Battery Energy Storage System (BESS) Development in Pacific Island Countries (PICs)

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우리들의미래
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An aerial view of Gapa Island, Jeju Province, Republic of Korea. Korea's first Carbon Free Island test-bed.
(Image retrieved from the Jeju Provincial Council, council.jeju.kr.)

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List of Acronyms

ADB – Asian Development Bank
ADFD – Abu Dhabi Fund for Development
ADUD – Act of Development, Use and Diffusion of New and Renewable Technology
AGC – Automatic Generation Control
BAU – Business as Usual
BESS – Battery Energy Storage Systems
BOT – Build-Operate-Transfer
BOOT – Build-Own-Operate-Transfer
CFI 2030 – Carbon Free Island 2030
CPUC – Chuuk Public Utilities Corporation
DBO – Design-Build-Operate
EBA – Electricity Business Act
EE – Energy Efficiency
ESS – Energy Storage Systems
EU – European Union
EV – Electric Vehicle
FIJ – Fiji
FiT – Feed-in Tariff
FSM – Federated States of Micronesia
GENCO – Generation Company
GDP – Gross Domestic Product
GMM – Generalized Method of Moments
GNI – Gross National Income
HVDC – High Voltage Direct Current
ICE – Internal Combustion Engine
IEA – International Energy Agency
IPP – Independent Power Producers
JEC – Jeju Energy Corporation
JICA – Japan International Cooperation Agency
JSSGP – Jeju Special Self-Governing Province
KAJUR – Kwajalein Atoll Joint Utilities Resource Inc.
KDB – Korean Development Bank
KEPCO – Korea Electric Power Corporation
KETEP – Korean Energy Technology Evaluation and Planning
KIRI – Kiribati
KPX – Korea Power Exchange
KUA – Kosrae Utilities Authority
LCOE – Levelized Cost of Electricity
Li-ion – Lithium-Ion
MEC – Marshalls Energy Company
MOTIE – Ministry of Trade, Industry and Energy
MRV – Measurement, Reporting & Verification
NaS – Sodium Sulfur
NAU – Nauru
NDC – Nationally Determined Contribution
O&M – Operations & Maintenance
PALA – Palau
PIC – Pacific Island Country

PPA – Pacific Power Association
PPP – Public-Private Partnerships
PUC – Pohnpei Utilities Corporation
PV – Photovoltaics
RE – Renewable Energy
REC – Renewable Energy Credit
RPS – Renewable Portfolio Standard
RMI – Republic of the Marshall Islands
SLMN – Solomon Islands
SPV – Special Purpose Vehicle
T&D – Transmission and Distribution
TEC – Tuvalu Electricity Corporation
TONG – Tonga
TOU – Time of Use
TUV – Tuvalu
VANU – Vanuatu
VRE – Variable Renewable Energy
WB – World Bank
WBG – World Bank Group
WSAM – Samoa
YSPSC – Yap State Public Service Corporation

Executive Summary

The World Bank (WB) and the Pacific Power Association (PPA) have been studying the energy markets in the Pacific Island Countries (PICs) to i) strengthen energy planning and enabling policy, and institutional and regulatory development, ii) improve utilities' performance/capacities, and iii) scale up renewable energy (RE) to promote sustainable development. Existing economic and technical feasibility studies (both WB-sponsored and others) have favorable opinions on developing battery energy storage systems (BESS) in PICs: rolling out BESS in PICs will have great effect on improving the performance and capacity of utilities by straying away from carbon-intensive and costly diesel generation, and supporting RE generation. The issue at hand is attracting private sector participation, in most cases unavailable due to high risks.

BESS investment in PICs for public and private participants is justified when:

i. (*for the public sector*) BESS contributes to the country's long-term climate and energy targets, or,
ii. (*for the private sector*) BESS investment returns profit to private investors.

For private investors, existing feasibility studies based on simulations and forecasts alone are not enough when deciding whether or not to invest. This is especially the case when the country lacks robust energy policy or market frameworks.

On the role of private sector participation in the development of BESS in PICs

This report aims to address these critical issues by creating a BESS development roadmap for PICs. Even with strong climate and energy targets, BESS development is hampered by limited policy and market frameworks. The absence of policy and market incentives is detrimental for long-term financing required for energy infrastructure projects like BESS since there are no mechanisms that reduce risks for private financing. Without private financing in the long-run and a heavy reliance on grants or long-term loans undermines the continuity of energy infrastructure projects. Private financing needs to be encouraged in conjunction with existing forms of funding to maximize the financing potential to PICs. Development of the ability to utilize blended finance by introducing enabling policies and market frameworks is necessary. Public-private partnership (PPP) and independent power producer (IPP) models are standard industrial practices recommended to PICs in order to procure financing from the private sector.

On the need for financial risk mitigation mechanisms

Even with the need for private financing in such PPP arrangements, PICs face major hurdles to sourcing it as a result of the high risk and low reward of investments in this region. The adoption of financial risk mitigation instruments and the utilization of blended finance will be necessary in order to overcome this. Guarantee products, such as those offered by the WB, specifically target PPP's involving build-operate-transfer projects. Combining such instruments with different types of finance including concessions, loans and equity, the risk to private investment can be reduced and private sector actors can be attracted. Moreover, developing the ability to promote structured finance could enable greater scalability. Structured finance offers lines of credit to those with complex financing needs, which is certainly the case in PICs.

In particular, PICs must make sure to standardize documents related to projects and their financing, and should aim to aggregate smaller projects. PICs might best be able to achieve this by utilizing the PPA as a hub for their projects - ensuring that documents are set to a PPA standard and pooling projects together under the banner of the PPA. Further down the line, green bonds can be offered to deliver long-term finance for energy projects. The small market size and other difficulties that PICs face makes the application of these financial instruments challenging, but it is worth trying for the benefit of attaining climate goals and energy security to PICs.

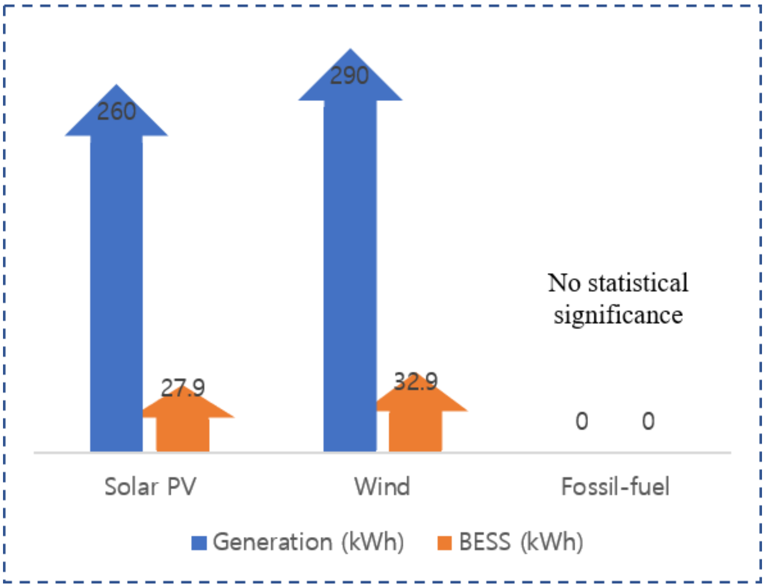
On exploring two case studies in Jeju, Korea

This report carried out the analysis of BESS deployed in the islands of Korea as a reference case for PICs. The empirical analysis on the relationship between power generation and BESS charging/discharging in *Jeju-do, Korea* and *Gapa-do, Korea* (hereinafter referred to as Jeju and Gapa, respectively)[1], finds that the importance of BESS as a supporting technology for expanded renewable generation is uncontested. Using the generalized method of moments (GMM), a generic method used in econometrics to estimate parameters in statistical models (the rationale behind using this method is explained in sub-chapter 2.4), this report finds that:

In the Jeju main-grid,

- An increase of 1% in daily wind power generation[2] has increased daily BESS usage by 32.9 kWh.
- An increase of 1% in daily solar PV generation[3] resulted in a daily BESS usage increase of 27.9kWh.

Figure 1. BESS usage increase in the Jeju Main Grid



[1] Jeju-do is an island-province located at the south of the Korean peninsula. Gapa-do is a small island located at the south of Jeju-do. The suffix ″do″ designates ″island″ in the Korean language.

[2] Analyzing data between August 2019 and October 2020, an 1% increase in daily wind power generation approximates to 290 kW.

[3] Like footnote #2, an 1% increase in daily solar PV generation approximates to 260 kW.

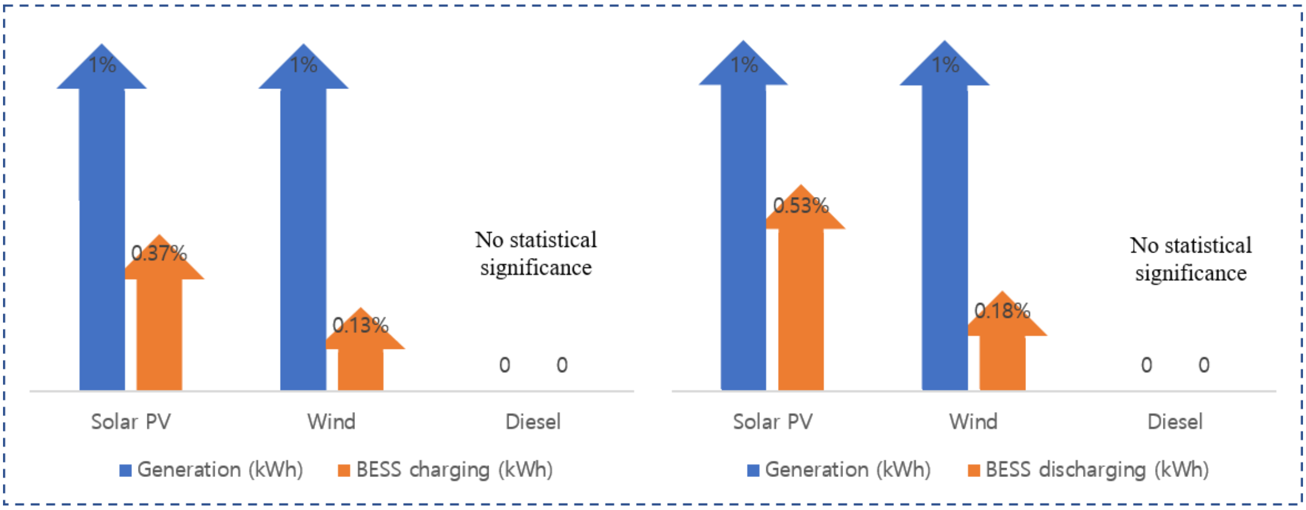
Analysis of the Gapa mini-grid[4] yields more conspicuous findings relevant to PICs. First, in relation to BESS charging,

- An increase of 1% in solar PV generation is correlated with a 0.37% increase in BESS charging.
- An increase of 1% in wind generation is correlated with a 0.13% increase in BESS charging.
- There is no observable correlation between diesel generation and BESS charging.

Second, in relation to BESS discharging,

- An increase of 1% in solar PV generation is correlated with a 0.53% increase in BESS discharging.
- An increase of 1% in wind generation is correlated with a 0.18% increase in BESS discharging.
- The relationship between diesel generation and BESS discharging is not statistically meaningful.

Figure 2. BESS usage increase in the Gapa Mini Grid



Variable renewable energy (VRE) sources like solar PV or wind are likely to be at the center of PICs' national energy transition. In this sense, the findings from the analysis above provides empirical support to the deployment of BESS in the PICs: once installed and in operation, BESS embeds well in the energy grid, supporting the transition from a fossil fuel- based energy mix to a renewable-based one.

Furthermore, a comparison between the usage of BESS in a main-grid (Jeju) versus a mini-grid (Gapa) reveals that storage technology plays a bigger role when the energy mix is less varied. In the Jeju main-grid (composed of eight different sources; see Table 22), a 1% increase in solar PV generation would increase BESS usage (both charging and discharging) by approximately 0.107%; a 1% increase in wind generation would increase BESS usage by 0.113%. In the Gapa mini-grid (composed of only solar PV, wind, and diesel generation), BESS usage is significantly higher, as examined throughout this page.

[4] The Gapa mini-grid is composed of three 150 kW diesel generators, two 250 kW wind turbines, eighty-six 3 kW solar PV panels, and a 1.4 MWh BESS. Daily peak electricity demand in 2020 was 400 kW.

This observation is particularly noteworthy for PICs. In the Jeju main grid, composed of varying energy sources, the availability of energy generation methods that reduces the shares of VREs lessens the grid's dependency on BESS. The Gapa mini grid's three-source generation arrangement, however, increases the grid's dependency on BESS. Nonetheless, this study does not claim that the availability of *dirty* alternatives to VRE (like coal or diesel) is an effective method in integrating VRE at the expense of lower BESS presence.

Examined in detail, even the current energy mix of the Jeju main grid shows slights signs of inefficiency that result from low levels of BESS (or other modes of energy storage/consumption)[5]. A phenomenon known as *curtailment*, the main-grid's solar PV and wind turbines have to be shut down in times of over-production that results from the variable nature of renewables. For instance, the year 2020 saw seventy-seven instances of curtailment for wind generation resulting in the loss of 19.45 GWh of clean energy generation opportunity. In 2021, these numbers are expected to reach two-hundred and 60 GWh. According to a simulation study by the Jeju Energy Corporation, the total amount of curtailed energy will total 2,078 GWh by 2030.

These numbers show that the expansion of solar PV and wind turbines alone cannot fully make PICs power grid low-carbon. While a number of options exist as to solve the issue of curtailment, such as vehicle-to-grid (V2G)[6], power-to-gas (P2G; using over-produced solar/wind power for hydrogen generation)[7], BESS will likely be the realistic to-go option for PICs in the coming decades due to its proven technical capability and decreasing cost (resulting from technological advancements, mass production, and increasing supply of 2nd-life batteries).

Despite technological and economic feasibilities, this study must reiterate the essential role of national energy policies such as the renewable portfolio standard (RPS) or the regional energy policies such as BESS mandates, which will be the main pillars for BESS investments in PICs. Such national and regional level BESS policies incentivize utilities, power generators, and private sectors to actively invest in and install BESS to support PICs greenhouse gas emissions reduction and renewable energy expansion targets.

On the policy and market framework development for BESS in PICs

Pivoting back to the discussion of policy and market framework development for BESS in PICs – particularly in developing the roadmaps for the Federated States of Micronesia (FSM), the Republic of Marshall Islands (RMI), and Tuvalu (TUV), the study identifies BESS policy and market measures to facilitate much needed private sector participation (see Table 1). Because BESS is a supporting technology, rather than an energy generation technology, the proposed policies and market mechanisms are highly related to energy generation – renewables, in particular.

In most PICs, single power utilities are entirely responsible for the generation, transmission, distribution, and sales of electricity[8], which limits direct private sector participation. However, the

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[5] For instance, Vehicle-to-grid, Power-to-gas, export to other regions via HVDC cables, etc.

[6] V2G requires both the purchase of electric vehicles and the installation of costly charging stations that can handle bidirectional (charging and discharging) energy exchange.

[7] Since 2021, a pilot test is being conducted in Jeju to verify the technological and economic feasibility of power-to-gas technology.

[8] In the Federated States of Micronesia, four utilities, Chuuk Public Utility Corporation (CPUC), Kosrae Utilities Authority (KUA), Pohnpei Utilities Corporation (PUC), Yap State Public Service Corporation (YSPSC) operate in their respective provinces of Chuuk, Kosrae, Pohnpei, and Yap. Their areas of operations are mutually exclusive from each

placement of the policies proposed in Table 1 will encourage and incentivize private sector participation in the short-term in the form of public-private partnerships (PPPs). A special purpose vehicle (SPV) can be set up that de-risks BESS projects by combining the public's know-how in political and social governance and the private sector's expertise in RE project operation and financing.

Table 1. Proposed BESS Policy Measures (direct and indirect)

		Proposed BESS Policy	**BESS Policy in Jeju**
Targets		Battery Energy Storage System (kWh or MWh)	Under examination
		Renewable Energy (%)	In place: 100% by 2030
		Transportation (# of vehicles)	In place: 375,000 EVs by 2030
Policy measures	Indirect	Auctions or Reverse Auctions	Under examination
	Indirect	Energy Access / Electrification Rate (%)	In place: 100% / 100%
	Direct	BESS mandate (%)	In place: 10% of capacity for all wind generation facilities
	Indirect	Feed-in Tariff (FiT)	Abolished after 2012
	Indirect	Interconnection Standards	-
	Direct	Investment tax credits	-
	Indirect	Renewable Portfolio Standard, RPS	In place: 9% for installed capacities over 500MW (2021)
	Direct	Tax Reduction or Exemption	-
	Indirect	Time of Use (TOU) & net metering	In place

In the long-term, reviewing the trend in global energy market liberalization, the central governments and public utilities in PICs may consider a transition from the current market structure towards one that opens certain aspects to the private sector. For instance, delegating the responsibility of power generation to the private sector will create multiple independent power producers (IPPs). In this case, BESS becomes an even more attractive technology that enables profit generation for IPPs.

The next decade will be crucial in fulfilling PICs ambition to construct a low-carbon renewable-based sustainable energy system. The WBG, according to its Climate Change Action Plan 2021-2025 (CCAP), has a cumulative target of adding 20 GW in RE over the next five years, which is a doubling of their current investments. An added 10 GW of variable renewable energy (VRE) is also planned.[9] BESS is one technology that can support governments and utilities to meet their ambitions, particularly as it has a strong impact on solar PV and wind penetration. In that the current issue with BESS in PICs is largely the lack of funding for implementation, rather than technical considerations, introducing aggressive BESS targets and implementing BESS-friendly policies to ensure private sector participation are critical. Policies favorable towards private sector funds, most likely in the forms of PPPs or IPPs, are key to ensuring that all involved parties – including the government, responsible ministries, utilities, private investors, and consumers, benefit from the development of BESS in PICs.

other and one utility does not pose competition to any other.

[9] In addition to RE investments, the WB will increase its share of energy efficiency operations and aim to invest US$1 billion to promote energy efficiency and resilient building in urban areas. It also aims to mobilize US$25 billion in commercial funding for clean energy over the next five years.

1 Introduction

The eleven PICs (see ***Appendix A***) have a combined population of 2.4 million, a combined gross domestic product (GDP) of US$ 10.64 billion, and an average gross national income (GNI) per capita of US$ 4,306. They consist of hundreds of islands stretching between the North and South Pacific Ocean, scattered in such a way that they cover an equivalent of 15% of the Earth's surface. The WB identifies the Pacific as a core region to its long-term energy development portfolio. The Energy Engagement Strategy for PICs prioritizes: i) strengthening energy planning and enabling policy, and institutional and regulatory development, including private sector involvement in Pacific countries; ii) improving utilities performance/capacity; and iii) scaling up renewable energy to promote sustainable development.

However, limited institutional capacity, relatively small geographic size, an economy concentrated on few industries, geographic remoteness, and power system's proximity to the ocean environment and consequent high operations and maintenance (O&M) costs are hurdles to the WB's energy strategy and to the power sector in PICs. Specific challenges include: i) a high dependency on costly imported fossil fuels; ii) a lack of adequate capacity and reliable data for energy planning and management; iii) the need for capital to finance battery storage and other facilities that can properly absorb renewable energy (RE) in isolated systems; iv) insufficient revenue from tariffs to meet O&M costs; and, v) the high maintenance cost of generation and distribution systems due to the system's proximity to the ocean environment and consequent vulnerability.

Acknowledging these limitations, the PPA[10] recently drafted a long-term strategy to deploy BESS and electric vehicles (EVs) to address the challenges in the energy sectors of PICs. As such, it has been deemed necessary that a study be undertaken to support the efforts of the PICs by reviewing regional BESS policy framework and technical guidelines, benchmarking available business models and best practices in the Republic of Korea (Korea), and designing BESS development roadmaps for PICs.

Chapter 2 reviews the regional BESS policy framework and technical guidelines to develop policy and regulation that enables a commercial market for private companies to invest in BESS. This chapter investigates BESS charging considerations and clustered charging constraints, the integration of BESS into the grid, minimum technical requirements for technology imports, and the maintenance and recycling/reuse/storage of obsolete equipment and batteries. It also reviews available business models and best practices in Korea, with the Jeju Special Self-governing Province (JSSGP) benchmarked. Jeju island, located in the south of the Korean peninsula, faced policy, technical, and market challenges a decade ago much like the PICs of today. Currently, it is midway through its plan to achieving carbon-neutrality[11] by implementing the Carbon Free Island (CFI 2030) initiative, in tandem with the national goal of reducing the total national greenhouse gas (GHG) emissions by 24.4% by 2030, from their 2017 level (709.1 MtCO2eq) . Reviewing the increased penetration of RE, BESS, and EVs over the past decade,[12] this chapter will analyze Jeju's electricity generation and BESS charge-discharge data[13] to assess the factors that affect BESS uptake and to provide take-aways and replicable lessons for PICs.

[10] The PPA acts as an over-arching institutional representative of energy sector utilities operating in PICs and provides institutional and technical capacity underpinning the future success of an energy sector transition.

[11] The share of coal-based generation was reduced from 48% in 2016 to 32% in 2020.

[12] In 2020, solar PV and wind generation amounted up to 19.0% of the total generation.

[13] Data provided by the JSSGP and the Korea Power Exchange (KPX).

Chapter 3 designs a roadmap for BESS development in PICs, focusing on three specific countries: the Federated States of Micronesia (FSM), the Republic of the Marshall Islands (RMI), and Tuvalu (TUV). This chapter examines BESS targets and proposes policy measures to support PICs' decarbonization through private/public sector BESS market opportunities. It also examines the possibility for symbiosis between future e-mobility trends and BESS, learning from various policy and business initiatives taking place in Jeju.

Chapter 4 concludes this report with key findings and suggestions for future endeavors. Three key lessons, i) the significance of BESS in relation to increased RE, ii) the importance of private sector participation, and, iii) private-public partnerships as enabling mechanisms for BESS development are summarized. Lastly, future endeavor such as the development of financial risk mitigation mechanisms tailored for BESS in PICs is discussed.

2 Regional Policy Framework and Economics in PICs

WB-sponsored studies like Chown G. (2019) find that BESS is an appropriate and versatile technology to strengthen and improve utilities' performance and capacity, and in scaling up RE to promote sustainable development.

> "Battery storage seems to be very well suited to islanded communities without connection to a mainland grid. Storage is competitive with electricity from diesel generators even when the environmental benefits are neglected, so it brings down cost for such locations. Additionally, it balances the grid and provides extra security. Energy storage is a justified investment in the cases where the electricity is supplied by renewable energy sources such as solar and wind, which at present offer a very competitive prices per unit of energy. The common feature between the given examples is that they are located in places with extremely good renewable energy resource (in this case – solar)." (Chown G. (2019))

In addition, studies like IRENA. (2013), ADB. (2020), and WBG. (2020) indicate that *extremely good* solar and wind potential, makes RE a promising solution for the various problems facing the energy sectors of PICs.[14] However, policy, market, environmental, social, and technical challenges hinder BESS development (see Table 2).

Table 2. Challenges and solutions to BESS development in PICs

	Challenges	Recommendations
Policy	▪ Limited institutional frameworks, government ministries, and policy aimed at developing a sustainable energy market poses challenges to an energy sector transition.	▪ Identify successful policy measures in advanced energy markets and strengthen renewable energy laws. ▪ Amend regulations as special Acts to facilitate energy transition. ▪ Designate a core ministry that can operate as an organizer/facilitator.
Market (Economics / Financial)	▪ Relatively scarce government capital resulting in a dependency on external funding to conceive, implement, and maintain costly infrastructural works in the energy sector. Lacking opportunities for considerable returns acts as a disincentive for private sector investment. ▪ Short-term perspectives encourage the continued use of diesel-dependent generation as the cheapest option. Considering the limited financial resources available, this approach can be quite attractive, despite potential price volatility concerns. Robust long-term economic rationale needs to be	▪ Design market mechanisms that incentivize investments in BESS (FIT, tax reductions, etc). ▪ Expand the share of renewable energy sources in the energy mix, and break free from a dependency on diesel with highly volatile prices, as this would draw more investors into the energy sector. ▪ Explore options for recycled EV batteries as they will considerably drop BESS cost. Renewable energy expansion, backed up with BESS which would ensure a secure power supply, would be economically

[14] As discussed in Chapter 1, PICs energy sectors highly depend on costly imported fossil fuels, lack adequate capacity and reliable data for energy planning and management, need capital to finance battery storage and other facilities that can properly absorb variable renewable energy (VRE) in isolated systems, generate insufficient revenue from tariffs to meet O&M costs, and suffer from a high maintenance cost of generation and distribution systems in a marine environment.

	employed in order to maintain a focus on working towards an energy sector transition.	feasible in the long-term and alluring for investors.
Climate change	▪ The threat of sea-level rise, exposure to the ocean environment, severe weather events, and natural disasters present risk-factors which can deter investment into costly and vulnerable energy infrastructure. The geographically dispersed nature of the islands and their small land mass areas present challenges to grid integration and electrification, as well as balanced dispersion of assets for optimal renewable generation.	▪ Challenges presented due to geographical limitations, such as grid integration, may be alleviated by securing a distributed generation. This could be established by expanding power generation through renewable energy sources. ▪ Risks must be assessed by conducting technical evaluations on the potential damages of weather incidents on BESS. Proper measures to protect BESS must be in place (even with added cost) to reduce investment risks.
Social	▪ Lack of public awareness and availability of general information can hinder larger social support structures and the acceptance of operations.	▪ Implement education and campaign programs. Social acceptance of site selection for the installation of photovoltaic panels and wind turbines can be more challenging. Potential solutions regarding problems arising from different stakeholders' interests should be dealt with using policy measures which involve consulting with different parties of interests and establishing appropriate compensation mechanisms.
Technical	▪ A small population inevitably results in lacking expertise and experience, particularly in the area of O&M.	▪ Lack of technical capacity can be dealt with through knowledge and expertise exchange, consultation, and benchmarking countries that have overcome similar challenges.

A dozen existing literature reviewed by this study addresses the environmental, social, and technical challenges. Thus, the primary focus of this chapter is to develop policies and regulations that overcome these barriers to developing BESS in PICs. Section 2.1 assesses the current status of the energy/climate targets of PICs and recommended benchmark policy frameworks**.** Section 2.2 reviews the electricity markets and market frameworks of PICs for BESS development.

2.1 Regional Energy and Climate Change Targets

PICs face great challenges in attempting to mold their energy sector to be more climate change resilient and to deliver greater energy security. Failure to address these challenges will result in increased electricity tariffs for consumers, and reduced rates of return and flexibility in pricing structures for utility operators and project financiers. Continued deterioration of the situation will require additional subsidies for public and private stakeholders, increasing capital expenditure and debt. Government policy surrounding BESS deployment has the potential to shape the future landscape of this situation, particularly by drawing on technical expertise, creating an attractive investment environment, and coordinating stakeholders to create multiplier effects. As such, this sub-section will review the national policy framework for energy sector development plans to implement further RE projects that includes solar PV, wind, and BESS.

National Energy Development Targets

Table 3 outlines PICs' National Policy Framework for the Energy Sector. Conceived with assistance from international institutions, these RE policies and frameworks address the need for low-cost and stable energy production to bolster climate change resilience and energy security. Of these "first generation" roadmaps, the "Tonga Energy Road Map 2010-2020"[15] is a forerunner. The roadmap aimed to replace 50% of its fossil-fuel-based generation capacity with RE - largely solar photovoltaics (PV) - and to improve energy efficiency at the source and during end-use. The "Kiribati Integrated Energy Roadmap: 2017-2025"[16] aims to reduce fossil fuel usage by 45%, 60%, and 60% in South Tarawa, Kiritimati, and the outer islands, respectively, by 2025. The gap created by phasing out diesel generation is to be filled, in part, by expanding RE sources by 23%, 40%, and 40% in the three regions. Of the three PICs studied in depth in this report, FSM and RMI have on-going energy development plans. TUV's energy development plan expired in 2020 and is subject to renewal, however, the country's "Infrastructure Strategy and Investment Plan" covers some courses of action up until 2025.[17] Similarly, many PIC energy development plans expired on the convenient landmark date of 2020.

Table 3. PIC National Policy Framework for the Energy Sector

Country	Most Recent Energy Development Plans and Policies	Year
Fiji (FIJ)	National Energy Plan, Green Growth Framework	2013 – 2020
Federated States of Micronesia (FSM)	Energy Master Plans for the Federated States of Micronesia	2018 - 2037
Kiribati (KIRI)	Kiribati Integrated Energy Roadmap (developed by IRENA and Pacific regional organizations)	2017 - 2025
Republic of Marshall Islands (RMI)	National Energy Policy and Energy Action Plan (NEPAP) Tile Til Eo 2050 Climate Strategy Navigating our Energy Future: Marshall Islands Electricity Roadmap	2015 – 2025 2018 – 2050 2018 onwards

[15] Tonga. (2010). Tonga Energy Road Map 2010-2020.
[16] IRENA. (2017). Kiribati Integrated Energy Roadmap: 2017–2025.
[17] Tuvalu. (2017). Infrastructure Strategy and Investment Plan.

Nauru (NAU)	Nauru Energy Road Map	2018 – 2020
Palau (PALA)	Palau National Energy Policy	2010 – 2020
Samoa (WSAM)	Energy Sector Plan	2017 – 2022
Solomon Islands (SLMN)	Solomon Islands National Energy Policy Renewable Energy Strategies & Investment Plan	2014 2014
Tonga (TONG)	Energy Road Map	2010 – 2020
Tuvalu (TUV)	Enetise Tutumau (Master Plan for Renewable Electricity and Energy Efficiency in Tuvalu) Supplemental – Tuvalu Infrastructure Strategy and Investment Plan	2012 – 2020 2017 - 2025
Vanuatu (VANU)	Updated Vanuatu National Energy Roadmap	2016 – 2030

Nationally Determined Contributions (NDCs) and RE Development Targets

For the most part, PICs have generated ambitious statements of intent via NDCs and RE development targets. Table 4 explores NDCs set forth by PICs. Ambition must be weighed against the scale of the challenge, and this is best exemplified by the ability of PICs to set unconditional targets, thereby signaling their confidence in achieving them. Of the eleven PICs, only Fiji, FSM, Kiribati, Nauru, and the Solomon Islands have set unconditional targets. These targets are far more restrained compared to their conditional counterparts. FSM's 28% emissions reduction from the energy sector by 2025 is the most ambitious of the selection. The ambition set forth in conditional targets clearly indicates the willingness of PICs to transition their energy sectors but highlights their lack of capacity to do so alone.

RMI and TUV did not make clear whether their targets are conditional or unconditional. With their plans largely comprising of RE and BESS implementation, as well as energy efficiency (EE) improvements, such a transition will be costly and technically complicated, requiring large capital investments and technical assistance from external sources. As NDCs are not submitted using a uniform measurement approach, Table 5 attempts to normalize these targets by framing approaches in terms of renewable generation targets by 2025. Projections and targets for Nauru do not extend past 2020, resulting in the figure provided being an estimation. Of the 15 targets provided by the PICs, thirteen extend total generation contribution from RE sources past 50%. It also displays which types of renewable generation are planned to be deployed by nations.

BESS is included in the renewable deployment category as core in supporting infrastructure enabling renewable deployment feasibility. Solar PV is considered by all PICs, while wind is planned for FIJ, RMI, WSAM, TONG, TUV, and VANU. Hydropower is considered by FIJ, FSM, WSAM, SLMN, VANU, and geothermal by SLMN and VANU. BESS features in the plans of all but FIJ and VANU. From the wording of commitments, and in labelling those most ambitious targets as "conditional", PICs appear to be well aware of the issues that overcommitment can bring. Only with diligent measurement, reporting and verification (MRV) will it be possible to assess whether the planned development of the energy sector, upon fruition, has been successful or has overreached.

Table 4. PIC NDCs Specific to the Energy Sector. All figures derived from NDC submissions to the UNFCCC

Country - NDC Status - Year of Submission	Unconditional Targets	Conditional Targets
Fiji – First NDC (updated) - 2020	10% energy sector emissions reductions from business as usual (BAU) scenario by 2030 via mixed approached to EE improvements and renewable generation.	Further 20% reduction in emissions by 2030.
FSM – First NDC – 2016	28% emissions reduction in energy sector from 2000 levels by 2025. Methods undisclosed.	35% emission reduction from 2000 levels by 2025.
Kiribati – First NDC - 2016	4.1% reduction in emissions from energy sector (48% power sector, 52% transport sector) of projected 2025 total and 3.8% of 2030 total via RE generation, both centralized and decentralized.	Further 48.8% reduction in emissions of projected 2025 total and 49% of 2030 total via RE and EE, and biofuel for generation and transport.
Nauru – First NDC - 2016	Funding of US$ 5 million to implement 0.6 MW solar PV system.	"Substantial" replacement of diesel generators with grid-scale solar PV by 2030, alongside demand-side management improvements including BESS implementation.
Palau – First NDC – 2015**	22% energy sector emissions reductions below 2005 level of 88,000 tCO2e, 45% renewable generation, and 35% increase in EE by 2025 largely via solar PV implementation, relevant EE improvements, and biofuel usage.	
Samoa – First NDC - 2015	All contributions explicitly conditional.	100% renewable generation by 2025 via RE implementation, bioenergy, and EE improvements. BESS will support RE.
RMI – Second NDC – 2018/20*	50% reduction in electricity sector emissions by 2025, rising to 65% by 2030 and 100% by 2050. Technological "first large steps" between now and 2030 largely consist of BESS and RE implementation, in addition to EE improvements and grid-loss rate reduction.**	
Solomon Islands – First NDC - 2016	12% below 2015 emissions levels by 2025, rising to 30% by 2030. 39% of reductions will come from the power sector via RE implementation and EE improvements.	With international assistance, power sector emissions reduction of 27% against 2015 levels by 2025, rising to 45% by 2030.
Tonga – Second NDC - 2020	No unconditional contributions listed.	50% renewable generation by 2025, rising to 70% by 2030 via RE and BESS implementation, EE improvements, grid improvements, and EVs *inter alia.*
Tuvalu – First NDC – 2015	Electricity sector emission reduction of 100%, and energy sector by 60% below 2010 levels by 2025. To be accomplished via RE and BESS implementation, and EE improvements. **	
Vanuatu – First NDC - 2016	All contributions explicitly conditional.	100% renewable energy generation and 30% energy sector transition to renewable energy by 2030 via RE implementation, EE and electrification improvements.

*RMI 2018 NDC is considered alongside the updated 2020 submission. The 2018 NDC contains greater information and quantitative data for targets such as the RMI 2050 Climate Strategy are attached. The 2020 update refers our attention to the 2018 RMI Electricity Roadmap. As a result, all four documents will be considered here.
** Conditional and unconditional are undefined.
Source: Fiji (2020); FSM (2016); Kiribati (2016); Nauru (2016);); Palau (2015); RMI (2018); RMI MoE. (2018a, 2018b, 2020); Solomon Islands (2016); Samoa (2015); Tonga (2020); Tuvalu (2015); Vanuatu (2016-A).

Despite continued reductions in the capital requirements of BESS, financial and technical challenges are still remaining. Relying too heavily on projected prices, projected financial support, and technical support from external sources leaves PICs exposed to factors outside of their control. Any developed plans should include contingency measures for continued operation of their infrastructural investments should financial flows become disrupted. With PICs adopting similar strategies toward their energy sector transitions, the opportunity for collaboration, knowledge sharing, and joint capacity building is present. Although outside the scope of this report, further liaising among the various stakeholders – possibly through the PPA, should better equip these nations to overcome the challenges ahead, as well as to build greater resilience against external shocks.

Table 5. PIC Renewable Generation Targets and Planned Deployment for 2025.[18]

Country	Renewable Generation Targets (% of total)	Planned Renewable Deployment
Fiji**	66	Solar, Hydro, Wind
Federated States of Micronesia	60	Solar, Hydro, BESS
Kiribati	Outer Islands: 100* Kiritimati: 40 South Tarawa: 23	Solar, Wind, BESS
Nauru	50	Solar, BESS
Palau	45	Solar, BESS
Republic of Marshall Islands	Majuro: 50 Ebeye: 50 Outer Islands: 90	Solar, Wind, BESS
Samoa	100	Solar, Wind, Hydro, BESS
Solomon Islands**	65	Solar, Hydro, Geothermal, BESS
Tonga	50	Solar, Wind, BESS
Tuvalu	100	Solar, Wind, BESS
Vanuatu**	83	Solar, Hydro, Wind, Geothermal

*Outer Islands data states 100% for rural public and private institutions, 40% for rural public infrastructure.
**No 2025 target made explicit. Fiji's target was calculated using renewable implementation timeline data. Vanuatu's and Solomon Islands' targets were calculated as the average of 2020 and 2030 targets.
Source: Fiji. (2017); Vanuatu. (2016-B); Solomon Islands MoMERE. (2014; ADB. (2018-A).

[18] Renewable target %, target year, and planned renewable deployment data derived from national energy plans (Table 1) and NDC submissions (Table 2).

2.2 Energy Market in PICs

This section discusses the energy markets in PICs. Main stakeholders, market arrangements, and possible frameworks for BESS development are reviewed after a brief overview of PICs total electricity generation, total installed power generation capacity, renewable electricity capacity, share of renewables in the power mix, and electricity access. The table below presents key data for each of these points of consideration.

Table 6. PICs' energy market overview

Country	Total installed generation capacity	Total electricity generation	Renewable electricity capacity	Share of renewables in power mix	Electricity Access 2018
Fiji	316MW (2016)	1,070GWh (2019)	Hydro 130MW; Biomass & Wind 21MW (2016)	60.26% (2019)	100
Federated States of Micronesia	21.95MW (2020) Chuuk 5.7 MW Kosrae 2.75 MW Pohnpei 8.0 MW Yap 5.5 MW	68GWh (2017)	3.1MW (Hydro 0.75MW, Solar 1.52 MW, Wind 0.83MW) (2020)	3% (2020)	82
Kiribati	11MW (2016) South Tarawa 7.01MW	30GWh (2019)	South Tarawa 1.56MWp (PV)	16.03% (2019)	100
Nauru	21.2MW, of which 17.9MW is operational (diesel)	40GWh (2019)	807kW (PV)	3.3% PV	100
Palau	28.04MW (2020)	78.5 GWh (2019)	2.4MW (2020)	2.5% (2020)	100
Republic of Marshall Islands	30MW (2020)	80.1 GWh (2019)	2MW (2020)	2.7% (2020)	96
Samoa	45MW (2016)	140 GWh (2019)	Approx. 22.5MW	34.33% (2019)	100
Solomon Islands	67MW (2018)	110 GWh (2019)	4MW (2018)	4.81% (2019)	67
Tonga	22.97MW (2017)	60 GWh (2019)	4.2MW (2017)	0% (2019)	99
Tuvalu	5MW (2018) 2.5MW (Funafuti, 2020)	9GWh (2017)	2MW (2018) 0.735MW (Funafuti, 2020)	23% (2017)	100
Vanuatu	34.79MW (2013)	70 GWh (2019)	4.39MW (2013)	13.56% (2019)	62

Source: ADB. (2019-A, B); ADB. (2020-A, B, C); CIA World Factbook. (2020-A, B); Hydro Review. (2019); IRENA. (2015); IRENA. (2018-A, B); Our World in Data - BP Statistical Review of World Energy & Ember. (2021-A, B, C, D, E, F, G); Parliament of the Republic of Fiji. (2017); U.S. DoE. (2020-A, B, C).

Apart from Fiji, power generation from diesel generators in PICs weigh over 50%. To better frame this regarding to the three PICs at the heart of this report, the energy sectors of the FSM, RMI, and TUV are separately reviewed in the table below. The percentage of diesel generators in terms of total installed capacity in FSM and RMI in 2020 were 86.0% and 97.0%, and the shares of power generations from diesel generators were 93.3% and 96.3%, respectively. In 2019, the shares of diesel generators in terms of total installed capacity in Tuvalu's capital, Funafuti, and the outer islands were 85.0% and 30.0%, respectively.

Table 7. Diesel-dependency in the energy sectors of FSM, RMI, and TUV

		Share of diesel generators in total installed capacity	Share of power generation from diesel generators	Note
Federated States of Micronesia		86.0%	93.3%	High share of diesel installed capacity may indicate underperformance from other generation sources such as RE.
Republic of Marshall Islands		97.0%	96.3%	-
Tuvalu	Funafuti	85.0%	N/A	-
	Outer islands	30.0%	N/A	

Source: U.S. DoE. (2020-A); U.S. DoE. (2020-C); ADB. (2020-C); ADB. (2019-C).

A high level of diesel dependency leaves utility operators and customers vulnerable to volatility in global fuel prices. Unpredictability in energy prices abroad means PICs' power systems are exposed to contingencies like blackouts, as outlined in reports by Chown (2019 A-E). This results in frequency and voltage instability, with or without considerable renewable generation.

Market stakeholders

This section reviews the major stakeholders in the PIC energy markets and the type of market arrangement for each PIC.[19] The energy markets of PICs are under the jurisdiction of one ministry from each country, chiefly responsible for planning, regulation, and licensing. Except for the FSM and RMI, single public utilities are responsible for the generation, transmission, distribution, and sales of electricity. The four utilities, Chuuk Public Utilities Corporation (CPUC), Kosrae Utilities Authority (KUA), Pohnpei Utilities Corporation (PUC), and Yap State Public Service Corporation (YSPSC), in the FSM are exclusively responsible for the country's four administrative regions, Chuuk, Kosrae, Pohnpei, and Yap, respectively. The two RMI power utilities, Kwajalein Atoll Joint Utilities Resource Inc. (KAJUR) and Marshalls Energy Company (MEC), are the only utilities in the Majuro and Ebeye regions, respectively. Consumer data is either extremely scarce or outdated. The last column of in the table below is an amalgamation of various unverified sources, the accuracy of which cannot be guaranteed by this report. While the table requires further confirmation and updating, it shows the general composition of energy demand per consumer by industrial, commercial, residential, and other sectors.

[19] This identification, explained later, is conducted via desktop research; further survey and research are required to improve accuracy.

Table 8. Main stakeholders in the energy market

Country	Government	Utility	Consumer
Fiji	Department of Energy (http://www.fdoe.gov.fj/)	Fiji Electricity Authority (FEA)	14% residential; 42% transport; 22% commercial; 14% industrial; 8% agriculture[20]
Federated States of Micronesia	Department of Resources and Development (http://www.fsmrd.fm/)	Chuuk Public Utility Corporation (CPUC) Kosrae Utilities Authority (KUA) Pohnpei Utilities Corporation (PUC) Yap State Public Service Corporation (YSPSC)	20% residential; 35% commercial and industrial; 28% government; 17% system losses
Kiribati	Ministry of Infrastructure and Sustainable Energy (https://www.mise.gov.ki/)	Public Utilities Board (PUB)	41% residential; 34% government and industry; 19% commercial
Nauru	Ministry of Commerce, Industry & Environment (http://www.naurugov.nr/)	Nauru Utilities Corporation (NUC)	N/A
Palau	Ministry of Public Infrastructure, Industries & Commerce (https://www.palaugov.pw/)	Palau Public Utilities Corporation (PPUC)	32.5% residential; 37.6% commercial; 24.9% national government; 5% state government
Republic of Marshall Islands	Ministry of Natural Resources and Commerce (http://www.rmimrd.com/)	Kwajalein Atoll Joint Utility Resources (KAJUR) Marshall Energy Company (MEC)	35% residential; 30% commercial; 35% government
Samoa	Ministry of Natural Resources and Environment (https://www.mnre.gov.ws/)	Electric Power Corporation (EPC)	28% domestic; 34% commercial; 22% government department; 7% industrial; 5% religion; 2% hotel; 2% school
Solomon Islands	Ministry of Mines, Energy and Rural Electrification (https://www.mmere.gov.sb/)	Solomon Power (SP)	19.2% residential; 65.4 commercial and industrial; 15.4% government
Tonga	Tonga Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications (https://www.mic.gov.to/)	Tonga Power Limited (TPL)	44% residential; remaining 56% by commercial, religious, government, and public service
Tuvalu	Ministry of Natural Resources, Energy & Environment	Tuvalu Electricity Corporation (TUV)	45% residential; 27% government; 28% commercial
Vanuatu	Department of Energy (https://doe.gov.vu/)	Unelco Engie (UNELCO)	28.7% residential; 61.6% commercial and industrial; 9.7% public sector

Source: Conrad et al. (2015); GGGI. (2016); Government of Samoa. (2015); IRENA. (2013); The United Nation's Climate Technology Centre and Network. (2018); WB. (2014-A); WB. (n.d.); U.S. DoE. (2020-A, B).

[20] Chandra and Hemstock (2015) 'A biomass energy flow chart for Fiji', Biomass and Bioenergy, Vol. 72, pp.117–122.

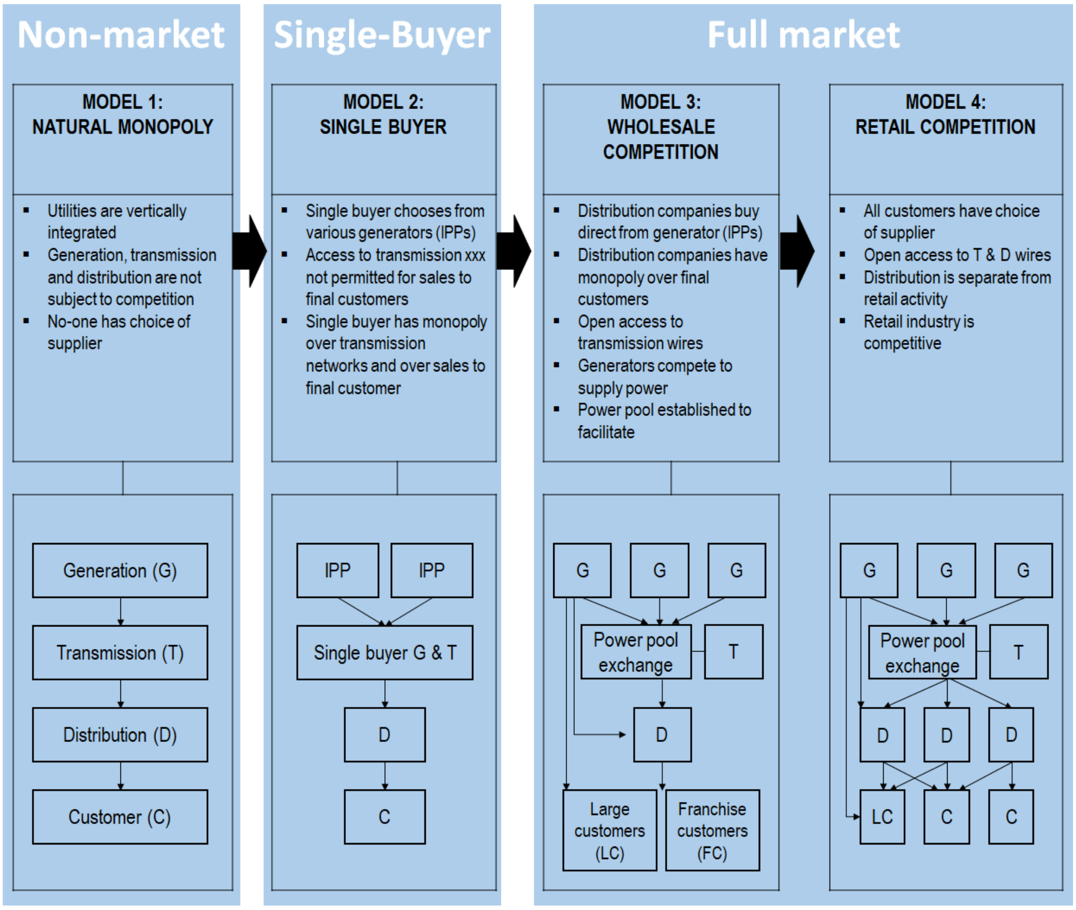
Market arrangement

Identifying the relationship among various stakeholders in each of the PICs' energy markets is necessary as it indicates current available BESS options and future directions for BESS deployment. Referring to the remuneration model produced in ESMAP. (2020-A), the table below outlines the fourteen functions that BESS can perform under a non-market, a single-buyer market, or a full market model:

- ***Non-market***: a regulated state utility receives regulatory approval to recover the cost of a flexible asset from its customers.
- ***Single-buyer market***: multiple suppliers compete, but there is only one buyer. The buyer in this case is generally a regulated entity.
- ***Full market*** (multiple buyers and sellers): there is competition on both sides of the market. The most relevant use of this model is in the case of wholesale markets where there are liberalized customers (retail competition).

Under a *non-market* arrangement, BESS can perform basic functions that include frequency and voltage control, RE ramp control, RE forecast error correction, firm capacity, RE generation time shifting, black start, grid congestion relief, and transmission and distribution (T&D) deferral. Under a *single buyer* market, BESS can be used for all tasks from a non-market arrangement, with the added benefits of uninterruptible power supply, demand response, and network charge reduction functions.

Figure 3. Independent Power Producers and Power Purchase Agreements.



Source: Eberhard, A.

Table 9. Possible Combinations of Use Cases and Remuneration Options

BESS Function	Remuneration option*			Comment
	Non-market	**Single buyer**	**Full market**	
	FSM, KIR, NAU, PAL, RMI, SAM, SOL, TON, TUV, VAN	Fiji	-	
Frequency and voltage control	✔	✔		Only system operator has demand for frequency and voltage control services. This means either the system operator has to procure service (single buyer) or provision is mandated (non-market).
RE ramp control	✔	✔	✔	Can also be required via grid connection code or power purchase agreement.
RE forecast error correction	✔	✔	✔	Can be required implicitly via power purchase agreement.
Firm capacity	✔	✔	✔	Market-based remuneration depends on capturing very high energy prices during periods of scarcity.
RE generation time shift	✔	✔	✔	Can be incentivized in single buyer model via time-based electricity pricing in PPAs.
Black start	✔	✔		No market demand for such services.
Grid congestion relief	✔			No market demand for such services, aside from system operators.
Transmission and distribution (T&D) deferral	✔			No market demand for such services, aside from grid owners and planners.
Uninterruptible power supply		✔		Customer side option, paid by customer, market where customers can generally choose from multiple providers.
Demand response		✔		Explicit demand response via single buyer model, implicit demand response via market-based model.
Network charge reduction		✔		Customer side option, grid tariffs crucial for determining economic viability.
RE self-consumption optimization			✔	Customer side option, electricity and grid tariffs crucial for determining economic viability.
Time of use optimization			✔	Customer side option, electricity and grid tariffs crucial for determining economic viability.
Backup power / micro grid islanding			✔	Customer side option, paid by customer(s).

* Remuneration determined based on in-house analysis

Source: ESMAP (2020-A); authors.

Under a full market, demand is created for BESS use in all fourteen functions except frequency and voltage control, black start, grid congestion relief, and T&D deferral. Based on the analysis, there is an absence of a *full-market* in PICs. The only *single-market* model is found in Fiji, with a *non-market* arrangement found in the rest. The null values in the *Remuneration option* column in the table below indicate that there is no market (or transaction) that can be created for it.

Granted, BESS has valuable uses at all remuneration levels and in all market structures. Hence, PICs should further evaluate their current markets and consider BESS as one of the various solutions to improving utilities' performance/capacity and scaling up RE to promote sustainable development.

Market frameworks

As it is the case in most energy infrastructure projects across the world, the development of BESS in PICs require a form of a public-private partnership (PPP) or an independent power producer (IPP) approach to reduce risks for both the government public and private participants. Because public utilities in PICs have difficulty in procuring the required financing for BESS, the importance of PPP/IPP as market mechanisms that enable BESS investment from the private sector cannot be stressed enough.

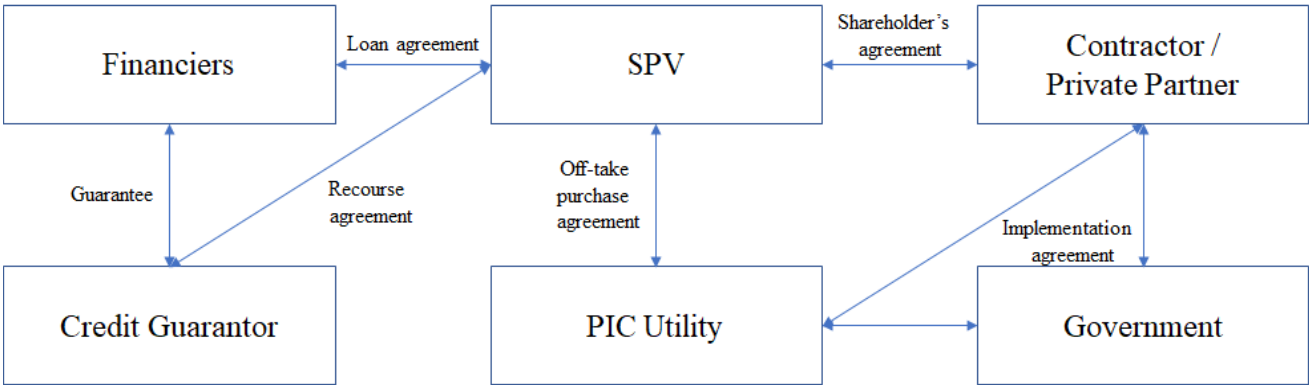
PPP, in general, refers to an arrangement between the government and one (or more) private company to deliver public sector services. PPP is effective for mega infrastructure project as it combines the expertise and knowledge of both the public and private. The public is responsible for stable governance that ensures fair financial play, thus reducing social and political risks, while the private is responsible for the efficient design, construction, and operation of the project.

IPP is a PPP variation for the energy sector. In an IPP approach, the public sector employs the services of a private company to deliver social services, while the private sector generates revenue through the sales of their product. According to Gardiner and Montpelier. (2000), the benefits of IPPs are:

- Attract outside capital to meet rapidly growing electricity needs without imposing large strains on the nation's internal financial capabilities;
- Reduce electricity costs though competitive pressures; and,
- Assign risks in a more efficient or desirable manner.

In a PPP/IPP, a project company is responsible for developing a project plan. Its responsibilities include arranging funding/financing from financial sources; acquiring permits or the rights to operate; supplying off-takers and consumers with electricity; and collecting revenue. Financing comes from two distinct sources: financiers and sponsors. The former loans capital and the latter invests, thereby becoming loaners or equity-holders, respectively. The government is responsible for both concession rights and for implementing and monitoring the operation. A generic IPP arrangement is shown and explained in the figure below:

Figure 4. High-level PPP structure of a battery storage implementation scheme



Source: Chown G. (2019-A)

In developing BESS in PICs, Chown G. (2019-A) recommends an IPP/PPP structure that involves six entities: financiers, credit guarantor, special purpose vehicle (SPV), PIC utility, contractor, and government entity (see Figure 4). In this high-level PPP structure, the involved parties can agree upon one of the following arrangements: build-operate-transfer (BOT), design-build-operate (DBO), or build-own-operate-transfer (BOOT). The first two options are concessions, whereas the third option involves a transfer of ownership after a certain period. Descriptions for a BOT/DBO or BOOT arrangement are outlined in Box 1.

PPP/IPP is a widely benchmarked practice for infrastructure projects. There are, however, various risks that IPPs may encounter such as currency and payment issues, political, managerial, and technological risks. The same can be said about the government and public utilities. Therefore, it is necessary for all involved parties to analyze the market demand for BESS and the contract arrangement to find an arrangement which can best satisfy existing needs.

Box 1. PPP/IPP arrangements.

BOT & DBO (concession): Under this arrangement, the contractor finances, designs, builds, operates and maintains the energy storage system and delivers the generation capacity and energy storage. The structure of this delivery option is such that the SPV provides the required capacity under the defined technical and commercial parameters, and the PIC utility pays capacity payments to cover the investment, interest and loan payback, that is, the required return and O&M costs of the contractor.

BOOT (transfer): The ownership of the battery storage system is transferred to the PIC utility after a certain period of time. The loan agreement includes the terms and conditions under which the project is financed by the debt providers. The implementation agreement provides the framework of the cooperation between the parties and sets out the main principles of the PPP arrangement in place. The project's bankability and financing viability can be improved by including some sort of credit guarantee in the structure.

Source: Chown, G. (2019-A)

In PICs specifically, an IPP arrangement is unrealistic for two reasons. One, the bulk of the electricity produced in PICs are generated, transmitted, distributed, and sold by the countries' main public utilities. In such a case, any other local power producers are likely to be very small in size incapable of participating in BESS financing activities. Two, the absence of robust energy policy frameworks and market incentives discourage private entities from participating in PICs' energy market. As such, PPP is likely to be the go-to option in the near future for private investors willing to participate in a BESS development project in PICs, assuming that there are RE policy measures and market mechanisms to protect their interests.

PPPs differ from IPPs in that they require the government to articulate their desire for the construction and operation of an infrastructure to meet public needs. Who is responsible and pays for what at each stage very much depends on which iteration of PPP is deployed. In the context of the PICs, we might expect that private entities would be required to pay the capital investment for the design, installation and operation of BESS, although these entities may choose to mitigate these initial costs by co-financing the project, or by asking the government for financial (sometimes similar to power purchase agreements) or non-financial guarantees. Such non-financial guarantees might include the use of public resources and services. We might also expect that the government will form a contract with the private entity to perform the public service on their behalf, delivering to the private entity a set payment until the contract expires, at which point the infrastructure will be transferred to the government.

2.3 Regional Technical Guidelines for BESS

With the technical use-cases of BESS were briefly described in the previous section, this section delves deeper into the technical aspects of BESS, discussing the advantages and disadvantages of different BESS types, and providing general guidelines that PIC government ministries and utilities may refer to.

Advantages and Disadvantages by BESS Type

Lithium-ion (Li-ion), nickel-based, sodium-based, lead-acid, and flow batteries are the most common types of BESS. Their advantages and disadvantages are discussed in Table 10. According to the Korean Battery Industry Association, li-ion BESS outperform all other types in terms of energy density and roundtrip efficiency, and are on par with the best performers in terms of lifetime. However, different types of BESS are designed and manufactured for different purposes. Utilities must find the optimal BESS to meet their current and future requirements.

The unique situation of PICs in terms of demand, capital resource availability and geographical location presents interesting challenges to identifying a suitable BESS technology. PICs have limited financial resources, replacement parts and technical support needed to repair BESS may need to be sourced from distant locations, and the grid size is relatively small. We might therefore first consider that PICs will desire the battery technology least likely to require replacement. Li-ion, nickle-based and lead-acid batteries are the standout contenders in terms of life span, which each technology averaging 10-15 years. Of these batteries, research published in 2020 reveals that Li-ion BESS was the cheapest of the available technologies in terms of total project cost, demonstrating cost advantages in construction and commissioning (Mongird. *et al*. 2020; 11). On the basis of this low cost, long life-span, and as the maintenance cost in no higher than its competitors, Li-ion would be a natural recommendation as the BESS technology to be used in PICs. However, a further investigation will need to be carried out on the impact of the higher-than-average temperatures experienced by PICs on the operational efficiency of Li-ion BESS in order to fully evaluate the technology’s potential in this region.

Table 10. Advantages and disadvantages of BESS.

Type	Energy density (kW/kg)	Roundtrip Efficiency (%)	Lifetime (years)	Advantages	Disadvantages
Li-ion	150-250	95	10-15	Size (compactness) Fast response time Rapid charge capability High cycle efficiency High energy density Low maintenance cost Design flexibility Long cycle and shelf life	Rupture risk Relatively high cost Poor performance at high temperatures Protective circuitry required
Nickel-based	40-60	75-85	10-15	High energy density High reliability Long cycle life Good charge retention	Relatively high cost Limited energy density
Sodium-based	125-150	70-75	5-10	Abundant materials Long cycle life Long discharge High roundtrip efficiency High energy density	Corrosive High operating temperature Only suiting large electricity systems High cost
Lead-acid	30-50	60-80	10-15	Low cost Availability High voltage Modular Good high-rate performance & charge retention Design flexibility High recyclability	Low cycle life Low energy density Difficult disposal High maintenance
Flow battery	60-80	60-70	3-6	Full discharge Long cycle life Long operational lifetime Modular Versatile	Capacity determined by tank size High capital cost Under development

Source: IRENA (2012); KBIA (2017).

BESS Technical Guidelines

Despite an abundance of literature and interest in the technical aspects of BESS, relatively little exists with regards to BESS deployments on islands. Of those sparing resources, Chown, G. (2019-A), provides a PIC-specific technical guideline for BESS (see Table 11).

Table 11. Technical requirements for battery storage systems

Topic	Requirements to be considered
Batteries	• Lithium-ion phosphate or other lithium-ion chemistries • Minimum battery life 10 years under normal use
Battery ratings	• kW (MW) and kWh (MWh) ratings to be determined for each site • Specified nominal battery ratings to be available throughout battery life • High charge/discharge cycle efficiencies required
Battery system	• Battery mounting system to be permanent and corrosion protected • Battery room layout to be fully accessible for personnel movement and emergency exit without obstruction • Interconnections and terminations to be accessible for easy maintenance and disconnection • Electrical protection by miniature circuit breakers or fuses to prevent battery short circuit or cable meltdown • Charge and discharge current metering • Energy output metering
Battery management	• Battery monitoring system • Cell monitoring • Battery condition alarms • Battery overcurrent to be limited to avoid combustion
Battery enclosure	• Permanent building preferred • Alternatively factory-built enclosure with permanent corrosion-proof cladding and roofing • Floor level to be minimum 1 meter above finished ground level or high flood level, whichever is highest • Cyclone proof • Vermin proof • Seismic considerations • Internal low energy switched lighting • Fire alarms and fire protection • High quality doors, locks, fittings and fixtures • Low maintenance • Cooling system and ventilation to prevent rain and dust entry • Cooling system to be low maintenance, have redundancy and failure remote alarms • Minimum 30 year life • Safety and emergency exit signage
Control system and communications	To be determined for each site and to take account of relevant power system requirements including: • Existing power station controls • Supervisory control and data acquisition requirements • Solar PV and/or other renewables intermittency • Standardization • Maintenance support
Energy storage kW (or MW) rating	To be determined for each site
Energy storage kWh (or MWh) rating	To be determined for each site
Inverters & inverter/chargers	• Established technology and proven design • Fail-safe • Reliability / mean time between failures

	• Suitable for tropical environments • Cooling • Harmonics limitation • Adjustable power factor controls • Frequency control/grid forming and grid following features • Facilities for external control and alarms • Ready repairs' support from Pacific rim countries • Maintenance support • Remote technical support availability
Standards and codes	• For most Pacific Islands, Australian, New Zealand or European standards • For Federated States of Micronesia, US or above standards
Power system connection	• In most PICs likely to be either 11kV 3 phase 50Hz or 13.8kV 3phase 60Hz • Low voltage switchgear and high voltage switchgear required • Cabling to depend on site and Employer requirements
Documentation and drawings	• All to be in English • Hard copies and soft copies • Clearly written • To cover As-Built details, operation and maintenance • To be reviewed and approved by Employer
Shipping and storage	• Refrigerated container • Temperature recording from factory onwards
Installation, testing and commissioning	• Must be checked • Test certificates needed • Full commissioning tests required
On-site operation and maintenance training & support	• Attendance on site of the contractor's personnel should be available after commissioning for a defined period

Source: Chown, G. (2019-A)

Box 2 provides a relevant case study of BESS deployment in the Galapagos islands, Ecuador, and the technical considerations for its 1MWh BESS.

Box 2. Budget Considerations for BESS Installations.

Case study: OEI's technical consideration for a BESS installation in the Galapagos Island, Ecuador

Supporting the initiative set by the Pacific Centre for Renewable Energy and Energy Efficiency, One Energy Island Co. Ltd. (OEI) assessed a project for the Galapagos Island. According to the Execution Plan provided by OEI, the budget[21] is calculated by: i) component, ii) delivery, and iii) installation.

No.	ITEM	QUANTITY	UNIT
A. Component			
1	1 MWh Battery pack	14	set
2	Balance of System, including inverters, transformer, and control cells per MWh	14	set
B. Delivery			
3	Maritime transportation (unit, 40 feet) ESS container from a port in South Korea to Guayaquil, Ecuador	7	Container
4	Logistics ESS container (unit, 40 feet) package at Guayaquil port	7	Container
5	Maritime transportation Guayaquil -San Cristobal (unit, 40 feet)	7	Container
6	Unloading ESS container (unit, 40 feet) package at San Cristobal Port	7	Container
7	Road transportation (unit, 40 feet) ESS container from the port to a planned construction site (length 10km) Guayaquil	7	Container
C. Installation			
8	Cleaning and leveling works	2,300	m2
9	Foundations, 240 kg/cm (for containers)	40	m3
10	Grounding system installation	1	set
11	Fence	1	set
12	Interconnection power line, 13,8 kV (overhead)	2	km
13	Foundations, 240 kg/cm2 (for electric cabinet)	42	set

The budget above is one case applicable to PICs. Although some geographical similarities among island states, including PICs, may exist, the composition of the land will not be uniform, indicating that a regional survey is a prerequisite for any BESS project.

While Table 11 outlines the general technical requirements for PICs, country-specific requirements may vary since each country's needs will be different from one another. Box 3 summarizes two reports, one from Ricardo Energy & Environment and one from the New Zealand Ministry of Foreign Affairs, prepared for Tuvalu. The former assesses optimal BESS types and the latter assesses the optimal BESS capacity.

[21] Costs for each item are omitted for privacy reasons.

Box 3. BESS Considerations in Tuvalu.

BESS considerations for Tuvalu

Determining BESS Type

Pertinent to considerations of BESS implementation are the characteristics of each battery configuration and how this relates to the grid's needs. For Tuvalu, a particular area of interest is frequency response and peak shaving, and the ability of li-ion and sodium sulfur (NaS) configurations when tasked with this. Chown, G. (2019-B) assesses the variable renewable energy grid integration in Tuvalu states that "Li-ion is thus a cheaper alternative as opposed to NaS regarding frequency response services. For peak shaving, however, and ultimately energy storage, NaS batteries are considered to be the better technology at the moment".

Determining BESS Capacity

In 2013, the New Zealand Ministry of Foreign Affairs and Trade conducted a study on the integration of solar PV and wind in Tuvalu's Funafuti electric grid by simulating various RE generation scenarios, including the installation, or lack thereof, of BESS. Resultantly, it was determined that "without storage, 100% renewable generation is not achievable – 10,000kW of renewable energy generation only provides 75% renewable energy" but that "with storage of 950kW/5,500kWh, the system would need 4,900kW of renewable energy to reach 85% renewable energy". (KEMA. (2013)). Considering that BESS has the potential to raise the share of RE generation to 85%, despite installed capacity being only half of the non-BESS scenario, it is easy to see why this can be attractive.

Other useful technical requirements highly relevant for PICs are discussed in *"Electricity Storage and RE for Island Power"* (IRENA. (2012)), which provides case studies of island BESS systems, including one such project in the PIC of Kiribati; *"Grid Connected PV Systems with Battery Energy Storage Systems Installation Guidelines"* (GSES. (2020-A)), which details the minimum requirements of BESS installations for solar PV systems; *"Grid Connected PV Systems with Battery Energy Storage Systems Design Guidelines"* (GSES. (2020-B)), which outlines the knowledge needed to effectively design a PV-BESS system; "*Electricity Storage Valuation Framework: Assessing system value and ensuring project viability"* (IRENA. (2020)), which discusses the method by which BESS can be integrated with RE installations and real-life examples of storage use in power systems; and the *"Handbook on Battery Energy Storage System"* (ADB. (2018)), which examines different technologies by storage characteristics, components, battery chemistry, scope, applications, technical requirements, O&M procedures, use cases, and microgrid applications.

Although not a technical guideline, the WB's *"Environmental and Social Management Framework"* instructs that energy facilities, including BESS, must be installed on lands other than "local, national, regional, or internationally-protected natural areas; culturally or historically significant sites or landscapes; foreshore or seabed (below mean high water springs / MHWS)" or "sites requiring the preparation of vehicular access routes" (PPA. (2015)).

EV Charging Challenges and Opportunities

While not explored as an option in previous reports, the introduction of EVs potentially offers an increase in the benefits of using EVs as BESS. This is because vehicles not currently in use are able to serve as batteries if they are connected to the grid at their charging stations, which drives costs down. Simultaneously, increased use of EVs presents interesting challenges and opportunities for the electric grids of the three nations. A development pathway involving the replacement of internal combustion engine (ICE) vehicles by EVs inevitably places further strain on the electricity grid, which will need to be expanded to account for the extra demand. Increased EV integration will need to be considered as there is potential for EV-related overloads to damage, and therefore require the replacement of, costly transformers. Schmidt. (2017), for instance, finds that an estimated 17% of transformers might need replacement due to EV overloads, at a cost of US$7,400 per transformer.

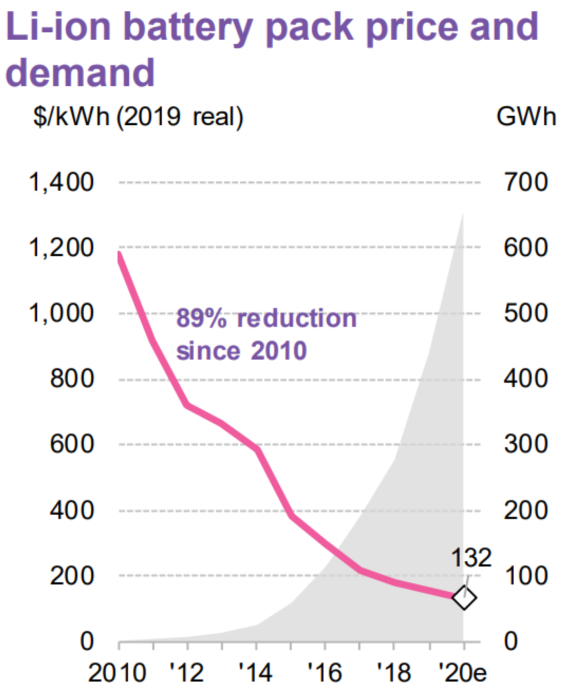
In the discussion between EVs and BESS, Graber. *et al.* (2020) identifies BESS as a potential solution for reducing demand peaks from charging stations, particularly by using second-life batteries to provide the charging service as an additional cost cutting measure. This could become an increasingly attractive solution over the course of the next decade as EVs achieve greater market penetration across the globe, resulting in greater availability of second life batteries. Similarly, the potential for EVs to act as temporary batteries when unused could be an attractive prospect for PICs, thereby tackling grid management and clean transport issues. Obvious concerns with this approach include the intermittency caused by vehicles being disconnected from the grid for personal use at any time, although usage in conjunction with automatic generation control (AGC) might alleviate some of these concerns. A further concern of EVs as grid-storage will be that vehicles are primarily used during the day, meaning that they may not be an effective solution for grids heavily reliant on solar PV.

A public-private pilot project is being carried out in Jeju island to verify the effectiveness of integrating V2G in the main grid. Dubbed the Smart City Challenge, the project’s consortium composed of 19 companies and institutions will experiment how increased EV presence enables larger RE penetration, and identify challenges that arise doing so.

Maintenance and Recycle/Reuse/Storage of Obsolete Equipment and Batteries

While li-ion battery pack prices have dropped 89% since 2010, the high capital expenditure (lithium-Ion battery packs currently require an average initial investment of $132/kWh, as in Figure 5, for implementation, support systems, and grid integration infrastructure deters widespread BESS deployment across the world. In developing countries, the high O&M cost (included in which is the cost required for a certain level of expertise) required to maintain proper BESS operation detracts further from their economic attractiveness.

Figure 5. Li-ion battery pack price and demand



Source: BNEF. (2020)

As an alternative to expensive new batteries, reused batteries from EVs have the potential to accelerate this price decline further. The International Energy Agency (IEA) expects this to be the case for li-ion technology, which could have knock-on effects for EV li-ion battery development. A report suggests that second-life batteries are expected to flood the market at a rate of 200 GWh per year by 2030. At present, a large portion of used batteries are not recycled or reused due to the process being cost-ineffective, although this is largely dependent on the battery's chemical configuration. As such, 99% of lead-acid batteries are currently recycled in the US, whilst li-ion battery recycling rates vary wildly according to each source of information but are generally far lower (Battery Council. (2020)). Reused and recycled BESS are crucial in pushing BESS prices down in the coming decade, which will make them more economically feasible and attractive to PICs.

2.3 Jeju Island: Policy and Strategy Review

Jeju's energy development targets – Carbon Free Island (CFI) 2030

Jeju island is the largest and southernmost island in Korea and became a UNESCO World Natural Heritage Site in 2007. Dubbed Korea's cleanest and most nature-friendly region, Jeju is home to a rich natural heritage and attracts more than 10 million tourists every year. More pertinent to our discussion, Jeju has emerged as a frontier of green growth and clean technologies. With a population of almost 700,000, Jeju has a total installed capacity of 1.88GW, 32.9% of which is renewable. Normally, actual power generation is less than 80% of the total installed capacity. Lee. *et al*. (2020) found that in 2019, total power generation was 5.7GWh, 14.4% of which came from renewable sources. The Korean government has been actively transforming the island into a green industrial powerhouse by expanding RE generation and BESS capacity, and rolling out EVs, all the while preserving the island's natural habitats. With major wind farms operating in Jeju since 2003 (Park. *et* al. (2011)), the island has considerable experience with renewable systems. The lessons learned from the experiences of Jeju will now be provided to support PIC plans for the development of RE and relevant enabling policy.

The CFI 2030 initiative was revised in June 2019, reflecting the changing landscape of RE commitments. Also known as the CFI 2020 Action Plan, the new policy roadmap is composed of nine policy measures and forty-six tasks.[22] The main investments of the Action Plan are as follows:

- KRW 209.1 billion (US$183.9 million) to expand RE capacity
- KRW 227.6 billion (US$200.3 million) to expand EV incentives and infrastructure
- KRW 12.4 billion (US$10.9 million) to secure innovative growth for new energy industries in connection with the Fourth Industrial Revolution
- KRW 8.7 billion (US$7.7 million) to introduce high-efficiency energy devices and smart energy systems
- KRW 10.1 billion (US$8.9 million) to strengthen energy policy and capacity building, such as energy governance

As an intermediate step in achieving the policy vision, four policy objectives and key indicators for CFI 2030 were established:

- Introduction of renewable energy facilities
- Supply of electric vehicles
- Final energy consumption units
- Leading the new industry for convergence and integration

[22] A total of KRW 476.7 billion will be invested in 14 relevant institutions and departments (provincial and administrative cities) in the form of 55 projects.

Table 12. Policy objectives and key indicators of Jeju CFI 2030

Policy goal	Indicator	2017	2020	2022	2025	2030
Introduction of renewable energy facilities	Installed capacity (MW)	605	1,137	1,821	2,490	4,085
	Power generation (GWh)	1,488	2,522	3,720	5,055	9,268
	Share of power generation to power demand (%)	30	44	59	67	106
Supply of electric vehicles	Number of EV	9,206	39,951	92,726	227,524	377,217
	Share of EV (%)	2.5	10	23	52	75
	Number of charging stations	8,284	22,419	34,603	59,167	75,513
Final energy consumption units	Final energy consumption (thousand TOE)	1,510	1,594	1,621	1,603	1,581
	Power demand (GWh)	5,014	5,694	6,290	7,600	8,723
	Energy consumption units (TOE/million Won)	0.096	0.088	0.085	0.078	0.071
Leading the new industry for convergence and integration	Including production (hundred million Won)	-	5,838	8,688	7,534	10,341
	Including employment	-	4,989	7,369	6,459	8,951
	Profitable project model for Jeju residents (unit)	8	12	18	21	21

Source: Jeju Special Self-Governing Province

Jeju's Electricity Market – single buyer

The Korean electricity market, including Jeju, is a single buyer market where the Korea Electric Power Corporation (KEPCO), with 51.1% of its shares owned by the Korean Development Bank (KDB),[23] is responsible for the transmission, distribution, and supply of electric power. In the Korean power market, the rights to generation are distributed between 17 independent power producers and five wholly KEPCO-owned subsidiaries, known as generation companies (GENCOs).[24] In addition to this, KEPCO relies on the Korea Power Exchange (KPX) to manage day-ahead demand forecasts and to receive generation bids from generators, which it does by utilizing pricing mechanisms stipulated under the Electricity Market Operation Rules rather than pricing occurring purely as a result of market mechanisms. Very few exceptions to this near-monopolization of the electricity market exist in a decentralized form. Those decentralized electricity businesses that generate and directly supply specific communities, consumers, or industrial businesses have been permitted to continue operations. (Park. *et al*. (2019))

Before turning our attention to Jeju alone, other sweeping policy measures and regulations pertinent to the electricity market need to be discussed, chiefly unbundling, foreign stakeholders and the

[23] Korea's 100% state-owned policy development bank

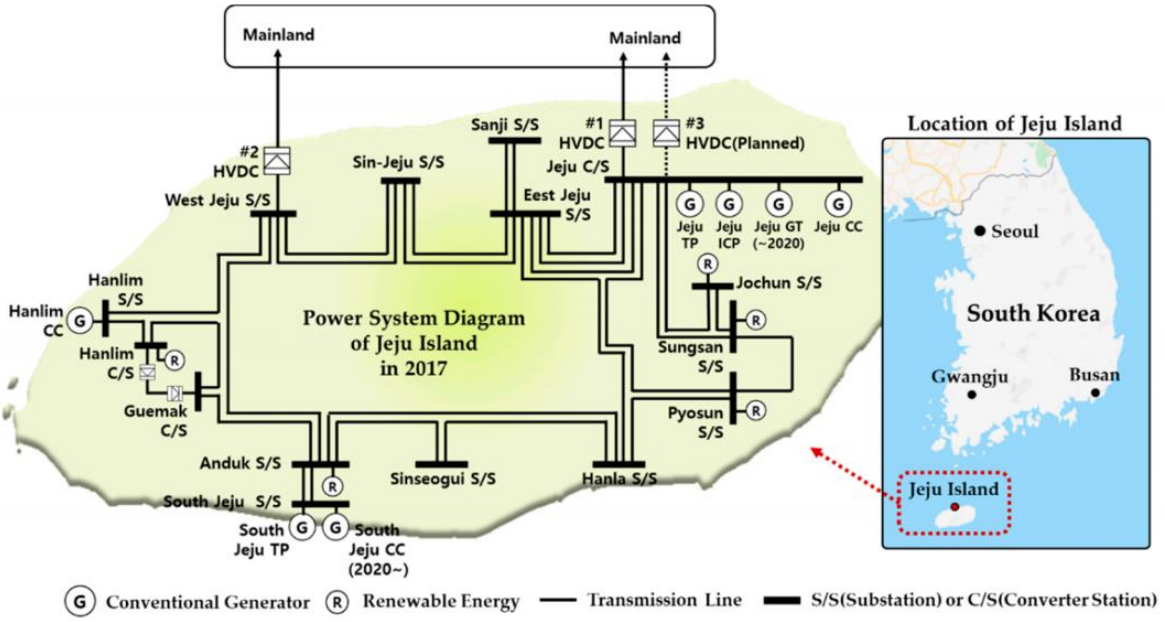
[24] KEPCO-Uhde. (2019). GENCOs.

investment climate, regulation of trade under the Electricity Business Act (EBA), the introduction of the Renewable Portfolio Standards (RPS) under the Act of Development, Use and Diffusion of New and Renewable Technology (ADUD), regulatory stakeholders such as the Ministry of Trade, Industry and Energy (MOTIE), and finally new pricing regimes introduced to reduce price volatility and increase renewable investment.

Unbundling, Foreign Stakeholders, and the Investment Climate

Excluding KEPCO, companies are not permitted to receive licensing under the EBA to operate more than one type of electricity-based business; this comes with a caveat for island-based businesses, which will become important in our later discussions. Opportunities for foreign stakeholders and for investment are similarly restricted, with foreign investors able to own no more than 30% of total installed capacity of KEPCO or any of its subsidiaries, whilst an investment ceiling of 3% of maximum available equity for single foreign or domestic investor. In addition, foreign shareholders may not own 50% or more of transmission and distribution infrastructure. The result is that KEPCO is primarily owned by the Korean Government; in fact, it is stipulated by the Korea Electric Power Corporation Act that the Korean Government must own no less than 51% of KEPCO's shares, ensuring the continuation of this. (Park. *et al*. (2019))

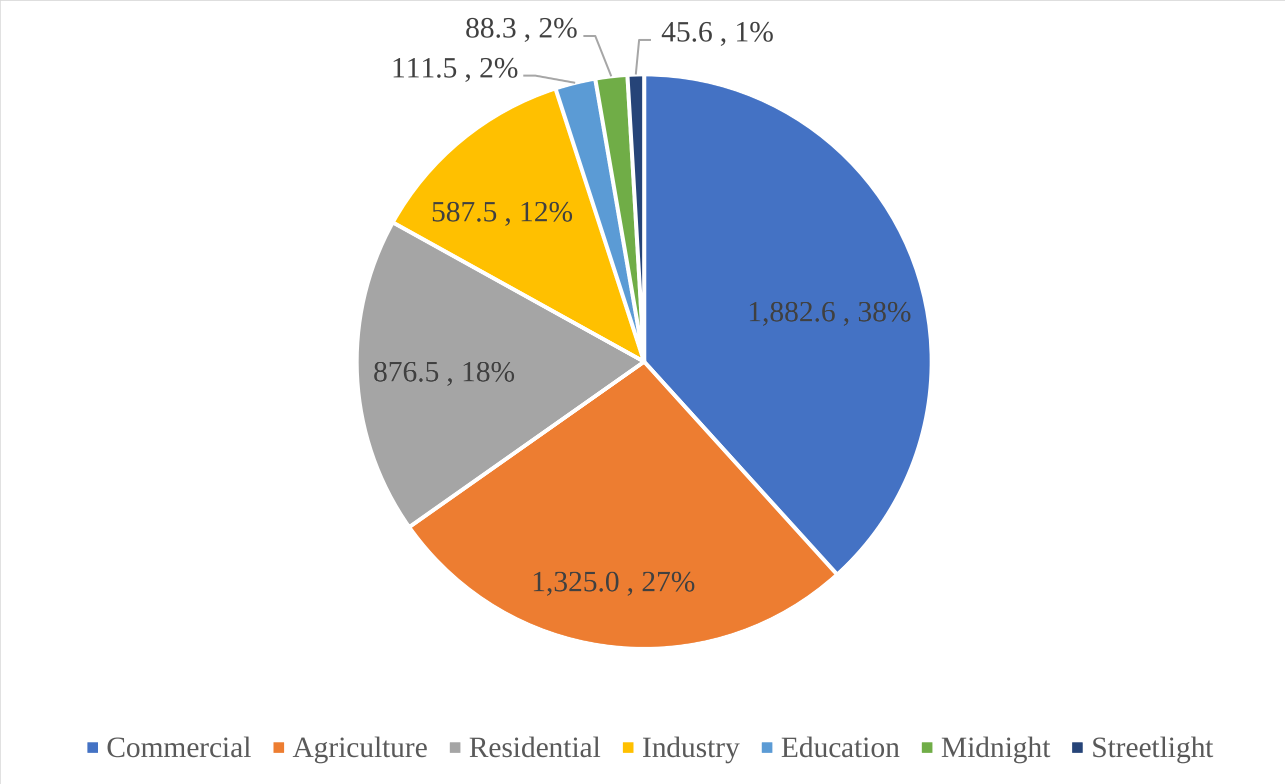
Figure 6. Jeju Power System Diagram



Source: Lee, Lee, and Wi. (2020). P.4.

As on the mainland, KEPCO holds the rights to sell electricity in Jeju. Figure 6 shows Jeju's power system. In 2020, KEPCO distributed roughly 4.92 TWh of electricity across the island General-purpose demand was the highest, totaling over 1.88 GWh, followed by agricultural demand at 1.32 GWh, and residential at 0.88 GWh. Figure 7 displays a breakdown of power demand in Jeju, and Figure 8 provides some examples of the variety of generation sources available.

Figure 7. Jan-Nov 2020 Jeju electricity demand by sector (unit: GWh, %)



Source: KEPCO

Figure 8. From left to right: Southern Jeju, Hangyeong, Hallim

		
Capacity: 200MW Type: steam turbine Fuel: diesel Established: Mar 2007	Capacity: 21MW Type: wind Fuel: - Established: Feb 2004 / Dec 2007	Capacity: 105MW Type: combined cycle Fuel: kerosene Established: July 1997

Electricity Market Price Restructuring

Following a surge in electricity demand following the incredibly hot summer of 2016, public outcry regarding electricity pricing and strain on household finances led to a restructuring of the tariff system. Resultantly, residential users have been subject to a 3-stage progressive tariff. The following table displays tariff rates, demand for each, and revenue in Jeju in 2017.

Table 13. Tariff rates, electricity used, average revenue by type of contract in Jeju 2017

Type	Tariff rates	Electricity used (GWh)	Electricity used (%)	Average rate (KRW/US$ per kWh)
Residential	3-stage progressive tariff	810.7	16.2	80.8/ 0.069
				121.9/ 0.10
				243.1/ 0.21
Commercial	Time-of-use tariff	1,913.3	38.2	130.4/ 0.11
Educational		130.4	2.6	103.07/ 0.08
Industrial		593.2	11.8	107.41/ 0.09
Agricultural	Flat tariff	1,390.7	27.7	47.57/ 0.04
Public lighting	A (fixed)	52.2	1.0	113.48/ 0.09
	B (metric)			
Midnight	A (heat)	123.1	2.5	67.48/ 0.05
	B (A/C)			

Source: Lee, Lee, and Wi. (2020). P.6.

Exploring the residential 3-stage tariff more deeply, Table 14 outlines this tariff's rates for high and low-voltage residential users in 2021 for the defined summer period of July 1st to August 31st. Table 15 outlines the prices for residential users for the remainder of the year throughout 2021. The 3-stage progressive tariff has been restructured, moving from charging differentiated rates at more specific levels of use, to three broader categorizations. In particular, the lowest categories of use now form a simplified <300kWh segment for summer use and <200kWh for the rest of the year. The level of usage required to qualify for the highest pricing regime has been lowered from >501kWh to >450kWh in the summer, and to >400kWh for the rest of the year.

To support the price reduction for higher levels of use, the now broadened initial category has seen prices rise from a minimum rate of KRW 60.7/kWh (here forth Won/kWh) for low voltage users to a standardized rate of Won 88.3/kWh. For high voltage users, the minimum charge has increased from Won 57.6/kWh to a standardized rate of Won 73.3/kWh. It is worth noting that the initial category has also had its maximum price decreased as a result.

The middle category of tariff has seen a price reduction, with low voltage users paying a minimum rate of Won 280.6/kWh under the previous scheme, whilst paying a standardized rate of Won 182.9/kWh under the current scheme. For high voltage users, this pricing change has been from a minimum rate of Won 215.6/kWh to a standardized rate of Won 142.3/kWh.

Finally, for the highest rate bracket, low voltage users have seen a change from a minimum rate of Won 417.7/kWh to a standardized rate of Won 275.6/kWh, whilst high voltage users have seen a change from a minimum rate of Won 325.7/kWh to a standardized rate of Won 210.6/kWh.

Pricing regimes for the remainder of the year have experienced a similar shift, with the only difference being the level of usage needed to qualify for each tariff rate bracket. For the remainder of the year, the initial rate is charged for usage under 200kWh rather than for usage under 300kWh. The middle bracket shifts to 201-400kWh from 301-450kWh. The highest bracket shifts to >400kWh, down from >450kWh.

The last change to draw attention to is the change in basic fees charged to residential customers under the new scheme. The approach to the change in basic fee follows the logic of the change to tariff rates, with reductions in price in the mid and latter brackets supported by price increases in the lowest bracket. In the summer period, this means low voltage users pay a standardized charge of 910

1,600, and 7,300 Won at each respective level, which replaces the previous minimum charges of 410, 3,850, and 7,300 Won. High voltage user pays a standardized basic fee of 730, 1,260, and 6,060 Won, whilst pre-change minimum payments stood at 410, 3,170, and 6,060 Won for each respective bracket.

Table 14. Summer Period (July 1st to August 31st) Tariff Rates and Basic Fees for Low and High-Voltage Residential Users Under the New 3-Stage Progressive Tariff, Compared with Pre-Change Pricing

Usage Level	Tariff Rate (KRW/kWh)	Basic Fee (KRW)	Pre-Change Tariff Rate (KRW/kWh)	Pre-Change Basic Fee
Low Voltage				
<300kWh	88.3	910	60.7-187.9	410-1,600
301-450kWh	182.9	1,600	280.6-417.7	3,850-7,300
>450kWh	275.6	7,300	417.7-709.5	7,300-12,940
High Voltage				
<300kWh	73.3	730	57.6-147.3	410-1,260
301-450kWh	142.3	1,260	215.6-325.7	3,170-6,060
>450kWh	210.6	6,060	325.7-574.6	6,060-10,760

Source: KEPCO (2020); So (2017)

Table 15. Rest of the Year Tariff Rates and Basic Fees for Low and High-Voltage Residential Users Under the New 3-Stage Progressive Tariff

Usage Level	Tariff Rate (KRW/kWh)	Basic Fee (KRW)
Low Voltage		
<200kWh	88.3	910
201-400kWh	182.9	1,600
>400kWh	275.6	7,300
High Voltage		
<200kWh	73.3	730
201-400kWh	142.3	1,260
>400kWh	210.6	6,060

Source: KEPCO (2020)

Renewable Portfolio Standards (RPS)

The RPS was introduced in Korea in 2012 to accelerate RE deployment in the country, replacing the previous Feed-in Tariff (FiT) system. The RPS aimed to achieve RE deployment by requiring the 13 largest power companies with installed capacities of over 500MW to gradually increase the share of renewables in their generation portfolio from the date of the project's introduction until 2024 (IEA. (2020)). Table 16 displays the gradually increasing obligations over time. In conjunction with this, renewable energy credits (RECs) were introduced in order to make investments in renewable generation more attractive. RECs are weighted to allow producers to multiply their supplied renewable energy by a pre-determined factor. This is intended to spur development in the areas most needed and discourage reckless or less beneficial development types. For example, solar PV installations in forests are subject to a multiplication factor of 0.7, meaning that producers will receive less for their energy than if they constructed their panels on buildings, in which case their project would be subject to a multiplication factor of 1.5 (KNREC. (n.d.)). Importantly, solar and wind projects linked with ESS are heavily favored under this scheme, with energy storage system (ESS) linked solar receiving a multiplier of 4-5 whilst ESS linked wind receives a multiplier of 4-4.5

(depending on when the project entered service). Appendix D displays the weight of RECs for each project, along with requirements.

Table 16. Required increase in the share of renewable generation by the top 13 power companies, subject to review every three years.

Year	Share of Renewables (%)	Obligation to supply (MWh/thousand REC)
2012	2	6,420
2013	2.5	9,210
2014	3	11,577
2015	3	12,375
2016	3.5	15,081
2017	4	17,039
2018	5	21,999
2019	6	26,966
2020	7	31,401
2021	9	35,588
2022	10	To be confirmed
2023<	10	To be confirmed

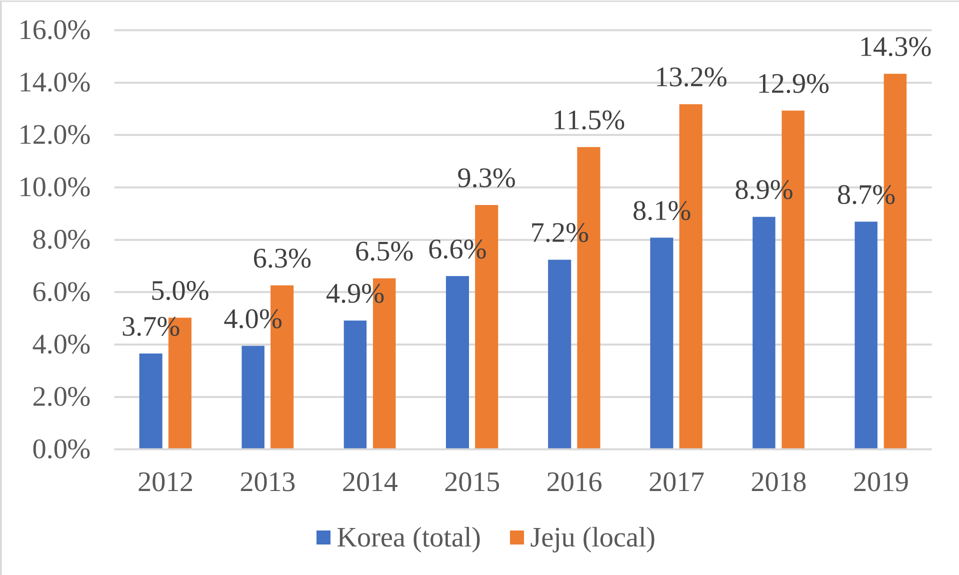
Source: Adapted from KNREC

The Future of Power in Jeju

The single-buyer Korean electricity market model has been critical to the nation's rapid growth. A simplified and standardized electricity price enabled the nation's manufacturing-based economy to reduce the risk associated with unpredictable electricity costs. However, with the rapid expansion of RE generation capacity, and new battery technologies, KEPCO's standardized but rigid pricing structure, and the Korean electricity market more broadly, is touted as being outdated and impeding the introduction of new technologies and efficiency at the expense of its shareholders. KEPCO is evaluating new plans for a changing national and global landscape. At the frontier of this endeavor lies Jeju. By the end of 2020, solar PV and wind turbine capacities reached 580MW, or 32.4% of total power capacity of Jeju, and total installed BESS capacity was 87MWh. Figure 12 outlines the increase in renewable generation capacity in Jeju and Korea.

Despite the addition of BESS, the island's electricity demand in 2019 was supplied by solar PV and wind turbines at a share of only 4.4% and 9.6%, respectively. RE underperformed due to two main factors: i) curtailment of wind and solar PV generation due to relatively high supply and low demand; and, ii) legal constraints banning the sale of electric power from non-KEPCO entities. These barriers to RE expansion are presenting some newly found opportunities for BESS development in Jeju.

Figure 9. Renewable energy penetration rate (2012-2019)



Source: JSSGP

In particular, sudden overgeneration by wind and solar PV due to variable weather events is one reason for their low participation in meeting demand, as curtailing must occur to prevent grid damage. The BESS can help to solve this problem. Table 17 details curtailment events from 2015-2020. In 2015, the island's RE generators were forced to shut down three times, losing 152 MWh of power. The number of shutdowns has been increasing, with 14,16, 46, and 77 shutdowns taking place in 2017, 2018, 2019, and 2020, respectively. The Korea Institute of Energy Technology Evaluation and Planning (KETEP) forecasts that the number of shutdowns will increase to 201 in 2021 and 240 in 2022, even after taking into consideration increased electricity demand. Considering the scale of curtailment taking place, it is clear that BESS has a future role in alleviating this issue.

Table 17. Wind Turbine Curtailment in Jeju

	2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021P**	**2030P**
Installed wind capacity (MW)	215	236	268	270	295	295	295	2,345
# of curtailment	3	6	14	15	46	77	240	-
Curtailment (MWh)	152	252	1,300	1,366	9,223	19,449	60,000	2,078,000
Generation (MWh)	352,183	470,576	542,525	540,730	556,999	579,762	611,790	3,091,154
Curtailment ratio	0.04%	0.05%	0.24%	0.25%	1.63%	3.25%	8.93%	40.20%

P Projected. Simulated results from the Jeju Energy Corporation

* Ratio $= \frac{\text{Curtailment}}{\text{Curtailment+Generation}}$

Source: KPX. (2021)

Policy bottleneck is another factor hindering increased RE presence in Jeju's energy mix. For instance, the Korea Power Exchange, having the authority to decide the type of generation to shut down in case of over generation, shuts down wind and solar PV ahead of other fossil fuel-based generations. This is the case as curtailing wind and solar PV, and then reactivating them, is cheaper than curtailing and reactivating fossil-based generators. Thus, while the national agenda to expand RE generation across the country including Jeju island is commendable, a number of technical and policy considerations must be made to support increased RE penetration.

One method that is of particular interest in solving the issue of curtailment is the discussions taking place regarding the decentralization of grids to incorporate more solar PV and wind generation to the main grid. This report previously acknowledged an increasing number of decentralized power grids across the country. The most notable of these is the island of Jeju. In March 2021, the MOTIE announced that Jeju will be designated as Korea's first special zone for distributed energy, following a visit from its minister to the island. KEPCO, with an obligation to respond the requests of MOTIE, will support this movement towards long-term institutional improvements that upgrade the electricity market and incentive system. Part of this plan is the installation of 23 MWh of BESS in Jeju which can aid in compensating for 150 MW of new RE installations. Additionally, demand for BESS is expected to increase with over 309MW of solar PV and 1,165MW of wind generation projects waiting for approval. While there is no specified BESS capacity target, the minimum regional policy BESS installation requirements should add at least 1.165MWh of BESS connected to wind projects.

Jeju's market frameworks for BESS – established PPP/IPP model

The PPP/IPP model has been befitting developing Jeju's RE market. The CFI 2030 initiative discussed earlier is a prime example. The revised CFI 2030 plan projects a total investment of KRW 2.06 trillion, or approximately US$1.86 billion, by 2030, with 60% coming from the private sector, 25% from JSSGP, and 15% from the central government. The financing structure of RE and BESS projects under CFI 2030 is such that the central government and JSSGP assume responsibility when the estimated social benefit outweighs the social cost. Conversely, the private sector invests when total expected revenue is large enough to outstrip investment costs. Many RE projects in Jeju have reaped the benefits of a PPP/IPP arrangement between the public and private sectors.

Table 18. Benefits of Private-Public Partnerships in Jeju, Korea

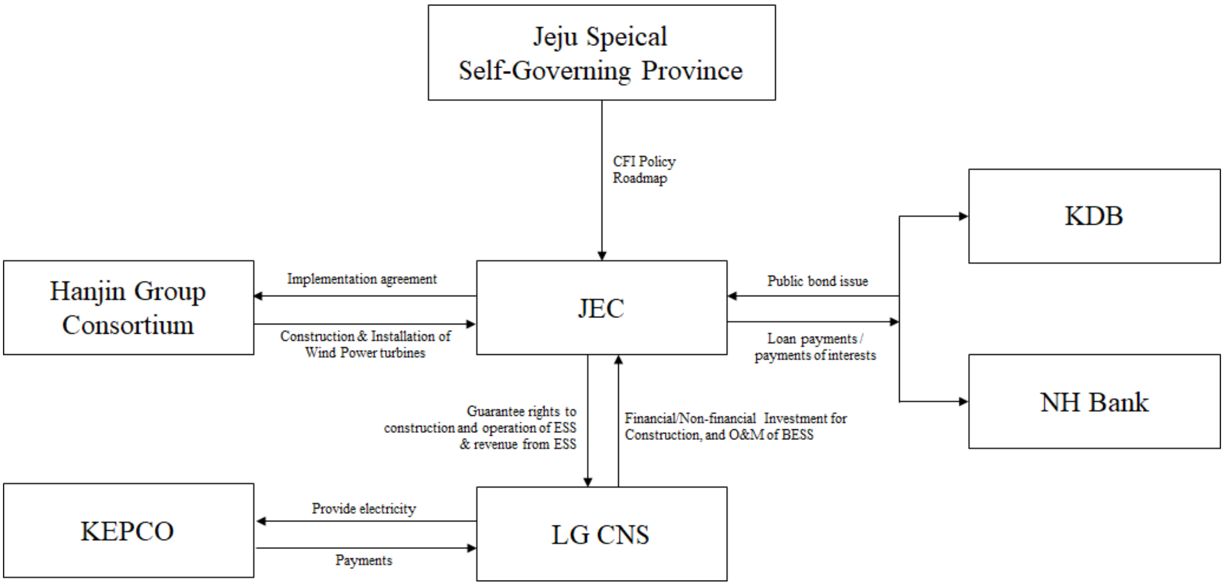
Benefits for Public sector	Benefits for Private sector
For both the public and private sector, the formation of a SPV (an industry practice) facilitates financial conditions, thus enabling financial risks to be managed easily.	
Borrow technical and financial expertise from the private sector to design profitable business.	The government provides legal and policy foundations related to RE projects including but not limited to project permits and right to access public resources (land, for instance).
Dividends to stakeholders are provided after the entirety of project financings have been repaid. This results in all stakeholders to commit to the project until the end, and during operations and management (O&M) which guarantees stable operations for the long-term.	Procuring funding from public loans available. This allows private sector participation in large-scale project financing required for RE projects (which is otherwise difficult).
Private sector participation increases the quality of public infrastructure services and reduces associated costs.	Even with the possibility of project failure, government participation in project financing mitigates risks associated with RE projects, protecting private sectors from financial instability.
From the perspective of the government, PPP enables expansion of RE, increased jobs, and increased economic activities with relatively lower cost.	Private sectors are presented with new business opportunities at low risk. They can also acquire new market opportunities by participating in RE projects

Box 4. Dongbok Wind Power Development Project

The Dongbok Wind Power infrastructure construction project, planned and managed by Jeju Energy Corporation (JEC), was completed in June 2015. Hanjin Group Consortium was responsible for the construction and installation of fifteen 2.0MW wind turbines. The project cost 70 billion KRW (US$61.5 million), of which the JEC financed 15 billion KRW (US$13.2 million). The remaining 55 billion KRW (US$48.3 million) was financed by loans from the KDB and NH Bank[25]. The loan is due in 2024.

Phase	Date	Loan Amount (KRW billion)	Interest Rate(%)	Institution (Bank)
1st	June 2014	16.30	3.28%	Korea Development Bank
2nd	February 2015	12.00	2.58%	Korea Development Bank
3rd	April~June 2015	2.67	(unknown)	Korea Development Bank
4th	unknown	5.00	2.86%	Nonghyup

LG CNS, one of Korea's largest BESS manufacturers, was solely responsible for the planning, investment, construction, and operation of the Dongbok Wind Power Plant's 18MWh BESS. The company generates revenue through the sale of BESS-stored electricity to KEPCO[26] and will operate the BESS for the first 15 years following its installation.[27]



Generally, a special purpose vehicle (SPV), composed of both public and private entities, is formed for offshore wind projects of more than 100MW. The government (usually the public entity in the

25 Korean Development Bank and Nonghyup Bank
26 Figure not open to the public.
27 NRS. (2016). Energy storage updated – September 2016.

SPC) is able to employ the expertise of private sector while private companies can participate in massive infrastructure projects that may otherwise be off-limits. In this way, PPPs are effective as involved stakeholders share revenue based on the ratio of investments, which are in turn based on perceived risk. PPPs, and particularly the Build-Own-Operate iteration, allow private sector actors with sufficient capacity to be responsible for not only one part of a project, but many parts or all of the project's stages. This includes financing, planning, construction and operation. Such cases are lucrative as the private sector actor enjoys an agreed period during which revenue and payments for the operation of public infrastructure is collected solely by themselves, rather than being payments being made to other involved actors as in other PPP iterations. Box 4 provides a development case study which highlights these partnerships and interactions, as well as a visualization of partnership arrangements.

Jeju's Battery Energy Storage System

BESS development in Jeju has been driven by policy measures to meet the CFI 2030 targets. In 2014, the provincial government announced the *Wind+ESS measure*, stipulating that all wind power plants must install BESS equal to or greater than 10% of the plant's generation capacity. This BESS requirement specifically aims to increase the efficiency and output of variable wind resources. As a result of this policy, a minimum BESS installation capacity of 26.9 MWh was guaranteed across twenty wind facilities with a cumulative installed capacity of 269MW. Currently, 35.2 MWh of BESS supports 119 wind turbines across the island. The table below are wind compounds with BESS attached.

Table 19. BESS attached to wind farms in Jeju

Operator	Facility	Wind capacity	ESS capacity	Investment type
Jeju Energy Corporation	Haengwon Wind Power Complex	11.45MW(12 units)	BESS 200kWh PCS 800kW	IPP
	Gasiri (Localization) Wind Power Complex	15MW(13 units)	BESS 9MWh PCS 3MW	IPP
	Dongbok Wind Power Complex	30MW(15 units)	BESS 18MWh	IPP
	Seongsan Wind Power	20MW(10 units)	BESS 2MWh	IPP
KOMIPO	Sangmyong Wind Power	21MW(7 units)	BESS 6MWh PCS 2MW	Public

Source: JSSGP

The law does not yet require solar PV to be supported by BESS. Despite this, a total of 51.9 MWh of BESS has been connected to thirty-four solar PV facilities. The ability to make profit out of the price difference has incentivized at least thirty-four solar PV facilities to install BESS.

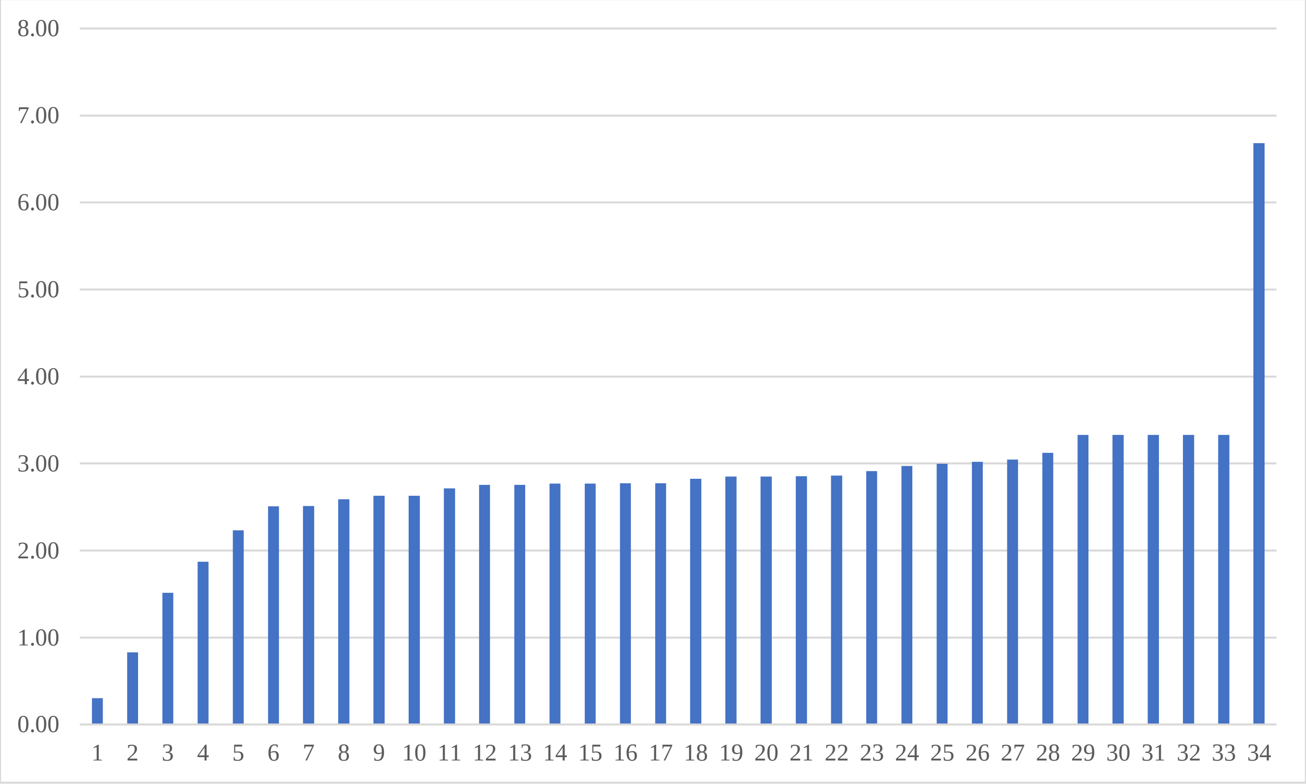
Table 20. BESS attached to Solar PV in Jeju

Operator	Solar PV (kW)	ESS capacity (kWh)	ESS capacity (kW)
(U)Megasola Solar Power Plant	1,800	4,018	2,000
Tamra Green Co., Ltd.	2,000	5,023	2,000
Keumnung No.2 Solar Power Plant	495	1,301	500
Keumnung No.1 Solar Power Plant	495	1,301	500
Sunlight Solar Power Co., Ltd. (Jeju Mureung Solar Power Plant)	900	2,995	800
Baekil Solar Power	97	274	100
Sun Solar Power Plant	99	274	100
Namjeon floating Solar Power(Sangmo Unit 2)	450	1,498	400
Jiyoung Solar Power Plant	500	1,664	400
Namjeon floating Solar Power(Sangmo Unit 1)	280	832	250
Yebit Solar Power Plant	250	832	250
PMJ Solar Power Plant	300	832	250
Baekil Energy	99	274	100
SOLATECH KOREA Co., Ltd. (SOLATECH KOREA Solar Power Plant)	467	1,331	400
Enhye Solar Power Co., Ltd.	349	998	400
Yeongrak Solar Power Co., Ltd. (Yeongrak Solar Power Plant)	300	832	250
Nanum Scholarship Co. (Nanum Solar Power Co. (Youngrak))	480	1,498	400
Daejung Solar Power Co., Ltd.	400	1,165	400
Daejung Solar Power Co., Ltd.	500	1,498	400
Sunlight Solar Power Co., Ltd. (Jeju Mureung Solar Power Plant)	900	2,995	800
JCG Energy 1 Solar Power Plant	398	1,096	400
JCG Energy 2 Solar Power Plant	192	548	200
Daemyung Solar 1 Energy	476	1,232	476
Sori Solar Co., Ltd.	1,202	3,013	1,000
Jeju University Solar Power Plant	1,040	2,824	1,000
Korea Central Power Co., Ltd. (Jeju Thermal Power Plant)	1,206	1,000	1,000
KT Mureung Transportation Solar Power Plant	496	1,497	500
Jeju Solar Core Solar Power Plant	668	1,904	500
J.C.G. Solar 2 Solar Power Plant	414	626	200
Godo Farm Solar Power Plant	41	274	100
Jiyu Solar Power Plant	90	274	99
Jungseong Solar Power Plant No. 2	901	274	1,000
Photovoltaic Power Plant of Bonggae-dong Residents' Countermeasures Committee	2,002	3,744	1,000
Photovoltaic Power Plant 2 of Bonggae-dong Residents' Countermeasures Committee	793	2,184	500

Source: JSSGP

Table 20 lists the thirty-four solar PV facilities with BESS attached. Comparing the ratio of solar PV (kW) to BESS (kWh)[28], twenty-nine facilities have a ratio between 2.23 and 3.33, four facilities have ratios less or equal to 1.87, and only one facility has a ratio of 6.68. This indicates that the range between 2.23 and 3.33 is a generally accepted solar PV to BESS ratio; in other words, a 1.0MW solar PV facility would attach a BESS at the range between 2.23MWh and 3.33MWh.

Table 21. BESS (kWh) to Solar PV (kW) ratio

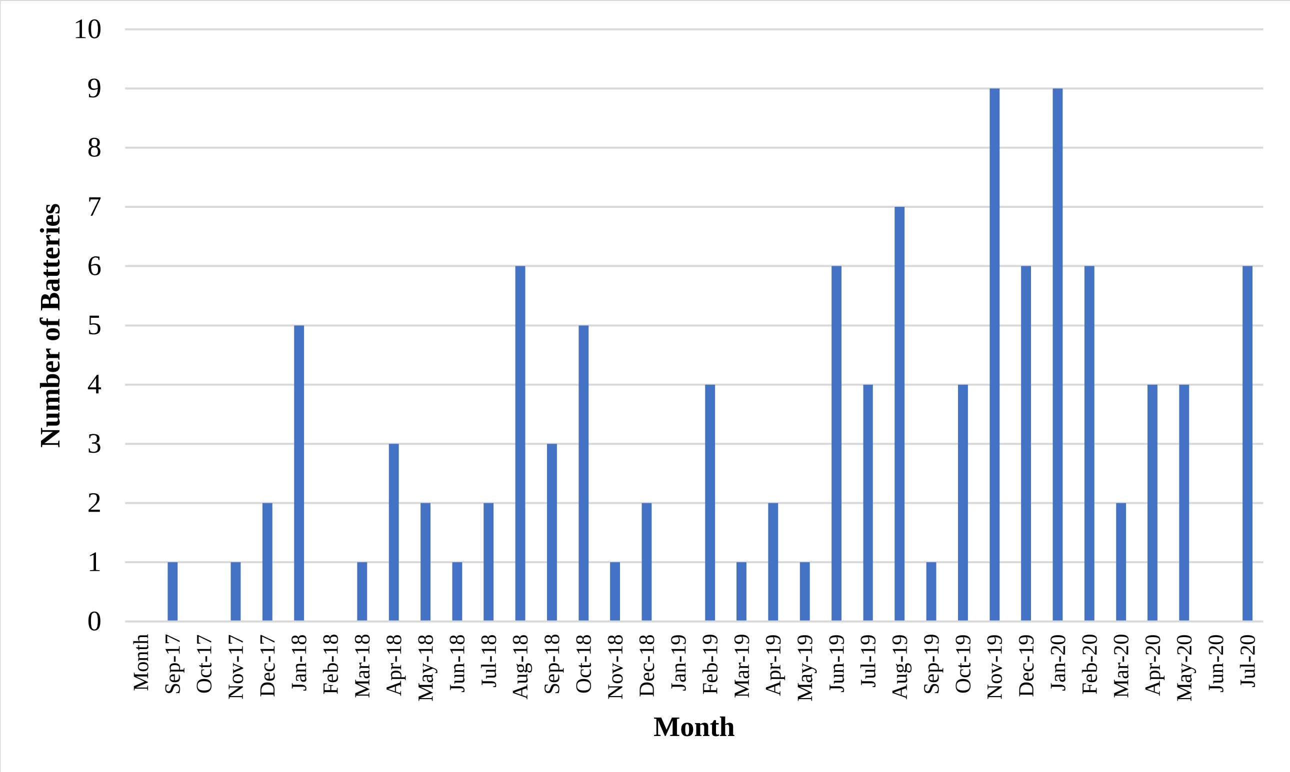


2nd Life Batteries

In addition to new BESS being manufactured, used EV batteries are being transformed into BESS. JEC, the main operator of the "2nd-life battery" pilot project, is experimenting with the technical and economic aspects of repurposing EV batteries that would otherwise have been landfilled. According to the JEC, used EV batteries maintain 70% of their original capacity. The figure below shows the number of EV batteries being repurposed for BESS usage since the start of the pilot test in October 2017. With EV production significantly increasing, a great quantity of used EV batteries can be expected to enter the market in the coming decades, making used battery applications a critical line of inquiry.

[28] This ratio is a measurement to simply examine the generally accepted BESS installation capacity as compared to the solar PV facility; hence, there is no scientific meaning to the unit (hour) that results from the calculation. To measure the amount it takes for the BESS to charge, the PCS capacity (kW) of the BESS should be considered.

Figure 10. Number of EV Batteries Repurposed for 2nd-life BESS



Source: Jeju Techno Park

2.4 Jeju Island: Main Grid Analysis

Data Description

Jeju's decade-long experiment is on-going. Data gathered on solar, wind, conventional power generation, and BESS charge/discharge allows for an empirical analysis of BESS operation. In this section, Jeju's electricity demand, peak and minimum generation capacity, renewable power generation, conventional generation levels, high voltage direct current (HVDC)[29] supply data, and BESS charge and discharge data are analyzed to uncover insights related to BESS operation in PICs.

Power Generation Data

Table 22 outlines the changes in the annual power generation of different sources from 2016-2020, while Figure 11 visualizes this. Figure 12 provides a direct comparison of the energy mix of Jeju for years 2016 and 2020. Jeju's annual power generation[30] increased from 5,123GWh in 2016 to 5,678GWh in 2018, but decreased to 4,759GWh in 2020. The decrease in Jeju's Gross Regional Domestic Product (GRDP) resulted in the 3.6% decrease in power generation between 2018 and 2019. The decrease of 13.1% between 2019 and 2020 was due to the stagnating regional economy that resulted from the outbreak of COVID-19. The pandemic reduced the number of tourists visiting the island, temporarily or permanently shutting down large parts of the commercial sector and leading to a decrease in electricity demand. Despite this, the contribution of renewable generation to the grid in 2020 increased overall. From 2016 to 2020, wind and solar PV generation increased, with the share of renewables increasing from 8.2% in 2016 to 19.0% in 2020. Conversely, the share of imported electricity via the two HVDC cables (hereinafter referred to as *Import*) and steam power has decreased by 3.8% and 13.3% from 2016 to 2020. The generation share of combined cycle power was 1.2% in 2016, before reaching a peak of 17.7% in 2019 and declining once again to 12.4% in 2020. In 2020, it ranked below HVDC and steam power generation.

Table 22. Jeju annual power generation by source (unit: GWh)

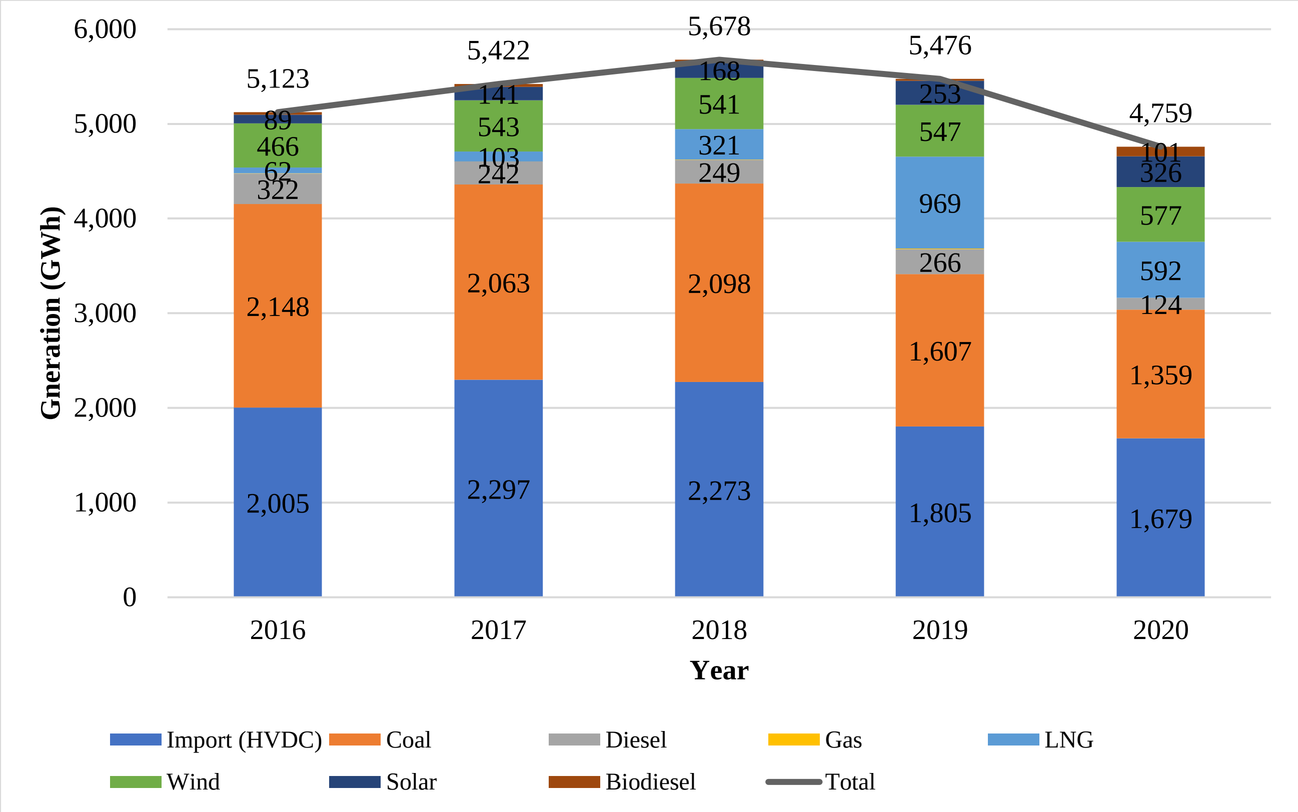
	2016	**2017**	**2018**	**2019**	**2020**
Import	2,005.32	2,296.92	2,273.38	1,804.95	1,679.04
Coal	2,148.36	2,063.07	2,098.13	1,607.09	1,358.83
Diesel	322.48	241.75	248.54	265.62	124.45
Gas	1.23	2.50	4.49	7.37	0.00
LNG	62.32	103.08	320.96	969.38	592.42
Wind	466.18	542.83	540.56	547.21	577.42
Solar	89.39	140.92	168.15	252.98	326.09
Biodiesel	27.64	30.68	23.28	20.91	101.04
Total	5,122.92	5,421.74	5,677.50	5,475.51	4,759.29

Source: KPX

[29] HVDC: Jeju receives electric power imported from the Mainland through two high voltage direct current cables submerged under the South Sea.

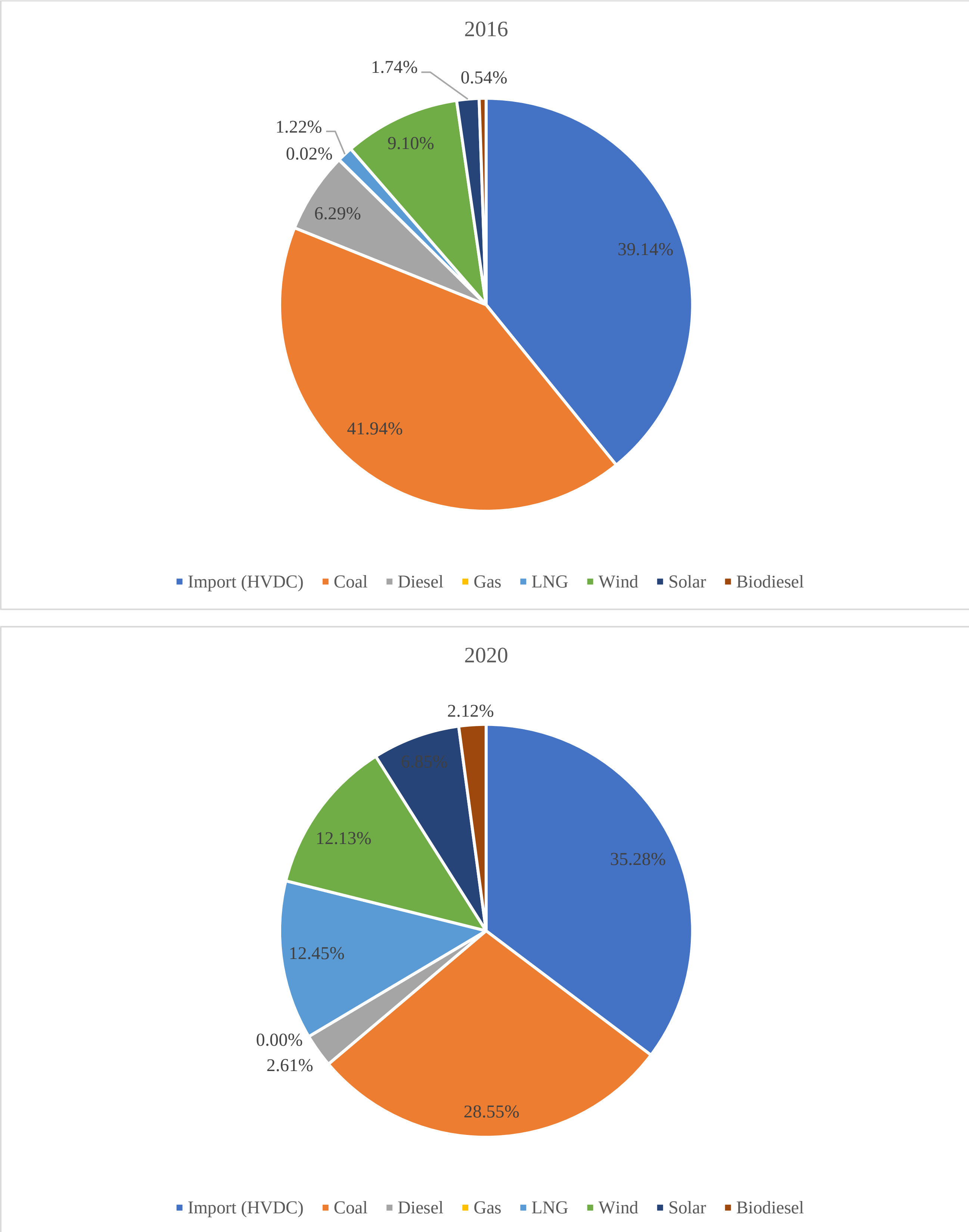
[30] Total power generation includes electricity supplied via HVDC from the mainland.

Figure 11. Jeju annual power generation by source



Source: KPX Jeju branch

Figure 12. Jeju's energy mix in 2016 vs 2020



Source: KPX Jeju branch

There have been significant changes between 2016 and 2020 in Jeju's energy mix. Most notably, a steep decline in steam has been observed along with a decrease in combustion-based generation. Combined cycle, wind, and solar PV have all seen a considerable increase in their generation, signifying a great step forward for Jeju in reducing the carbon emissions of its energy sector.

Relationship among different energy sources

Measuring the Pearson correlation coefficient, this study analyzes the relationship among different power generation sources. An absolute value of the correlation coefficient of less than 0.3 renders the correlation insignificant.

Table 23. Correlation among different power generation sources (2016-2020)

	Import (HVDC)	Coal	Diesel	Gas	LNG	Wind	Solar	Biodiesel
Import (HVDC)	1.00	-	-	-	-	-	-	-
Coal	0.62	1.00	-	-	-	-	-	-
Diesel	0.14	0.21	1.00	-	-	-	-	-
Gas	-0.03	0.07	0.44	1.00	-	-	-	-
LNG	-0.38	-0.39	-0.25	0.27	1.00	-	-	-
Wind	0.16	0.07	-0.27	-0.18	0.07	1.00	-	-
Solar	-0.51	-0.63	-0.38	0.07	0.50	-0.09	1.00	-
Biodiesel	-0.35	-0.49	-0.40	-0.39	0.06	0.12	0.57	1.00

The results of our analysis of the relationships between activity of different generation sources are shown in Table 23. The most notable observations made from the analysis are as follows:

- Import and steam (+0.62): significant positive correlation
  - Increase in HVDC demand (HVDC from the mainland) is related to increased steam generation
- Solar PV and steam (-0.63); solar PV and HVDC (-0.51): significant negative correlation
  - Increase in solar PV generation is related to decrease in steam generation and HVDC demand
  - Solar generation is exogenous as it highly depends on variable weather conditions
- Solar PV and biodiesel (0.57); solar PV and ICE (0.50): positive correlation
  - Increase in solar PV generation is related to increase in generation from biodiesel and from internal combustion engines (using gasoline and diesel)
- Wind and biodiesel: there are no significant correlation between wind generation and biodiesel generation

A high negative correlation between solar PV and HVDC, steam and combustion generation suggest that solar PV is contributing a large amount to the island's energy needs, resulting in a large reduction in supply from HVDC, steam and combustion when doing so. However, when solar PV is not generating, these other sources are ramping up to compensate, which is expected. As wind power has no significant relationship with biodiesel, the following two assumptions can be made about renewable generation in Jeju:

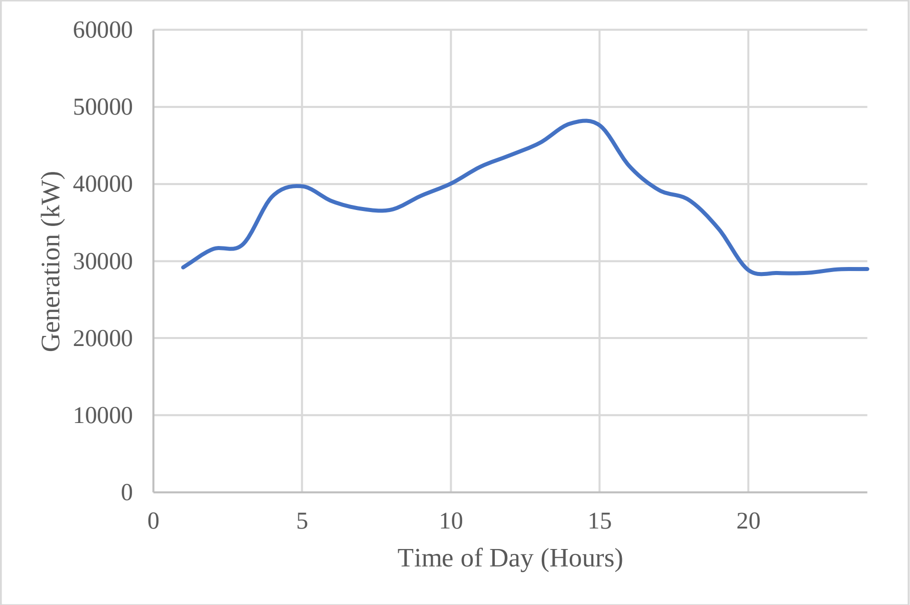
- First, there is evidence to suggest that electricity generated from solar PV supplies the island's demands in place of HVDC and fossil-fuel generation when solar PV generation is feasible; and,
- Second, electricity generated from wind power is a much more stable generation source and is not being replaced by other sources with any notable pattern (e.g. in the case of solar generation being replaced during evening peaks by HVDC, steam, and combustion generation).

In addition, sudden increases in wind generation are harder to predict and react to, resulting in conventional generation sources not being ramped down and instead wind is being curtailed instead. In addition, due to policy designs, wind turbines are the first to be shut down in case of over-production – followed by solar PV. These assumptions are reflected in curtailment figures being much higher for wind than solar in the case of an oversupply. So far, this study has observed a positive phenomenon in which increased RE generation results in lower fossil fuel utilization. The following sub-section reviews what role BESS plays when integrated in the central grid.

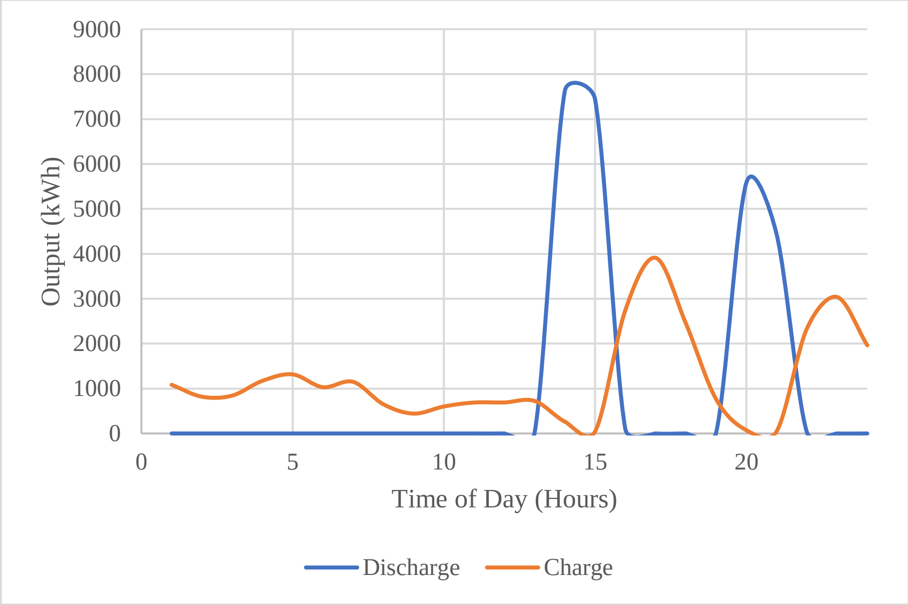
BESS Charging and Discharging Patterns

In this section, the relationship between BESS and other variables provide insights as to what PICs may expect with increased RE generation and BESS installation. Graph 1 and Graph 2 show the average wind generation and wind connected BESS charge and discharge throughout the day in August 2020. Graph 3 and Graph 4 display the same data for solar PV and solar PV connected BESS. From the wind generation data, it is clear to see that there is no pattern throughout the day. Wind connected BESS discharge data shows two distinct peaks, around lunch and dinner time, during which a large amount of electricity is provided to the grid to account for sudden growth in demand during these times. Solar PV connected BESS discharge data mirrors the evening peak demand widely expected; however, the BESS is in the process of charging during the lunch-time peak which limits its contribution.

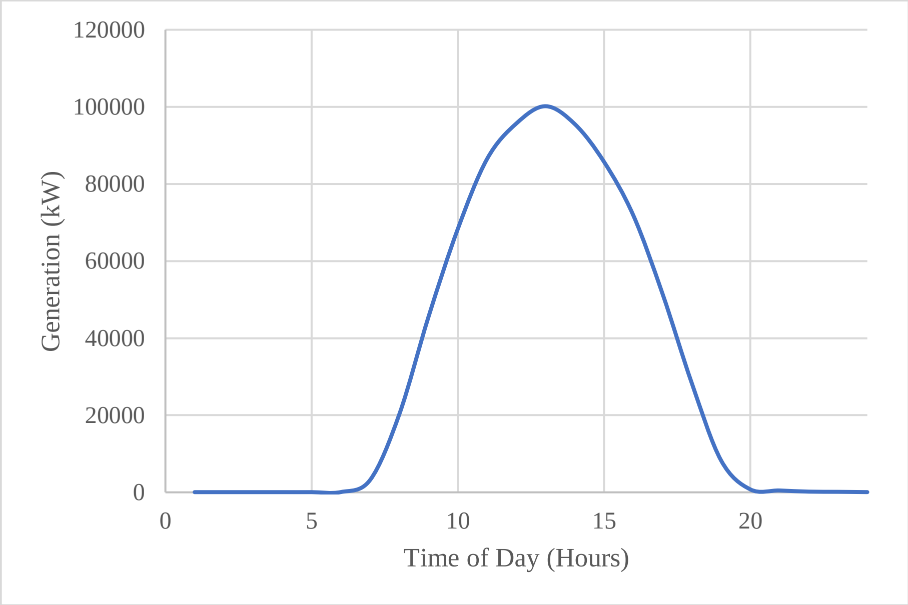
Graph 1. Average August Wind Generation in 2020



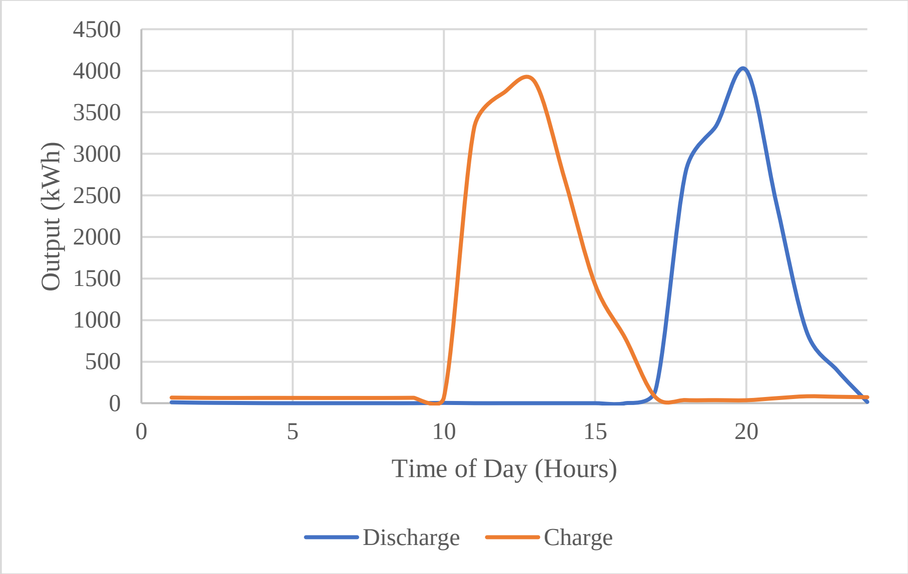
Graph 2. Average August BESS Charge-Discharge in 2020 (Wind + BESS)



Graph 3. Average August Solar PV Generation in 2020



Graph 4. Average August BESS Charge-Discharge in 2020 (Solar PV + BESS)



The generalized method of moments (GMM), a generic method used in econometrics to estimate parameters in statistical models, is the main tool used in this section. GMM is advantageous over the ordinary least square (OLS) method in analyzing time-series datasets. The commonly used OLS method is effective when the dependent and the independent variables are orthogonal – meaning, the dependent variable must not have any effect on the independent variable. However, this is rarely the case for time-series datasets, which creates biases and inconsistencies in the result. The GMM, using an instrumental variable, avoids creating biases or inconsistencies (or, endogeneities), thereby ensuring consistency throughout the analysis process.

Using the generalized method of moments (GMM), daily BESS charging and discharging data is compared with daily energy generation data (examined in the previous section), daily temperature data, and daily humidity data. To closely examine the effects being had on BESS by RE, temperature, and humidity, the dataset is adjusted to combine all fossil-fuel based energy sources into a single variable, termed “fives fuels”. Table 24 below provides a description of the variables analyzed.

Table 24. Variable Description

No.	Variables	Variables Description	Unit
1	SOLAR	Daily power generation from solar PV	kWh
2	WIND	Daily power generation from wind	kWh
3	BIODIESEL	Daily power generation from biodiesel	kWh
4	FIVE_FUELS	Daily combined power generation from fossil fuels	kWh
5	RAIN_DAY	Average temperature in rainy days	°C
6	SNOW_DAY	Average temperature in snowy days	°C
7	TEMP_MAX	Maximum daily temperature	°C
8	WIND_MED	Median wind speed	m/s
9	HUMID_MED	Median humidity	g/kg
10	RAIN_DAY	Average humidity in rainy days	$cal/cm^2 \cdot min$
11	SNOW_DAY	Daily solar radiation in snowy days	$cal/cm^2 \cdot min$
12	SOLA_DAY	Daily solar radiation in solar days	$cal/cm^2 \cdot min$

Variables 1-4 are used for the analysis between BESS usage and electricity generation from different sources. Variables 5-8 are used to observe the effect of weather temperature on BESS utilization. Variables 8-12 are used in testing the correlation between BESS usage and humidity.

The first test analyzes the relationship between BESS usage and power generation. Solar PV, wind, and biodiesel are compared separately to evaluate the efficiency of the BESS+RE hybrid model. Below are the results after 254 observations:

Table 25. Correlation between BESS usage and energy generation by source

	Variable	Coefficient	Std. Error	t-Statistic
SOLAR	27.94476	16.25603	1.71904	0.0869
WIND	32.92425	8.265491	3.983338	0.0001
BIODIESEL	-3.91811	7.855385	-0.49878	0.6184
FIVE_FUELS	10.82615	58.09619	0.186349	0.8523
T	4.476019	12.037	0.371855	0.7103
C	-175159	131897.1	-1.328	0.1854

The highlighted variables in Table 25 show significant correlation with BESS usage. In this analysis BESS and PV/wind data show significant correlations. Notable observations include:

- An increase of 1% in wind power generation has increased daily BESS usage by 32.9 kWh.
- An increase of 1% in solar PV generation resulted in a daily BESS usage increase of 27.9kWh.

In addition, the following can be said about the analysis above:

- BESS usage data and fossil fuel generation have no statistically significant relationship.
- An observation of the relationship between BESS and biodiesels is not necessary, whether statistically meaningful or not, since the amount of power generated from biodiesels is very low.

Next, this study analyzes the effect of weather variables on BESS usage, given that RE power output strongly depends on weather conditions.

Table 26. Correlation between BESS usage and weather conditions.

	Variable	Coefficient	Std. Error	t-Statistic
RAIN_DAY	111.9875	89.02474	1.257937	0.2096
SNOW_DAY	-360541	500242.4	-0.72073	0.4718
TEMP_MAX	167.4424	97.82739	1.711611	0.0882
WIND_MED	3877.703	899.491	4.310997	0
T	8.242077	4.707888	1.750695	0.0812
C	-109443	40889.72	-2.67655	0.0079

The highlighted variables in the table above show significant correlations with the BESS dataset. Conclusions drawn are as follows:

- An increase of 1°C in the daily maximum temperature is correlated with a 167.4 kWh increase in BESS usage.
- An increase of 1 m/s in the daily median wind speed is correlated with a 3,877.7 kWh increase in BESS usage.

Finally, the relationship between BESS and two additional weather variables, humidity and daily solar radiation, are analyzed. The table below displays the results of this examination.

Table 27. Correlation between BESS usage and energy generation by source

	Variable	Coefficient	Std. Error	t-Statistic
HUMID_MED	173.6742	104.1476	1.667578	0.0967
RAIN_DAY	-64.16201	180.1838	-0.356092	0.7221
SNOW_DAY	-530531	540424.9	-0.981692	0.3272
SOLA_DAY	43.90517	100.5003	0.436866	0.6626
WIND_MED	4473.568	1104.989	4.048516	0.0001
T	8.168191	4.91445	1.662076	0.0978
C	-119857.7	50193.39	-2.387917	0.0177

Notable conclusions for this examination include:

- An increase in daily median humidity of 1 g/kg is correlated with an increase in daily BESS usage of 173.7 kWh.
- An increase in daily median wind speed of 1m/s is correlated with an increase in daily BESS usage of 4473.6 kWh.

In this section, the relationship between energy generation and BESS utilization in Jeju's main grid was analyzed. While the total BESS storage capacity installed in Jeju's main grid is relatively small in comparison to the total installed generation capacity, its usage contributes to increasing the efficiency of solar PV and wind. That BESS usage increases when solar PV and wind capacities increase, generally at an optimum BESS capacity of two to three times the multiple of the solar PV capacity, indicates the role BESS can play in PICs energy mix. This takeaway is important as it shows how, with proper operations and management, BESS can be developed in the PICs to support their RE expansion.

Another lesson from the Jeju main-grid is the issue of curtailment (see Table 17). While RE sources are undoubtedly cleaner than other conventional sources, they are also extremely unpredictable, forcing operators to curtail RE generation. This issue of curtailment, which has significantly constricted generation contributions from wind – 3,042.8 GWh over the past six years (and expected to increase even more), is opening up new discussions at the municipal, utility, and consumer levels for the introduction of supporting technologies such as BESS.[31] Per protocol, wind turbines are the first to be curtailed, followed by solar PV.[32] Given that, at the current stages of discussion, BESS is the only economical and readily available technology to support RE generation – particularly to reduce instances of wind and solar PV curtailment, developing roadmaps and planning budgets for BESS for PICs are imperative.

[31] Solutions being tested in Jeju include green hydrogen, EV, V2G, among many others.

[32] Until April 2021, all curtailments pertained to wind generators. The first instance of solar PV curtailment of 7.4MWh occurred in April 2021

2.5 Gapa Island: Case Study

Overview

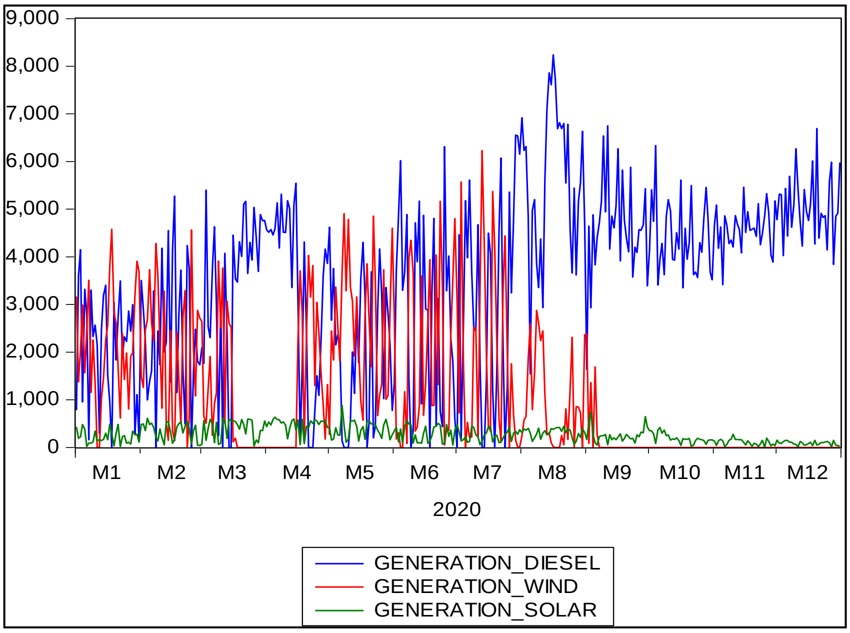
Gapa is a speck of land off the southern coast of Jeju, designated as a test-bed for the Jeju Green Big Bang Project over a decade ago. The 126 households of the island depend on fishery and tourism for income. With fewer than 300 residents on less than 1 sq km of land, two wind turbines are able to compensate for much of the community's energy demands. Solar-powered houses generate additional electricity for the local residents.

In 2016, not long after the start of the project, Gapa's 3,000 kWh electricity demand was completely supplied by RE and BESS for seven consecutive days. The island's 1.4 MWh BESS capacity is able to provide reliable and stable power for six hours in case of complete solar PV and wind turbine malfunction. This accomplishment was accompanied by a reduction in electricity tariffs for the residents. The monthly electric bill fell from US$100 to US$20. However, hurricane Maysak in August 2020 damaged the wind turbine's power conditioning system, putting it out of service. Currently, the island runs on solar PV and diesel, with BESS providing various supporting roles. Unlike Jeju, Gapa is unable to be supported by a much larger electricity grid in its proximity should the grid become unable to meet the demands of residents. As a result, Gapa is an excellent small-scale comparison from which key insights can be gleaned for PICs, particularly now that the island has been forced to integrate diesel generation in what is something of a reverse of what is expected in PICs.

Electricity generation and BESS operation data

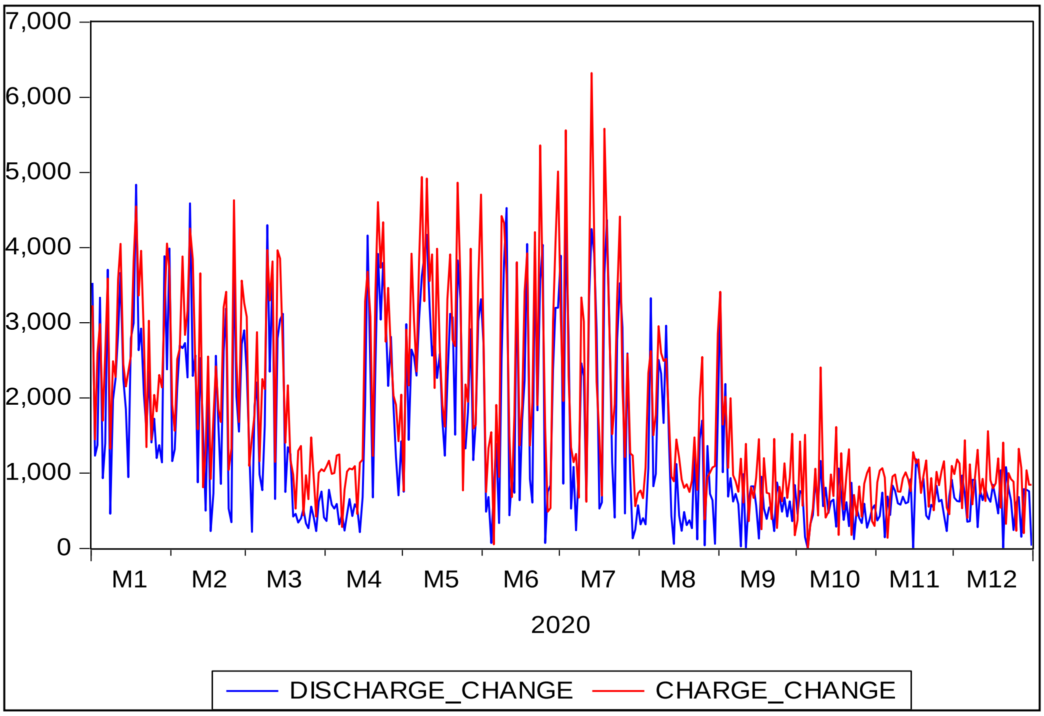
As of 2020, the island's 400 kW peak demand was supplied by three 150 kW diesel generators, two 250 kW wind turbines, eighty-six solar PV panels (totaling 111 kW), and one 1.4 MWh BESS. Graph 5 shows the yearly electricity generation by source in 2020. Graph 6 shows power charged and discharged from the installed BESS. Graph 7 shows the amount of cumulative energy charged and discharged from BESS.

Graph 5. Gapa Electricity Generation by Source (2020)

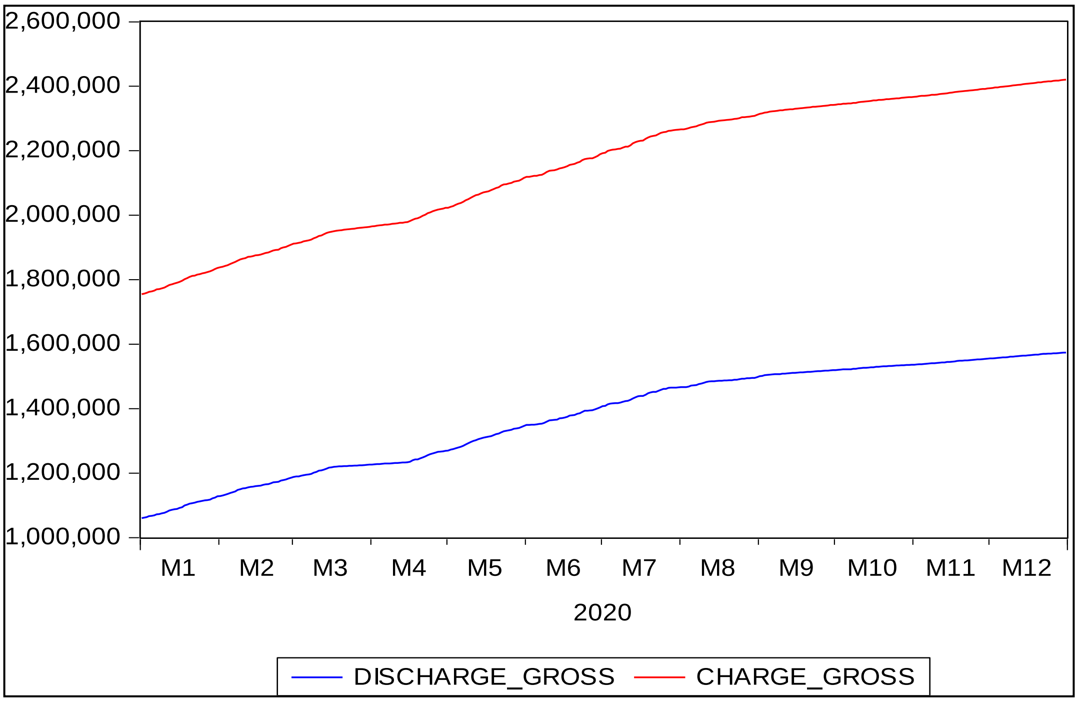


Notable of Gapa's electricity mix of diesel, wind, and solar are the following: i) solar PV constitutes a small portion of the island's electricity generation; ii) wind and diesel constitute the majority of electricity generation; iii) diesel generation supplies the majority of the island's electricity when its wind turbines are under maintenace or are unoperational.

Graph 6. Gapa BESS power charge-discharge (2020)



Graph 7. Gapa BESS cumulative charge-discharge (2020)



As a case study for PICs, this section uses the generation data presented above and the BESS charge/discharge data to extract relevant insights. As an empirical analysis of Gapa's independent microgrid, the relationship between energy generation and BESS is examined in two parts: rate of change and storage change.

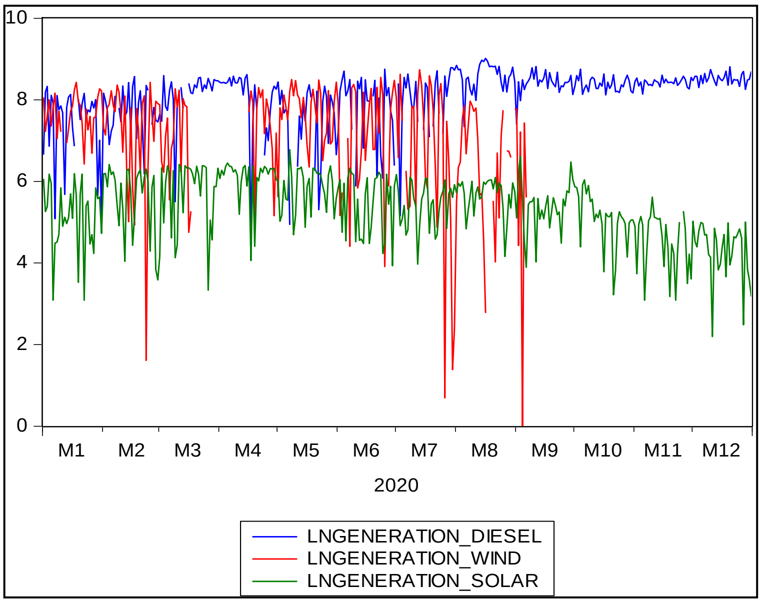
A comparison of the change in BESS charging and discharging, in relation to the change in energy generation by source, provides a picture that may serve as reference to PICs. A hypothetical scenario in which BESS charging and discharging is highly related to the changes in the energy mix (e.g. in the case of RE replacing diesel generation) should indicate that the hybrid RE+BESS model may be replicated in PICs. Using GMM analysis, daily BESS charging and discharging data is compared with daily the energy generation data from different sources. below provides a description of the variables analyzed.

Table 28. Variable Description

No.	Variable	Variable Description	Unit
1	LNGENERATION_DIESEL	Daily diesel generation (logarithmic)	-
2	LNGENERATION_SOLAR	Daily wind generation (logarithmic)	-
3	LNGENERATION_WIND	Daily solar PV generation (logarithmic)	-
4	GENERATION_DIESEL	Daily diesel generation	MWh
5	GENERATION_WIND	Daily wind generation	MWh
6	GENERATION_SOLAR	Daily solar PV generation	MWh
7	LNCHARGE_GROSS	Cumulative BESS charge (logarithmic)	
8	LNDISCHARGE_GROSS	Cumulative BESS discharge (logarithmic)	
9	CHARGE_CHANGE	BESS charge	MWh
10	DISCHARGE_CHANGE	BESS discharge	MWh

Variables 1-3 are the logarithmic forms of variables 4-7, which include: daily diesel generation, daily wind generation, and daily solar PV generation. The results of an investigation of variables 1-3 are displayed by Graph 8**.**

Graph 8. Log of generation by generation source throughout 2020



BESS usage in relation to changes in energy generation

The first test asks the following question: by how much do BESS charging and discharging activities change in response to a 1% increase in diesel, solar PV, and wind generation? Running the GMM model, the results of 90 observations after adjustments are shown in the table below:

Table 29. Correlation between energy source and BESS charging (logarithmic)

	Variable	Coefficient	Std. Error	t-Statistic
LNGENERATION_DIESEL	0.000518	0.001442	0.359028	0.7205
LNGENERATION_SOLAR	0.003671	0.001479	2.482986	0.015
LNGENERATION_WIND	0.001256	0.000589	2.133326	0.0358
C	14.35775	0.018755	765.5545	0
T	0.001122	9.04E-06	124.1597	0

The highlighted rows in the table above show significant correlations between BESS charging and RE generation. Notable observations include:

- An increase of 1% in solar PV generation is correlated with a 0.37% increase in BESS charging at a significance interval of 95%.
- An increase of 1% in wind generation is correlated with a 0.13% increase in BESS charging at a significance interval of 95%.

According to an interview with the manager of the Gapa grid, the two wind turbines and several solar PVs directly feed the – the operator has full control over the operation of these sources of generation. Thus, in case of a steep rise in generation, the operator might choose to shut down wind and some solar PVs, or direct the remaining power to BESS. This interpretation is backed by the observations above. However, shutdowns of wind between March and April 2020, and from September and onwards may also account for the observed effect on BESS charging. It can be thus hypothesized that, under normal circumstances, BESS charging in relation to wind generation might have increased.

In addition, the following can be said about diesel:

- There is no observable correlation between diesel generation and BESS charging.

Table 30 shows the results of analyzing the relationship between log energy generation and BESS discharging.

Table 30. Correlation between energy source and BESS discharging (logarithmic)

	Variable	Coefficient	Std. Error	t-Statistic
LNGENERATION_DIESEL	0.000694	0.002286	0.303759	0.7621
LNGENERATION_SOLAR	0.005343	0.002281	2.34198	0.0215
LNGENERATION_WIND	0.001761	0.000934	1.884781	0.0629
C	13.84879	0.02968	466.6021	0
T	0.001395	1.42E-05	98.35423	0

The highlighted variables reveal important correlations with the BESS dataset:

- An increase of 1% in solar PV generation is correlated with a 0.53% increase in BESS discharging.
- An increase of 1% in wind generation is correlated with a 0.18% increase in BESS discharging.

Comparing these two results to those obtained for BESS charging, it can be concluded that discharging activities are more affected than charging activities by solar PV and wind generation. In this case, large amounts of RE generated power charges the BESS during daytime and is discharged during the night.

Additionally,

- The relationship between diesel generation and the BESS discharging is not statistically meaningful.

BESS usage in relation to daily net changes in energy generation

This section analyzes how BESS charging and discharging activities are affected by daily net changes in energy generation by source.[33] The table below displays the results of this analysis.

Table 31. Correlation between energy source and BESS charging

	Variable	Coefficient	Std. Error	t-Statistic
GENERATION_DIESEL	-0.148946	0.080427	-1.851952	0.0649
GENERATION_WIND	0.605679	0.149845	4.042029	0.0001
GENERATION_SOLAR	1.464886	0.927185	1.579929	0.115
C	1275.87	353.2913	3.611382	0.0003

The highlighted variables are the result of GMM after 364 observations. Notable insights include:

- An increase of 1 kWh in diesel generation is correlated with a decrease of 0.15 kWh in BESS charging.
- An increase of 1 kWh in wind generation is correlated with an increase of 0.61 kWh in BESS charging.

As for the first statement, it can be re-interpreted as:

- Diesel generation has a negative correlation with BESS charging.

Next, this study analyzes the effect of weather variables on BESS discharging, given that RE power output strongly depends on weather conditions. The results are as follows:

[33] Observing the net change (in this case, today′s electricity generation – yesterday′s electricity generation, etc.) is a conventional method to eliminate the unit root in a time-series dataset.

Table 32 Correlation between weather impacted energy generation and BESS discharging

	Variable	Coefficient	Std. Error	t-Statistic
GENERATION_DIESEL	-0.274496	0.11109	-2.470934	0.0139
GENERATION_WIND	0.414553	0.1448	2.862939	0.0044
GENERATION_SOLAR	0.714739	0.325031	2.198984	0.0285
C	2162.213	556.5557	3.884989	0.0001

The highlighted variables reveal the following correlations with the BESS dataset.

- An increase of 1 kWh of diesel generation is correlated with a decrease of 0.27 kWh in BESS discharging.
- An increase of 1 kWh of wind generation is correlated with an increase of 0.41 kWh in BESS discharging.
- An increase of 1 kWh of solar PV generation is correlated with an increase of 0.71 kWh in BESS discharging.

In short, diesel generation has a negative correlation with BESS discharging, while RE has a positive correlation with BESS discharging.

The results from this section demonstrate that combining BESS and RE is effective. In addition, it can be said that a share of diesel generators may be replaced by BESS if enough supporting RE capacity is available. To conclude, Gapa's demonstrates that BESS plays an important role in replacing diesel generation, which can provide a rationale for their deployment in PICs.

Jeju main grid versus Gapa

Jeju's experiment with RE, EV, and smart grids, known as Carbon Free Island 1.0, ultimately resulted in 16% of power being generation by RE as well as the introduction of 24,000 EVs by 2020. The analysis of the experience of Jeju and Gapa with BESS provides key insights, particularly in determining that, in the case of Jeju, BESS has the ability to support RE generation expansion and that, in the case of Gapa, BESS can be combined with solar PV to reduce electricity costs. It should be noted that the two initiatives were largely supported by the provincial government, local communities, and central and independent generators, highlighting the level of cooperation required for successful implementation.

Despite the benefits reviewed so far, RE curtailment has remained problematic for the utilities of Jeju and Gapa, with public utilities suffering the most. As a result, the municipal government has been searching for options to relieve this issue, including distributed energy systems, BESS, and fuel cells. A key takeaway from Jeju's experience with RE and BESS is that such a combination is successful and is worthy of implementation, although the issue of curtailment must be well understood and considered, especially in terms of the impact this could have on utility companies. Key to understanding this is a method known as Price Arbitrage Trade, which is one facet of ESS economics, with the majority of economic approaches to ESS coming from reducing the reserve cost expense from wind.

In total, Jeju and Gapa two cases with different insights. The case of Jeju outlines how BESS can be used to support an expansion of RE generation capacity and can act as a baseline from which PICs can base their own expansions. Meanwhile, Gapa provides insights extremely relevant to PICs in the ability of BESS to combine with existing RE, and particularly with solar PV, to reduce the cost of electricity. Both studies find that the importance of BESS increased with added solar PV and wind capacities. In fact, the rapid expansion of RE capacity and a relatively slower growth in BESS capacity have resulted in solar PV and wind curtailments in the Jeju Island main grid – a problem that all VRE projects in PICs is likely to encounter. This challenge presents opportunities for BESS in three different ways: one, BESS demand is likely to increase to support VRE expansion; two, EV batteries no longer viable for EVs can be refurbished into 2^{nd}-life batteries; and, three, the increase in e-mobility (EVs, e-bicycles, e-scooters, etc.) can absorb increased RE generation. Further insights can be expected from the current pilot experiments in Jeju (regarding 2^{nd}-life batteries and e-mobility).

3 BESS Development Roadmap

This chapter designs BESS development roadmaps for the three countries of FSM, RMI, and TUV, as well as considering expanded EVs as mobile forms of BESS. For each country, the roadmap i) identifies the challenges in the power sector of the selected country, ii) reviews the proposed options for BESS integration, and iii) assesses the availability of enabling policy, market, and financial mechanisms. It concludes by discussing the future of BESS in PICs in consideration of EV fleet expansion and by reviewing what direction considerations PICs should take in preparation of the upcoming decade.

Common challenges in PICs include limited institutional capacity, relatively small land size, narrow economy, geographic remoteness, and proximity to the ocean environment. In addition, there are several hurdles that PICs must overcome in order to construct sustainable power grids: high dependency on costly imported fossil fuels, lack of adequate capacity and reliable data for energy planning and management, the need for capital to finance battery storage and other facilities that can properly absorb variable RE in isolated systems, insufficient revenue from tariffs to meet O&M costs, and, the high maintenance cost of generation and distribution systems close to a marine environment.

Proposed BESS capacity

The previous chapter examined the interaction between BESS and various sources of power generation in the Jeju main grid and the Gapa microgrid. The results indicate that BESS works best with wind in the main grid, whereas it works best with solar PV in the microgrid. While conditions surely vary among Jeju, Gapa, FSM, RMI, and TUV, BESS is one of several green technologies optimal for PICs as it offers them the opportunity to reap maximum benefits from their planned upgrades to the electric grid and RE installations by reducing the consumption of costly imported diesel, and providing a continuous and stable electricity supply.

Similar to Jeju island's main grid and Gapa's mini grid, standard models integrating BESS in PICs' power grid is shown in Table 33 based on the capacities of each region calculated by consultancies that have partnered with the governments of FSM, RMI, and TUV. Generally, the three countries have regional RE development plans composed of mixing solar PV, Wind, and BESS.

Table 33. BESS integration options (including benefits and cost) for energy and BESS

Standard RE models	Proposed option	Stakeholders
Solar PV + BESS	▪ FSM: Chuuk	▪ CPUC
Solar PV + Diesel^{R} + BESS	▪ FSM: Kosrae	▪ KUA
	▪ FSM: Pohnpei	▪ PUC
	▪ FSM: Yap	▪ YSPSC
	▪ RMI: Majuro pathway 2	▪ MEC
	▪ TUV: Funafuti	▪ TEC
Solar PV + Wind + BESS	▪ RMI: Majuro pathway 1	▪ MEC
Solar PV + Wind + Diesel^{R} + BESS	▪ RMI: Ebeye	▪ KAJUR

^{R} denotes reserve purposes

Source: CSA. (2018); RMI. (2018); Entura. (2019).

Policy measures and financing mechanisms

PICs' efforts to develop BESS infrastructures must be backed by robust and continued policy support. As it is in the case with many emerging technologies or industries, the absence of policy or market guaranteed by the government presents too high of technical and financial risks for private sector participation in new RE projects. Listed under the table below, reducing those risks in part are official government targets and policy measures that are determined to support BESS development. Government (central or regional) targets of designated BESS capacity for buildings, RE targets, and EV targets are directly related to the expansion of BESS in PICs.

Policy measures that support BESS development can be direct or indirect. Direct policy measures including BESS mandate, investment tax credits, and tax reduction or exemption for BESS projects directly incentivize private sectors to engage in BESS roll-out. Indirect measures are typically energy policies that reward increased RE usage. Auctions or reverse auctions, energy access / electrification rate, feed-in-tariff, interconnection standards, renewable portfolio standard, and TOU & net metering are energy measures that, by incentivizing utilities/generators to supply electricity more effectively or by incentivizing them to scale-up RE, provide platforms for private sector participation. For each of the three countries of FSM, RMI, and TUV, this study evaluate what targets/measures are in place and proposed, and recommends time frames as to when each target or policy measure should be placed for PICs to increase RE in their energy mix.

Table 34. Recommended BESS Targets and Policy Measures for PICs

Items			Note
Targets	Battery Energy Storage System (kWh or MWh)		Setting a BESS capacity target for each province enables a clearer calculation for private capital in how much to invest. Adopting the BESS targets discussed in the previous section is recommended as a first-step.
	Renewable Energy (%)		The national RE target paves the way for various RE and BESS expansion policies.
	Transportation (# of vehicles)		Setting an EV or e-mobility target provides a clear picture of the increasing power demand which enables government ministries and utilities to respond to increasing demands.
Policy measures	Direct	BESS mandate (%)	Mandatory BESS installation for utilities or public/government buildings is an effective practice to reduce curtailed RE generation.
		Investment tax credits	Private or public funds are incentivized to invest in BESS.
		Tax Reduction or Exemption	Tax reductions and exemptions for BESS projects (or BESS profits) incentivize private investors to participate in BESS projects .
	Indirect	Auctions or Reverse Auctions	The presence of an auction or reverse auction platform attracts private players (investors, operators, etc.) to compete based on cost-effectiveness, incentivizing BESS installation to increase performance. Prerequisite: single-buyer or higher-level market.
		Feed-in Tariff	A FiT incentivizes consumers to invest in BESS. Feeding the grid with energy stored in BESS provides a source of income to either the utility or the system developer that owns the BESS.
		Interconnection Standards	Standards enforcing the safe incorporation of small/medium/large BESS is necessary.

	Energy access / Electrification rate	Particularly pertaining to remote areas in PICs, energy access and/or electrification rate policies can channel source of financing that would otherwise go to transmission and distribution line investments.
	Renewable Portfolio Standard, RPS	RPS and BESS are highly synergistic. The presence of RPS serves as an incentive for utilities to adopt BESS.
	TOU & net metering	TOU, net metering schemes enables utilities, system operators to make energy profit from arbitrage: selling energy stored in BESS charged during low-cost hours at high-paying hours.

Setting BESS targets and policy measures prepares both the public and private for new sources of income. The next step would be to consider how to reduce financial risks, inherent in large energy infrastructure projects like BESS. In PICs' current market arrangement, deriving greater levels of funding from private sector investors is challenging because of the high-risk and low-reward investments in the region. In the absence of financial safeguards like guarantee products or other structured financial mechanism that hedge risks for the private sector, attracting private sector participation will be challenging even with the appropriate BESS policies.

Guarantee products, such as those offered by the WB's International Bank for Reconstruction and Development (IBRD) and International Development Association (IDA), specifically target PPP's involving build-operate-transfer projects. Combining such instruments with different types of finance including concessions, loans and equity, the risk to private investment can be reduced and private sector actors can be attracted. Moreover, developing the ability to promote structured finance could enable greater scalability. Structured finance offers lines of credit to those with complex financing needs, which is certainly the case in PICs. IPP is key to introducing competition to the power sector, reducing electricity prices, and reducing the strain on the government to pay for and manage these developments (IRENA. (2016)).

Other opportunities exist within FSM, RMI, and TUV for the PPA to act as medium to facilitate this without handing over complete control of the power sector to private parties. This means allowing private entities to invest in and own installed capacity, perhaps as part of their own demonstration before moving on to a larger grid elsewhere. Due to the geographic positioning of PICs, additional incentives may need to be provided in order to attract these private investors, and these incentives could be developed in partnership with multi-lateral development organizations among others. Developing some competition within the power sector in this way could benefit FSM, leading to a reduction in the price of electricity and enabling greater level of deployment of key renewable and BESS infrastructures.

In order to facilitate this, robust policy frameworks defining responsibilities in terms of generation infrastructure ownership, energy ownership, and remuneration must be established. This is particularly important for the introduction of BESS, as a definition of where BESS falls in the generation and distribution landscape must be reached. Developing such clarity will allow potential investors to better understand what the product of their investments will be, increasing confidence and the likelihood of interest. With PICs having stated their desires to introduce BESS already, the next steps will be critical in deciding the level of BESS introduction and what market environment it will inhabit which, as previously discussed, has clear implications on the roles that BESS can be expected to play within the power grid.

The Future of EVs and e-mobility in PICs

Considering that EVs are relatively costly compared to their non-EV counterparts, this report does not expect a steep rise in EV penetration in the near future. However, small-scale e-mobility such as e-bicycles and e-scooters are viable options for PICs. In this context, a gradual transformation of the transportation sector from gasoline/diesel-based vehicles to EVs is possible with the placement of policies that incentivize various stakeholders in PICs. The expansion of e-mobility and EVs is welcoming since, despite the increase in electricity demand, it can address the issue of RE curtailment. Policies that incentivize e-mobility owners to charge during RE over-generation and those that encourage them to sell power when demand is high (and thus electricity price is high) are but few policy considerations that are likely to expedite RE expansion in PICs.

3.1 Federated States of Micronesia

The Federated States of Micronesia (FSM) is composed of 607 islands that are grouped into the four administrative states of Chuuk, Kosrae, Pohnpei, and Yap. The four regions are supplied by the Chuuk Private Utilities Corporation (CPUC), the Kosrae Utilities Authority (KUA), the Pohnpei Utilities Corporation (PUC), and the Yap State Public Service Corporation (YSPSC), respectively. Each utility is the single operator in its respective province.

Challenges in the power sector

The four utilities face common issues including the reliability of supply, low electricity access rates (particularly in Chuuk), constraints for developing RE, dependence on imported fuels, and a high cost of electricity and tariffs (WB. (2018))[34]. The table below outlines the cost of electricity production in addition to the tariffs charged as a result of the above issues.

Table 35. FSM Average Electricity Costs and Tariffs in 2016

States	Residential Tariff (US$)	Commercial and Industrial Tariff (US$)	Government and Public Authorities Tariff (US$)	Weighted Average Electricity Tariffs (US$/kWh)	Weighted Average Revenue Collected* (US$/kWh)	Cost of Electricity Supplied (US$/kWh)
Pohnpei	0.39	0.39	0.39	0.39	0.31	0.32
Chuuk	0.41	0.44	0.46	0.44	0.36	0.33
Yap	0.41	0.49	0.77	0.63	0.58	0.38
Kosrae	0.44	0.48	0.52	0.48	0.43	0.37

* Inclusive of collection & distribution losses (losses: PUC-21%, CPUC-17%, YSPSC-8%, KUA-10%)

Source: WB. (2018)

The dependency of the FSM on diesel imports is having a clear impact on the pricing regime of its electricity market. Renewable energy in the FSM contributed only 2.5% towards total generation in 2018, whilst petroleum-based fuels accounted for the remaining 97.5% of generation. Table 36. Provides general electricity demand and supply statistics for the four states of the FSM, outlining the total installed capacity and share of RE in each region: Pohnpei – 0.98MW (7.0%); Chuuk – 0.24MW (3.0%); Yap – 1.59MW (22.0%); Kosrae 0.49MW (8.0%).

Table 36. Electricity Demand and Supply of FSM in 2017

States	Peak Load (MW)	Installed Capacity (MW)	Installed RE Capacity (MW)	RE Capacity (%)
Pohnpei	6.6	13.93	0.98	7.0%
Chuuk	2.7	8.04	0.24	3.0%
Yap	2.3	7.23	1.59	22.0%
Kosrae	1.2	6.15	0.49	8.0%

Source: WB. (2018)

[34] Tariffs are considerably higher than those of developed countries. To put this into reference, a 2020 IEA study on select economies found Germany to have one of the highest costs of residential electricity in 2018 at US$0.35/kWh. Other major economies such as Korea, the United States, and the United Kingdom were priced at US$0.11/kWh, US$0.13/kWh, and US$0.23/kWh, respectively. IEA. (2020). Energy Prices 2020.

Even with a higher installed capacity (supply) compared to peak load (demand), frequent maintenance and operation stoppages render the current grid system unsustainable. As such, even with planned RE capacity expansion, diesel gensets are likely to continue operation to maintain the sustainability of the grid.

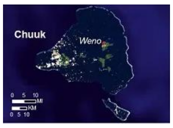
Proposed BESS capacity for the Federated States of Micronesia

The *Energy Master Plans for the Federated States of Micronesia*, submitted to the Department of Resources and Development by Castalia Limited, outlines the following targets:

- Increasing the population's electricity access rate to 100% by 2027.
- Increasing RE percentage to 84% by 2037.
- Reducing annual diesel consumption to 64% of 2018 levels by 2037.[35]
- Reducing emissions from electricity production to 63.75% of 2018 levels by 2037.[36]

The above goals are in line with the nation's NDC emissions reduction targets submitted to the United Nations Framework Convention on Climate Change (UNFCCC). The report concludes that "in all states, increasing RE generation is the least-cost way" and that "the reduction in the use of diesel more than compensates for the additional investment cost." (CSA. (2018)) The focus of the proposed energy investment strategy consists of four approaches: considerably increased installation of both centralized and de-centralized solar PV (with accompanying BESS for utility-scale systems), re-investment into the distribution network, additional investments for the electrification of communities, and the use of diesel as a fuel reserve. A summary of the cumulative BESS capacity required for the four regions of the FSM is available in the table below.

Table 37. Cumulative BESS capacity required for Chuuk, Kosrae, Pohnpei, and Yap

Region			2022	2025	2030
Chuuk		Main-grid	1 MW 7 MWh	3 MW 20 MWh	4 MW 30 MWh
		Outer-islands	0.48 MW 1.34 MWh		
Kosrae		Main-grid	1.25 MW 5 MWh	2.5 MW 13 MWh	3.22 MW 16 MWh
		Outer-islands	15 kW 120 kWh		
Pohnpei		Main-grid	1 MW 1 MWh	1.5 MW 6 MWh	5 MW 13 MWh
		Outer-islands	20 kW 60 kWh		
Yap		Main-grid	0.5 MW 3 MWh	2 MW 10 MWh	2.5 MW 20 MWh
		Outer-islands	120 kW 300 kWh		

i) Table does not include stand-alone solar systems
Source: CSA. (2018)

[35] 64% of 2018 oil consumption levels is equal to 1.5 million gallons.
[36] 63.75% of 2018 electricity generation emissions is equal to 15,769 tonnes of CO_2.

BESS targets in Table 37 takes into consideration numerous factors such as population growth and willingness-to-pay to forecast future electricity demands across the four provinces and their outer islands. Based on this forecast it proposes that the national energy targets be met by adding 50.6MW of solar PV capacity and 121MWh of BESS. This will undoubtedly accelerate the FSM's ambition to achieve an electricity access rate of 100% by 2027 and increase RE percentage to 84% by 2037. Doing so will also reduce both diesel consumption and emissions from electricity production. Assuming that a bulk of the 2,078 stand-alone solar systems can be integrated to the main grid, the projected RE percentage has more room for improvement (in this case, the role of BESS will also become more important). The difficulty lies in how FSM can muster the finances required to build a cleaner grid across its four provinces, and whether private entities are incentivized to participate.

Budget required for installing 80.9MWh of BESS in Chuuk, Kosrae, Pohnpei, and Yap by 2030

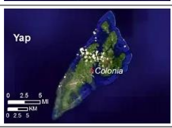
In assessing the required budget for the 80.9MWh of BESS targeted for 2030, this study refers to the li-ion battery cost forecasted in U.S. DoE (2020-D). Table 38 outlines the price of 1kWh of BESS, assuming a linear reduction in price. Multiplying the targeted amount in 2022, 2025, and 2030 by the projected BESS cost in 2022, 2025, and 2030, respectively, the budget required for the installation of a total of 80.88MWh of BESS by 2030 across the four states is US$ 31.78 million.

Table 38. Forecasted li-ion BESS (1MW/4hr) unit price

	2022	2025	2030
Unit Price ($/kWh)	421.8	382.5	317

Source: authors, DOE (refer to ***Appendix F*** *for the full parameters)*

Table 39. BESS budget required per select year (unit: million US$. Base-year 2020)

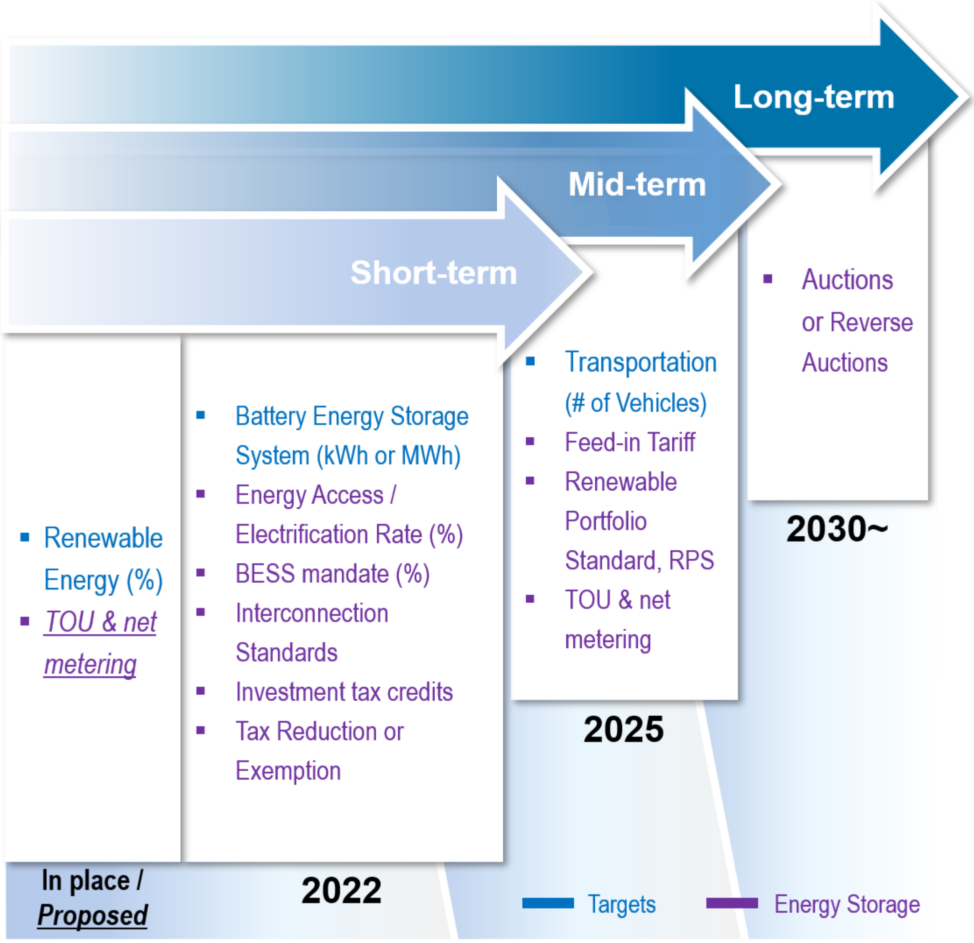
Region			2022	2025	2030
Chuuk		Main-grid	2.95	4.97	3.17
		Outer-islands	0.57	-	-
Kosrae		Main-grid	2.11	3.06	1.27
		Outer-islands	0.05	-	-
Pohnpei		Main-grid	0.42	1.91	2.95
		Outer-islands	0.03	-	-
Yap		Main-grid	1.27	2.68	4.22
		Outer-islands	0.13	0.02	-
Federated States of Micronesia		Total	7.52	12.65	11.61

BESS policy, market, and finance roadmap for the Federated States of Micronesia

Policy-wise, the FSM renewable energy and energy efficiency targets indicate a degree of climate ambition. Nonetheless, the country does not have robust enough legal frameworks to support energy storage development. While the government is in the process of considering net metering and energy access policies, they are not enough to entice private investors to actively participate in the financing process. The figure below lists the recommended targets and policy measures most relevant to BESS financing from both the public and private sectors, and evaluates whether these targets and measures are in place in FSM.

The four utilities in the FSM are regional utilities responsible for the generation, transmission, distribution, and sales of electric power in their respective jurisdictions. None of the four utilities pose any form of competition to one another since the markets are, both geographically and legally, mutually-exclusive. Frequency and voltage control, RE ramp control, RE forecast error correction, firm capacity, RE generation time shifting, black start, grid congestion relief, and transmission and distribution deferral are functions that can be performed by these utilities. Strengthened institutional capacity is necessary as low institutional capacity may limit the utilities' ability to install and operate

Figure 13. BESS Development Roadmap for the Federated States of Micronesia



As discussed in the previous chapter, RE ramp control alone can provide enormous financial benefits. With an expansion in solar PV capacity, how the installed BESS is utilized will completely depend on what the utilities prioritize. Considering that PUC is struggling with shutdowns resulting from unstable supplies, the opportunity presents itself to invest in BESS as an alternative to full investment in diesel generators. Meanwhile, CPUC, the utility operator for Chuuk, faces challenges in providing electricity access to the island's population, which accounts for 47% of the total population of the FSM. The state's access remains below 30%, which therefore makes electricity access a foundational step in this area. This should be implemented alongside renewables and BESS to expand electricity access and ensure continuous supply.

Conversely, both Pohnpei and Kosrae enjoy electrification rates of over 95%, whilst Yap's electrification rate sits at 87%. Despite this, the cost of electricity is high due to expensive imported fossil fuel. This is making conventional methods of generation increasingly economically unfeasible. With RE generation already being installed as part of the effort to reduce the cost of electricity generation, coupling such installations with BESS has the potential to drive prices down further by reducing curtailment issues and allowing renewable-sourced energy to be consumed.

Finance-wise, the FSM will initially have to depend heavily on foreign grants. Box 5 illustrates the external funding situation of the energy sector of the FSM. In the meantime, it is absolutely necessary that the government design and enforce energy policies that encourage solar PV (and wind, if appropriate). Without the necessary policies that returns profits to private investors, it will be extremely difficult for all four states to embed BESS in their main grids (WB. (2018)).

Box 5. World Bank's investment plans in FSM's energy sector

Table 40 outlines the flow of finances to the FSM for energy sector development projects. Since 2018, such flows totaled US$35.6 million, with a further US$56.5 million planned for the following year at the time. By far the largest financier is the WB, providing 48% of the total funds across the two years. This is followed by significant commitments by the ADB and the EU for a combined total of US$33.5 million, or 36.4% of total funds. Further to this, Table 38 details the type of projects being funded by financiers. In line with its funding commitments, the WB is the only financier to engage in all listed activities; similarly, the ADB and the EU engaged in all but one activity.

Table 40. Energy Sector Financing (US$, millions).

Development Partner	World Bank	EU	ADB	US	JICA	Global Environment Facility	New Zealand	Total
Ongoing (2021)	44.4	12	21.5	1.2	10	2	1	92.1

Table 41. Financier Involvement.

Development Partner	World Bank	EU	ADB	US	JICA	Global Environment Facility	New Zealand
Thermal generation	X	-	X	X	X	-	-
Access	X	X	X	-	-	-	-
RE	X	X	X	-	-	-	X
Governance and reform	X	X	X	X	-	-	-
Energy efficiency	X	X	-	-	-	X	-
Capacity building	X	X	X	X	X	X	-

Source: WB (2018)

3.2 The Republic of Marshall Islands

Current Electricity Market in the RMI

The Republic of Marshall Islands (RMI)'s energy sector transition inevitably centers itself around the power stations operated by Kwajalein Atoll Joint Utilities Resource Inc. (KAJUR) and the Marshalls Energy Company (MEC) . The two utility operators are tasked with i) expanding RE installed capacity and share of generation, ii) reducing interruptions to supply in their respective grids, and iii) reducing distribution losses. Further to this, the RMI should also explore the possibility of iv) converting existing diesel-based s into solar-hybrid s for remote island utilization.

Two power utility companies operate the electricity grid for the RMI. KAJUR provides access to the island of Ebeye, whilst MEC's electricity grid provides for the rest. Both companies are state owned. The MEC requires approval from the RMI Cabinet and the President, in lieu of a utilities regulator, in order to make adjustment to tariffs (World Bank. (2017)). This could cause electricity prices to lag behind fuel price changes, resulting in additional costs for the company. The on-grid tariffs for the RMI are high and are uniformly applied at US$ 0.416/kWh for government use, US$ 0.406/kWh for commercial use, and US$ 0.346/kWh for residential use, although 60% of residential users received a subsidized rate of US$ 0.326/kWh (ADB. (2017)). Facing similar problems as the FSM, investment in green infrastructures is essential for the RMI to incorporate more solar PV capacity while reducing gensets. This plan is outlined in the *Marshall Islands Electricity Roadmap* (RMI. (2018)).

Proposed BESS capacity for the Marshall Islands

The roadmap outlines planned technology pathways, human resource strategies, enabling policies, and financing and implementation arrangements. Targets for 2022, 2025, 2030, and 2050 are provided for the state's major regions, Majuro and Ebeye. With only a 2% share of generation coming from renewable sources, the *Majuro pathway* intends to integrate more RE into the diesel dominated electricity grid. World Bank funded projects[37] are expected to increase this level to 7~9% by 2022. The *Majuro pathway* is divided into two sub-paths with the first incorporating wind generation, whilst the second excludes wind in favor of a heavier emphasis on solar PV and BESS. The specifics of the two pathways are shown in the table below. Box 6 outlines that increase in electricity demand that these plans aim to respond to.

Table 42. Cumulative BESS capacity required for Majuro and Ebeye

<table>
<tr><th colspan="3">Region</th><th>2025</th><th>2030</th></tr>
<tr><td rowspan="2">Majuro</td><td rowspan="2">
</td><td>Pathway 1</td><td>20 MWh</td><td>20 MWh</td></tr>
<tr><td>Pathway 2</td><td>38 MWh</td><td>75 MWh</td></tr>
<tr><td>Ebeye</td><td>
</td><td>Main-grid</td><td>6 MWh</td><td>6 MWh</td></tr>
</table>

i) Table does not include stand-alone solar systems
Source: RMI. (2018).

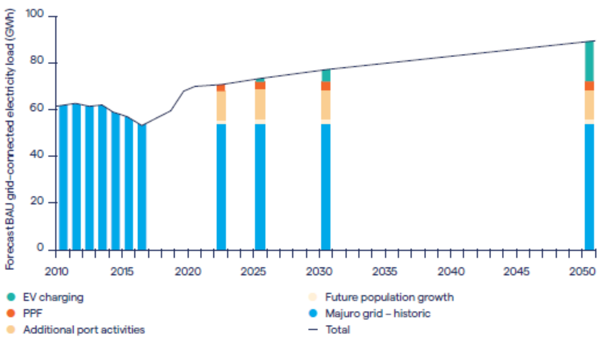
[37] World Bank Sustainable Energy Industry Development Project (SEIDP) project.

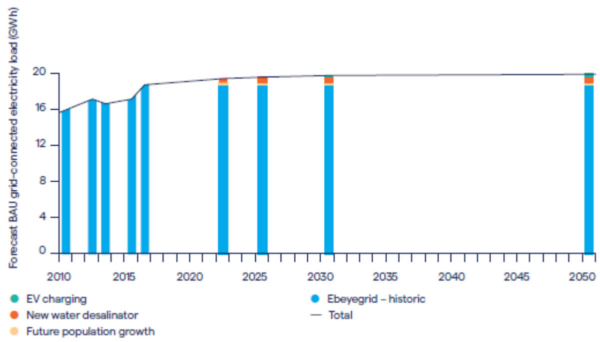
The first Majuro pathway includes deployment of solar PV, wind, and BESS to achieve full RE generation. According to this pathway, which is still pending, the Majuro region will add solar PVs in the range between 3.4MW to 6.8MW to the existing 3MW of installed capacity by 2022, increase wind capacity by 12MW, increase BESS capacity by 20MWh by 2025, and add 9MW of solar PV by 2030. This pathway splits into two by 2050: the first adds biodiesel; the second installs 30MW of wind, 60MW of solar PV, and 280MWh of BESS.

The second Majuro pathway begins by installing the same 1MW of solar PV to the existing 3 MW installed capacity by 2022. By 2025, an additional 25MW of solar PV and 38MWh of BESS will be installed. An additional 5MW of solar PV and 37MWh of BESS are installed by 2030. Lastly, an additional 60MW of solar and 1,050MWh of BESS will be installed by 2050.

Box 6. Projected change in demand by use in Majuro and Ebeye

The two graphs in this box outlines the projected change in demand by use at each of the aforementioned milestone dates. Assuming operation under the BAU model, additional port activities are projected to account for the greatest increase in electricity demand by 2022 for the Majuro grid. EV charging becomes the dominant cause thereafter, accounting for a demand of approximately 15 GWh by 2050. For the Ebeye grid, demand remains relatively stable for the entirety of the projection, although small increases due to the requirements of EV charging and new water desalination operations are present.





Source: RMI. (2018)

The *Ebeye pathway* presents a single track for development. The pathway reflects the *Majuro pathway* in that the 2050 target is split between biodiesel and asset replacement, and further RE and BESS installations. The *Ebeye pathway* adds 3MW of wind and 6MWh of BESS by 2025, 2MW of solar PV by 2030, and 5MW of solar PV, 4.5MW of wind, and 1,050MWh of BESS by 2050 (RMI. (2018)). Box 7 outlines the least-cost pathway for Ebeye to reach its RE targets.

Box 7. Guarani Center. Least-cost Option for Ebeye

In the context of the RMI, a modeling study from the Guarini Center proposed that "the least-cost solution for Ebeye would be to replace 35% of Ebeye's current diesel generation with… 3,800 kW of PV and 3,800 kWh of battery storage", which requires a land of 11.4 acres. In blending the energy system and deploying BESS in support, the levelized cost of electricity (LCOE) could be lowered from US$ 0.22/kWh to US$ 0.20/kWh. The model also notes that the renewable portion of the system produced an LCOE of US$ 0.16/kWh. As an attractive LCOE to aim for, this could encourage future investments thereby increasing the share of RE generation further.

Source: Spiegel-Feld (2015)

Budget required for installing 81 MWh of BESS in Majuro and Ebeye by 2030

There are no immediate proposals for BESS installations in Majuro or Ebeye by 2022 despite increases in RE. Rather, the first BESS installation is planned for 2025. Depending on which option Majuro adopts, BESS installation will total 26 MWh (Majuro pathway 1 + Ebeye) or 44 MWh (Majuro pathway 2 + Ebeye) by 2025. By 2030, BESS storage capacity will increase to 81 MWh under pathway 2. Otherwise, it will remain at the proposed 2025-levels. Although not within the scope of this study, the 2050 levels indicate a great deal of ambition from RMI in integrating more than 1 GWh of BESS. Table 40 isolates proposed BESS installed capacities over time under the different pathways, while Table 41 displays the project unit price for installing BESS.

Table 43. Forecasted li-ion BESS (10MW/4hr) unit price

	2025	2030
Unit Price ($/kWh)	361	301

Source: authors, DOE (refer to ***Appendix F*** *for the full parameters)*

Table 44. Budget Required for Majuro and Ebeye in 2025 and 2030 (unit: million US$)

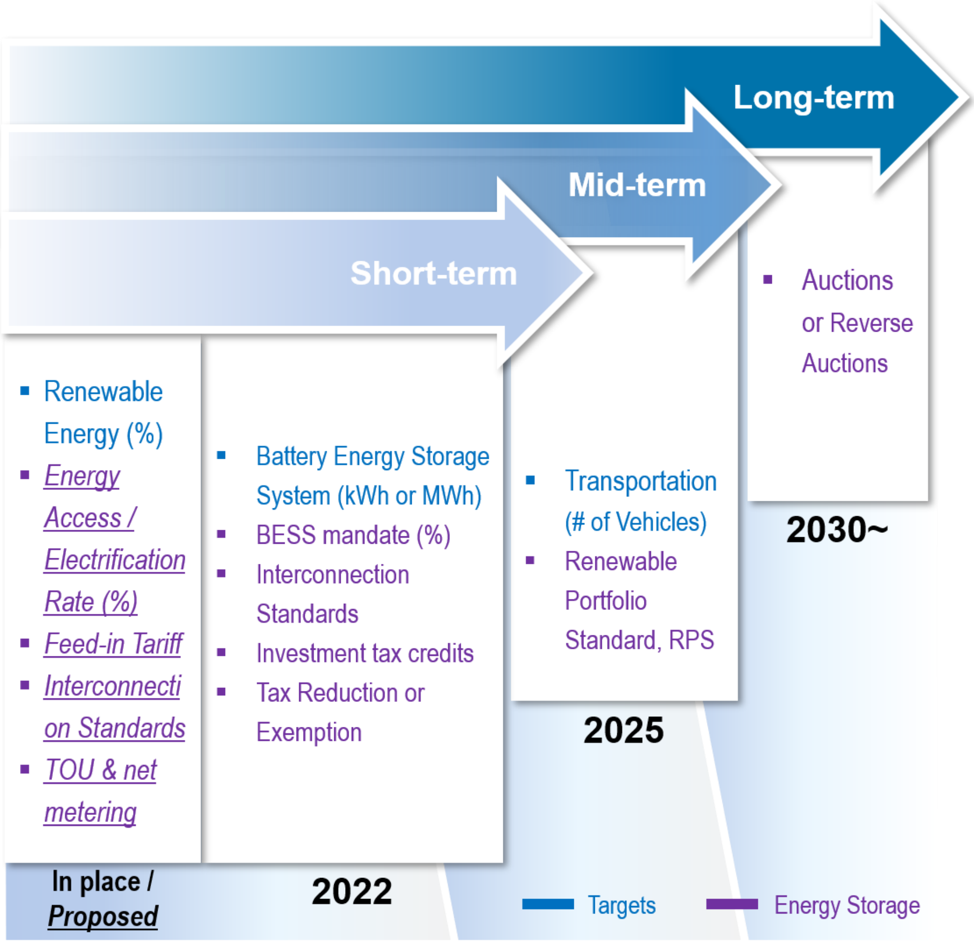
Region			2025	2030
Majuro		Pathway 1	7.22	0
		Pathway 2	13.72	11.14
Ebeye		Main-grid	2.17	0
Republic of Marshall Islands	Total	Majuro pw1 + Ebeye	9.4	0
		Majuro pw2 + Ebeye	15.9	11.14

If Majuro decides on a smaller BESS capacity (pathway 1), the budget required for the installation of the 26 MWh BESS in the RMI in 2025 is US$ 9.4 million. If Majuro chooses to go with pathway 2, the RMI's required budget for the 44 MWh BESS is US$ 15.9 million. An additional BESS installation of 37 MWh in 2030 will cost US$ 11.1 million. In conclusion, depending on which pathway Majuro chooses, the total required budget for BESS until 2030 will be in the range of US$ 9.4 million and US$ 27.0 million. Budget availability is an issue. A WB surplus budget of US$ 4.6 million will not be able to cover the full cost of the proposed BESS capacity, and financing must be procured from elsewhere.

BESS policy, market, and finance Roadmap for the Republic of Marshall Islands

For the 26~44 MWh BESS planned for installation by 2025, RMI has to create policy measures that attract private investments. First, it must announce clear BESS and EV targets that align with its national energy goals. Second, it must expedite the already proposed policy measures such as energy access, FiTs, interconnection standards, and TOU & net metering. Additionally, issuing BESS mandates, and passing measures related to investment tax credits, RPS, and tax reduction or exemption for BESS shall create a solid platform for private sector participation.

Figure 14. BESS Development Roadmap for the Republic of Marshall Islands



A growing fleet of solar PVs and wind will require that a large portion of newly installed BESS performing frequency control. Nonetheless, transforming the market from a non-market to a single-buyer market will create a market where private finances can flow in to support BESS financing. With a roadmap goal of adding between 26 to 44 MWh BESS by 2025, swift policy measures that can draw investments from the private sector will take the RMI closer to its various energy goals.

Under these circumstances, it is important to evaluate the capital required and available for BESS development. Resources have been mobilized such that the RMI is in receipt of investment and support from the European Union (EU), Asian Development Bank (ADB), Abu Dhabi Fund for Development (ADFD), Japan International Cooperation Agency (JICA), China, Taiwan, and New Zealand. The WB, for one, committed US$ 34M to develop green energy infrastructures back in 2018.

The 2018 roadmap suggested that a total of US$ 130 million and US$ 45 million were required to meet the 2025 and 2030 targets. However, the budget proposed in the study requires a more conservative approach with a budget range between the region of US$ 30-40 million. As discussed earlier, grant funding is limited, forcing RMI to search for other finances. With a high possibility that loans are unavailable due to RMI's high risk of debt, inviting private investments like PPP or IPP, depending on how the energy market landscape changes, is essential to finance the proposed BESS capacity that can support RMI's energy goals.

3.3 Tuvalu

Current Electricity Market in Tuvalu

Tuvalu (TUV)'s electric market composition is similar to that of Jeju: one main grid that serves electricity to the majority of the population in the main island and several others that supply power to the outer islands. The Tuvalu Electricity Corporation (TEC), TUV's public energy utility, is responsible for delivering power services to the country's three islands and six atolls. The majority of TUV's electricity demand comes from Funafuti. While Funafuti is heavily dependent on fossil fuel, close to 100% of the outer islands are closing in on the RE 100% goal – the average share of RE in the islands of Nuitao, Vaitupu, Nanumaga, and Naumea is above 90%, and the average share of RE in the islands of Nukulaelae, Nukufetau, and Nui is between 60-70% (Entura. (2019)).

Thus, issues within TUV's electricity market, common to all PICs studied thus far, mainly concerns Funafuti. The island's high dependency on imported fuel, inadequate tariff revenue for utilities, encompassment by the marine environment, and a lack of capital presents serious challenges to the development of a sustainable power grid (World Bank. (2014-B)). TUV's dependency on imported fuel stems from the 84% share of electricity generation which diesel generators currently enjoy. Duly, utility operators are over-exposed to rising fuel prices, resulting in a very high cost of electricity – US$ 0.86/kWh.[38] This high price translates into a tiered tariff system for private users in Funafuti, beginning at US$ 0.28/kWh for the first 50kWh of use (the so-called "lifeline tariff"), before rising sharply to US$ 0.39/kWh for the subsequent 50kWh, and rising sharply once more to US$ 0.54/kWh for all usage following the initial 100 kWh. Commercial and government use was charged at US$ 0.56/kWh in Funafuti and US$ 0.53/kWh on the outer islands.

An update from the ESMAP. (2020) highlights two of the most immediate challenges for TUV's electric market: one, the high cost of electricity for Tuvalu's population; and, two, the country's high dependency on inefficient diesel generators (92%) and low solar PV capacity (8%) which results in frequent blackouts.[39]

The government of TUV has devised a national-level energy master plan available for reference, the *Enetise Tutumau 2012-2020*,[40] which is supplemented by the Tuvalu Infrastructure Strategy and Investment Plan 2017-2025.[41] The plan targets the energy sector in reducing imported oil dependency, expanding electricity access, improving energy efficiency, and reducing carbon emissions. These goals are dependent on the country's ability to achieve 100% renewable generation by 2025 and to increase energy efficiency by 30% on Funafuti and the outer islands.

Proposed BESS capacity in Tuvalu

According to Entura, an Australian power and water consulting firm, a cumulative BESS capacity of 3MW/14MWh in a solar PV-BESS hybrid model is the optimal amount of green infrastructure to meet 100% RE in TUV (Entura. (2019)). This is composed of a 2MW/3MWh BESS installation in 2021, followed by a 1MW/11MWh installation in 2025 (see Table below).

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[38] World Bank. (2014-B). Energy Sector Development Project (P144573): Project Information Document (PID) Appraisal Stage. P. 3.

[39] Shortages of fuel and spare parts are also pointed out as the reasons behind the blackouts.

[40] TEC. (2012). Enetise Tutumau 2012-2020.

[41] Tuvalu. (2017). Infrastructure Strategy and Investment Plan.

Table 45. Funafuti's RE100% Roadmap with BESS

Region		2021	2023	2025
Funafuti		2 MW 3 MWh	2 MW 3 MWh	3 MW 14 MWh

i) funded by the World Bank and ADB
Source: TEC (2021).

BESS has the potential to be an effective solution to these concerns, with the planned replacement of diesel generation by solar PV requiring grid intermittency, frequency, and curtailment support. Whilst the potential of wind generation is yet to be fully realized, feasibility studies have revealed a power density range of 228.18W/m^2 to 145.1W/m^2, indicating an effective supply. Any attempt to implement large-scale wind power as an additional component in the drive for renewable generation will further amplify the need for BESS support, particularly as wind power density potential has been termed only "reasonably good". (Talama. *Et al*. (2020))

Budget required for installing 14MWh of BESS in Funafuti by 2025

Of the seven administrative regions examined so far, Funafuti is likely to be the fastest to reach 100% RE by 2025, given the right amount of BESS integration. BESS financing, however, remains a key issue. The WB funded 1MWh and the ADB funded 2MWh BESS projects will begin operations this year. Financing of the 11MWh BESS, estimated at US$ 4 million, will be the main concern for the government and TEC (U.S. DoE. (2020-D)). Table 44 outlines an estimated budget for TUV's BESS plans.

Table 46. Estimated budget required for BESS in TUV

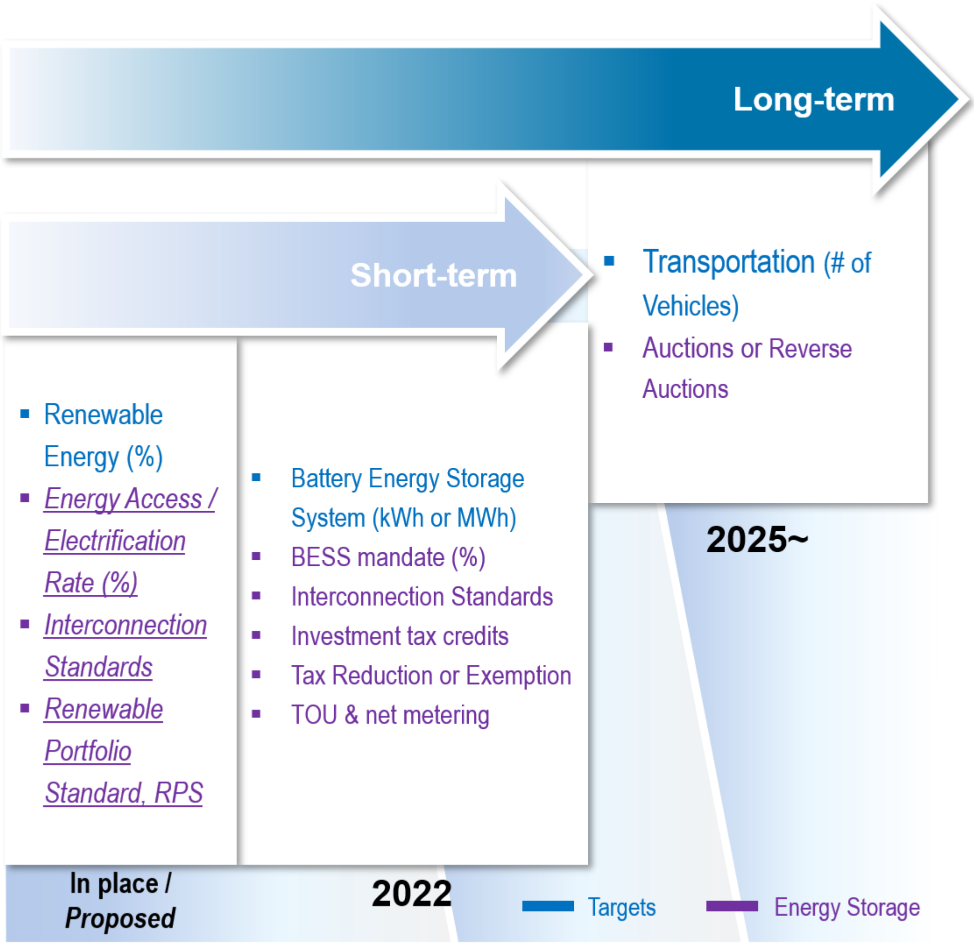
	2025
Funafuti BESS	11 MWh
Unit Price ($/kWh)	361
Total (million US$)	3.97

BESS policy, market, and finance roadmap for Tuvalu

In implementing an ambitious but feasible plan for an energy sector transition, various technologies and stakeholders are necessarily involved, and deep considerations and robust planning must be afforded to each. To address the most pressing challenges facing BESS investments, Table 45 outlines policy measures recommended to facilitate BESS investments.

Of the eleven PICs, Tuvalu ranks third, after Fiji and Samoa, in the share of renewables. The fact that it is able to focus all its efforts on Funafuti to see a considerable rise in RE generation makes all the more sense for Tuvalu to roll out the optimal level of BESS. Favorable policies such as those listed in the figure below will expedite Tuvalu's efforts to attract private investments much needed for the 11 MWh BESS.

Figure 15. BESS policy measures and target dates for Tuvalu



3.4 Recommendations

The BESS development roadmap proposed in this chapter calls for increased activities in FSM, RMI, and TUV's energy ministries[42] responsible for preparing national/regional BESS targets and policies, and utilities[43] responsible for supplying electric power to consumers. While BESS alone should not be considered a *silver-bullet* to all the challenges in PIC's energy sectors, it is a technology that can accelerate the replacement of diesel generators by supporting solar PV and wind generation; technical and economic feasibility studies reviewed in this chapter reveal the extent to which BESS can support the energy transition in the three countries.

Building on their ambitious climate and energy targets, it is vital that FSM, RMI, and TUV set up BESS targets that can be reinforced with policy measures. This study strongly recommends the various measures discussed earlier in this chapter since doing so opens opportunities for all stakeholders involved. Policies such as BESS mandate for utilities or public/government buildings, feed-in-tariff, interconnection standards, investment tax credits, tax reduction or exemption, and TOU & net metering schemes directly support the development of BESS. Energy access and electrification rate policies and RPS are highly synergistic with VRE and, consequently, BESS.

Strong policy measures from the part of the government will reduce the financial and political risk for private financing which will open opportunities for PPPs. Given that grants or loans from the WB and multilateral development funds are finite, it is crucial to explore options mobilizing commercial and private funding. Similar to the PPP practices in Jeju, Korea examined earlier, public utilities in PICs can form a consortium with private stakeholders (including but not limited to contractors, battery manufacturers, national pension funds, international banks, and etc.).

In the long run, public utilities may delegate some of their responsibilities to IPPs. Under such arrangements, existing utilities will purchase electric power from multiple IPPs while still responsible for the operation and maintenance of the power grid. From a technical point of view, the transition from a non-market to a single-buyer market will open new opportunities for BESS financing to the private sector.

[42] For instance, the Department of Resources and Development in FSM, the Ministry of Natural Resources and Commerce in RMI, and the Ministry of Natural Resources, Energy & Environment in TUV

[43] CPUC, KUA, PUC, YSPSC in FSM; KAJUR and MEC in RMI; TEC in TUV

4 Key Lessons and Next Steps

The significance of BESS increases along with the share of RE

The case studies of Jeju island and Gapa island reveal the importance of BESS with increased with additional solar PV and wind capacities. In fact, the rapid expansion of RE capacity and a relatively slower growth in BESS capacity have resulted in solar PV and wind curtailments in the Jeju Island main grid – a problem that all VRE projects in PICs are likely to encounter. This challenge presents opportunities for BESS in three different ways: firstly, BESS demand is likely to increase to support VRE expansion; secondly, EV batteries no longer viable for use in EVs can be refurbished into second-life batteries; and, thirdly, the increase in e-mobility (EVs, e-bicycles, e-scooters, etc.) can absorb increased RE generation. Further insights can be expected from the current pilot experiments in Jeju (regarding second-life batteries and e-mobility). PIC decision makers can therefore refer to either example as a baseline for their own plans, and these examples can facilitate a better understanding of the role and contribution that can be expected from BESS. PICs should remain mindful of the curtailment issue and carefully plan RE and BESS deployment so as to minimize this.

Private sector participation is key to BESS development in PICs

This study finds that appropriate policy, market, and financial mechanisms that enable large-scale public and private investments in BESS will accelerate RE expansion in PICs. The introduction of such mechanisms will, in both the short-term and long-term, strengthen energy policies and markets, improve the capacities of utilities, improve environmental performance, and ensure the successful transition of the energy sector of PICs. It further finds that increasing private sector participation is key to ensuring continued BESS development in PICs; currently, BESS funding is limited to public funding sources, such as grants or loans from foreign governments and multinational development banks. The roadmaps designed for the three countries of the Federated States of Micronesia, the Republic of Marshall Islands, and Tuvalu suggest aggressive and immediate energy policies to facilitate private sector participation in BESS projects.

Private-public partnerships are key enabling mechanisms for BESS development in PICs

This study recommends the formation of a public-private partnership (PPP) and the participation of independent power producers (IPP) to hedge risks associated with BESS infrastructure projects in PICs. Relevant mechanisms that mitigate financial risks must be placed in order for PPPs to operate. PICs should adopt financial risk mitigation instruments and utilize blended finance to overcome low private sector participation. Guarantee products, such as those offered by the WB's International Bank for Reconstruction and Development (IBRD) and International Development Association (IDA), which specifically target PPP's involving build-operate-transfer projects, should be prioritized for consideration by PICs. Other types of finances including concessions, loans, and equity, should also be considered to attract private sector participation.

The Next Step

As explored in this report, PICs have set strong climate and energy targets for the next decade. They must now turn their attention to implementing robust policy, market, and financial frameworks to support the introduction of BESS. Of particular importance to achieving the aforementioned climate and energy goals is the role of the private sector. Participation by private sector actors is critical as they are not only able to deliver much needed capital resources for project development, but can also share their invaluable expertise in operations and management. To enable private sector involvement, PICs must be able to de-risk investments. This can be achieved by designing standardized frameworks and guidance for investments and financing pathways, and project development, operation, and ownership. These frameworks must be robust so as to build the confidence of the private sector. The application of developed frameworks by PIC governments must be consistent, which help to further reduce the risk of investing in BESS and RE projects.

As well as de-risking investments, investment pathways must be streamlined. A platform for BESS/RE project investments has not yet matured within PICs, and this foundation must be in place before PPP arrangements can be engaged in effectively and reach their full potential. Investments in BESS projects require the presence of financial mechanisms that protect the private sector, and given that BESS and RE developments are likely to accompany each other, exploring and making use of the financial landscape in PICs' RE market, such as existing local/international financial institutions and risk mitigation mechanisms, will be required. An investment platform to pool projects and bring financiers together will be crucial in uncovering new financing pathways among those existing financial institutions and new private sector players looking for opportunities in this arena.

With all of this in mind, the right energy policies and robust financial risk mitigation structures, combining the local expertise of PIC public utilities and the technical expertise of private entities should open up new opportunities for PPP/IPPs which expedite RE expansion and a move away from diesel towards a low-carbon energy sector transformation.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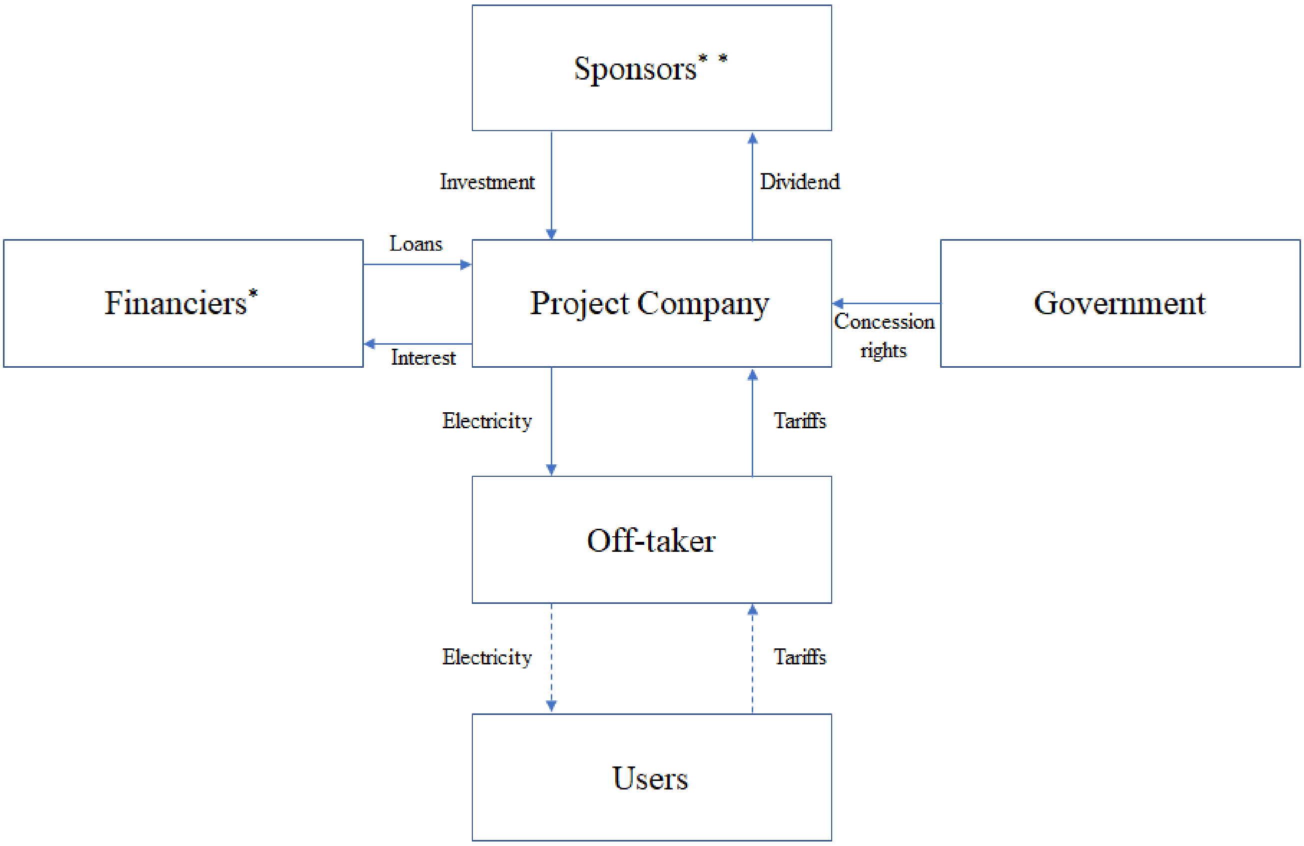
Appendices

Appendix A. Pacific Island Countries Factsheet

Countries	Population (thousand)	Land Area (km2)	Number of Islands and/or atolls	GDP per Capita (US$)	Electricity Access 2018 (%)
Fiji	895.0	18,333	320 islands, 106 inhabited	6,134.2	100
Federated States of Micronesia	102.0	701	607 islands	4,098.4	82
Kiribati	11.5	811	32 widely scattered atolls	1,587.0	100
Marshall Islands	54.8	181	34 islands, mostly atolls	4,198.7	96
Nauru	12.7	21	Single island	9,297.0	100
Palau	18.6	444	596 islands, 12 inhabited	14,840.4	100
Samoa	200.9	2,934	10 islands	4,231.3	100
Solomon Islands	684.9	28,230	About 1000 islands, 350 inhabited	2,060.9	67
Tonga	105.1	749	176 islands, 36 inhabited	4,793.5	99
Tuvalu	11.6	26	9 atolls	3,661.3	100
Vanuatu	290.2	12,281	Over 80 islands, 65 inhabited	3,196.2	62

Appendix B. Independent Power Producers: Project structure and sources of finance



*   Mix of products available depending on the sector, location, size, sponsor background, source of equipment, etc.
** Equity contribution from the sponsors and co-investors
Source: Ricardo Energy & Environment

Appendix C. Risk for independent power producers

Risk Type	Description
Currency	IPP payments may be in local currency yet many IPP costs such as fuel costs, equipment and repair costs, and cost of capital may be in U.S. dollars.
Payment	The purchaser of power from an IPP may be financially weak creating the risk of non-payment.
Political	The existing or future government may change the rules.
Management	IPP participation through minority equity ownership increases risk of loss of IPP management oversight.
Technology and Performance	The technology selected may not perform as originally expected

Source: Gardiner, M.& Montpelier, V., Best Practices Guide: Implementing Power Sector Reform.

Appendix D: REC multiplication factors for different types of energy projects in Korea.

Project Type	Supply certificate weight	Target energy and standards: Installation type	Target energy and standards: detailed standards
Solar energy	1.2	In case of installation on a general site	less than 100kw
	1.0		from 100kW
	0.7		From over 3,000kW
	0.7	When installing in the forest	-
	1.5	When using existing facilities such as buildings	3,000kW or less
	1.0		From over 3,000kW
	1.5	When installing floating on the water surface, such as il	-
	1.0	In case of trading electricity through private power generation facilities	-
	5.0	ESS facilities (connected to solar power facilities)	From 18 to 30 June 20
	4.0		From July 1st to December 31st, 2020
Other new and renewable energy	0.25	IGCC, by-product gas, waste energy (except those produced from non-renewable waste), Bio-SRF	
	0.5	Landfill gas, wood pallets, wood chips	
	1.0	In case of trading electricity through hydropower, onshore wind power, tidal power (with seawall), and other bioenergy (bio heavy oil, biogas, etc.) private power generation facilities	
	1.5	Unused forest biomass co-firing facility, hydrothermal	
	2.0	Fuel cells, algae, and unused forest biomass (applies only to bioenergy burning facilities)	
	1.0 to 2.5	Tidal power (without seawall), geothermal	Fixed/variable type
	2.0	offshore wind power	Linkage distance less than 5km
	2.5		Linkage distance more than 5km and less than 10km
	3.0		Linkage distance greater than 10km and less than 15km
	3.5		Linkage distance exceeding 15km
	4.5	ESS (Wind Power Linkage)	From 18 to 30 June 20
	4.0		From July 1st to December 31st, 2020

Source: KNREC

Appendix E. Existing literatures on the challenges of BESS Development in PICs

■ Literature exists □ Literature does not exist

	Challenges	Fiji	Kiribati	Marshall Island	Micronesia	Nauru	Palau	Samoa	Solomon Island	Tonga	Tuvalu	Vanuatu
Policy	No installation and action planning					■					■	
	Limited capacity and knowledge				■	■			■		■	
	Lack of legal and regulatory basis and guidelines	■	■	■					■			
	No institutional, policy, and inter-ministerial framework	■	■	■	■	■	■	■	■			■
	Heavy dependence on imported fuel					■					■	
	Poor implementation of projects						■					
	Failure to achieve original RE target	■										
	Lack of inventory control for spare parts		■									
	Lack of technical guidelines and standards		■	■				■				
Social	Lack of informational and public awareness										■	■
	Continuous turnover of technical personnel											
	Limited expertise, knowledge, and experience	■	■	■	■						■	
	Community grievance issues related to land use			■						■		

	A small population with few economies of scale					■					■	
	Urban unemployment							■				
	Lack of local training and education							■	■			
	Theft of solar PV panels											
Economic	The lower financial cost and greater ease of use of petroleum fuels	■					■		■		■	
	Fluctuations of the global oil supply	■				■					■	
	Poor near-term national outlook					■						
	The high price of imported equipment parts						■					
	Trade imbalance							■				
	Low domestic resource mobilization							■				
	The small and limited scope of economies of scale							■				■
	Isolation from major international markets							■			■	
	Huddles for local businesses to participate									■		
Financial	Dependence on external funding		■				■	■				
	Private sector investment could not be easily mobilized	■	■									■

	High cost of importing necessary technology		■	■	■	■						
	Non-hydro resources need to be capitalized	■										
	Lack of long-term financing			■						■		
	Difficulty in budget structure due to lack of monitoring											
	Limited cash flow for maintaining O&M							■				
	Weak banking subsector								■		■	
Technological	Lack of technical capacity, expertise, and experience	■	■	■	■	■	■	■	■			■
	No assessment of technology compatibility for locals	■										
	Integration issues		■									
	Concerns about grid stability		■									
	Lack of technical knowledge on O&M			■	■	■	■	■		■	■	■
	Poor choice of hardware and contractor						■					
	Technically unavailable in large scale									■		
	Technology inertia											
	Lack of adequate technical data								■			

Environment /Climate	Severe weather and natural disasters (cyclones, etc.)	■		■	■	■	■		■		■	
	Isolation from other islands (geographically dispersed)	■				■			■			
	Inadequate environment for equipment maintenance					■						
	Land use issues		■					■				
	Vulnerability to climate change impacts										■	
	Scattered nature of renewable energy resources											■

Appendix E. Jeju Carbon-Zero and Clean Island 2030 Vision

Vision	**Jeju Carbon-Zero and Clean island**
Goals	"Net-zero" greenhouse gas (GHG) emissions by 2030, World's Best Practice
Strategy	1. Realization of a clean and energy-independent island with renewables
	2. Moving forward as a global Mecca of the electric vehicles industry
	3. Facilitating low-carbon life based on residents' participation
	4. Beautiful and safe Jeju with ecosystem protection and climate change adaptation
	5. World prestigious tourism spot by leading eco-friendly and carbon-free strategy

Main Business (Projects)

1. Clean and Energy-independent island
- Renewable energy supply expansion
- Smart Grid expansion
- Waste-to-Energy

2. Global Mecca of electric vehicles
- Distribution of eco-friendly electric vehicles
- Expansion of incentives and infrastructure establishment
- Regulation Free zone

3. World prestigious tourism spot
- Development of Ecotourism Model
- Building an International Partnership

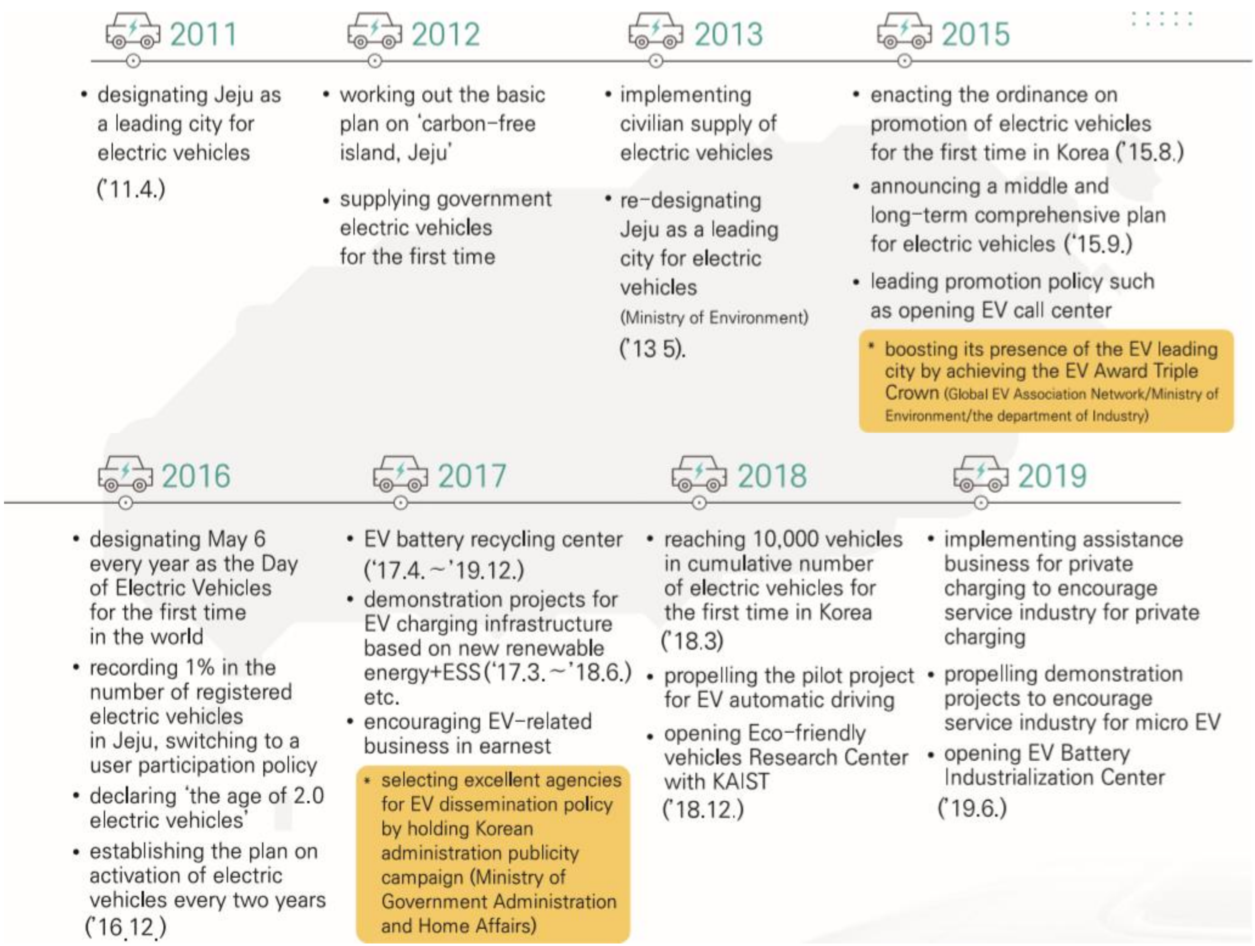
4. Climate change adaptation
- Building climate-resilient infrastructure
- Improvement the adaptability of Jeju's local industries
- Marine and land ecosystems protection

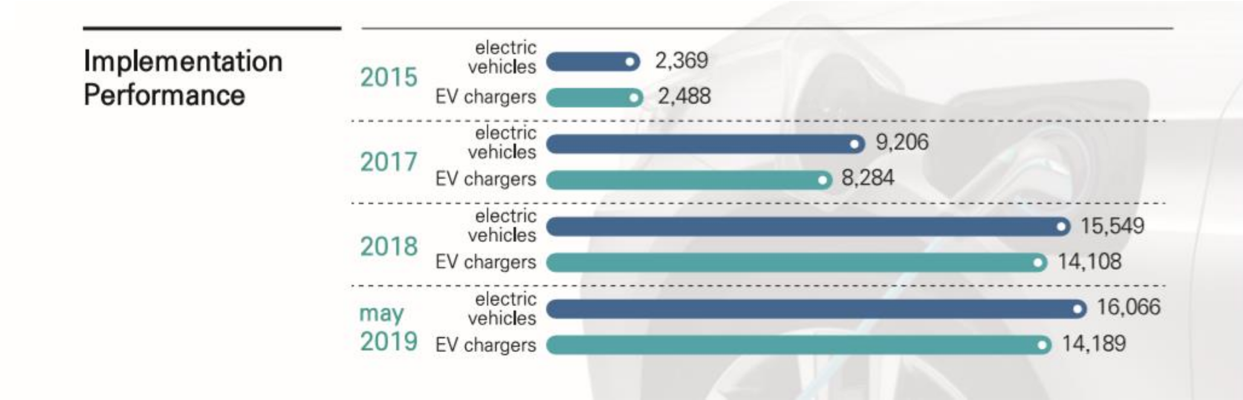
5. Low-carbon lifestyle
- Energy demand management
- Providing low-carbon living incentives
- Low-carbon transportation infrastructure

Introduction of renewable energy facilities to meet 100% of the island's power demand

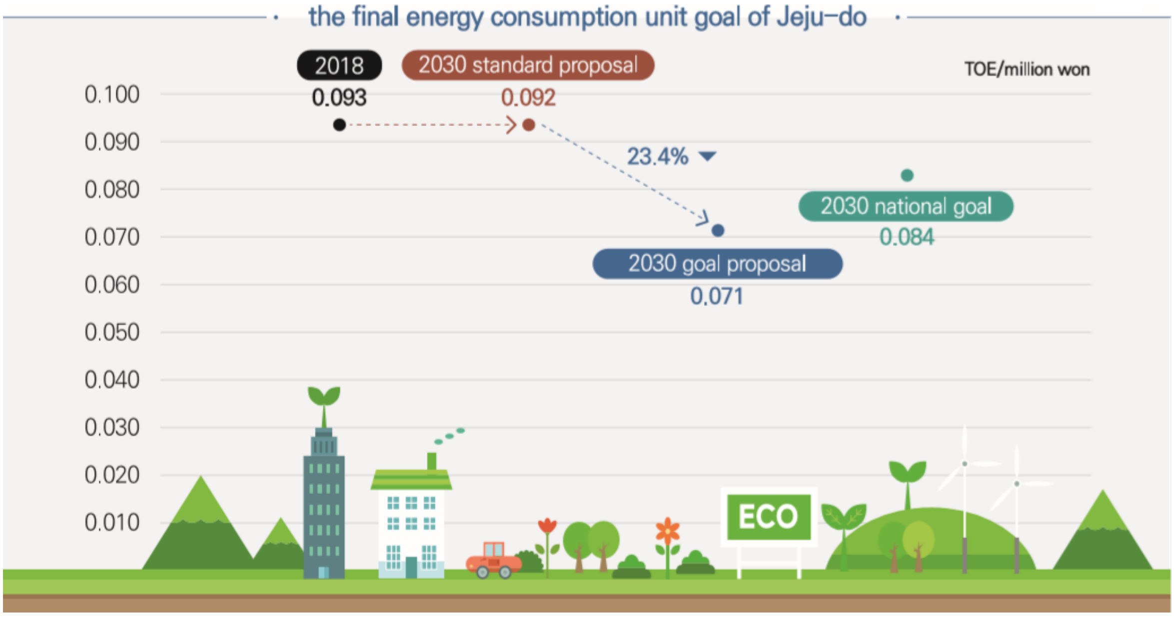
- Renewable energy facilities' installations capacity totaling 2,490MW and 4,085MW by 2025 and 2030, respectively.
- Renewable energy generation is 5,055GWh by 2025 and 9,268GWh by 2030.
- The share of power generation to the power demand on the island shall achieve 67 percent by 2025 and 106 percent by 2030.
- Reducing the curtailment of renewable power and Minimizing the variability of renewable energy by utilizing central generators and High-voltage direct current (HVDC) technology

1. **Supplying 37.7 million eco-friendly electric vehicles**
    - The aim is to supply 2.27 million eco-friendly electric vehicles by 2025 and 37.7 million by 2030, thereby achieving the share of electric vehicles within the vehicle sector can be 52 percent by 2025 and 75 percent by 2030.
    - The essential infrastructure for introducing eco-friendly electric vehicles, the number of installed charging stations, will be 5.90 million by 2025 and 7.50 million by 2030.





2. **Realization of the final energy consumption units as 0.071 TOE/million**
   - Reducing 23.4% in the '2030 final energy consumption unit' of the goal proposal to meet that of the standard proposal with reducing 15.9% to meet the national goal.
   - The energy basic unit will be dropped, enabling low energy intensity from 0.096 as of 2017 to 0.078 TOE/million won by 2025 and 0.071 TOE/million won by 2030. (National goal – 0.084 TOE/million won; Standard proposal – 0.092 TOE/million won)
   - The strategy is presented by dividing it into direct and indirect emissions of household, commercial, industrial, and transportation sectors by supplying eco-friendly electric vehicles and enhancing energy demand management.



3. **Leading the new industry for energy convergence and integration**
   - Securing innovative growth for new energy industries focusing on downstream areas in connection with the Fourth Industrial Revolution
   - Creating synergy through convergence between key industries such as renewable energy, electric vehicles, and blockchain
   - Direct and indirect 7.4 million jobs creation by 2030

Appendix F. Lithium-ion costs findings and predictions

Lithium-ion LFP

	Lithium-ion LFP					
	1MW		10MW		100MW	
Parameter	**2020**	**2030**	**2020**	**2030**	**2020**	**2030**
Storage Block ($/kWh)	164-200 182	87-128 109	156-191 174	83-122 104	149-182 165	79-116 99
Storage Balance of System ($/kWh)	38-47 42	25-35 30	34-44 40	24-33 28	35-42 38	23-32 27
Power Equipment ($/kW)	76-93 85	59-77 73	66-80 73	51-66 63	57-69 63	44-57 54
C&C ($/kW)	36-44 40	24-33 28	7-9 8	5-6 5	1-2 2	1-1 1
System Integration ($/kWh)	37-56 50	37-46 36	35-52 47	35-42 33	33-49 44	33-40 31
EPC ($/kWh)	48-74 61	45-56 50	44-68 56	42-51 46	42-64 53	39-48 43
Project Development ($/kWh)	57-90 73	54-67 60	52-83 67	50-61 55	49-78 63	47-58 52
Grid integration ($/kW)	28-34 31	23-28 25	22-27 25	18-23 20	18-22 20	15-18 16
Total Installed Cost ($/kW)	1517-2040 1793	1105-1460 1266	1389-1868 1643	1008-1334 1156	1302-1752 1541	944-1249 1081
Total Installed Cost ($/kWh)	379-510 448	276-365 317	347-467 411	252-333 289	326-438 385	236-312 270

Source: U.S. Department of Energy. (2020). 2020 Grid Energy Storage Technology Cost and Performance Assessment. p.15

Lithium-ion NMC

	Lithium-ion NMC					
	1MW		10MW		100MW	
Parameter	**2020**	**2030**	**2020**	**2030**	**2020**	**2030**
Storage Block ($/kWh)	175-213 194	93-136 116	166-203 185	89-129 111	158-194 176	84-123 106
Storage Balance of System ($/kWh)	30-45 37	22-30 26	29-43 35	21-29 25	27-41 34	20-28 24
Power Equipment ($/kW)	76-93 85	59-77 73	66-80 73	51-66 63	57-69 63	44-57 54
C&C ($/kW)	36-44 40	24-33 28	7-9 8	5-6 5	1-2 2	1-1 1
System Integration ($/kWh)	38-58 51	38-47 42	36-54 48	35-44 39	34-51 45	33-41 37
EPC ($/kWh)	49-77 63	46-57 51	45-71 58	43-52 47	42-67 54	40-49 44
Project Development ($/kWh)	58-94 75	56-68 62	53-87 69	51-63 57	50-81 65	48-59 53
Grid integration ($/kW)	28-34 31	23-28 25	22-27 25	18-23 20	18-22 20	15-18 16
Total Installed Cost ($/kW)	1537-2122 1838	923-1239 1089	1408-1947 1685	1031-1365 1204	1320-1827 1581	965-1279 1128
Total Installed Cost ($/kWh)	384-531 459	231-310 272	352-487 421	258-341 301	330-457 395	241-320 282

Source: 2020 Grid Energy Storage Technology Cost and Performance Assessment, U.S. Department of Energy (2020)

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