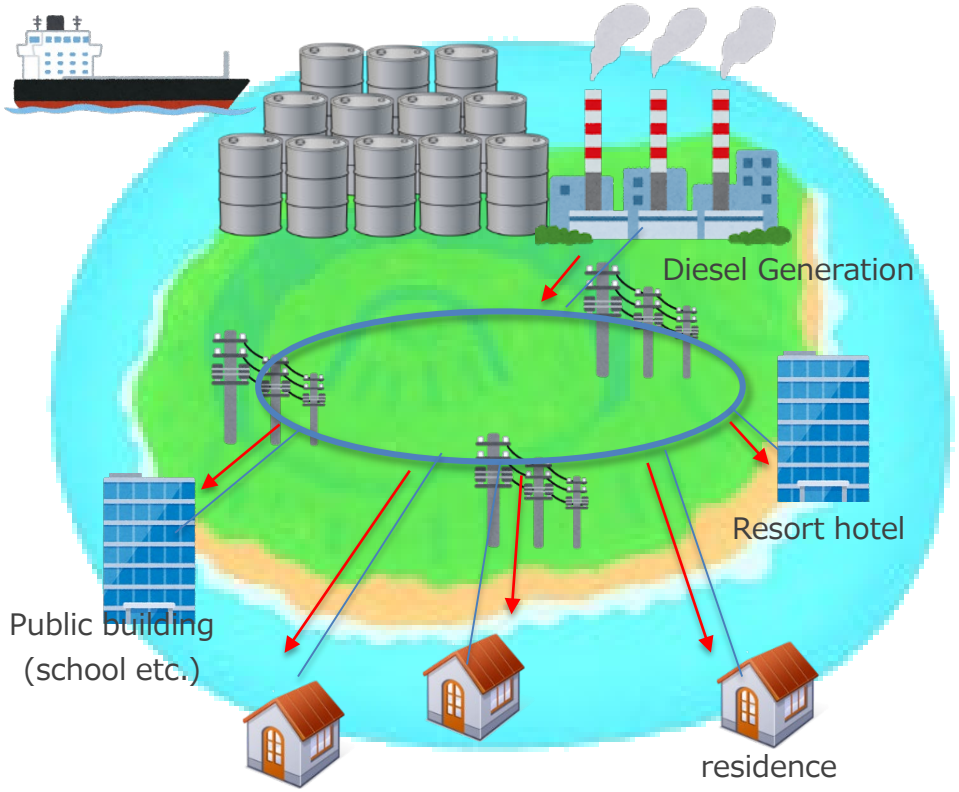
- The power supply of Phayam Island, which is the target of this study, highly depends on diesel power generation. It is assumed that the system proposed in this survey will replace this with renewable energy as much as possible.

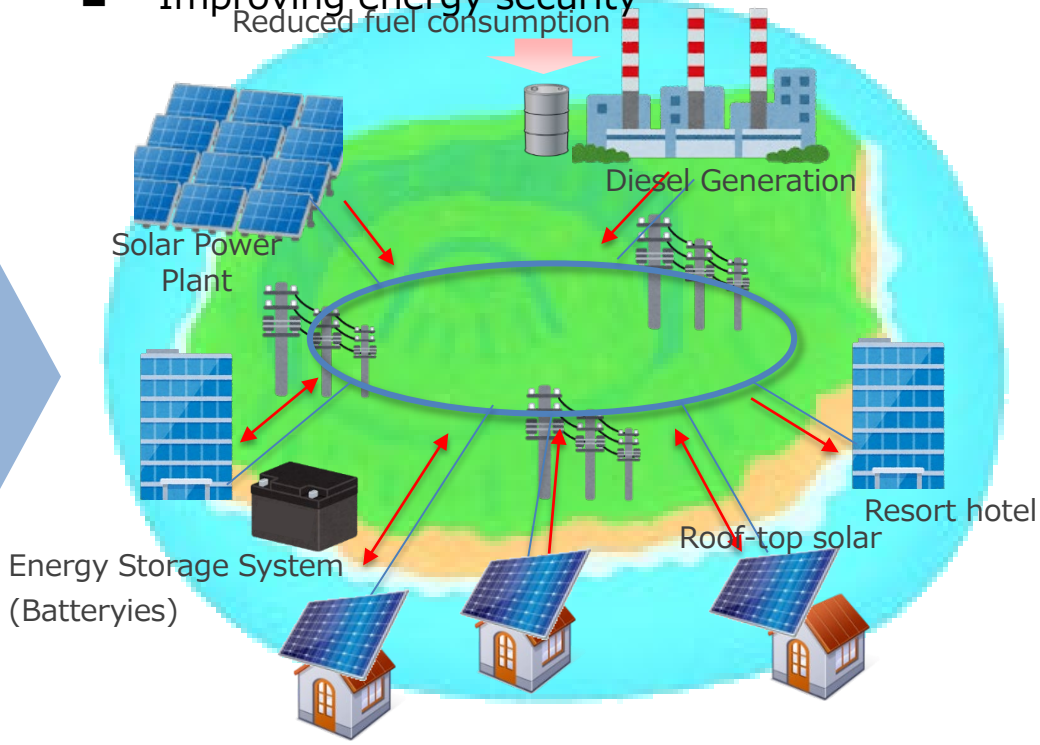
At the present

- Generation Cost is so high
- Energy cost tends to be affected by fuel price
- Electricity Sales price is 21 Bahts/kWh



Distributed Energy System

- Reducing fossil fuel consumption
- Fuel cost reduction → Power generation cost reduction
- Reduction of greenhouse gas emissions
- Improving energy security



Methodology of the study

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Preparation of the study	Identify of the needs by Thailand Basic data Collection
Online Meeting (19-Jan, 2023)	Explanation of the methodology of the Study Data Collection Agreement of the scope of the study
Site Survey (26-Jan to 3-Feb, 2023)	Interview to the local stakeholders Survey on the candidate site to be installed PV and BESS
Outline design of Distributed Energy System	Outline design of Distributed Energy System Pick up the candidate of technology and Interview to Manufacturers Supply and demand simulation → Estimate system kWh cost Estimation of the Project Cost Economic and Financial Analysis GHG reduction Effect Positive impact to the economy Environmental Impact Assessment
Project Evaluation	Preparation of the final draft report Introduction of Japanese Official Support Scheme and Energy Saving Technologies
Final Reporting (14-Mar, 2023)	Final reporting to DEDE

Schedule

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	Items	Dec	Jan	Feb	Mar
1	Preparation of the study Identify of the needs by Thailand Basic data Collection				
2	Explanation of the methodology of the Study Data Collection Agreement of the scope of the study				
3	Interview to the local stakeholders Survey on the candidate site to be installed PV and BESS				
4	Outline design of Distributed Energy System Pick up the candidate of technology and Interview to Manufacturers Supply and demand simulation Estimation of the Project Cost Economic and Financial Analysis GHG reduction Effect Positive impact to the economy Environmental Impact Assessment				
5	Preparation of the final draft report Introduction to Japanese Official Fund				
6	Final reporting to DEDE				

Work in Japan

Work in Thailand

Situation of Phayam Island

Renewable Energy Potential on the island

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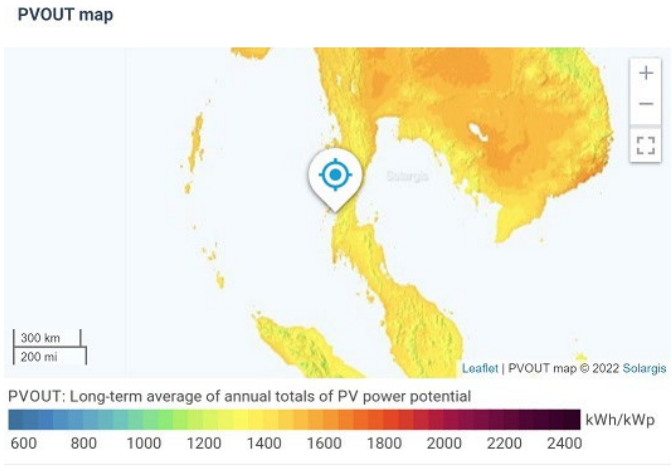
Solar Potential

- Global tilted irradiation at optimum: 1,836.8kWh/m^2
- 1MWpp Solar generates 1.472GWh annually. The potential is enough.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
5 - 6												
6 - 7			1	6	13	13	8	5	6	11	5	0
7 - 8	64	68	99	124	106	90	80	81	99	124	121	94
8 - 9	255	276	292	301	233	179	177	201	219	255	275	261
9 - 10	430	467	474	470	370	286	296	348	336	385	412	416
10 - 11	565	615	619	584	446	388	371	407	442	485	514	534
11 - 12	648	705	710	668	507	444	432	466	510	536	567	597
12 - 13	672	737	739	692	524	465	458	488	517	541	564	609
13 - 14	639	714	705	649	485	444	438	469	490	489	514	562
14 - 15	556	636	615	536	400	384	379	412	432	408	422	473
15 - 16	425	502	481	377	280	282	287	305	344	300	295	346
16 - 17	261	327	288	214	167	178	179	189	177	149	158	193
17 - 18	81	132	112	80	69	79	84	82	63	35	30	40
18 - 19	2	6	6	5	5	10	12	7	2			
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	4,598	5,185	5,140	4,707	3,605	3,242	3,201	3,461	3,637	3,718	3,877	4,125

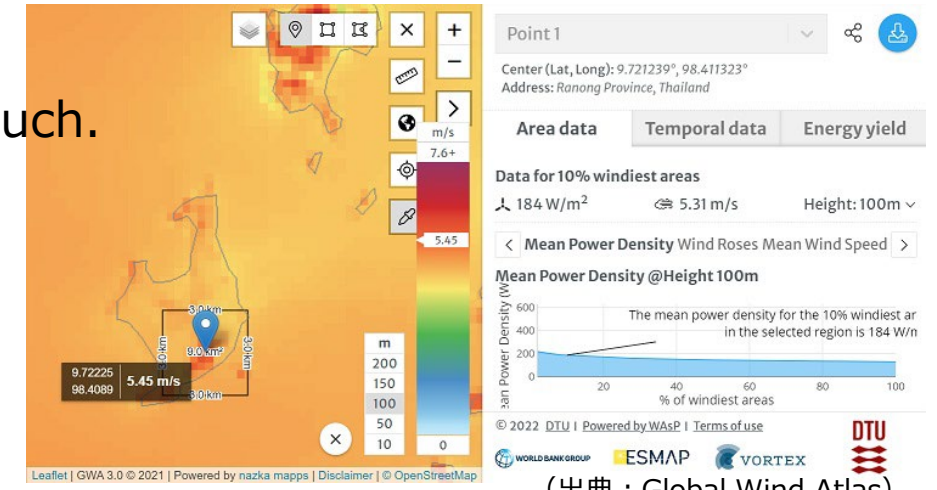
Source: globalsolaratlas.info

(source : Global Solar Atlas)

Wind Potential

- Mean wind speed : 4-5 m/s @height:100m
- Wind power doesn't generate electricity very much.

We target Solar+Battery+Diesel Hybrid System



(出典：Global Wind Atlas)

Power System on Phayam Island

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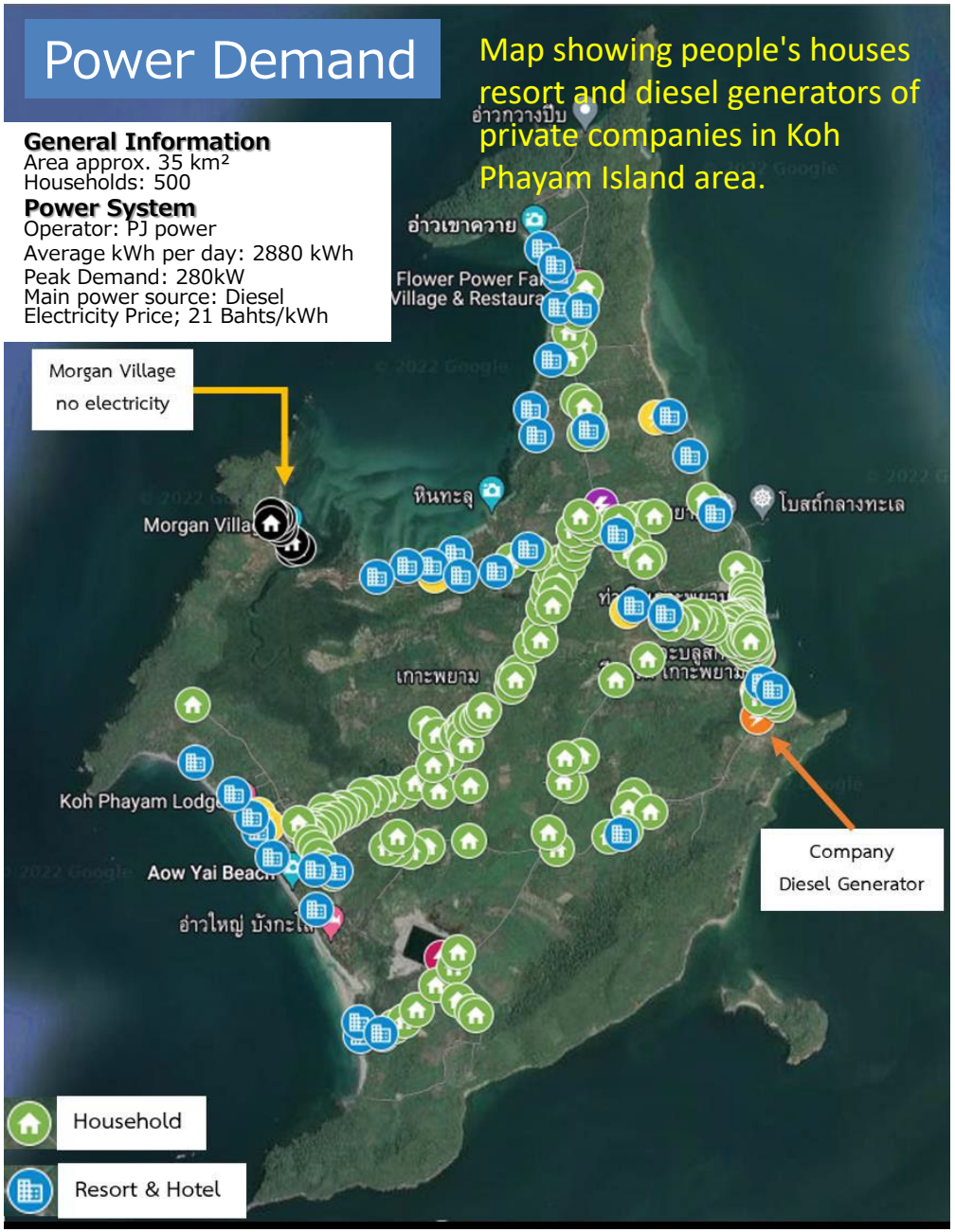
Power Demand

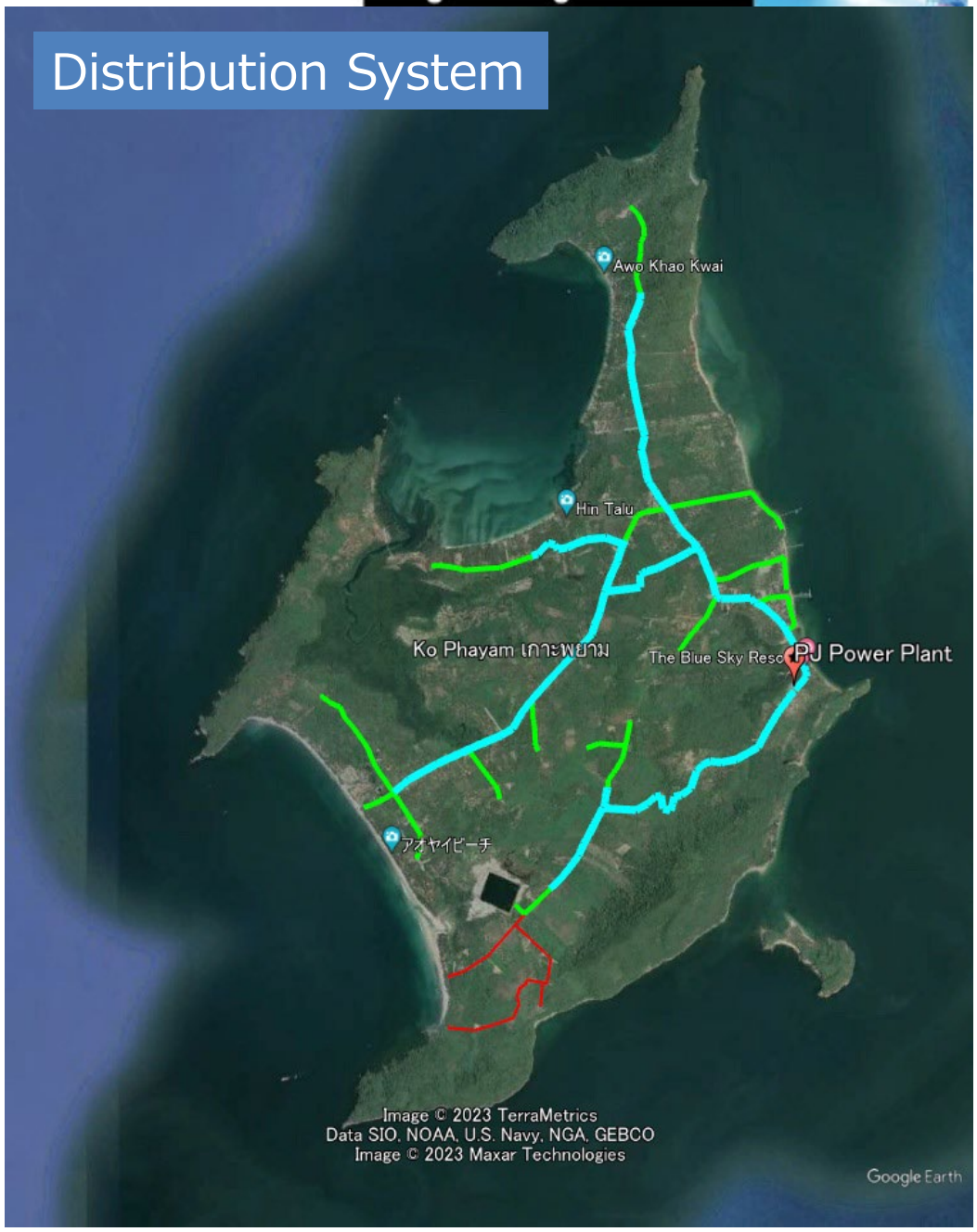
Map showing people's houses resort and diesel generators of private companies in Koh Phayam Island area.

General Information
Area approx. 35 km²
Households: 500

Power System
Operator: PJ power
Average kWh per day: 2880 kWh
Peak Demand: 280kW
Main power source: Diesel
Electricity Price; 21 Bahts/kWh



Distribution System



Renewable Energy Potential on the island

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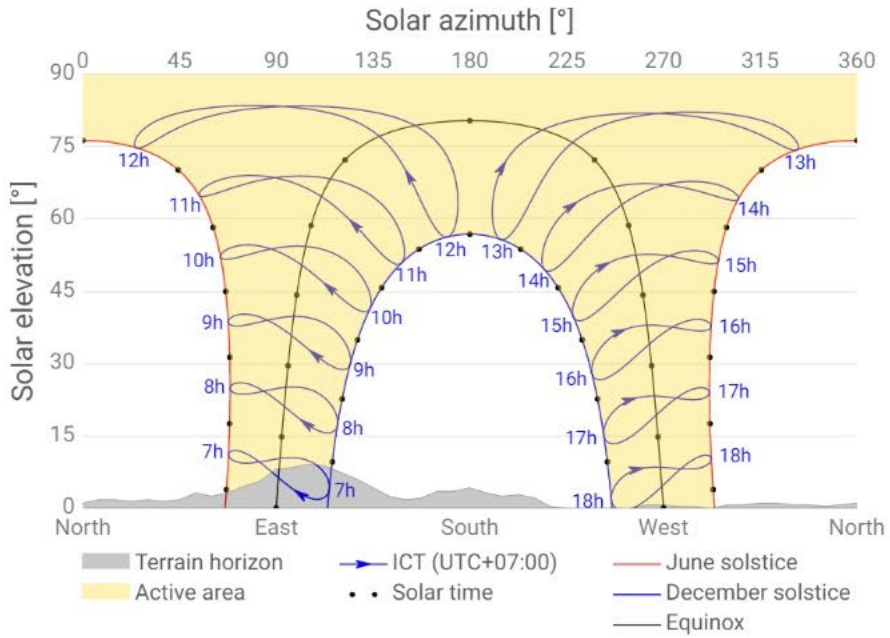
Map data

Per year

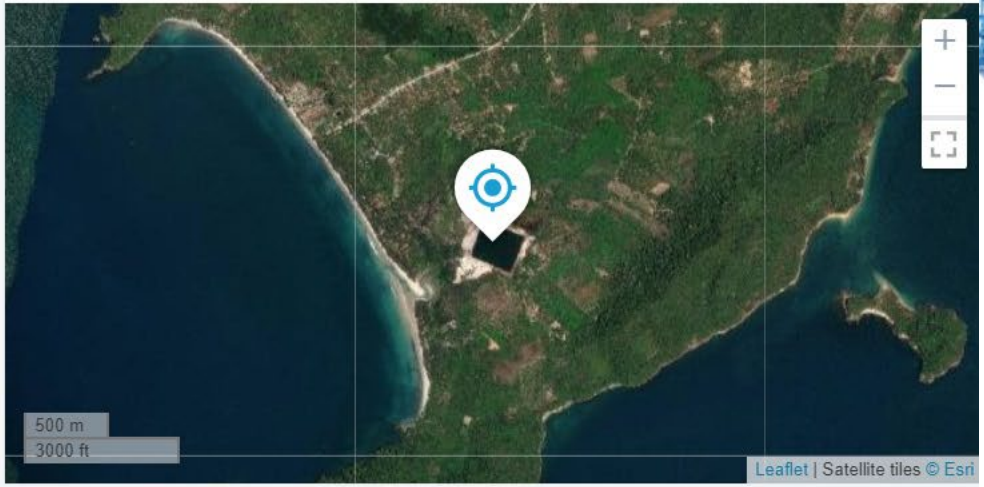
Direct normal irradiation	DNI	**1303.3**	kWh/m²
Global horizontal irradiation	GHI	**1816.6**	kWh/m²
Diffuse horizontal irradiation	DIF	**828.5**	kWh/m²
Global tilted irradiation at optimum angle	GTI opta	**1851.5**	kWh/m²
Optimum tilt of PV modules	OPTA	**12 / 180**	°
Air temperature	TEMP	**27.3**	°C
Terrain elevation	ELE	**8**	m

Horizon and sunpath

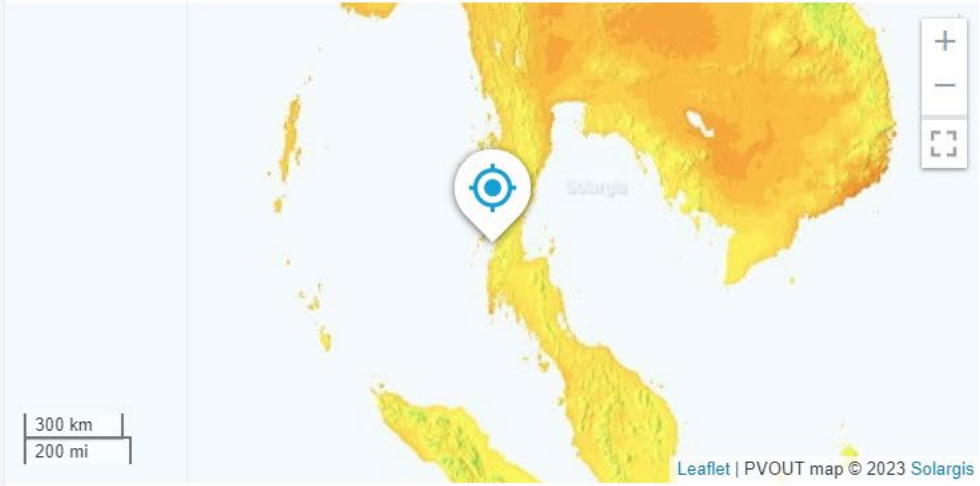


Map

Swich to map



PVOUT map



PVOUT: Long-term average of annual totals of PV power potential

kWh/kWp

600 800 1000 1200 1400 1600 1800 2000 2200 2400

Renewable Energy Potential on the island

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PV system configuration

Pv system: **Floating large scale**

Azimuth of PV panels: **Default** (180°)

Tilt of PV panels: **12°**

Installed capacity: **1000 kWp**

Change PV system

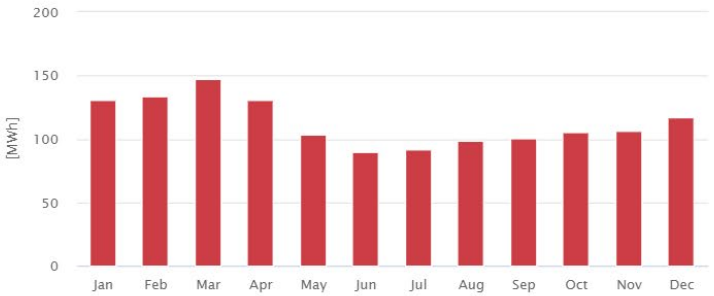
Annual averages

Total photovoltaic power output and Global tilted irradiation

1.353	1847.7
GWh per year	kWh/m^2 per year

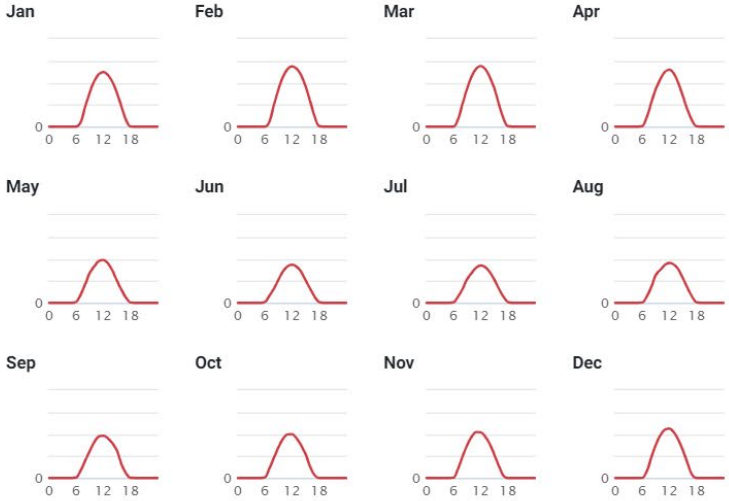
Monthly averages

Total photovoltaic power output



Average hourly profiles

Total photovoltaic power output [kWh]



Show details

UTC+07

Average hourly profiles

Total photovoltaic power output [kWh]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
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6 - 7			0	5	11	11	7	4	5	7	3	0
7 - 8	52	57	87	111	95	81	71	72	88	110	107	79
8 - 9	228	247	263	274	213	162	160	181	199	231	247	233
9 - 10	390	426	434	434	343	264	272	320	307	351	375	379
10 - 11	518	567	571	544	416	360	341	376	408	446	472	489
11 - 12	598	655	661	624	475	415	401	432	473	497	523	551
12 - 13	621	686	691	648	488	433	425	454	481	500	521	562
13 - 14	589	662	657	604	451	413	407	435	453	450	472	518
14 - 15	510	588	569	495	369	355	350	380	397	374	386	433
15 - 16	386	460	441	345	255	257	264	279	315	272	267	313
16 - 17	233	295	261	194	150	162	163	171	159	132	140	172
17 - 18	78	117	100	71	61	71	75	74	56	32	28	39
18 - 19	1	6	6	4	4	8	10	6	2			
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	4,205	4,765	4,741	4,353	3,333	2,991	2,946	3,184	3,343	3,400	3,542	3,767

Proposed Distribution Energy System for Phayam Island

Proposed Distributed Energy System in Koh Phaya

Based System and Proposed System for Electricity Supply

Base System: Diesel Generation

Proposed System: Diesel Generation + PV + Battery Storage System

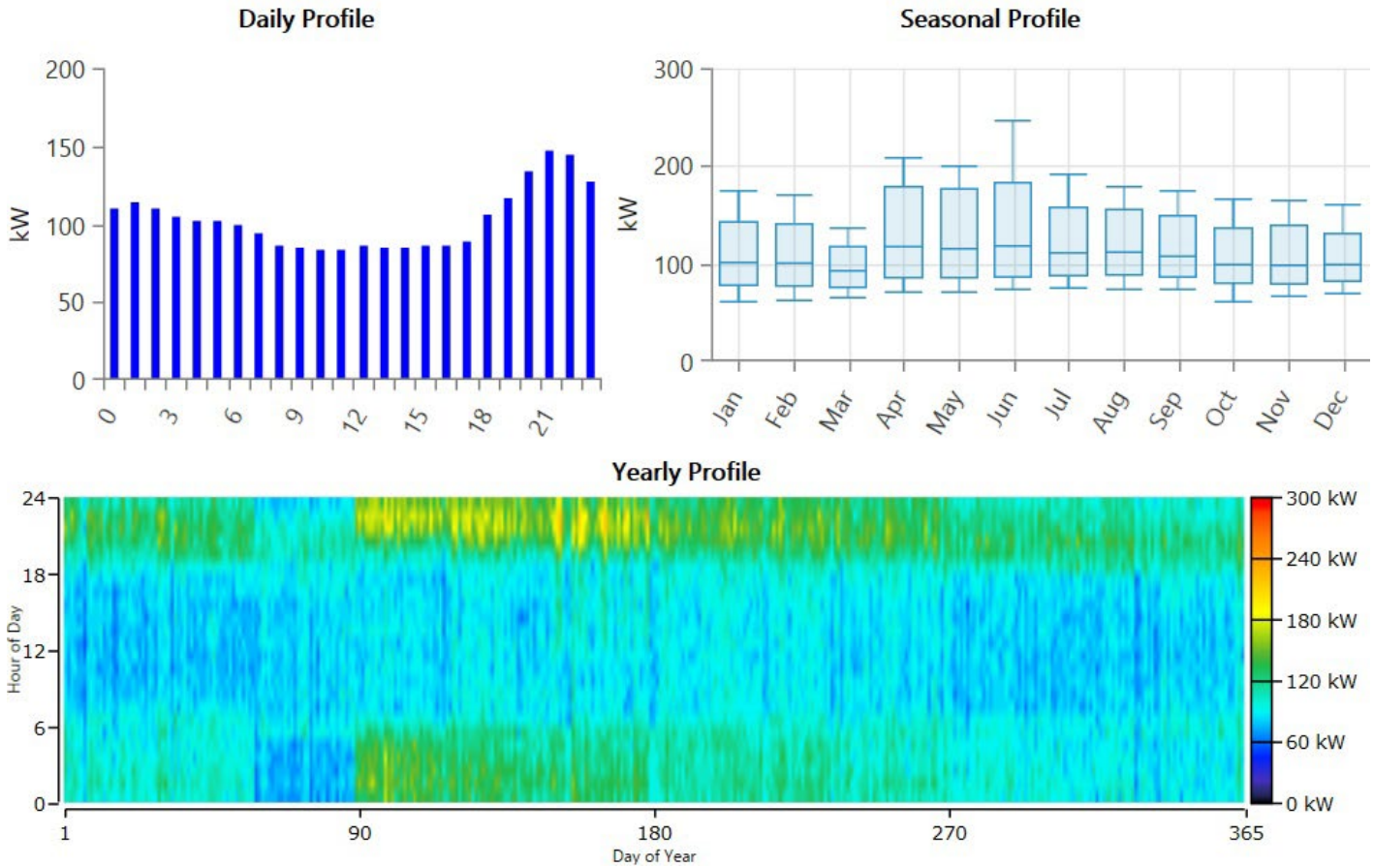
- Currently, Electric Power of Koh Phayam Island is mainly supplied by diesel generation.
- Hybrid system that combines Diesel Generation, PV and Battery Storage System is proposed.

Indicators and parameters for Evaluation

Evaluation Indicator	EIRR
Project Lifetime	30 years
Social Discount Rate	3%

- Evaluation indicator: EIRR (Economic IRR)
- The evaluation period of the project is 30 years
- Social discount rate for the evaluation is considered as 3% in reference to the recent long-term interest rate of Thailand

Load Profile



Estimated Annual Load Profile for Koh Phayam

- Load profile is estimated based on data provided from DEDE and daily load curve published by Load Research of PEA
- Average kWh per day is 2880 and peak demand is 280 kW

Parameter Assumptions of Equipment

	Parameters	Values
Diesel generator	Minimum load	70%
	lifetime	20,000 hours
	Fuel curve	Intercept: 0.0417 l/hr Slope: 0.28 l/hr/kW
	Capital cost	400 USD/kW
	Replacement Cost	280 USD/kW
	O&M	0.11 USD/hour
	Diesel Fuel Price	0.88 USD/litre
Solar PV	Lifetime	30 years
	Capital cost	960 USD/kW
	Replacement cost	960 USD/kW
	O&M(PV & Inverter)	20 USD/kW/year
PV Inverter	Efficiency	98%
	Lifetime	10 years
	Capital cost	Included in PV costs
	Replacement cost	135 USD/kW
Battery	Battery technology	Li ion
	Capital cost	500 USD/kWh
	Replacement cost	350 USD/kWh
	O&M	12 USD/kWh
	Lifetime	Time: 10 years, throughput: 3,000 kWh
	Round-trip efficiency	90%
	Initial SOC	100 %
	Minimum SOC	10%

Simulation Results of Electricity Production(MWh)

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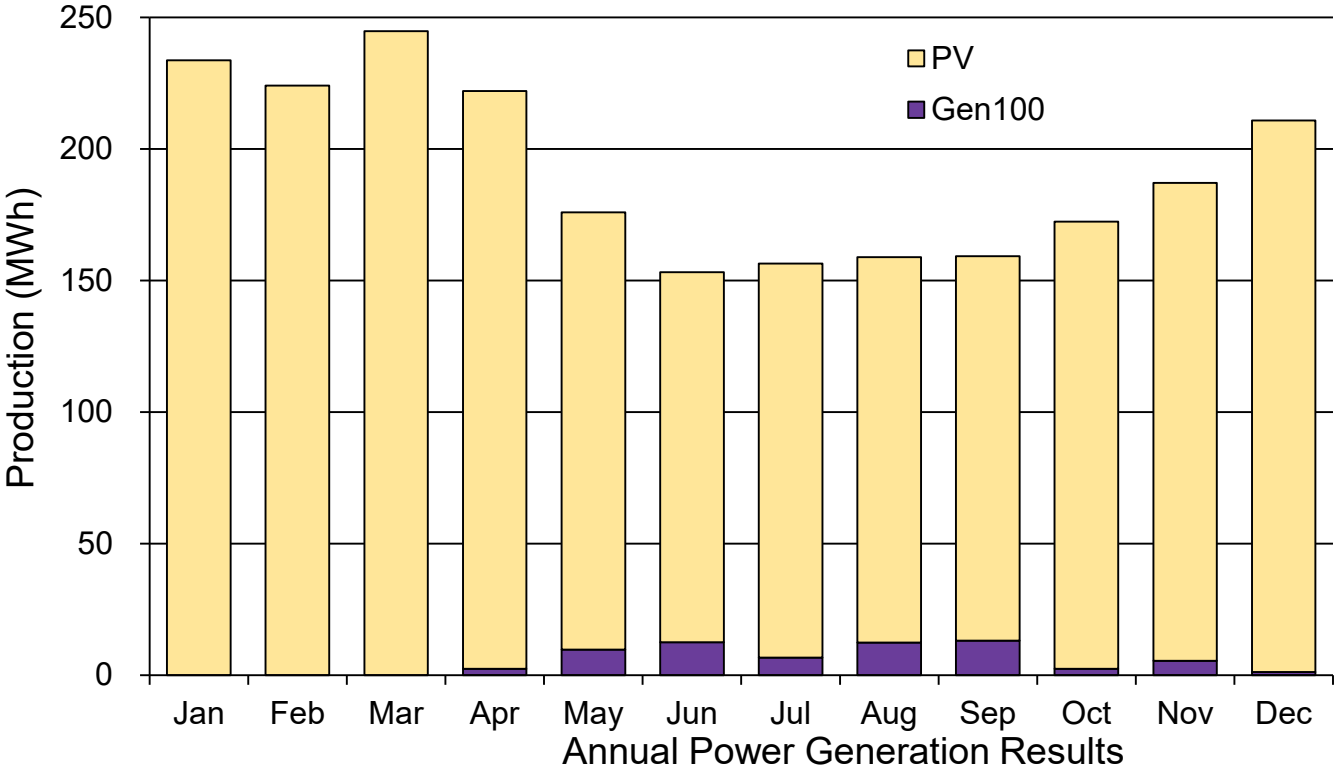
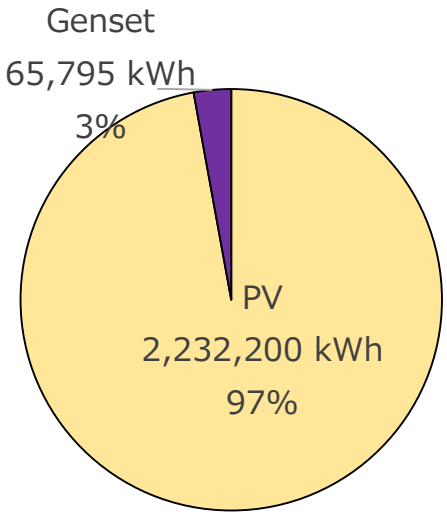
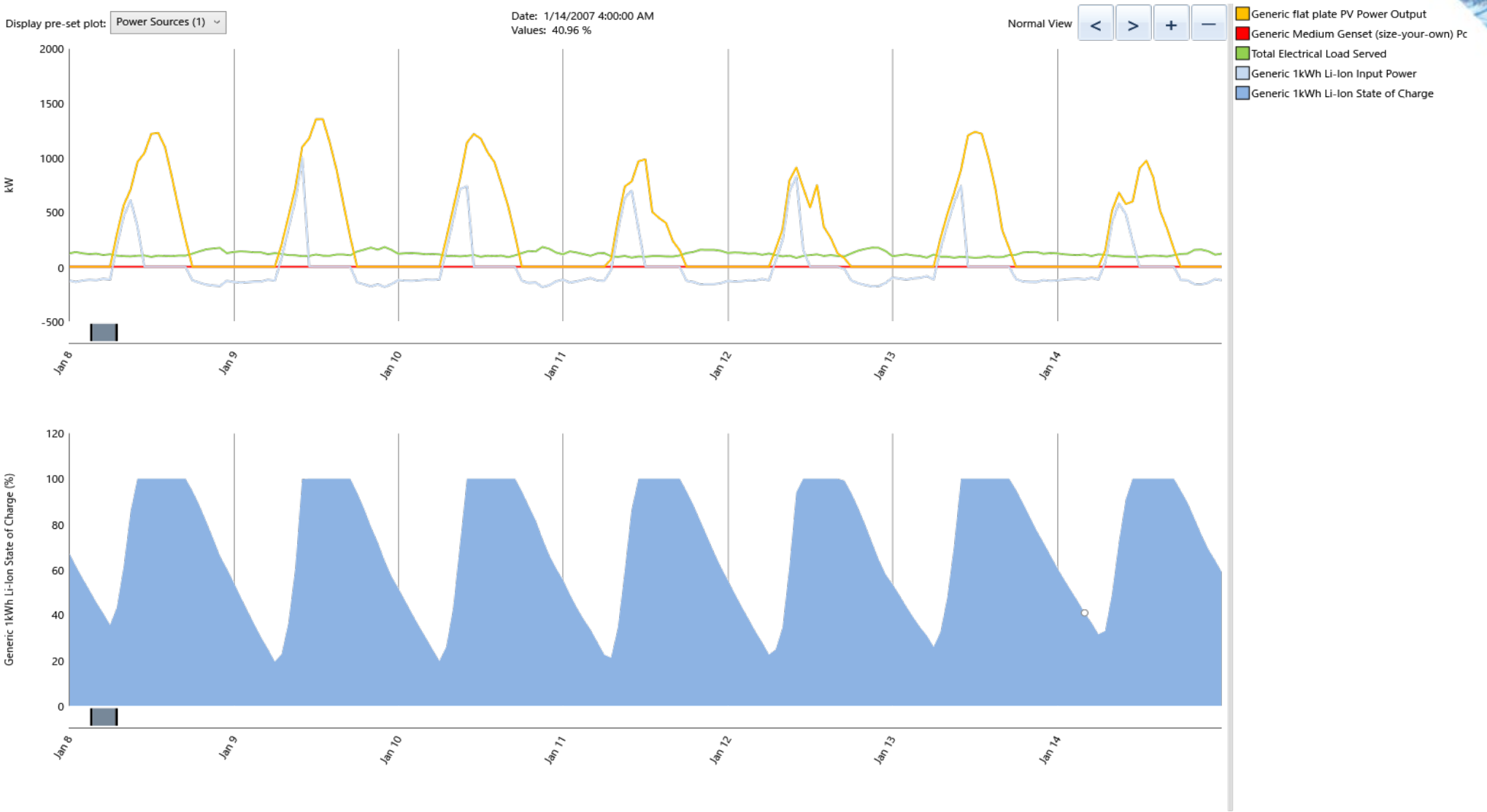




- 2,232,200 kWh by PV, 65,795 kWh by Genset
- From May to September, the amount of power generated by PV decreases due to the monsoon season
- As a result, the operating performance of diesel power generation increases.
- In June, electricity production by PV is 125.8 MWh and by diesel is 13.94 MWh.

Simulation Results of Power Demand and Supply

- In this week, solar radiation is high enough to cover electricity demand
- And so electricity can be supplied only by PV and Battery without operating Diesel Generation



Weekly Power Demand and Supply Results in January

Simulation Results of Power Demand and Supply

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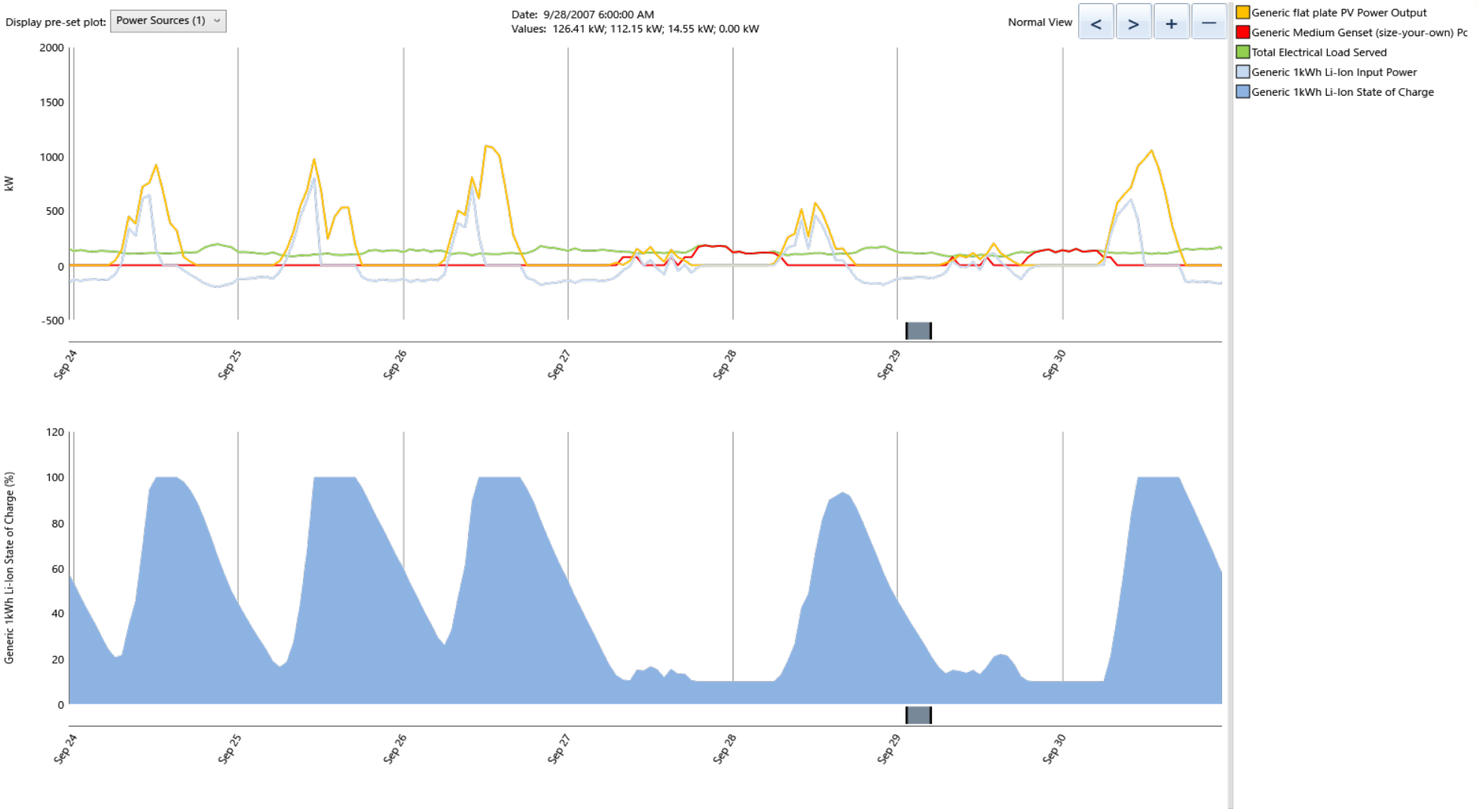
- According to the graph, the amount of power generated by PV is insufficient to meet the demand.
- So, Diesel Generation is needed to operated frequently.



Weekly Power Demand and Supply Results in September

Diesel Generation

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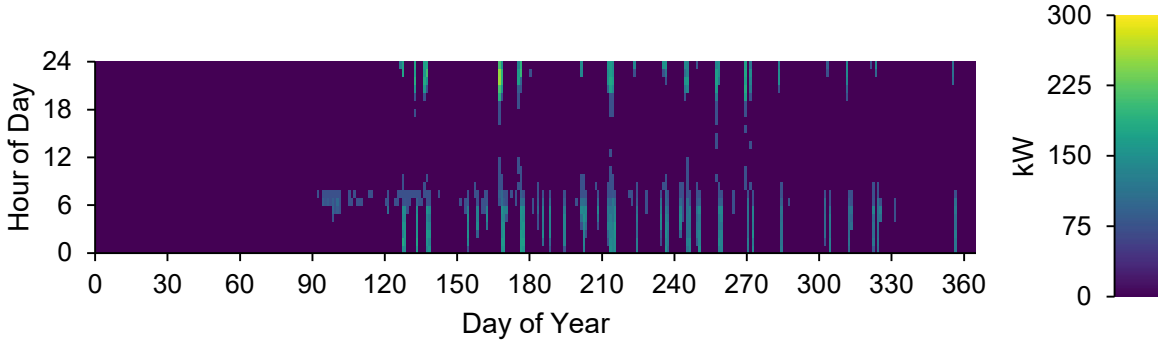
Annual Operation Results of Diesel Generator System

Power output from the Generic generator system, rated at 300 kW using Diesel as fuel, is 65,795 kWh/yr.

Capacity	300 kW
Operational Life	33.4 yr
Capital Cost	$120,000
Fuel Consumption	25,916 L
Hours of Operation	599 hrs/yr
Fixed Generation Cost	48.2 $/hr

Generator Fuel	Diesel
Generator Fuel Price	0.880 $/L
Maintenance Cost	19,767 $/yr
Electrical Production	65,795 kWh/yr
Marginal Generation Cost	0.246 $/kWh



- LCOE of Diesel Generation is 24.6 cents per kWh.
- It is mostly operated in the night- time during monsoon season when PV generation is insufficient.

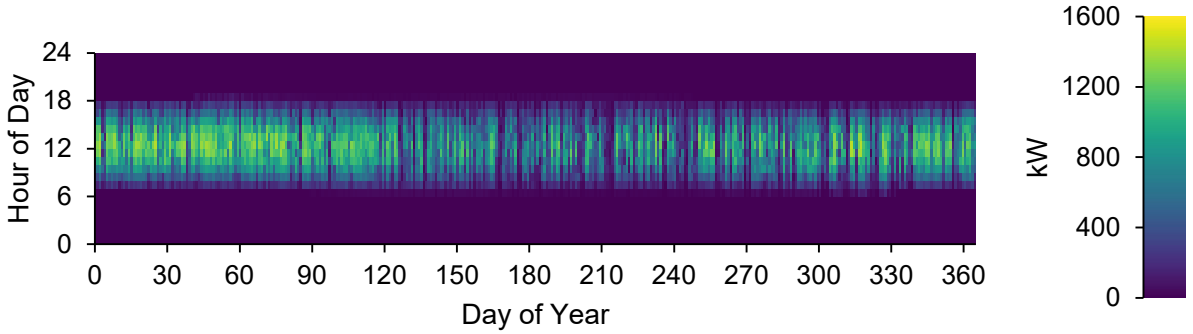
PV System

Annual Operation Results of PV System

The Generic PV system has a nominal capacity of 1,472 kW. The annual production is 2,232,200 kWh/yr.

Rated Capacity	1,472 kW
Capital Cost	$1.41M
Specific Yield	1,516 kWh/kW
PV Penetration	212 %

Total Production	2,232,200 kW
Maintenance Cost	29,441 $/yr
LCOE	0.0343 $/kWh



- LCOE of PV is 3.43 cents per kWh.
- Due to the weather effect of monsoon period, the amount of electricity produced by PV is 10% to 20% of maximum PV output.

Battery Storage System

The Generic storage system's nominal capacity is 2,420 kWh. The annual throughput is 623,754 kWh/yr.

Rated Capacity	2,420 kWh	Expected Life	10.0 yr
Annual Throughput	623,754 kWh/yr	Capital Costs	$1.21M
Maintenance Cost	30,250 $/yr	Losses	65,700 kWh/yr
Autonomy	18.2 hr		

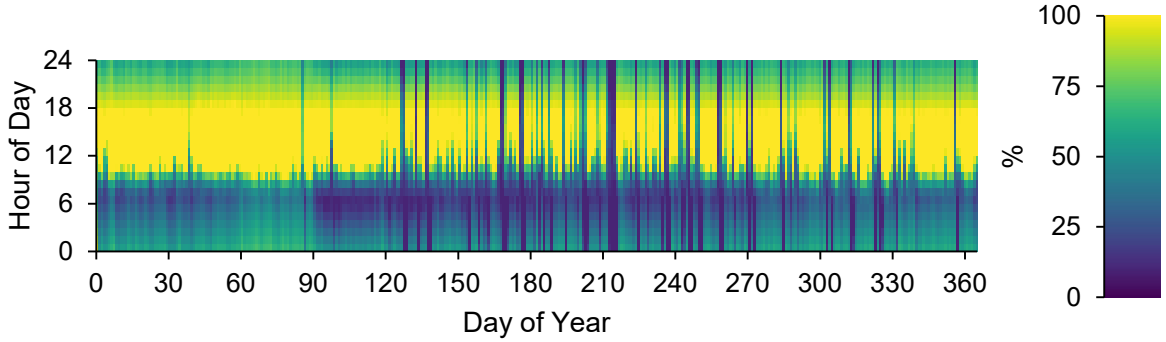


Fig 8. Annual Operation Results of Battery Storage System

- Battery is charged to 100% from 7:00 to 18:00.
- It can provide power when electrical loads require more power than the PV panels are generating.

Optimization of Capacity

Optimum Results of Installed Generation Capacity

	PV (kW)	Genset (kW)	Li-ion (kWh)	Cost/NPC ($)	Cost/LCOE (Cent/kWh)	OPEX ($/yr)	CAPEX ($)
(Proposed) PV+BATT+Diesel	1,472	300	2,420	5.87 M	24.0	166,229	2,610,000
(Base Case) Diesel		300		13.6 M	65.7	686,881	120,000

- In this proposed Micro Grid System, installed capacity of PV is 1,472 kW, Diesel Generator 300 kW and Battery is 2,420 kWh.
- Although LCOE (Levelized Cost of Electricity) of the current power generation system on Koh Phayam is 65.7 Cent/kWh, it can be reduced to 24.0 Cent/kWh in this combined Micro Grid System.
- Moreover, fuel consumption can be reduced from 403,934 liter per year to 25,916 liter per year. (93% reduction)

Economic Analysis

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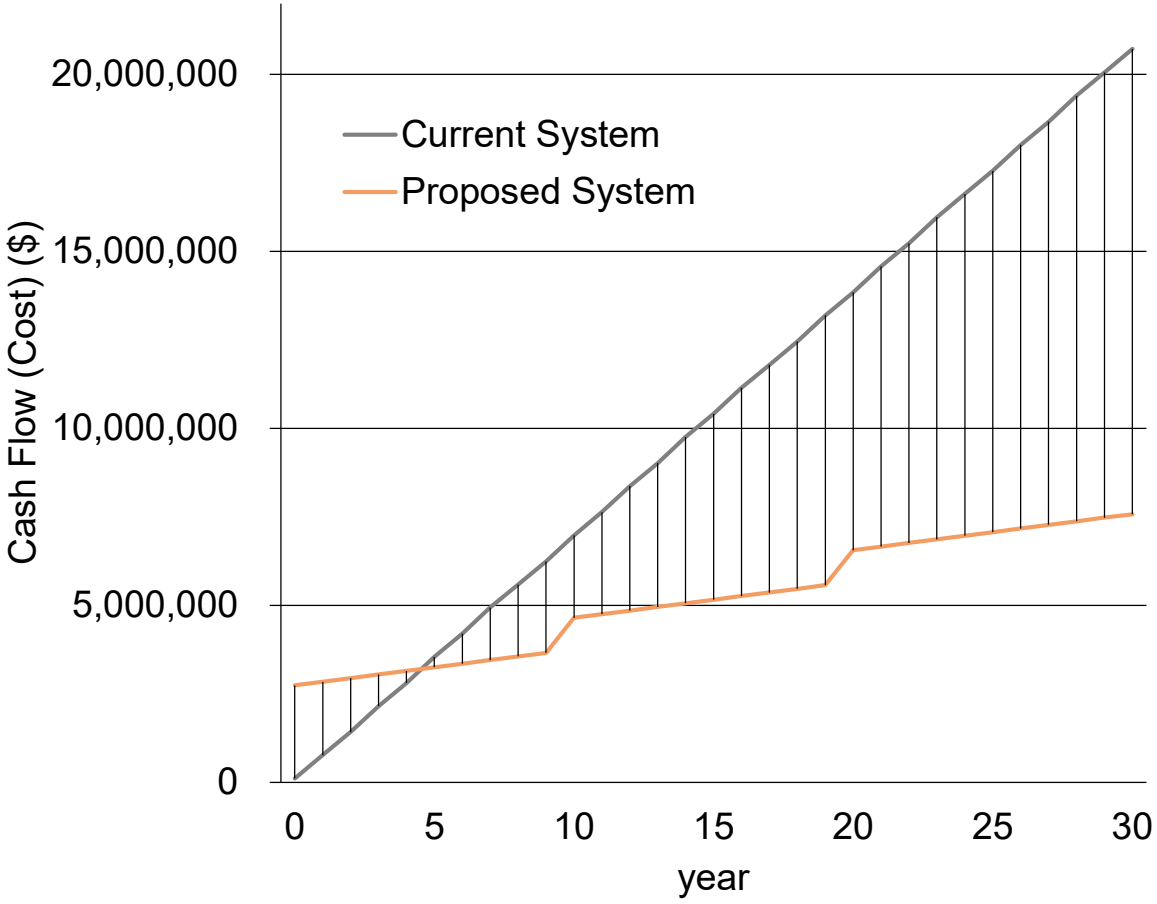
Simple payback:	4.53 yr
Return on Investment:	16.7 %
Internal Rate of Return:	20.8 %

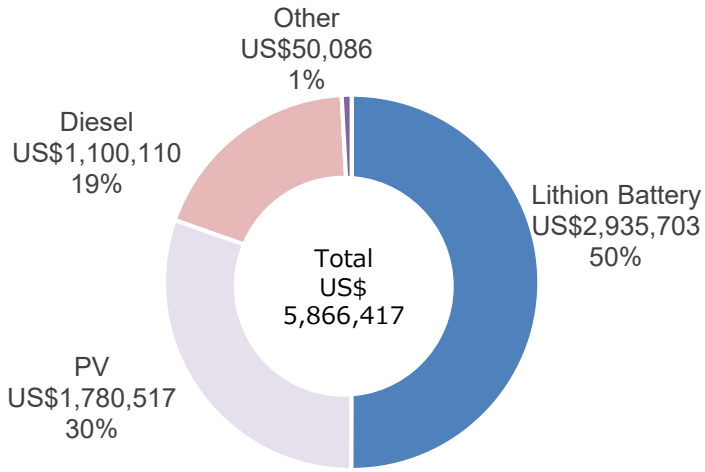
Net Present Value:	$13.1M
Capital Investment:	$2.62M
Annualized Savings:	$525,464

EIRR＝20.8%



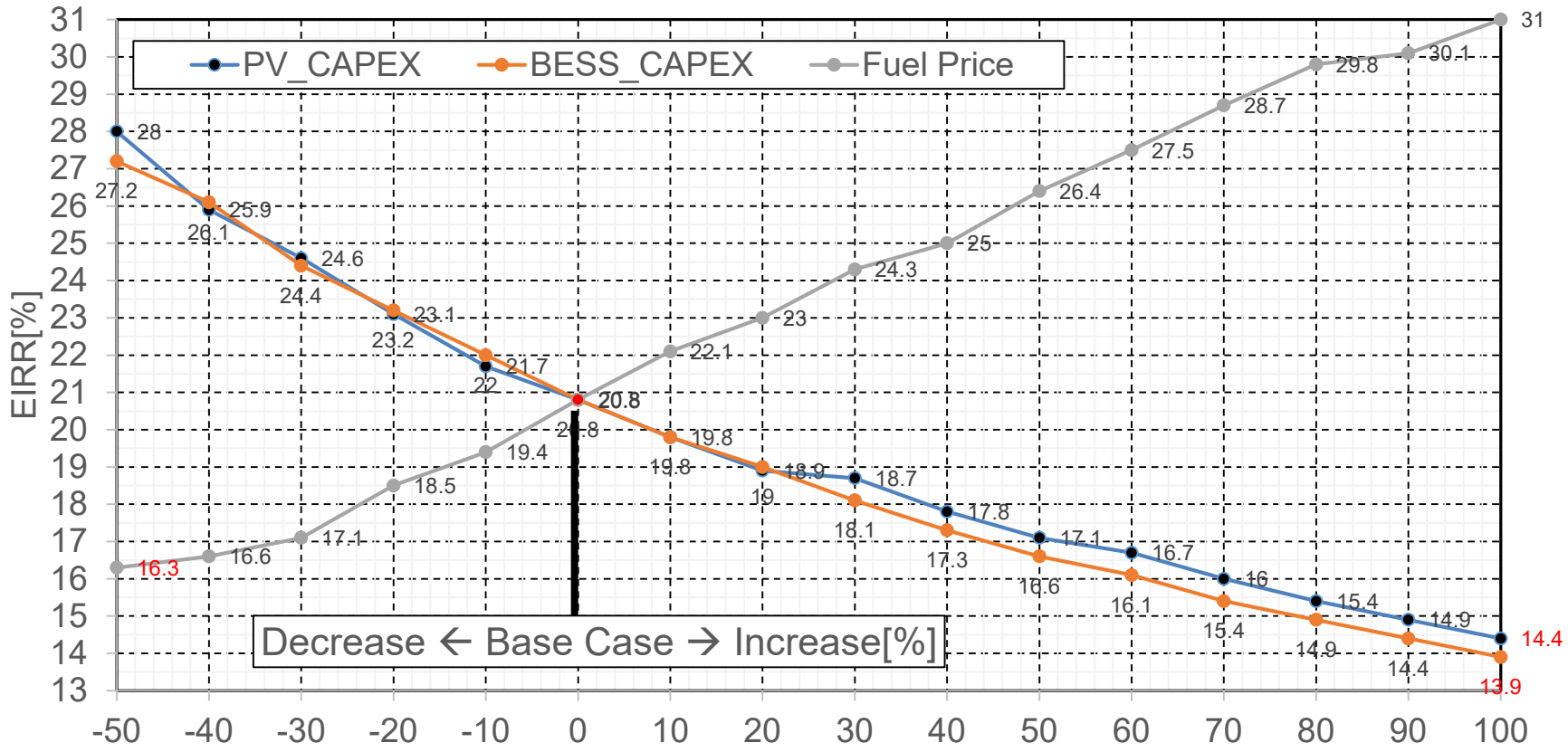
Cumulative Cash Flow over Project Lifetime

- Financial Analysis is evaluated based on distributed energy system (Solar + Battery Storage + Diesel) compared with current system operated with 100% diesel generation
- Return on Investment of Micro Grid Project is resulted as Simple Payback of 4.53 years and EIRR of 20.8%.



Net Present Cost throughout the Project Lifetime (Proposed System)

Sensitivity Analysis



Sensitivity Analysis of PV, Battery and Fuel Cost within the range from -50% to +100%

- Sensitivity analysis with EIRR was simulated by changing the CAPEX of PV and storage batteries from -50% to +100%.
- EIRR was decreased from 20.8% to 14.4% in the case of increasing of PV CAPEX to 100%.
- EIRR was decreased from 20.8% to 13.9% in the case of increasing of Battery CAPEX to 100%.
- EIRR was decreased from 20.8% to 16.3% in the case of decreasing of fuel cost to 50%.

Reduction of Greenhouse Gas (GHG) Emission

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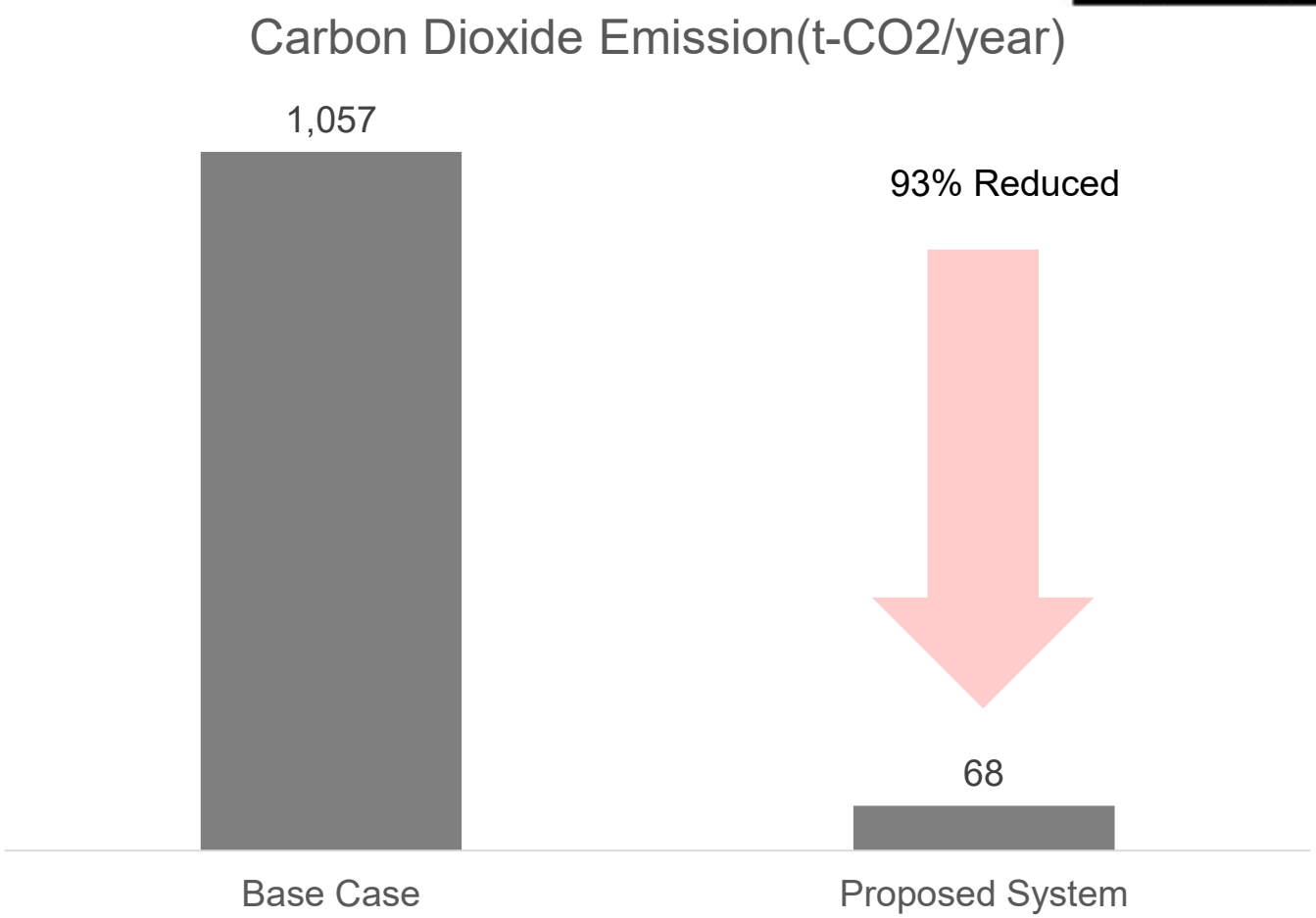


Reduction of Emission (kg/year)

Quantity	Based Case	Proposed System	Amount of Reduction
Carbon Dioxide	1,056,523	67,785	988,738
Carbon Monoxide	7,188	461	6.727
Unburned Hydrocarbons	291	18.7	272.3
Particulate Matter	28.8	1.85	26.95
Sulfur Dioxide	2,589	166	2,423
Nitrogen Oxides	575	36.9	538.1

Candidate Site for Solar PV (Ao Yai Reservoir)

- Ao Yai Reservoir is the best candidate site for solar PV
- It has sufficient space to install floating solar (Width 200m×Length 200m×Depth 3m)
- Not located inside National Park area

Summary

- According to the simulation results, optimized installed capacity of generation system, and economic analysis of micro grid system can be identified.

- Conventional diesel power generation had an LCOE of 65.7 Cent/kWh, but in the proposed hybrid system (1.472 MW of photovoltaic power generation, 2.420 MWh of storage battery, and 300 kW of diesel generator), Levelized Cost of Electricity will be 24.0 Cent/kWh.

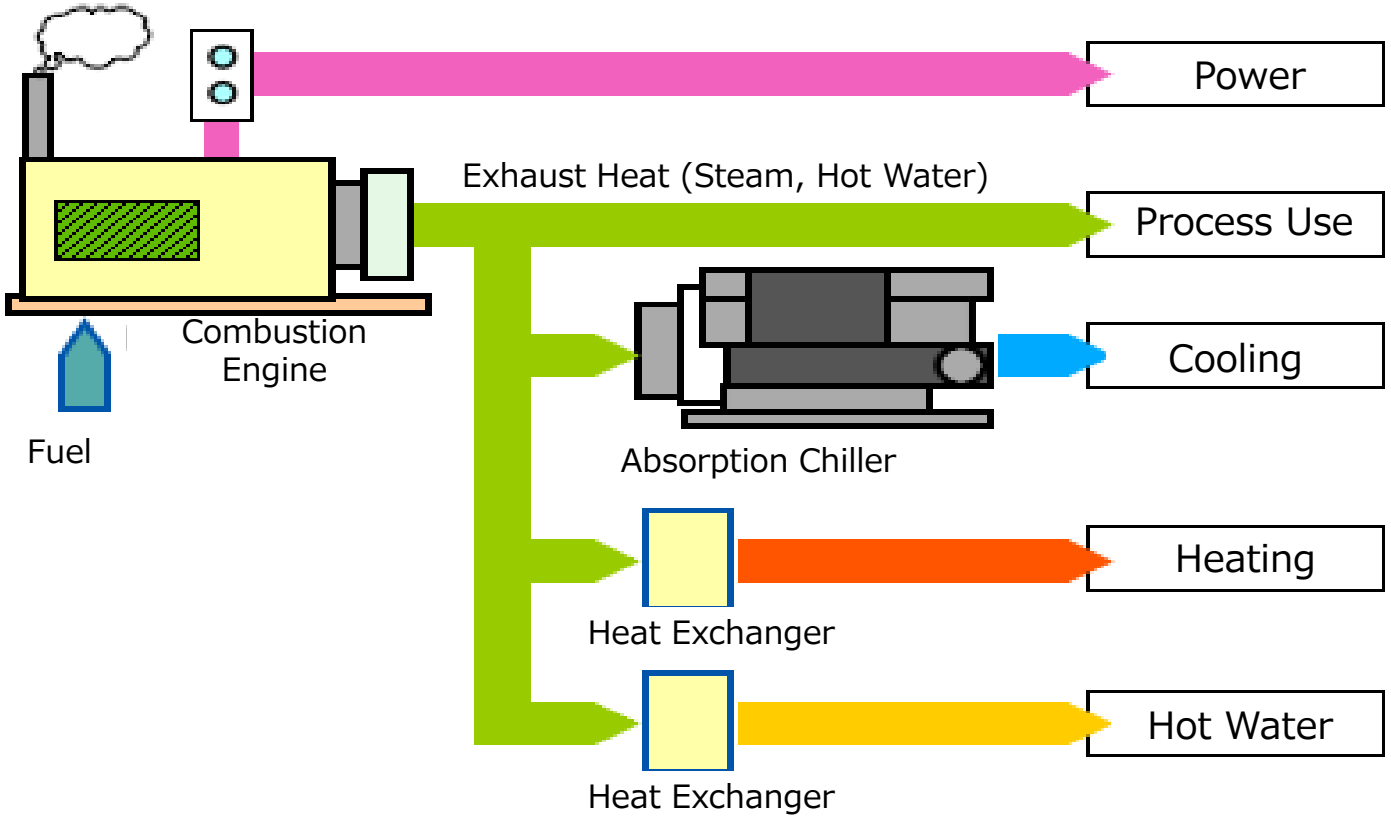
- When evaluating the proposed system comparing with diesel power generation as a base case, the investment effect of the proposed system will be 4.53 years with an EIRR of 20.8%, indicating that the project is extremely economically effective.

- In the base case, 1,056 t-CO2 of carbon dioxide was emitted every year, but in the proposed system, emission of CO2 can be reduced by 93% due to annual carbon dioxide emission of 68 t-CO2.

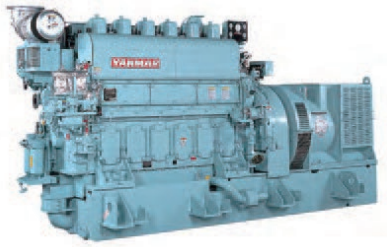
Energy Efficiency Technology for Phayam Island

Co-Generation

- Diesel engine for electricity production is used now in Phayam Island.
- In general, heat in the exhaust gas can be used for heating by attaching heat recovery system.
- However, there is some conditions to be advantageous for using heat. Pipeline for circulating the heat energy is necessary. Heat demand has to be close to the diesel generator considering heat loss reduction.



Various Types of Co-Generation in Japan

	Internal Combustion Engine			Electro Chemical Type
	Gas Engine	Gas Turbine	Diesel Engine	Fuel Cell
	 (Source:Yammar)	 (Source:Mitsui E&S)	 (Source:Yammar)	 (Source:Fuji Electric)
Fuel	LNG, LPG, Biogas	LNG, Kerosene	Heavy oil, diesel, Kerosene	LNG, Biogas, Pure Hydrogen
Heat recovery	Steam 0.8-0/9 Mpa Hot water 80-90 degC	Stem 0.8-0.9 Mpa	Stem 0.8-0.9 Mpa Hot water 80-90 dec C	Hot water 60-90 deg C
Power generation	135-10,780 kW	295-50,800 kW	60-2.900 kW	3.5, 4.2, 100kW
Power generation efficiency	26-50%	23-40%	32-42%	40-50%
Combined efficiency	70-80%	80%	70-85%	84-95%
features	-High power generation efficiency compared to the turbine	-Smaller and lighter than the same capacity of engine -Low vibration	-Wide range of the lineup -Applicable without LNG or LPG	-High generation efficiency -Low noise & vibration

(Source: The Study Team)

LED Lighting

Comparison of Lighting types

Lamp type	Mercury lamp	High pressure sodium vapor lamp	Ceramic metal halide lamp	**LED**
Fixture				
Efficiency	55 lm/W	114 lm/W	114 lm/W	**70-80 lm/W**
Power Consumption	470W	285W	285W	**158W**
Lamp life	12,000 h	24,000 h	24,000 h	**60,000 h**
Reduce illuminance	possible	possible	possible	**Possible**

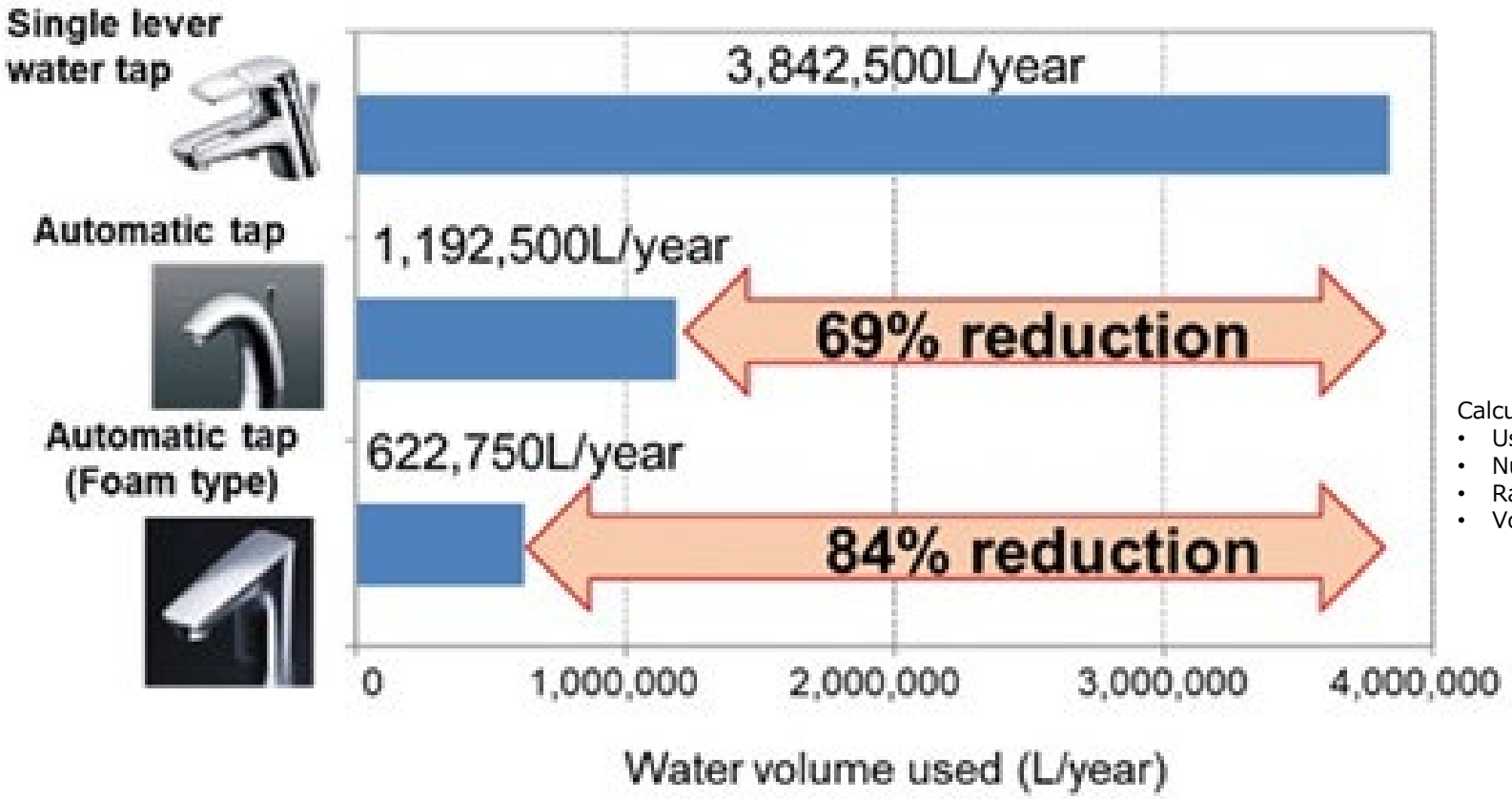
(Source: Iwasaki Electric)

- LED is now used for street lighting in Japan.
- The power consumption is low compared with other types.
- long lifetime
- Dimming function to adjust the brightness for energy efficiency.

Street lighting with LED

Automatic Water Taps

- Compared with a conventional tap operated manually, an automatic water tap can drastically reduce the volume of water used.
- Automatic water taps can switch on by sensors for hands.
- It can automatically start or stop the water.
- In Japan, they are used for sinks in toilets to wash hands.
- Retrofitting is possible at a reasonable price.



Calculation conditions:
- Users: 1,000 persons
- Number of annual working days:265
- Rate of usage 5 times/person(hand washing)
- Volume of water per instance of use
  Dual handle tap fixture:
  hand washing 2.9L/instance
  Automatic tap:0.93/instance
  Automatic tap(Foam type):0.47L/instance

Water Consumption depending on type of taps (Source: TOTO)

Battery Assist Bicycle (BAB)

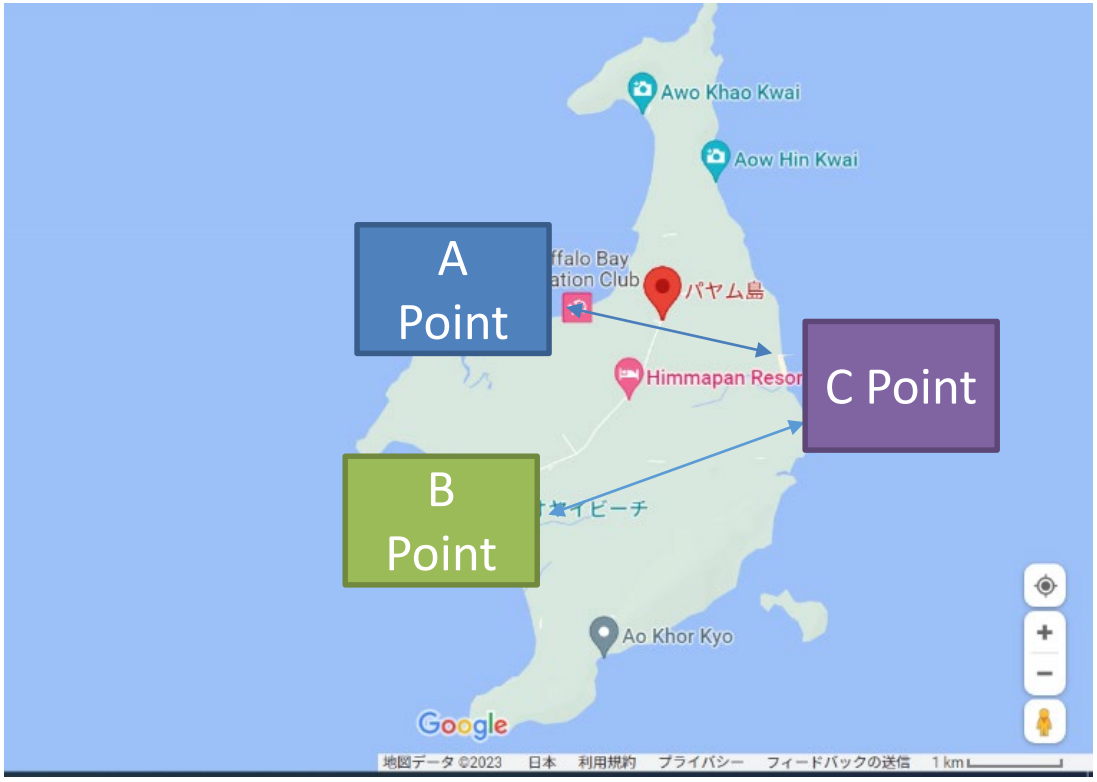
Normal Bicycle in Phayam (Rental)

(Source: Panasonic)

- Battery Assist Bicycle (BAB) is very popular in Japan. It has a storing battery assist enabling to climb up a steep.
- Rental BAB or shared BAB is also adaptable for Phayam Island because the similar system using normal bicycle has already been introduced.
- If the battery is charged by solar power, it can be green bicycle instead of fossil fuel car.
- The price can be purchased from 500 US$ in EC market.

Delivery Drone

- Drone is convenient for the last one mile for delivery for a remote area.
- If the drone is charged by RE, it can reduce CO2 emission instead of car or auto bike.
- Permission for use of drone may be necessary for securing .
- For Phayam Island, delivery for the tourists may be useful for the drone service because they sometimes require quick delivery service for entertainment.



Demonstration in Saru Island in Japan

Engineering for the NEXT

- Some tourists in Saru Island make a BBQ for their leisure.
- Foods and drinks can be delivered from a shopping center of Seiyu in the main land (1.5 km far from the main land) through Rakuten services.
- On demand delivery using a drone is made under the demonstration project (500 JY=130 Baht is paid for 1 transportation (max 5kg)).

(Source: Rakuten)

Conclusion

Conclusion

- According to the simulation results, optimized installed capacity of generation system, and economic analysis of micro grid system can be identified.

- Reduced LCOE
  - Conventional diesel power generation had an LCOE of 65.7 Cent/kWh, but in the proposed hybrid system (1.472 MW of photovoltaic power generation, 2.420 MWh of storage battery, and 300 kW of diesel generator), Levelized Cost of Electricity will be 24.0 Cent/kWh.

- Economic Benefit
  - When evaluating the proposed system comparing with diesel power generation as a base case, the investment effect of the proposed system will be 4.53 years with an EIRR of 20.8%, indicating that the project is extremely economically effective.

- Reduced CO2 emission
  - In the base case, 1,056 t-CO2 of carbon dioxide was emitted every year, but in the proposed system, emission of CO2 can be reduced by 93% due to annual carbon dioxide emission of 68 t-CO2.

Conclusion

- Ripple Effect to Local Community
  - Improved livelihoods of the residents of Phayam Island due to cheaper electricity cost, which is currently about 5 times more expensive than the mainland.
  - Creation of employment opportunities and empowerment of the local people
  - Increase attractiveness of the Island as an environmentally friendly tourist destination

- Potential of Energy Saving
  - Introduced several energy-saving technologies. Among them, the introduction of LED lighting, Automatic Water Taps, Battery Assist bicycles, etc. can be considered.