ESMAP
Energy Sector Management Assistance Program

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Energy Storage Roadmap for the Maldives

Executive Summary

November 2019

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This report was researched and prepared by the World Bank and its consultant and software maker Acelerex Inc., Acelerex Chile SpA, and Acelerex Yazılım Danışmanlık Limited Şirketi with inputs and comments from the Ministry of Environment, Republic of Maldives and the Maldives' utilities STELCO and FENAKA. The work was financially and technically supported by the Energy Sector Management Assistance Program (ESMAP).

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FOREWORD FROM THE MINISTRY OF ENVIRONMENT, REPUBLIC OF MALDIVES

The Energy Storage Roadmap for the Maldives is an essential study performed to evaluate the potential of implementing renewable energy sources and energy storage on islands of the Maldives. This report will provide guidance in helping Nationally Determined Contribution (NDC) towards low greenhouse gas (GHG) emission and climate-resilient pathways.

The Maldives presents a unique energy challenge with its geographical location, geophysical characteristics and limited resources. Diesel has been the main fuel source to supply electricity in all the islands and is the major contributor to the overall Maldives carbon footprint. As the Maldives is determined to reduce emissions, it is inevitable to find alternatives to generate electricity.

The study performed on 5 islands of the Maldives, provides a clear analytical methodology for informing energy transition towards solar PV and Energy Storage proving the financial feasibility. It shows the fuel savings with the adoption of PV plus storage to form a hybrid system for each island to achieve reduced emissions and cost of generation.

This report will play an essential role to frame policies and plans to implement renewable energy sources and energy storage. It will also help Maldives develop a mechanism to monitor the target of energy source composition towards maintaining a low emission development.

This report has been developed through the assistance of the World Bank, a consultant, and consultations with representatives of the Ministry of Environment and the utilities STELCO and FENAKA.

The ultimate goal of the Maldives Government is to achieve low GHG emissions and ensure energy security for the Maldives people. The Maldives Government has a clear objective of improving the quality of life of the Maldivian people through the provision of safe, reliable, clean, affordable, accessible, environmentally appropriate and sustainable energy services and ensuring that electricity systems meet Maldivian people's needs whilst minimizing their undesirable impacts on the society, economy, and environment.

Sincerely,

Dr. Hussain Rasheed Hassan
Minister of Environment
Ministry of Environment

FOREWORD FROM THE WORLD BANK GROUP

It has been a privilege for the World Bank to partner with the Government of Maldives and examine how solar energy and modern battery systems can meet the country's growing energy needs and environmental objectives.

The World Bank through its technical expertise and wide geographic experience is uniquely positioned to research how technological advancements can address difficult energy sector development challenges. The Energy Sector Management Assistance Program has for decades contributed to the Bank's ability to develop the knowledge that Governments need so that they can adopt more effective policies and take better investment decisions in the energy sector.

As renewable energy technologies have expanded exponentially across the world in the last decade, their costs sustained a downward trajectory, creating new possibilities for the provision of sustainable and affordable energy services in developing countries. Nevertheless, the natural variability of renewable energy has always been a major constraint on reliability. Only recently large-scale battery technologies and systems are emerging as the bridge that connects clean and affordable renewable energy with reliable supply. Large-scale battery systems are still a novel technology; their flexibility in near-instantaneous switching from consumption to production presents enormous potential, but also difficulties in estimating their engineering and economic value. At the same time, uncertainties regarding the future costs of fossil fuels make investment choices especially challenging for power systems in smaller, remote, developing countries.

This report demonstrates that a robust techno-economic analysis can be carried out successfully. After considering detailed, real-world, data on performance and costs, the report confirms that modern battery systems open up a substantial potential of expanding solar energy in the Maldives, while ensuring reliable supply at lower costs. The reduced risks of local pollution from oil spills and lubricants disposal are an additional –unquantified in this analysis— benefit that is nevertheless of very high value to the Maldivian beautiful, pristine, environment.

Looking forward, the World Bank will continue to work with the Government of Maldives to move from theory to practice and realize such clean energy technology projects in several islands.

Sincerely,

Demetrios Papathanasiou
Energy and Extractives Practice Manager for South Asia
The World Bank Group

EXECUTIVE SUMMARY

The Maldives is the smallest Asian country by land area and population. It is also one of the world's most geographically dispersed countries and consists of 26 coral atolls with 1,192 islands, where the geography presents both challenges and opportunities for innovative energy solutions. The geographic and geophysical characteristics such as the small size, low elevation, narrow width and dispersed nature of its coral islands, make the Maldives vulnerable to natural hazards, which are expected to increase in frequency and intensity due to climate change.

The Maldives power sector currently relies on diesel generation, and this increases the country's economic vulnerability to global oil prices. Approximately 80 percent of the land area lies within one meter of the sea level, exacerbating the country's physical vulnerability to climate change impacts. The Government of Maldives fully recognizes that in order to effectively manage climate change risks in the context of sustainable development, it is necessary to integrate climate risk planning and climate change adaptation into the country's development policy and planning frameworks. This could be achieved through utilizing natural solutions, adopting innovative and new technologies, and enhancing access to finance.

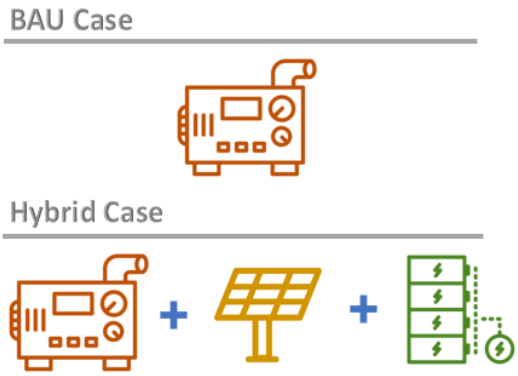
For the Maldives, hybrid systems with renewable energy and energy storage technologies are critical in moving towards low-emission development. In its 2015 NDC, the Maldives has committed to reduce greenhouse gas emissions by 10 percent by 2030. Increasing the diversity of renewable energy technologies in the national energy mix is the most effective way to reduce emissions through 2030.

This report establishes the Maldives at the forefront of efforts by developing countries to use energy storage to integrate variable renewable energy to the grid and reduce emissions. This study provides a roadmap for adopting energy storage with solar photovoltaics (PV) for a population of ~480,000 people, enabling more renewables and reducing emissions.

The objective of this study is to assess the value of energy storage for enabling the integration of solar PV to displace diesel generation. The study is carried out over five islands: Greater Male, Addu, Fuvahmulah, Hulhumeedhoo, and Thimarafushi.

Two cases are compared. First, the Business as Usual (BAU) case which is characterized by the expansion of diesel capacity; and second, the Hybrid case which allows solar PV and Battery Energy Storage Systems (BESS) to displace diesel operation and defer diesel generator purchases for provision of power.

Figure 1: Analyzed Cases

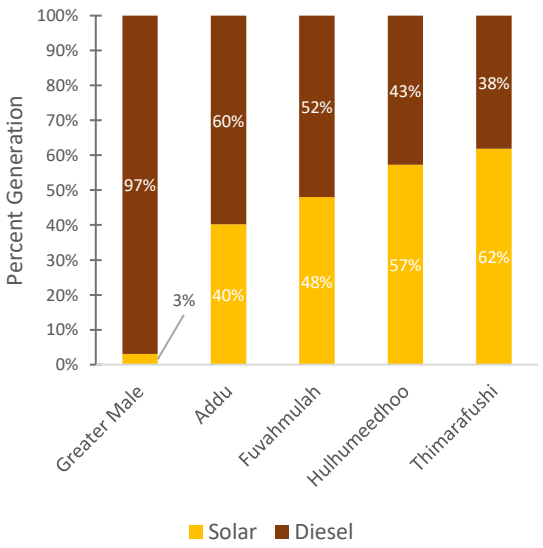


For many of the islands studied in this report, at least 40% renewable generation is forecasted in the first year of the study horizon, because there is significant solar potential that is already economic against diesel generators. A four-hour lithium-ion battery is assumed as it is commercially available today with well-characterized cost estimates. Further cost optimization of battery systems could be achieved by

considering hybrid battery systems with shorter duration power batteries and longer duration energy batteries. For both cases analyzed in this study, techno-economic metrics such as the installed capacity mix, fuel burn, emissions, lube expenses, capital cost, and others are calculated. The results of the two cases are compared using the Net Present Value (NPV) and Levelized Cost of Energy (LCOE) for each island over the period 2020 to 2040. Additionally, sensitivities with different loan financing terms were considered.

The model used in the study calculates the generation plan that satisfies reliability requirements at the least cost using the Acelerex software. The diesel price used for the study is US$0.85 per liter. As shown in Figure 2, solar PV and BESS would displace diesel generators to provide at least 40% of electricity in 2020, on all islands except for Greater Male.

Figure 2: Renewable Energy Generation in Year 2020 for Each Island

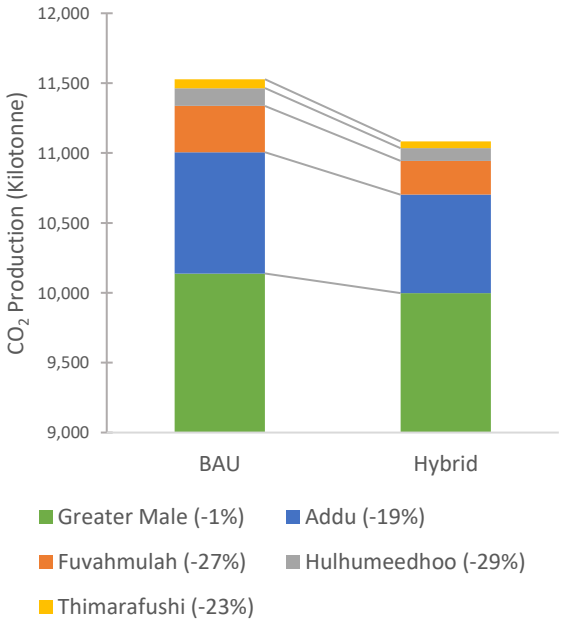


Land availability is a major issue in the Maldives, especially in Greater Male due to the scarcity of suitable land for large-scale ground-mounted solar PV installations and rooftop PV because of the high population density and limited rooftop space, particularly on public buildings available to the electricity utility. In such a scenario, new technologies like floating solar PV systems could help the Maldives mitigate the scarcity of suitable land on rooftops.

For the Maldives, the assumptions included a conservative cost estimate for solar PV installation considering remoteness of islands, lack of supply chain, and implementation of new technologies like floating solar PV. The assumed costs are expected to decline over time and with increased deployment. Exploration of floating PV potential could further increase renewable penetration in the Maldives islands. As more PV sites are identified, PV's role in the power system would be further unlocked as storage costs fall and new technologies become commercially available, including flow batteries and hydrogen.

The results suggest that a minimum total investment of US$44.5 million in PV and US$35.8 million in BESS together will yield positive savings in diesel burn and achieve a net positive NPV.

Figure 3: Reduction in CO_2 Production Over 20 Years for Each Island



Across the 5 islands, as indicated in Figure 3, it is found that pursuing solar PV and BESS would reduce the total carbon dioxide (CO_2)

emissions of the Maldives by 445,000 tonnes over the period 2020 to 2040. For each of the islands except Greater Male, a reduction of 19-29 percent of CO_2 emissions would be achieved by adopting a generation mix with solar PV and BESS. In the case of Greater Male, since there is limited space for additional land-based solar PV, CO_2 emissions could be further mitigated with the addition of floating solar PV projects that would unlock additional solar potential. Without additional solar PV, BESS can still provide immediate value to the power system in terms of mitigating outages, providing spinning reserve, and facilitating the integration of Electric Vehicle (EV) charging loads.

Following the guidelines of the World Bank, the economic merit of the project considers the carbon externality associated with GHG emissions. A shadow price of carbon, starting at US$40 per metric ton of CO_2 equivalent in 2020, is multiplied by annual GHG emissions over the economic life of the project.[1] This assessment for carbon externalities results in US$14.7 million of cost savings, as shown in Figure 4.

Table 1 shows the PV and BESS capacity built in the year 2020 in addition to the existing PV capacity under the Hybrid case. The PV capacity of Greater Male includes the 1.5 MW solar PV commissioned and 5 MW solar PV currently under a bid as part of the Accelerating Sustainable Private Investments in Renewable Energy (ASPIRE) project.

Figure 4: Carbon Externalities Cost Savings Over 20 Years for Each Island

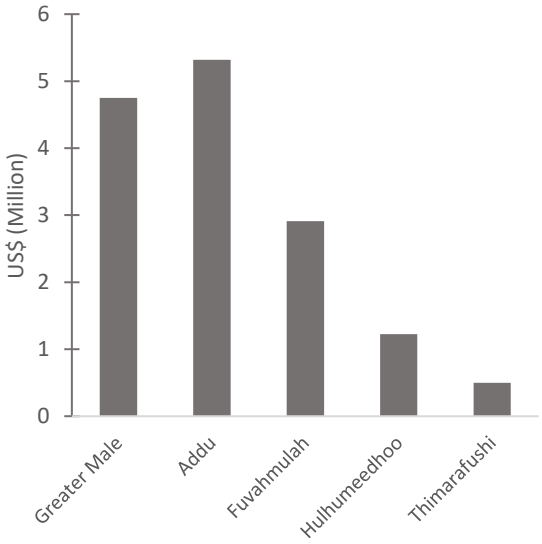


Table 1 Summary of Study Results for Each Island

	Greater Male	Addu	Fuvahmulah	Hulhumeedhoo	Thimarafushi
PV Capacity* (MW)	10.0	11.6	5.0	2.0	1.0
BESS Capacity* (MW)	10.0	8.4	5.0	2.0	1.0
BESS Energy Capacity* (MWh)	40.0	33.6	20.0	8.0	4.0
Diesel Capacity* (MW)	191.3	24.0	7.6	1.6	1.2
Total Capacity* (MW)	211.3	44.0	17.8	5.6	3.2
PV Investment** (US$ million)	14.3	16.8	8.4	3.4	1.7
Battery Investment** (US$ million)	12.8	12.8	6.4	2.6	1.3
Total Diesel and Lube Oil Savings** (US$ million)	32.2	34.0	18.8	8.0	3.4
CO_2 Reduction** (kilotonnes)	140.2	163.5	89.5	37.3	14.8
PV+BESS LCOE (US$/kWh)	0.140	0.097	0.111	0.111	0.111

[1] The shadow price used is in line with the High-Level Commission on Carbon Prices

* Values are by year 2040 with the Hybrid case
** Values are over the period 2020 to 2040

With a total capital investment of US$80.4 million in solar PV and BESS, the Maldives would save US$96.4 million on diesel and lube oil expenses over 20 years, would defer US$17.5 million in capital expenses of diesel generator purchases, and reduce carbon externalities by US$13 million.

Figure 5: Investment Costs and Savings for Each Island Over 20 Years

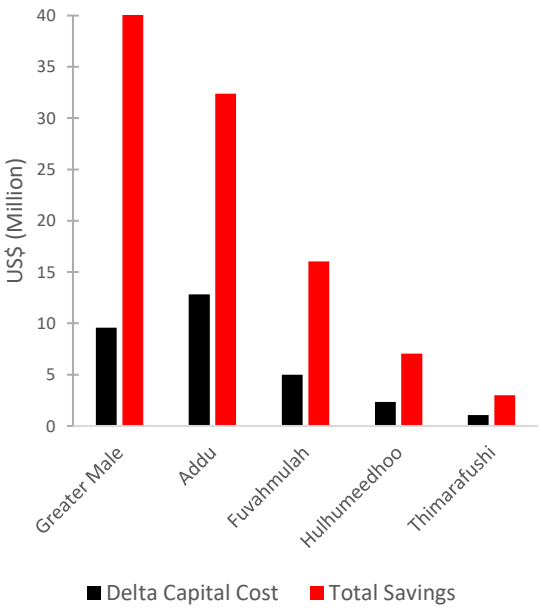


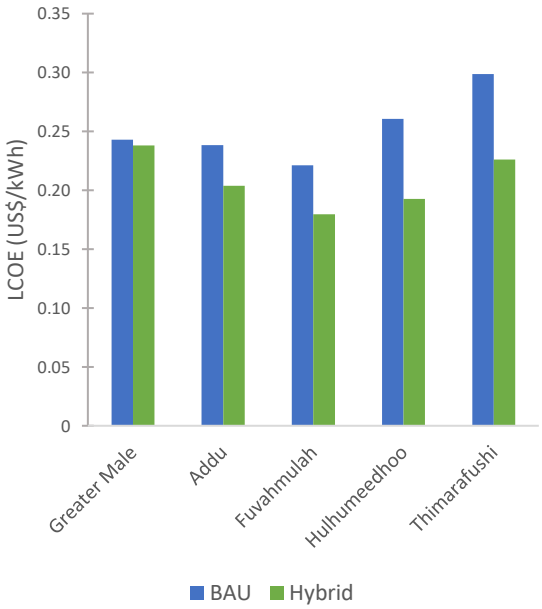
Figure 5 shows the investment costs involved in solar PV and BESS, and estimated savings in diesel and lube oil costs obtained by comparing BAU and Hybrid cases. Here, the total savings are the present value of the savings over 20 years, and the delta capital cost is the difference in the present value of annual payments over 20 years. In the case of Greater Male, the savings also include the deferral of distribution capital investments with the installation of BESS. As a result, the availability of solar PV and BESS provides net positive value (measured by NPV) for all the islands. The results in Figure 5 have assumed that concessional resources are available for financing the solar PV and BESS systems. These values are based on a standard loan of World Bank Climate Technology Funds (CTF), with an interest rate of 0.25% and a loan tenure of 40 years.

Solar PV and BESS still have positive NPV under financial sensitivities with a 10% interest rate and loan tenure of 20 years. Although annual capital costs would be higher and total savings would be reduced, all NPVs of the investments would remain positive.

In the case of Greater Male, if we consider an opportunity cost of unserved energy of US$1000/MWh, serving one instance of 5 MW for 4 hours would be valued at US$20,000. This is an added benefit of energy storage for an island grid system which provides an estimated savings of US$2.4 million in the general economy over 10 years.

Looking at the Hybrid case, with penetration of PV and BESS, the LCOE of each island would reduce as shown in Figure 6. The island of Hulhumeedhoo would observe a reduction of 26 percent, and Thimarafushi of 24 percent.

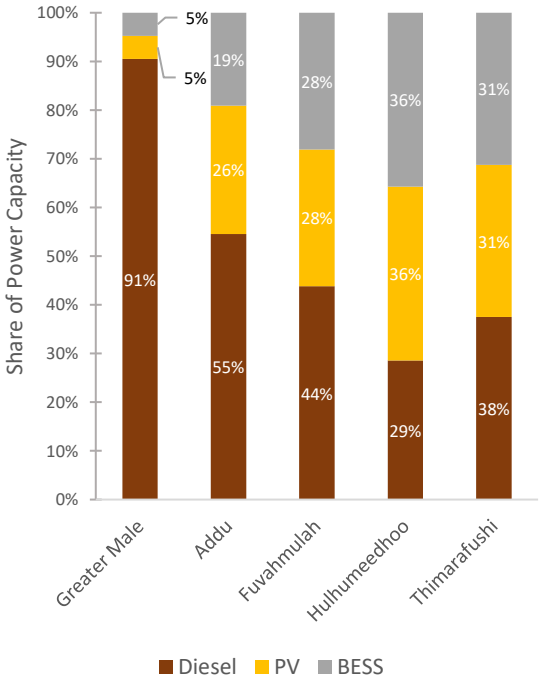
Figure 6: Reduction in System LCOE for Each Island



For each of the five islands in the study, the capacity expansion scenario results shown in Figure 7 indicated there are positive economic benefits to invest in solar PV to its

maximum extent as soon as possible (in the first year of the analysis). The availability of batteries for energy storage provides firming of PV generation and the ability to shift the PV energy to periods when it is needed most, displacing the role of diesel.

Figure 7: Installed Capacity Ratio in Year 2040 for Each Island



Over the study horizon of the year 2020 to 2040, solar PV investments are justified by the offset of ongoing diesel fuel purchases and a reduction in CO_2 emissions. BESS paired with solar PV has the potential to substantially reduce power costs for consumers and utilities in the Maldives across islands, but the value proposition is highest where BESS can enable integration of additional solar PV which is already highly competitive against diesel generators.

Given the space constraints on land-based solar PV, a future for the Maldives that further replaces diesel will require floating solar PV or other renewable alternatives. With the demand growth scenarios considered, diesel-based generation is still required unless or until alternatives are available. To achieve a further reduction in CO_2 emissions, a techno-economic dispatch of diesel generators can be facilitated by reducing the usage of less efficient generators.