



---

# SOLAR UNDER STORM FOR POLICYMAKERS

Select Best Practices for Resilient Photovoltaic Systems for Small Island Developing States

---

BY CHRISTOPHER BURGESS, JUSTIN LOCKE, LAURIE STONE



# AUTHORS & ACKNOWLEDGMENTS

---

## AUTHORS

Christopher Burgess, Justin Locke, Laurie Stone

*\* Authors listed in alphabetical order*

## ADDITIONAL CONTRIBUTORS

Sanya Detweiler, Clinton Climate Initiative, Clinton Foundation

Shifaana Thowfeequ, UN-OHRLLS

## CONTACTS

Christopher Burgess, [cburgess@rmi.org](mailto:cburgess@rmi.org)

Sanya Detweiler, [sdetweiler@clintonfoundation.org](mailto:sdetweiler@clintonfoundation.org)

Shifaana Thowfeequ, [thowfeequ@un.org](mailto:thowfeequ@un.org)

## SUGGESTED CITATION

Laurie Stone, Christopher Burgess, and Justin Locke, *Solar Under Storm for Policymakers: Select Best Practices for Resilient PV Systems for Small Island Developing States*, 2020, [www.rmi.org/insight/solar-under-storm-for-policymakers](http://www.rmi.org/insight/solar-under-storm-for-policymakers).

*All images from iStock unless otherwise noted.*

## ACKNOWLEDGMENTS

The authors thank the following individuals/organizations for offering their insights and perspectives on this work:

Joseph Goodman, Rocky Mountain Institute (previously)

Chris Needham, FCX Solar

Frank Oudheusden, FCX Solar

# ABOUT US

---



## ABOUT ROCKY MOUNTAIN INSTITUTE

Rocky Mountain Institute (RMI)—an independent nonprofit founded in 1982—transforms global energy use to create a clean, prosperous, and secure low-carbon future. It engages businesses, communities, institutions, and entrepreneurs to accelerate the adoption of market-based solutions that cost-effectively shift from fossil fuels to efficiency and renewables. RMI has offices in Basalt and Boulder, Colorado; New York City; the San Francisco Bay Area; Washington, D.C.; and Beijing.



## ABOUT THE CLINTON FOUNDATION

Building on a lifetime of public service, President Clinton established the Clinton Foundation on the simple belief that everyone deserves a chance to succeed, everyone has a responsibility to act, and we all do better when we work together. For nearly two decades, those values have energized the work of the Foundation in overcoming complex challenges and improving the lives of people across the United States and around the world. The Clinton Climate Initiative (CCI) collaborates with governments and partner organizations to increase the resilience of communities facing climate change while reducing greenhouse gas emissions.



## UN-OHRRLLS

### ABOUT UN-OHRRLLS

The United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries, and Small Island Developing States (UN-OHRRLLS) assists vulnerable countries in areas including economic growth, poverty reduction, and meeting targets laid out in the Sustainable Development Goals.

# TABLE OF CONTENTS

---

FOREWORD ..... 06

EXECUTIVE SUMMARY ..... 09

PURPOSE AND APPROACH OF REPORT..... 11

INTRODUCTION.....13

BENEFITS OF SOLAR ENERGY TO SIDS .....16

ENERGY RESILIENCE .....18

RECOMMENDATIONS.....21

CONCLUSION .....24

APPENDICES .....25

ENDNOTES.....30

# TABLE OF ACRONYMS

---

<b>AOSIS</b>	Alliance of Small Island States
<b>CAREC</b>	Caribbean Renewable Energy Community
<b>CARICOM</b>	Caribbean Community
<b>CARILEC</b>	Caribbean Electric Utility Services Corporation
<b>CCI</b>	Clinton Climate Initiative
<b>CSU</b>	Colorado State University
<b>EWA</b>	Effective wind area
<b>FMEA</b>	Failure mode effects analysis
<b>IRENA</b>	International Renewable Energy Association
<b>NDC</b>	Nationally determined contribution
<b>PV</b>	Photovoltaics
<b>RMI</b>	Rocky Mountain Institute
<b>SIDS</b>	Small Island Developing States
<b>UN-OHRLLS</b>	United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States
<b>UNFCCC</b>	United Nations Framework Convention on Climate Change
<b>QA/QC</b>	Quality assurance/quality control

# FOREWORD

---

## **Foreword by Ms. Fekitamoeloa Katoa 'Utoikamanu, Under-Secretary-General and High-Representative for Least Developed Countries, Landlocked Developing Countries, and Small Island Developing States (UN-OHRLLS)**

Some 38 small island nations, or close to one-fifth of the member states of the United Nations, find themselves dispersed over the vast ocean spaces of the Caribbean, the Pacific, the Atlantic and Indian oceans, and the South China Sea region. It is for a reason that the phrase “small island but large ocean nations” was coined!

It is well documented and known that these nations and their peoples face specific, intricate, and complex challenges due to the very nature of their geographies and demographics. In fact, some 26 years ago, the 1994 Barbados Global Conference on the sustainable development of island nations was already forcefully alerting the world to the complex set of challenges we would have to live up to for an inclusive and sustainable future of island nations.

While island nations share the challenging economic, social, and institutional characteristics of developing nations, they have to contend with unique challenges.

Not only are they small but they are also geographically highly dispersed. This limits the operational scope on so many fronts to realize economies of scale; distance to markets engenders excessive transport costs; limited resource bases barely give scope for product diversification and enhancing exports.

These intricate challenges are made even more complex given the high level of exposure island nations experience in regard to climate and environmental challenges, global economic and financial shocks, and needless to say such global health crises as COVID-19.

Climate change has and continues to impact Small Island Developing States (SIDS) in unparalleled ways. The costs associated with ever more frequent and

extreme climate events not only are staggering but also exceed what local economies can sustain for rebuilding and adaptation. This is compounded by the too often difficult access to global and regional sources of funds to implement adaptation and mitigation measures. Of course, given the many economic, social, and financial challenges the COVID-19 pandemic will bring about, this situation is unlikely to improve in the near future or even medium term.

Yet, tackling climate change is an imperative for SIDS. Inherent to this is the urgent need to make the transition to a sustainable energy future. For too long, action was tied to crisis-mode responses. We need to move beyond this, and the opportunities are many given technological and cost advances to realize entirely new climate and environmentally responsive energy futures. Technologies such as solar photovoltaics (PV) facilitate independence from fossil fuels and are already the most rapidly growing source of power for many SIDS.

I hope the concrete recommendations and practical examples this study presents on how to increase solar PV installations will be of use to you.

Of course, this does require the full engagement of stakeholders, including governments, the private sector, local communities, regional entities, and international organizations. Only together and with shared vision and determination will we be set on the path of ensuring that we live up to the renewable energy targets called for by Agenda 2030.

UN-OHRLLS thanks Rocky Mountain Institute (RMI) and the Clinton Foundation for their partnership and we look forward to further collaboration to facilitate support to the SIDS to move forward in their drive toward renewable energy futures.



A handwritten signature in blue ink that reads "Fekitamoeloa Katoa 'Utoikamanu".

Fekitamoeloa Katoa 'Utoikamanu

## LETTER FROM PRESIDENT BILL CLINTON, FOUNDER AND BOARD CHAIR, CLINTON FOUNDATION; 42ND PRESIDENT OF THE UNITED STATES

Year after year, the world faces more frequent and more severe extreme weather events. The 2017 hurricane season was one of the most catastrophic yet, responsible for the loss of thousands of lives and billions of dollars in economic costs throughout the Caribbean. Two years later, as communities were still rebuilding from the previous destruction, more storms wreaked havoc in the Bahamas and beyond.

It is no secret that climate change is exacerbating these storms and that Small Island Developing States (SIDS) face disastrous consequences. While SIDS have contributed very little to global carbon emissions, they are uniquely vulnerable to the consequences of climate change, and are getting hit harder and sooner. I have seen the damage firsthand, and have tried to support the hard-working, resilient people as they rebuild their lives and their beautiful communities.

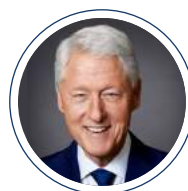
As we work together to prepare for and mitigate the impacts of climate change, particularly in SIDS, delivering real results in a timely manner is critical.

My foundation has been working with SIDS for many years, helping to leverage millions of dollars in renewable energy investments and convening hundreds of disaster response and recovery organizations in the aftermath of natural disasters. In 2012, we launched the Islands Energy Program to support islands as they transition from using imported fossil fuels to generate electricity to the renewable energy sources, largely solar and wind, that are abundant in the islands.

With the price of solar photovoltaic (PV) technology less than half of what it was in 2012, the case for using renewables in SIDS and around the world has grown even stronger. Not only do they reduce energy costs and CO<sub>2</sub> emissions, they also provide a solution to frequent and prolonged grid outages, damaging economies and essential services like health care and education.

Solar Under Storm was created by the Clinton Climate Initiative and our partners at Rocky Mountain Institute as a resource to share best practices for installing solar PV in locales that are threatened by high-wind events and can benefit greatly from the resilience that solar PV provides. The lessons and best practices laid out in these publications are valuable tools, but they will make a difference only if they are widely put into practice. I know it can be incredibly difficult to move individuals and organizations from dialogue to action, but leaders like you are in a unique position to implement these recommendations.

I would like to thank the UN Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries, and Small Island Developing States for its commitment to promoting this resource and to mitigating the toll of climate change and related disasters on SIDS and other developing countries around the world.



*Bill Clinton*

Bill Clinton

## NOTE OF THANKS FROM RMI CEO JULES KORTENHORST

Small island developing states (SIDS) are on the front lines of climate change, even though they emit immaterial amounts of CO<sub>2</sub>. Due to climate change, the past few years have seen increasingly severe cyclonic events during which island countries and territories in the Caribbean and the Pacific lost power for weeks and even months at a time. The need for climate resilience is abundantly clear.

SIDS around the world are flipping the script, transforming from victims of climate tragedies into global leaders in clean, secure energy. Islands have compelling economic reasons for embracing the green-energy transition. For generations, reliance on imported fossil fuels and the uncertainties of world oil markets caused significant cost fluctuations for electricity. But as solar and storage prices continue to fall, renewable energy systems are not only cleaner and more resilient, but also more economical.

Localized energy solutions offer unique advantages in terms of reducing emissions, lowering electricity costs, and keeping the lights on after a disaster. They point the way to a better future for electricity systems around the world. By embracing the clean-energy transition, islands can set an example for the rest of the world—and particularly for those countries that are responsible for the overwhelming share of global greenhouse gas emissions.

In order to provide real resilience, these new energy solutions need to be able to withstand the storms, which tend to ravage power lines and disconnect communities from centralized sources of energy generation. Thus, in the case of solar photovoltaics, much depends on the methods used to secure solar panels to the ground and to rooftops.

That is why I am so excited to share this report that details how policymakers can ensure best practices for solar photovoltaic systems to withstand severe weather events. We are grateful to our partners, the Clinton Foundation and UN-OHRLLS, for helping support this project and the transition to a clean energy future for islands around the world. This report would also not be possible without the support of the Caribbean Electric Utility Services Corporation, Anguilla Electricity Company Limited, the US National Renewable Energy Laboratory, FCX Solar, Solar Island Energy, ATEC Energy BVI, Caribbean Solar Company, Solar Energy Industries Association, AZ Engineering, CJQ Engineering, Energy Solutions Inc., and EP Energy.

We look forward to working together to help not only island nations, but communities around the world, embrace the clean energy transition.



A handwritten signature in black ink that reads "Jules Kortenhorst". The signature is written in a cursive style with a long horizontal line extending to the left.

Jules Kortenhorst

# EXECUTIVE SUMMARY

---

Since their inception, electricity systems in Small Island Developing States (SIDS) have been vulnerable to weather-related events. Many are primarily dependent on power generated centrally by fuel oil or diesel-fired generators and distributed across the island by overhead transmission lines, making them more susceptible to fuel price volatility and disruption in supply. When the electric grid goes down, all aspects of life from health care services to education and economic development are disrupted.

In recent years, electricity has been supplemented in homes, businesses, industries, government facilities, and utilities by solar photovoltaics (PV). In fact, over half of Caribbean islands' electric utilities already own or operate solar PV as part of their generation mix, with more than 571 MW of solar installed across rooftops, parking canopies, and vacant land.<sup>1</sup> And solar PV—the most rapidly growing source of power for many SIDS—helps islands reduce their dependency on imported fossil fuels while instead utilizing a local resource. It is a cost-effective and reliable solution for power generation, and supports island nations' actions on climate change adaptation and mitigation.

Solar PV systems can also be more resilient than traditional oil and gas-powered generation during extreme weather events. However, the systems must incorporate the best available engineering, design, construction, and operational practices to increase the reliability and survival rates from extreme winds and storms.

Cyclonic events around the globe in 2017 were some of the most destructive in history. Hurricanes Harvey, Irma, and Maria brought widespread destruction throughout the Caribbean and Southeastern United States while Cyclones Fehi and Gita wreaked havoc in the Pacific region. In 2019, Hurricane Dorian

decimated the northern Bahamas bringing historic winds, rainfall, and unprecedented destruction to the electricity system and other critical infrastructure. In 2020, Cyclone Harold caused widespread destruction in the Solomon Islands, Vanuatu, Fiji, and Tonga. This trend will only continue to worsen. Colorado State University (CSU), among the United States' top seasonal hurricane forecasters, has predicted that the 2020 hurricane activity will be approximately 140% more than the average season.<sup>2</sup> CSU predicts that there will be 16 named tropical storms—four of which are expected to develop into major hurricanes, meaning Category 3, 4, or 5 on the Saffir-Simpson Scale. In addition to the emotional toll these severe storms have on island communities, the disruption of critical infrastructure leaves many without basic electric services for prolonged periods of time.

Despite the record sustained wind speeds of over 180 miles per hour (290 kilometers per hour) throughout the 2017 hurricane season in the Caribbean, many solar PV systems survived. Some solar installations in the British Virgin Islands, Turks and Caicos Islands, Puerto Rico, and Sint Eustatius faced wind gusts above 190 miles per hour (306 kilometers per hour) yet survived and continued producing power the following day. In contrast, other PV systems in the region suffered major damage or complete failure with airborne solar modules, broken equipment, and twisted metal racking.

Although PV systems can increase resilience of the grid and greatly improve people's access to reliable electricity, they are useless if they fail. This is even more critical during a time of global pandemic where public resources are strained and health facilities are under significant pressure. Over the coming months and years, it will be vital for SIDS to maintain reliable power to health facilities in light of more intense storms.

Following hurricanes Harvey, Irma, Maria, and more recently Dorian, Rocky Mountain Institute (RMI) and Clinton Climate Initiative (CCI) sent joint teams to the Caribbean to evaluate the root failures of solar PV systems and key success factors of systems that survived. The teams then developed a list of recommendations to increase system resilience. The recommendations are a crucial resource to increase the survival of PV systems and the resilience of the grid during extreme weather events.

One of the most important recommendations is to ensure inclusive multi-stakeholder collaboration. This entails communicating clear market signals to suppliers and upstream equipment providers and coordinating closely among practitioners and installers. In addition to collaboration, codes and regulations should be amended and performance standards created or revised for procurement. This guide, specifically tailored for policymakers in SIDS, is a follow-up to two technical reports on enhancing resilience of solar PV systems.



Image courtesy of Carlos Quiñones, CJQ Engineering

# PURPOSE AND APPROACH OF REPORT

---

In 2014, the Third International Conference on Small Island Developing States (SIDS) was held in Apia, Samoa. The participants of the conference developed an international framework entitled the SAMOA Pathway, which recognized the need for supporting and investing in SIDS so that they can achieve sustainable development. The SAMOA Pathway clearly recognized that SIDS' dependence on fossil fuels is a major source of economic vulnerability and a key challenge for sustainable development. The SAMOA Pathway calls for concrete actions to address the challenges SIDS face in transitioning to sustainable energy systems and to promote energy efficiency. Furthermore, the Political Declaration adopted by the United Nations General Assembly at the mid-term review of the SAMOA Pathway in September 2019 stresses the importance of access to affordable, reliable, sustainable, and modern energy for SIDS.

The purpose of this report is to provide actionable recommendations to policymakers on how to enhance resilience in SIDS, specifically enhancing the resilience of new construction and retrofitting of ground-mount and rooftop solar photovoltaic (PV) installations. Expert structural engineering teams were deployed to the Caribbean region in the fall of 2017 to investigate root causes of solar ground-mount PV system failures in the wake of Hurricanes Irma and Maria. These same structural experts were reengaged in the fall of 2019 following Hurricane Dorian to assess 25 rooftop PV systems across five islands. These experts reviewed over 500 photos taken by solar professionals and system owners immediately after the respective hurricanes. They uncovered several root causes of partial or full system failure and determined several potential failures that could have occurred if other failures did not occur first (lurking failure modes).

Rocky Mountain Institute (RMI) and Clinton Climate Initiative (CCI) produced two joint reports on best

practices for hurricane-resistant solar PV, *Solar Under Storm: Select Best Practices for Ground-Mount PV Systems with Hurricane Exposure* and *Solar Under Storm Part II: Select Best Practices for Resilient Roof-Mount PV Systems with Hurricane Exposure*. The reports combine field observations along with expert analysis to deliver actionable recommendations for increasing resilience among retrofit and new construction solar PV installations. The reports are intended for engineering professionals responsible for solar PV system design, solar PV system specifications, and/or solar PV system construction oversight and approval. They are available online at <https://rmi.org/insight/solar-under-storm/>.

This guide for policymakers is intended for a non-technical audience of governments, regulators, and developers interested in improving solar PV system survivability to intense wind-loading events.

## **Guiding principles for this work include:**

- Collaborate across organizations and integrate local experience and expertise;
- Address observed failure modes and lurking failure modes (ones that did not occur only because something else failed first);
- Plan for advancement of hardware, reliability statistics, and expert knowledge;
- Provide performance-based recommendations where possible to allow for innovative solutions;
- Limit recommendations to only those that provide a risk-adjusted economic benefit; and
- Ensure guidelines are executable with currently available solutions.

**In order to realize these guiding principles, the RMI and CCI team:**

- Conducted an analysis of failures at sites impacted by the 2017–2019 hurricane seasons;
- Engaged experts responsible for managing or analyzing historical failures of both ground-mount and rooftop solar PV projects;
- Identified and prioritized root causes through collaborative completion of a “fishbone” diagram (a cause-and-effect tool);
- Completed a failure mode effects analysis (FMEA) for the prioritized root causes;
- Synthesized recommendations from the FMEA for communication and consideration; and
- Sought and incorporated ongoing feedback from industry experts.

The key output of this paper is a list of recommendations for building more resilient solar PV power plants and rooftop systems. The recommendations are organized into two categories: 1) specifications, and 2) stakeholder collaboration. To the extent possible, the specifications are performance-based to allow for individual project teams to provide the most cost-effective and resilient solution. Stakeholder collaboration recommendations identify opportunities for increased resilience, which require multiparty consideration and action but do not represent industry standard actions.



Image courtesy of Carlos Quiñones, CJQ Engineering

# INTRODUCTION

---

The political will in Small Island Developing States (SIDS) to address climate change and drive adaptation to it is clear. SIDS contribute the least to climate change—roughly less than 1% of greenhouse gas emissions—yet are among the most vulnerable to its impacts. SIDS have continually taken the lead in climate action, and worked tirelessly in the climate negotiation process to include the provision within the Paris Agreement for 196 parties to pursue efforts to further limit the global temperature increase to 1.5°C. A large majority of SIDS have included renewable energy in their intended nationally determined contributions (INDCs) and in their national and regional policy plans to support their transition to renewable energy while also strengthening their energy security and resilience.

## CYCLONIC EVENTS AND ENERGY INFRASTRUCTURE

As climate change increases the intensity and possible frequency of cyclonic events, SIDS are suffering disproportionate damage to their energy infrastructure and economies, and thus their people's health and wellbeing. The COVID-19 pandemic has only served to exacerbate this disparity as island economies suffer greatly from the lack of tourism and health impacts of the pandemic. The Caribbean Catastrophe Risk Insurance Facility estimates that losses from wind, storm surges, and inland flooding already amount to 6% of GDP per year in countries in the region.

In 2004, Hurricane Ivan caused more than US\$1 billion in damage and economic losses in Grenada, one and a half times the country's GDP. The cost to rebuild the electrical grid was approximately US\$42 million, about 6% of GDP.<sup>3</sup> In 2015, Hurricane Joaquin ravaged the Bahamas, with extensive damage to infrastructure, resulting in economic losses of more than US\$100 million—affecting nearly 10,000 people. Costs to replace damaged infrastructure exceeded US\$60 million.<sup>4</sup> Widespread power outages were reported, and it took more than two weeks to restore power to a majority of customers.<sup>5</sup> In 2016, Cyclone Winston hit Fiji with such force that it damaged or destroyed

40,000 homes and 229 schools, and left 720,000 people without power. The total damage from the storm amounted to US\$1.4 billion.<sup>6</sup>

In 2017, Category 5 hurricanes Irma and Maria struck the Caribbean within 10 days of each other affecting Anguilla, Antigua and Barbuda, The Bahamas, Dominica, the Dominican Republic, Puerto Rico, Saint Martin, Sint Maarten, the Turks and Caicos Islands, the British Virgin Islands and the US Virgin Islands. The respective hurricanes caused thousands of deaths and more than US\$100 billion in economic costs, both of which were exacerbated by loss of power. Many communities spent months—and in the case of Puerto Rico, more than a year—living without electricity-dependent services and infrastructure that keep their communities functioning such as water supply, hospitals, schools, banks, grocery stores, cell phone towers, airports, and seaports. Utilities in the affected region (which often self-insure their grids) worked tirelessly to put overhead distribution systems back in place, repair power stations, reestablish fuel supplies, and reconnect homes and businesses to the grid. Even with an around-the-clock effort, a surge in utility support from the Caribbean Electric Utility Services Corporation (**CARILEC**) mutual aid agreements, and federal support through the Federal Emergency Management Agency in the US Virgin Islands and Puerto Rico, thousands of homes, businesses, and critical services across the islands remained dark for extended periods of time.

In 2018, Cyclone Gita hit the Pacific islands of Vanuatu, Fiji, Wallis and Futuna, Samoa, American Samoa, Niue, and Tonga. In Tonga, Gita left more than 80% of the homes without power, and economic damages totaled US\$164 million, 40% of the island's GDP.<sup>7</sup>

The 2018–2019 Southwest Indian Ocean cyclone season was the costliest and deadliest cyclone season recorded in region in decades. Cyclone Gelena destroyed 90% of the electricity grid on Rodrigues Island, causing an estimated \$1 million in damage.<sup>8</sup>

In 2020, Tropical Cyclone Harold left an estimated 160,000 people, almost half the population, on Vanuatu homeless and destroyed 65% of the buildings in the island's second-largest town. This included many health centers and hospitals, all while the island was grappling with the COVID-19 pandemic. At the time of this writing it is expected to take months to restore electricity to many of the affected areas.<sup>9</sup>

## CURRENT USE OF SOLAR IN SIDS

In recent years, electricity throughout the Caribbean and the Pacific has been supplemented in homes, businesses, industries, government facilities, and utilities by solar photovoltaics (PV). In fact, over half of Caribbean electric utilities already own or operate solar PV as part of their generation mix. There are at least 571 megawatts (MW) of solar installed across rooftops, parking canopies, and large tracts of land. Solar PV is the most rapidly growing source of power for many Caribbean islands. It is estimated that the Caribbean holds 2,525.9 MW of potential solar energy,<sup>10</sup> almost 2 gigawatts more than what is currently installed. Solar energy use is spreading throughout the Pacific as well. For example, the 15 islands that make up the Cook Islands in the South Pacific (12 of which are inhabited) are on their way to being 100% powered by solar and battery storage.

The many solar energy installations among island nations include the following:<sup>11</sup>

- Sint Eustatius—A 4.1 MW solar park coupled with 5.9 MW of storage is providing the island with 45% of its electricity;
- Saint Lucia—A 3 MW solar farm is providing the 5% of the island's peak electricity demand and reducing the volume of fuel purchased by 300,000 gallons per year;
- Jamaica—A 20 MW solar farm powers more than 20,000 homes and reduces fuel imports by approximately 3 million gallons per year;
- Dominican Republic—A 69 MW solar project is providing power to 50,000 homes and created 300 direct and 1,000 indirect jobs;
- Tokelau— 4,032 solar panels (~1 MW) and 1,344 batteries provide 150% of the island's electricity demand, allowing the islanders to expand their electricity use without increasing diesel use;
- Ta'u in American Samoa—A 1.4 MW solar system and 60 Tesla Powerpacks provide 100% of the electricity for the island's 600 residents; and
- Nauru—A 6 MW solar plant and 5 MW storage system provide almost 50% of this Pacific island's electricity needs.

Augmenting or replacing fossil energy supply with solar energy can make islands' energy systems less reliant on imported fuel, more resilient, cleaner, and can help islands save on energy costs in the long term.

## POLITICAL CONTEXT

SIDS have pursued investments in renewable energy technologies in recent years to diversify their energy supplies, to build resilience, and as part of their efforts to enhance climate change mitigation ambition. However, looking at the moderate growth rates of sustainable energy over the last years, the overall share remains low in a number of SIDS. The deployment of renewable energy and energy efficiency solutions remains hindered by a broad range of challenges related to lack of access to affordable finance, legal and regulatory barriers, technical limitations, and limited human and institutional capacity.

The SAMOA Pathway is the overarching framework setting out the sustainable development priorities for SIDS for the period 2014–2023. Among these areas, it is recognized that SIDS' dependence on fossil fuels is a major source of economic vulnerability and a key challenge for sustainable development. Thus, the SAMOA Pathway calls for concrete actions to address

the challenges SIDS face in transitioning to sustainable energy systems and to promote energy efficiency. Furthermore, the Political Declaration adopted by the General Assembly at the mid-term review of the SAMOA Pathway in September 2019, stresses the importance of access to affordable, reliable, sustainable, and modern energy for SIDS.

Additionally, a transformative SIDS Climate Action Summit package on sustainable energy toward a pathway of enhanced renewable energy transition targets by 2030 was presented at the UN Climate Summit in September last year. This package is committed to supporting SIDS' energy transition through a set of cross-cutting initiatives and partnerships including advice on policy and market frameworks, technology options, access to affordable finance, and capacity building.

SIDS share political consensus mechanisms through AOSIS, SIDS DOCK, and the Initiative for Renewable Island Energy. They have been outspoken supporters of the UNFCCC, and leaders in raising awareness of, and the need for action on, climate change adaptation and mitigation.<sup>12</sup> In addition to the UNFCCC, SIDS have supported the Kyoto Protocol, reaffirmed support for the process through the SAMOA Pathway during the 2014 International Year of SIDS,<sup>13</sup> and advocated for the Paris Agreement. SIDS are also supported by the IRENA Lighthouse Initiative and The UN Industrial Development Organization's regional renewable energy and energy efficiency centers based in Tonga, Barbados, and Cape Verde. Caribbean nations actively cooperate and collaborate with each other through various fora, including through SIDS DOCK and frameworks such as the Saint George's Regional Climate Change Agreement, the CARICOM Regional Framework for Achieving Development Resilient to Climate, and the Pilot Programme for Climate Resilience.



# BENEFITS OF SOLAR ENERGY TO SIDS

---

Recently, solar energy has demonstrated increased technical and economic ability to support island communities' energy transitions. Solar is now competitive with traditional fossil fuel generation and in some cases has become the primary energy source for island power systems. When paired with battery energy storage, it can also provide baseload power. It also is proven to enhance resilience of island electricity systems to both economic and climate shocks.

## REDUCED DEPENDENCY ON IMPORTED FUELS

The Caribbean generates 87% of its energy from imported fossil fuels. Trinidad and Tobago is the only net exporter of fossil fuels, while all other Caribbean countries are net oil importers. In the Pacific, only two of the region's 15 countries—Papua New Guinea and Timor-Leste—have proven fossil fuel reserves. That means the region has relied largely on imports of fossil fuels. This dependence on imported oil leaves these island nations vulnerable to oil price shocks, which in turn reduces GDP growth. Fuel supplies can also be disrupted due to hurricanes and other natural disasters. For example, after hurricane Maria in Puerto Rico, it took weeks to reestablish fuel supplies.<sup>14</sup>

## ENHANCED RESILIENCE

Depending on centralized generation can mean an entire island goes dark when the grid goes down during a disaster event. Without power available to critical facilities—including hospitals, fire and rescue, and other community facilities—many lives can be lost. Solar PV is a decentralized form of power that can isolate from the grid, so the lights can stay on when the central grid is down.

## COST-EFFECTIVENESS

The Pacific Island Countries pay some of the world's highest electricity costs with households paying an average of \$0.42/kWh. Customers in Tuvalu and the Solomon Islands pay the highest rates at \$0.89/kWh and \$0.68/kWh respectively.<sup>15</sup> Caribbean island residents also pay some of the highest retail electricity prices in the world, paying between \$0.20 and \$0.50/kWh. By comparison, the average for mainland US residential customers is \$0.13/kWh.<sup>16</sup> Cost declines over the last few decades have made solar PV cost-competitive and often cheaper than fossil fuel generated electricity. The global levelized cost of electricity for solar PV was an average of \$0.085/kWh in 2018, and is expected to fall to between \$0.014/kWh and \$0.05/kWh by 2050.<sup>17</sup>

## CLIMATE GOALS

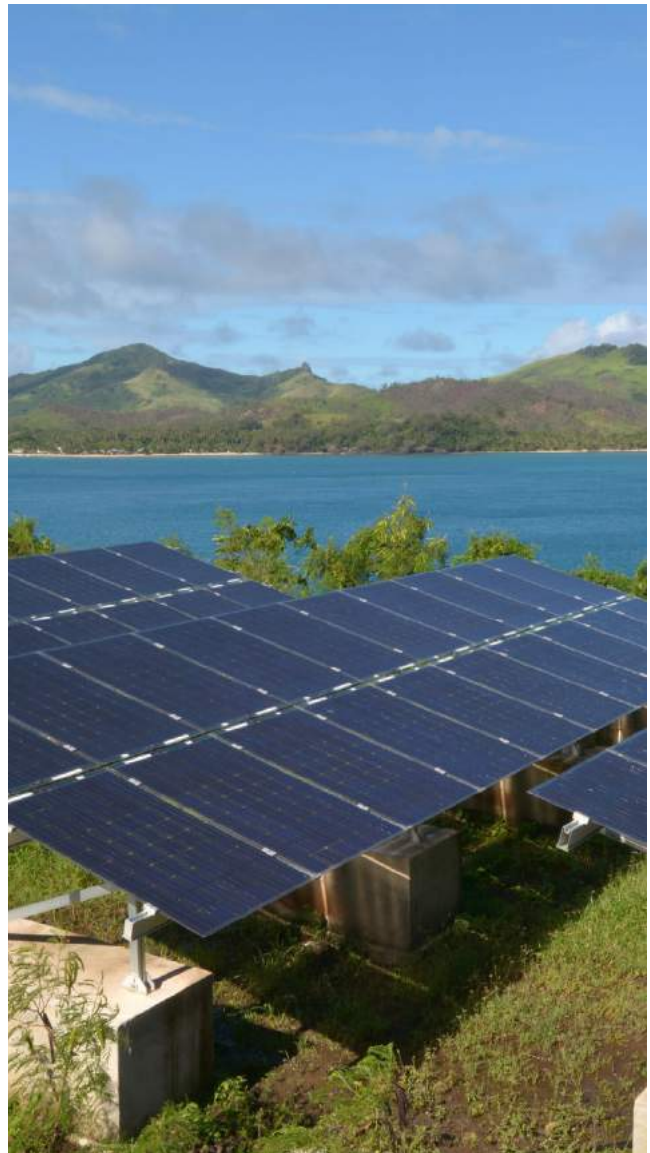
Many SIDS have ambitious climate goals, with almost all having set national renewable energy targets.<sup>18</sup> For example, Latin American and the Caribbean have a regional initiative to install 312 GW of renewables by 2030, reaching at least 70% of their electricity needs. And several islands in the Caribbean—including Aruba, Dominica, Grenada, Puerto Rico, and Montserrat—have 100% renewable energy goals.<sup>19</sup> In the Pacific, seven islands have declared 100% renewable energy targets: The Cook Islands, Niue, Tuvalu, Fiji, Vanuatu, and the Solomon Islands.<sup>20</sup>

## ECONOMIC RECOVERY

Transitioning to renewables is especially important to SIDS in recovering from the economic toll that the COVID-19 pandemic has taken on island nations around the world due to their heavy dependence on tourism. Renewable energy growth can lead to job creation in the construction sector and access to reliable and affordable energy can increase income-generating opportunities as well as provide a platform for new electricity-reliant industries.

By accelerating the transition of islands toward an energy system that includes clean energy and energy efficiency, island governments, utilities, and stakeholders can:

- Stabilize the cost of electricity for households and businesses;
- Reduce dependence on imported fossil fuels and reduce greenhouse gas emissions;
- Create on-island investment opportunities and investment returns;
- Increase resilience of the distribution grid and defer maintenance on transmission and distribution systems; and
- Diversify the local job market with higher-skilled, better-paying jobs.



# ENERGY RESILIENCE

---

Solar PV systems—both rooftop and ground-mounted—have demonstrated an ability to withstand major cyclonic events despite a portion of the installed base experiencing catastrophic damage. For example, after the 2017 hurricanes in the Caribbean region, with sustained wind speeds of over 180 miles per hour (290 kilometers per hour), many solar PV systems in the Caribbean survived. This included solar PV installations in the British Virgin Islands, Turks and Caicos Islands, Puerto Rico, and Sint Eustatius that experienced wind speeds over 190 miles per hour (306 kilometers per hour) yet suffered little to no damage and continued producing power the following day. In contrast, other solar PV systems in the region suffered major damage or complete failure, with airborne dislodged solar modules, broken equipment, and compromised racking.

## WHY SOME PV SYSTEMS FAIL AND OTHERS SURVIVE

The most common reasons for the solar PV systems failing is the use of shared **top-down clips**. These clips are designed to retain groups of modules with shared clamps. However, when one module becomes loose due to the wind, the other module will become loose as well.

The second-most common failure is when the system is struck by **debris**, especially from dislodged modules. For rooftop systems, a third point of failure is **corner overturning**. This is mostly due to incorrect assumed wind loading calculations.

For ground-mounted systems, other reasons for failure include:

- Undersized rack or rack not designed for wind load;
- Lack of lateral racking support (rack not properly designed for wind loading from the side);
- Undersized bolts;
- Under torqued bolts;
- Lack of vibration-resistant connections;
- PV module design pressure too low for environment; and
- Use of self-tapping screws instead of through bolting.

However, many observed PV systems survived the hurricane-force winds. Some common PV attributes of surviving ground-mount systems include:

- The use of dual post piers for ground-mounted systems;
- Through bolting of solar modules (no top down or T clamps);
- Lateral racking supports;
- Structural calculations on record;
- Owner's engineer of record with QA/QC program; and
- Vibration-resistant module bolted connections such as Nylocs.

Similarities of surviving roof-mounted PV systems include:

- Appropriate use/reliance on ballast and mechanical attachments;
- Sufficient structural connection strength;
- Through-bolted module retention or four top-down clips per module;
- Structural calculations on record;
- Owner's engineer with QA/QC program; and
- Vibration-resistant module bolted connections.

**EXHIBIT 1**

## Similarities of Systems

Similarities of Failed Systems	Similarities of Surviving Systems
Top-down or T-clamp cascading failure of module retention	Appropriate use/reliance on ballast and mechanical attachments
Lack of vibration-resistant connections	Sufficient structural connection strength
Corner of the array overturned due to incorrect design for wind	Through-bolted module retention or four top-down clips per module
Insufficient structural connection strength	Structural calculations on record
Roof attachment connection failure	Owner's engineer with QA/QC program
System struck by debris/impact damage, especially from liberated (dislodged) modules	Vibration-resistant module bolted connections
Failure of the structural integrity of the roof membrane	
PV module design pressure too low for environment	

## ADDITIONAL COST TO INCREASE RESILIENCE

Calculating the additional cost to implement the recommendations outlined in this report depends on the specific projects and the sites and/or roofs. RMI estimates concluded that incorporating Category 5 resilient considerations in solar PV projects, on average, would incur an increase of approximately 5% in engineering, procurement, and construction (EPC) costs versus the current industry standard Category 3 or 4 rated solar PV installation considerations. These additional costs come in the form of labor for the extra time needed to fasten modules and install more connections.

There are also additional costs in material (higher-rated modules, racking supports, and fasteners) as well as minor costs for additional engineering and construction oversight. However, these upfront costs are more than offset by the fact that a surviving solar PV system negates the costs of requiring a system rebuild.

Based on RMI's recent solar PV procurement for a 250 kW standing seam roof-mounted solar PV system in the Caribbean, implementing these best resilience practices added approximately \$30,000 or 5% in EPC costs to the budget versus the previous Category 3 baseline. The Clinton Climate Initiative supported the procurement of a 263 kW solar PV system on a flat roof in Puerto Rico and it increased costs by 5.5% to achieve a 175 mph (Category 5) rating versus 145 mph (Category 3).

When considering lifetime costs (25 years), the additional mitigation costs for resilience have proven to be money well spent for those exposed to cyclone events (hurricanes and typhoons) and other high-wind events.

## ENERGY STORAGE SYSTEMS FOR RESILIENCE

While this paper is focused solely on solar PV systems, it is worth adding that solar PV systems combined with a battery storage system can continue to deliver baseload power to a home, business, or critical facility even during a grid outage. Most grid-connected solar PV systems without battery storage will shut down when a grid outage is detected, to avoid back-feed to the grid and to ensure safety of the system and utility personnel. A solar PV system with a multi-mode inverter, transfer switch, battery storage system, and other appropriate components can be disconnected ("islanded") from the grid during a power outage. During extended power Outages. This additional resilience can ensure continued critical services to the community such as communications, water treatment and pumping, medical operations (ventilators, lighting, etc.), and refrigeration for food and medicine storage. By pairing batteries with a resilient solar PV system, facilities can count on uninterrupted power even after the most severe storms. Additional discussion on the many benefits of solar PV coupled with battery energy storage can be found on RMI's [blog post](#) "Critical Facilities: Where Government and Utility Services Redefine Resilience."<sup>21</sup>

# RECOMMENDATIONS

---

Generating energy with solar PV is a cost-effective and reliable solution for power generation in SIDS. But it only helps improve system resilience if it is designed and installed to meet certain standards. Incorporation of the best available engineering, design, delivery, and operational practices can increase the survival rates from extreme wind loading. To ensure this happens, policymakers should ensure that resilient solar PV design and construction standards are incorporated into local building codes and compliance is ensured by certified engineers.

One of the most important ways to enhance the resilience of the entire value chain and life cycle of solar PV projects is through inclusive multi-stakeholder collaboration. The benefits of stakeholder collaboration are multifaceted. While collaboration cannot be fully measured, it ensures that the correct equipment is available, best practices are enforced, and the systems are built to the highest standards. This means communicating clear market signals to suppliers and upstream equipment providers and coordinating closely among practitioners. Simply put, policymakers can influence the entire value chain from local installers to global solar equipment manufacturers by requiring and enforcing high wind resilience standards for solar PV systems in their respective jurisdictions.

Collaboration recommendations include:

- Identify opportunities for increased resilience, which require multiparty consideration and action but do not represent current industry standard actions;
- Collaborate with module suppliers for implementation of static and dynamic load tests representative of Category 5 hurricane winds;
- Collaborate with equipment suppliers to implement incentives so that Category 5 standards are incorporated without putting local suppliers out of business;
- Collaborate with equipment suppliers to document material origin and certificate of grade and coating consistent with assumptions used in engineering calculations;
- Collaborate with the installer to implement and continuously improve full QA/QC and operation and maintenance processes throughout the life of the project;
- Collaborate with professional engineers of record on calculation best practices and intent;
- Collaborate with racking suppliers to carry out full-scale and connection tests representative of ASCE 7 3-second design wind speeds (Saffir Simpson Category 5), specifically including wind tunnel testing review and rigidity assessment;
- Encourage collaboration with roofers, roofing manufacturers, and insurance companies to maintain roof warranty and roof integrity;
- Collaborate with equipment suppliers to document material origin and certificate of grade and coating consistent with assumptions used in engineering calculations; and
- Encourage collaboration between installers and module suppliers/distributors to ensure local availability of specified modules.

Perhaps the most opportune recommendation is for a regional and even international community of solar PV power plant stakeholders who have extreme wind exposure to regularly share lessons learned from new designs and extreme weather events. To that end, CARILEC formed a solar PV Resilience working group on the online Caribbean Renewable Energy Community (CAREC) to connect, innovate, and collaborate. The working group is open to the public. Individuals and representatives of organizations may join the working group at: <http://community.carilec.org/c/PVResiliency>.

In addition to collaboration, more technical recommendations are listed below for policymakers and regulators related to codes, regulations, and procurement, as well as recommendations for installers.

## CODES AND REGULATIONS

For ground-mounted systems:

- Prohibit the use of trackers for projects in locations with Category 4 or higher wind zones;
- Require structural engineering in accordance with ASCE 7 and site conditions, with sealed calculations for wind forces, reactions, and attachment design (ground-mount foundation); and
- Require structural engineer review of lateral loads due to racking and electrical hardware—often lateral loads are missed, and recent failures have proven them to be a critical source of weakness.

For rooftop systems:

- Require that pitched-roof systems only have modules installed within the envelope of the roof structure (no overhanging modules over the roof edges);
- Pitched-roof systems should only be allowed within wind zones one and two;
- Require that roof pre-inspections be performed to verify that the roof conditions are acceptable and match the assumptions in the structural design;
- Do not allow ballasted-only systems—all systems should have positive mechanical attachments to the building structure that meet the minimum mechanical attachment recommendation (see Appendix C);

- Require roof pre-inspections be performed to verify that the roof conditions are acceptable and match the assumptions in the structural design (see Appendix B); and
- Require structural engineering be performed in accordance with ASCE 7 and site conditions, with sealed calculations for wind forces, reactions, and attachment design.

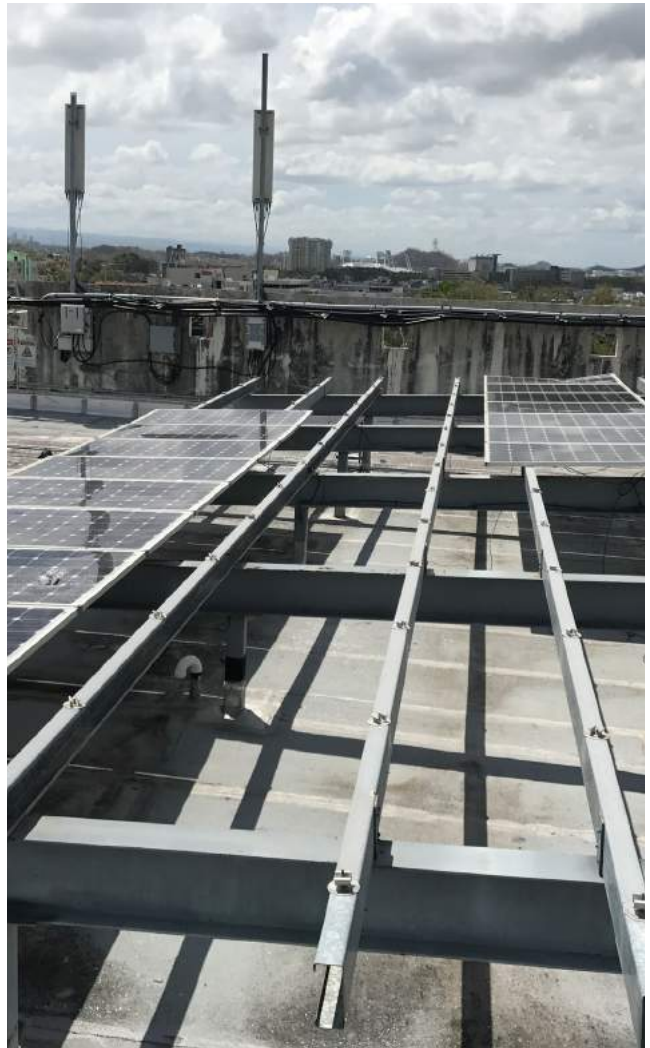


Image courtesy of Carlos Quiñones, CJQ Engineering

## PROCUREMENT

General:

- Specify high-load solar PV modules (target 5,400 Pa front load rating and 4,000 Pa back load or uplift rating);
- Specify all hardware be sized based on 25 years (or project life) of corrosion;
- Specify bolt hardware that is vibration resistant and appropriate for the environment and workforce;
- Confirm with racking vendor and project engineer that actual site conditions comply with their base condition assumptions from wind-tunnel testing;
- Confirm with the project engineer that design best practices are met relating to worst-case joist loading, base velocity pressure, rigidity assessment, area averaging, and minimum mechanical attachment scheme (see Appendix B); and
- Specify a project QA/QC process including items like bolt torqueing, ballast placement, and mechanical attachment quality.

For ground-mounted systems:

- Specify dual post fixed tilt ground mounts, which significantly reduce foundation failure risk;
- Do not use trackers for projects in Category 4 or higher wind zones;
- Confirm with racking manufacturer that actual site conditions comply with their base condition assumptions from wind-tunnel testing;
- Specify a bolt hardware locking solution; and
- Specify through bolting of modules as opposed to top-down or T clamps, or if top clamping is required, use clamps that hold modules individually or independently.

# CONCLUSION

---

Although SIDS contribute little to climate change, they bear the disproportionate brunt of its impacts. Their historic reliance on imported fossil fuels makes their systems extremely susceptible to disruption as well as polluting and costly. Furthermore, worsening cyclonic events have caused widespread devastation and destruction for SIDS, damaging and in some cases completely destroying the islands' critical infrastructure. Having a resilient electricity system is key for human development, as it impacts almost all aspects of life—health, education, economic growth, and quality of life.

Fortunately, there is a solution: Generating energy with solar PV is a cost-effective and reliable way to provide electricity in SIDS. Its use has grown from the Caribbean to the Pacific and the Indian Ocean. It is critical and cost-effective to incorporate the best available engineering, design, delivery, and operational practices to increase the survival rates of solar PV systems from extreme wind loading. Policymakers and regulators can therefore take certain steps to ensure building codes incorporate resilient solar PV design and construction standards, incentivize the use of the correct equipment, and encourage a framework of multistakeholder collaboration to increase the resilience of the entire value chain and life cycle of solar PV projects.



Image courtesy of Fidel Neverson, Energy Solutions, Inc.

# APPENDICES

---

## APPENDIX A: SOLAR PV POWER PLANT WIND PRESSURE CHECKLIST FOR PROJECT OWNERS

The determination of a design wind pressure is a complex science conducted by expert scientists and engineers. Solar PV power plant owners may generally confirm that wind pressures have been appropriately determined through familiarization with the process.

### General process for solar PV power plant wind pressure determination:

**Conduct wind tunnel study on a scaled system model in a boundary-layer wind tunnel.** Project stakeholders may review the wind tunnel test report to confirm the scale model represents the project's proposed system layout. Deviations in row length, spacing, tilt, height, and leading-edge height should be limited to the range identified in the wind tunnel report.

**Analyze pressure measurements to determine pressure coefficients for the module or structural member of interest.** The wind tunnel test report should contain a table of pressure coefficients for each structural member of interest corresponding to the tributary area of said member or component. A project stakeholder should be able to identify

that an appropriately selected table of pressure coefficients was used for each member or component. For components that do not have a dedicated table, rounding down should provide a near approximation as long as the aspect ratio and location are also similar. If an appropriate table does not exist, the wind tunnel can most likely reprocess existing data with minimal time and resources.

### Determine the wind dynamic pressure by accounting for the design wind speed, local topography, system height, directionality, and importance.

Project stakeholders should be able to review a site-specific determination of wind dynamic pressure. The calculation should comply with the governing code and version (e.g., ASCE 7-10) and incorporate the regional design wind speed, system height, topography, and importance. Projects with any topographic features should ensure appropriate treatment of said features.

**Combine the pressure coefficients and dynamic pressure to calculate a wind pressure.** Project stakeholders should be able to review the structural calculations to determine a design wind pressure for each component or member of interest.



Image courtesy of FortisTCl, Turks and Caicos

## APPENDIX B: PROJECT RESILIENCE CHECKLIST

### Pre-Inspection of the Rooftop

Roof type	Skylight locations are marked on the planset
Roof age	Equipment locations are marked on the planset
Roof condition	Other obstruction locations are marked on the planset
Building parapet wall height	Nearby debris risk (nearby loose items on rooftop, overhanging trees, etc.)
Drain locations are marked on the planset	

### Project Wind Load Inputs

Building height assumptions are accurate	Project wind speed is accurate
Project risk category, topographic factor, and exposure category are accurate	Building joist locations and sizes are accurate

### Mechanical Fasteners

Mechanical fasteners should be utilized in high-wind zones to a minimum acceptable standard (supplied within this document). No ballasted-only systems.

### Discussions with the Professional Engineer of Record

Does the project engineer have access to the building design calculations to determine capacity?	Has the project engineer verified whether the local wind pressure from the wind tunnel test and project calculations exceeds the module specification for static loading?
Has the project engineer reviewed the wind tunnel testing of the racking vendor and its application to the project?	Has the project engineer verified that the mechanical attachment scheme meets or exceeds the applicable minimum mechanical attachment recommendation? (See Appendix B)
Has the racking vendor supplied a rigidity assessment specific to their geometry that validates the effective wind areas they assume in the design? If not, the effective wind area should be assumed to be a single module (see Appendix B)	Has the project engineer verified that existing practices incorporate all “current mitigations” identified in the FMEA tables? Has the racking vendor performed and supplied their own FMEA to the project engineer?
Has the project engineer evaluated the worst-case joist loading of the building and not simple array area average loading? (See Appendix C)	

### Hardware

Does the project use vibration-resistant hardware? Does the module mount with hardware independent of adjacent modules?

## APPENDIX C: PROJECT OWNER'S HIGH-WIND DESIGN PROCESS (ROOFS)

Project engineers often aren't privy to the logic that connects wind tunnel testing assumptions and structural calculation packages on ballasted/mechanically attached hybrid flat-roof racking projects. Design errors are often found within this connective space. The project owner's high-wind design checklist is meant to be a process by which anyone can walk through the structural calculation package and double-check that the system meets a minimum requirement for roof attachments and ballast assignment to resist high-wind scenarios. It builds the case for the minimum roof attachment scheme and should be used on projects with design wind speeds of 120–145 mph depending on wind exposure, and certainly on any flat-roof project with a design wind speed greater than 145 mph.

### Three wind-loading cases that must be checked according to governing factored load cases:

1. Pure uplift
2. Uplift and Sliding
3. Overturning

### DESIGNING FOR PURE UPLIFT

Racking vendors must demonstrate that structural loads can be shared among the grouping of modules for which wind loads are being determined (effective wind area [EWA]). Loads are considered shared if no more than 1" of uplift is experienced anywhere within an area without ballast.

For example, if a "3x3" (3 modules wide x 3 rows = 9 modules) area is to be considered as a maximum EWA size, the appropriate peak wind load to be applied to this EWA is evenly applied and the perimeter of this 3x3 array is fixed to the ground. Peak deflection upward (gap between roof and racking) should be

less than 1" for this EWA to be considered structurally connected. This testing should be done without including any ballast or mechanical attachments (simply done with self-weight of modules plus racking). Once the uplift EWA is established, the ballast may be distributed evenly over the area considered or otherwise as determined by the racking vendor.

### DESIGNING FOR UPLIFT AND SLIDING

Racking vendor needs to demonstrate that intermodule and inter-row structural elements can supply bracing to prevent sliding of every size of the array being considered.

For example, if considering a maximum uplift and sliding EWA of 9x9 (81 modules), the process to check sliding resistance is as follows:

1. Check that 1x1 sliding loads can be resisted by modules adjacent and downwind.
2. Check that 2x1 sliding loads can be resisted by module adjacent and downwind.
3. 2x2, 3x1, 3x2, 3x3, 4x1, 4x2, 4x3, 4x4, etc. all the way up to 9x9 are to be checked against adjacent modules and downwind module rows to ensure structural elements can resist/brace against sliding forces.

### DESIGNING FOR PURE OVERTURNING

Racking vendor needs to consider module overturning for every combination of modules up to the EWA used for pure uplift checks. In the above example of a 3x3 EWA, this means overturning needs to be checked for 1x1, 2x1, 2x2, 3x1, 3x2, and 3x3. Wind loading can be assumed to apply equally to the center of each of the module(s) of the EWA being considered. Ballast can be applied along with self-load of racking plus modules as they are distributed to determine resistance to overturning.

## MINIMUM SPECIFICATION FOR ROOF MECHANICAL ATTACHMENTS

Racking vendor should include a minimum number of mechanical roof attachments that satisfies the following:

1. Mechanical attachment acting on the corner module of every array.
2. No more than a three-module span along a northern row between mechanical attachments.
3. No more than a three-module span along a southern row between mechanical attachments.

The above requirements are a minimum and a given project may require further mechanical attachments. Adhering to the above will dramatically reduce the risk of catastrophic wind failures (overturning modules leading to cascading failure modes). It also provides

significant resistance to both lift/sliding and “walking” of the system over the roof over longer periods of moderate wind and/or seismic activity.

A module is considered to be within a northern or southern row if there is no direct mechanical attachment to another row of modules on both the north and south sides of it that would prevent overturning in both directions. This means obstacles such as A/C equipment, skylights, and walkways that break up arrays can generate significant numbers of northern and southern row sections and thus may require significant numbers of new mechanical attachments.

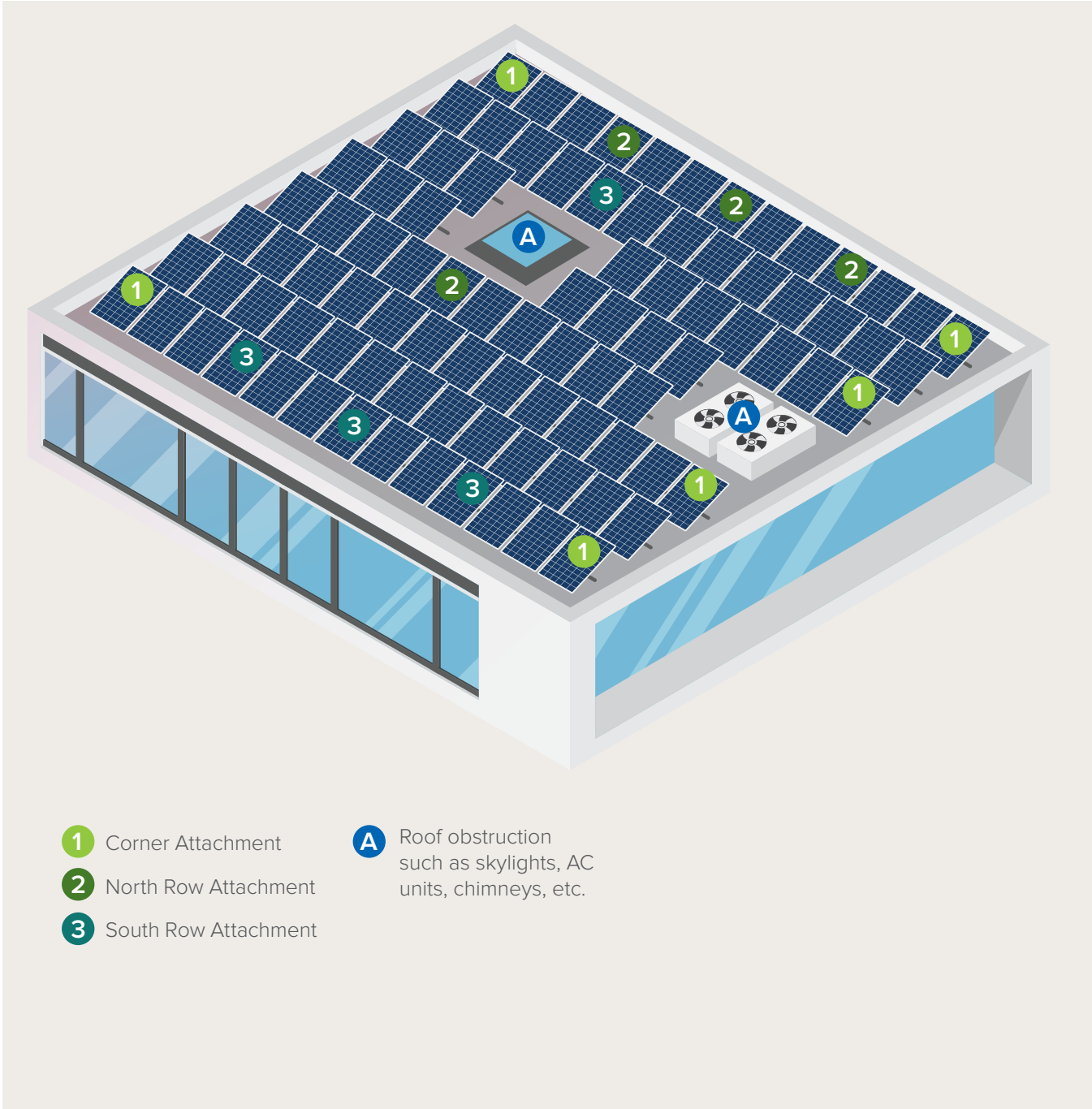
A module is considered to be a “corner module” if located at the end of a row and if no module is attached to both northern and southern edges to prevent overturning in both directions.



Image courtesy of Rocky Mountain Institute

**EXHIBIT C1**

Minimum Roof Mechanical Attachment Scheme



# ENDNOTES

---

1. *The Status of Renewable Energy in the Caribbean: Ten Years of Island Innovation*, Renewable Energy Caribbean & New Energy Events, 2018. <https://renewableenergycaribbean.files.wordpress.com/2018/12/the-status-of-re-in-the-caribbean.pdf>
2. Philip J. Klotzbach, Michael M Bell, and Jhordanne Jones, *Extended Range Forecast of Atlantic Seasonal Hurricane Activity and Landfall Strike Probability for 2020*, Department of Atmospheric Science, Colorado State University, April 2020. <https://tropical.colostate.edu/media/sites/111/2020/04/2020-04.pdf>
3. *Gone with the Wind: Estimating Hurricane and Climate Change Costs in the Caribbean*, International Monetary Fund, 2016. <https://www.imf.org/external/pubs/ft/wp/2016/wp16199.pdf>
4. “\$60m+ To Rebuild: PM Reveals Cost Of Hurricane Joaquin Repairs,” *The Tribune*, <http://www.tribune242.com/news/2015/oct/15/60m-rebuild-pm-reveals-cost-hurricane-joaquin-repa/>
5. *The Bahamas National Energy Policy 2013–2033*, Ministry of the Environment and Housing and Ministry of Works & Urban Development, <http://www.thebahamasweekly.com/uploads/16/energypolicy.pdf>
6. “\$2.98 billion damage caused by TC Winston,” *Newswire*, 2016. <https://web.archive.org/web/20160617111016/https://www.newswire.com.fj/national/tc-winston/2-98-billion-damage-caused-by-tc-winston/>
7. *Cyclone Gita Recovery Project: Report and Recommendation of the President*, Asian Development Bank, 2018. <https://www.adb.org/sites/default/files/linked-documents/52129-001-ssa.pdf>
8. Rodrigues Island – Tropical Cyclone Gelena, Mauritius Meteorological Services, Media, Reliefweb, 2019. <https://reliefweb.int/report/mauritius/rodrigues-island-tropical-cyclone-gelena-mauritius-meteorological-services-media>
9. “Cyclone Harold Leaves 160,000 Homeless: CAT II Disaster Declared,” World Vision, 2020. <https://www.worldvision.com.au/media-centre/resource/cyclone-harold-leaves-160-000-homeless-cat-ii-disaster-declared>
10. *The Status of Renewable Energy in the Caribbean: Ten Years of Island Innovation*, Renewable Energy Caribbean & New Energy Events, 2018. <https://renewableenergycaribbean.files.wordpress.com/2018/12/the-status-of-re-in-the-caribbean.pdf>
11. Ibid.
12. SIDS Accelerated Modalities of Action [SAMOA] Pathway, UN Conference on Small Island Developing States, 2014. <http://www.sids2014.org/index.php?menu=1537>
13. SIDS DOCK, Small Island Developing States. <http://sidsdock.org/>
14. Gabriel Stargardt and Hugh Bronstein, “Fuel Deliveries Finally Start to Arrive in Hurricane-Damaged Puerto Rico,” *Huffington Post*, 2017. [https://www.huffpost.com/entry/puerto-rico-hurricane-maria-fuel-deliveries\\_n\\_59d338e6e4b048a44324bd5f](https://www.huffpost.com/entry/puerto-rico-hurricane-maria-fuel-deliveries_n_59d338e6e4b048a44324bd5f)
15. UNELCO electricity rates, accessed April 24, 2020, <https://www.unelco.engie.com/en/electricity/electricity-rates>

16. “Four Reasons Why Natural Gas is the Wrong Choice for Electricity in the Caribbean,” Rocky Mountain Institute, 2014.
17. “Latin America and Caribbean on the Brink of Massive Solar Power Growth,” International Renewable Energy Agency, November 2019. <https://www.irena.org/newsroom/pressreleases/2019/Nov/Latin-America-and-Caribbean-on-the-Brink-of-Massive-Solar-Power-Growth>
18. *SIDS Lighthouses Initiative 2.0: Accelerating the energy transformation through renewables*, IRENA, 2018, [https://islands.irena.org/-/media/Files/IRENA/Sids/IRENA\\_SIDS\\_UNGA\\_Brochure.ashx](https://islands.irena.org/-/media/Files/IRENA/Sids/IRENA_SIDS_UNGA_Brochure.ashx)
19. “Latin America, Caribbean announce 70% renewable energy goal,” *Hydro Review*, 2019. <https://www.hydroreview.com/2019/12/11/latin-america-caribbean-announce-70-renewable-energy-goal/#gref>
20. *100% Renewable Energy Targets in the Pacific Islands*, International Partnership on Mitigation and MRV, 2012. [https://www.transparency-partnership.net/system/files/migrated\\_document\\_files/2012ongoingrenewableenergy\\_pacificislands.pdf](https://www.transparency-partnership.net/system/files/migrated_document_files/2012ongoingrenewableenergy_pacificislands.pdf)
21. Christopher Burgess and Ana Sophia Mifsud, “Critical Facilities: Where Government and Utility Services Redefine Resilience,” Rocky Mountain Institute, 2018. <https://rmi.org/government-utility-define-resilience/>



Image courtesy of Carlos Quiñones, CJQ Engineering



22830 Two Rivers Road  
Basalt, CO 81621 USA  
[www.rmi.org](http://www.rmi.org)

© July 2020 RMI. All rights reserved. Rocky Mountain Institute® and RMI® are registered trademarks