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CCREEE

CARIBBEAN CENTRE FOR RENEWABLE ENERGY & ENERGY EFFICIENCY

Caribbean Institute for Meteorology and Hydrology
CIMH

USAID
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NREL
Transforming ENERGY

INTEGRATED RESOURCE AND RESILIENCE PLANNING

CLIMATE VULNERABILITY MODELLING CAPACITY BUILDING SESSION

Tuesday, March 9, 2020
10:00 a.m. – 1:00 p.m. AST

ccreee.org/event/climate-vulnerability-modelling/

SUPPORTED BY

german cooperation
DEUTSCHE ZUSAMMENARBEIT

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giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Resilient Energy Platform

The USAID-NREL Partnership

USAID and NREL partner to deliver clean, reliable, and affordable power to the developing world. The USAID-NREL Partnership addresses critical aspects of deploying advanced energy systems in developing countries through:

- Policy, planning, and deployment support.
- Global technical toolkits.

www.nrel.gov/usaid-partnership

Global Technical Platforms

The USAID-NREL Partnership's global technical platforms provide free, state-of-the-art support on common and critical challenges to scaling up advanced energy systems.

REexplorer — MAPPING OUR ENERGY FUTURE — www.re-explorer.org

Greening the Grid — www.greeningthegrid.org

I-JEDI — www.i-jedi.org

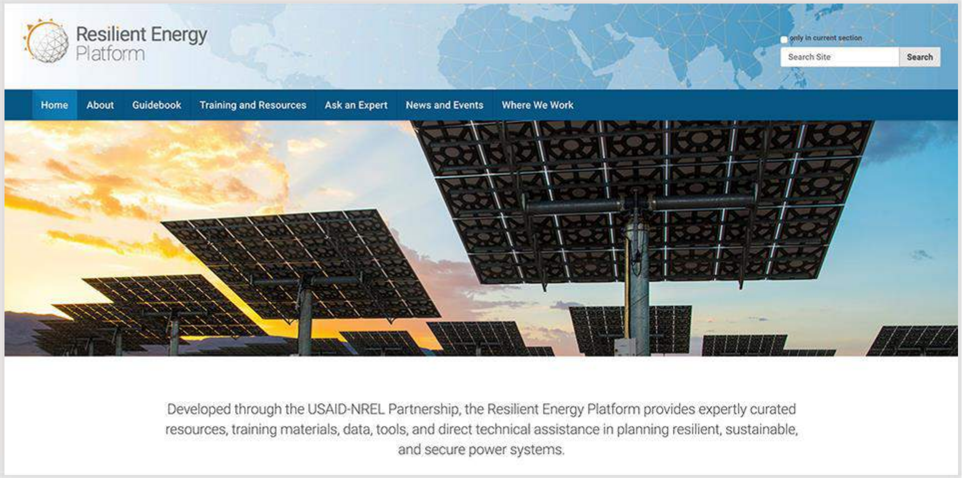
Resilient Energy Platform — www.resilient-energy.org

Resilient Energy Platform

Resilient Energy Platform

Developed through the USAID-NREL Partnership, the Resilient Energy Platform provides expertly curated resources, training materials, tools, and technical assistance to enhance power sector resilience.

The platform enables decision makers to assess power sector vulnerabilities, identify resilience solutions, and make informed decisions to enhance power sector resilience at all scales.



https://www.resilient-energy.org

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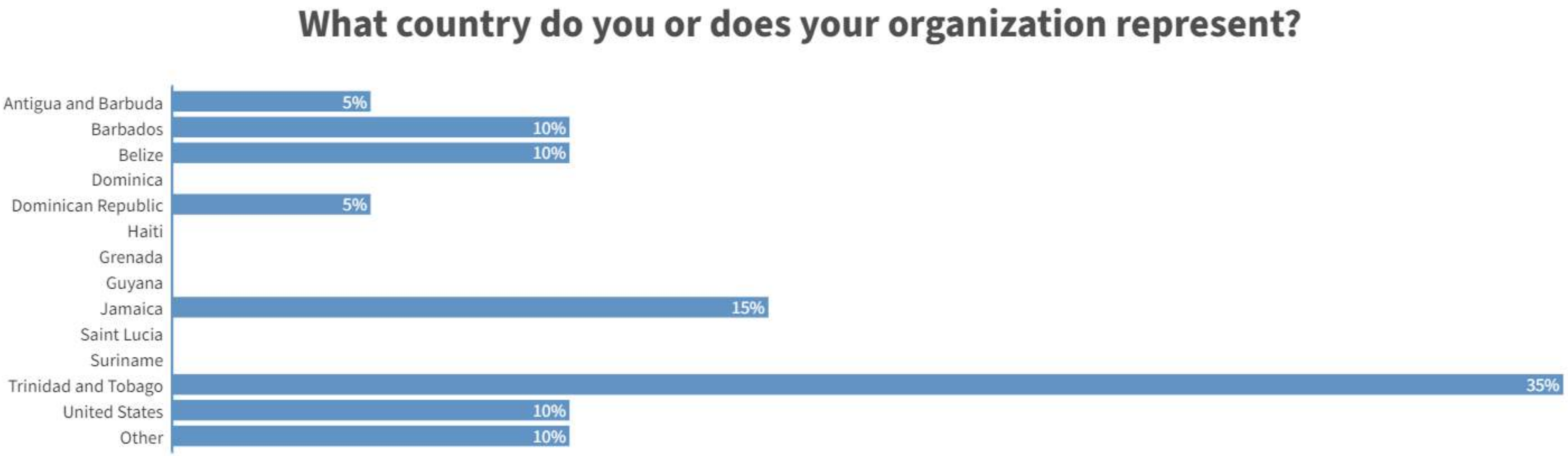
Feedback Poll

https://www.PollEv.com/lcrow118

Polls



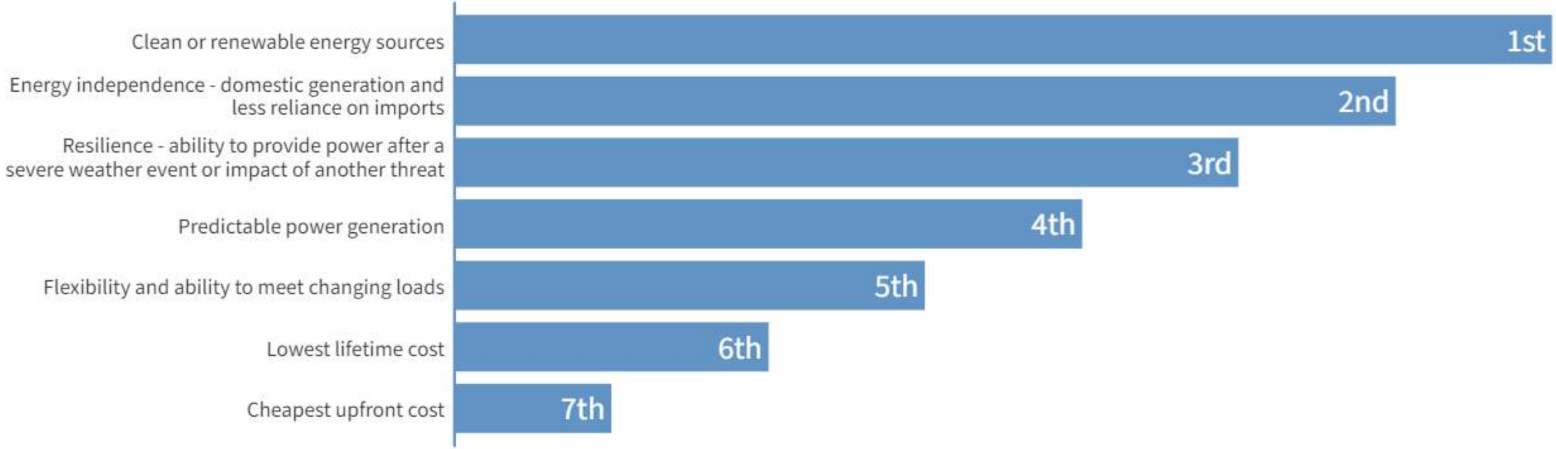
What country do you or does your organization represent?
Antigua and Barbuda
5%
Barbados
10%
Belize
10%
Dominica
Dominican Republic
5%
Haiti
Grenada
Guyana
Jamaica
15%
Saint Lucia
Suriname
Trinidad and Tobago
35%
United States
10%
Other
10%

Polls

What type of agency or organization do you represent?
Utility
24%
Regulator
Energy agency/ministry
6%
Environmental Group
12%
USAID
6%
Other
53%

Polls

Rank the following in order of importance for power sector generation (in your opinion)



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Resilient Energy Platform

Climate and Vulnerability Assessments for Integrated Resource and Resilience Planning

Shawn A. Boyce
Caribbean Institute for Meteorology and Hydrology

March 08, 2021

About CIMH

- WMO Regional Training Centre
- Centre for Research in Meteorology, Hydrology and Climatology
- Regional Data Centre
- Regional Instruments Centre
- Regional Centre of Excellence in Satellite Meteorology
- WMO Regional Climate Centre
- Caribbean Centre for Climate and Environmental Simulations
- WMO Pan American Centre for Sand & Dust Storm Warning Advisory & Assessment System (SDS-WAS)
- Advisor to regional governments and service provider to industry

Functions of the Caribbean Institute for Meteorology and Hydrology

Presentation Outline

- Definitions and Concepts
- Climate Risk
- Risk Assessment
- Risk Assessment Applications

Definitions and Concepts

What is meant by hazard?

- *A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.*
- *Hazards may be natural, anthropogenic or socionatural in origin and are characterized by their location, intensity or magnitude, frequency and probability*

Source: UNDRR

Definitions and Concepts…cont'd

What is meant by exposure?

- *The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas.*

- *Measures of exposure can include the number of people or types of assets in an area*

Source: UNDRR

Definitions and Concepts…cont'd

What is meant by vulnerability?

- *The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards*

Source: UNDRR

Definitions and Concepts...cont'd

What is meant by capacity?

- *The combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience.*
- *Coping capacity is the ability of people, organizations and systems, using available skills and resources, to manage adverse conditions, risk or disasters.*

Source: UNDRR

Definitions and Concepts…cont'd

What is meant by risk?

- *The effect of uncertainty on objectives*
- *Effects can be positive, negative or both and can address, create or result in opportunities and threats*
- *Risk is usually expressed in terms of risk sources, potential events, their consequences and their likelihood*

Source: ISO 31000

Definitions and Concepts…cont’d

What is meant by risk?

$$Risk = f(Hazard, Vulnerability)$$

$$Risk \propto \frac{Hazard \times Exposure}{Coping\ Capacity}$$

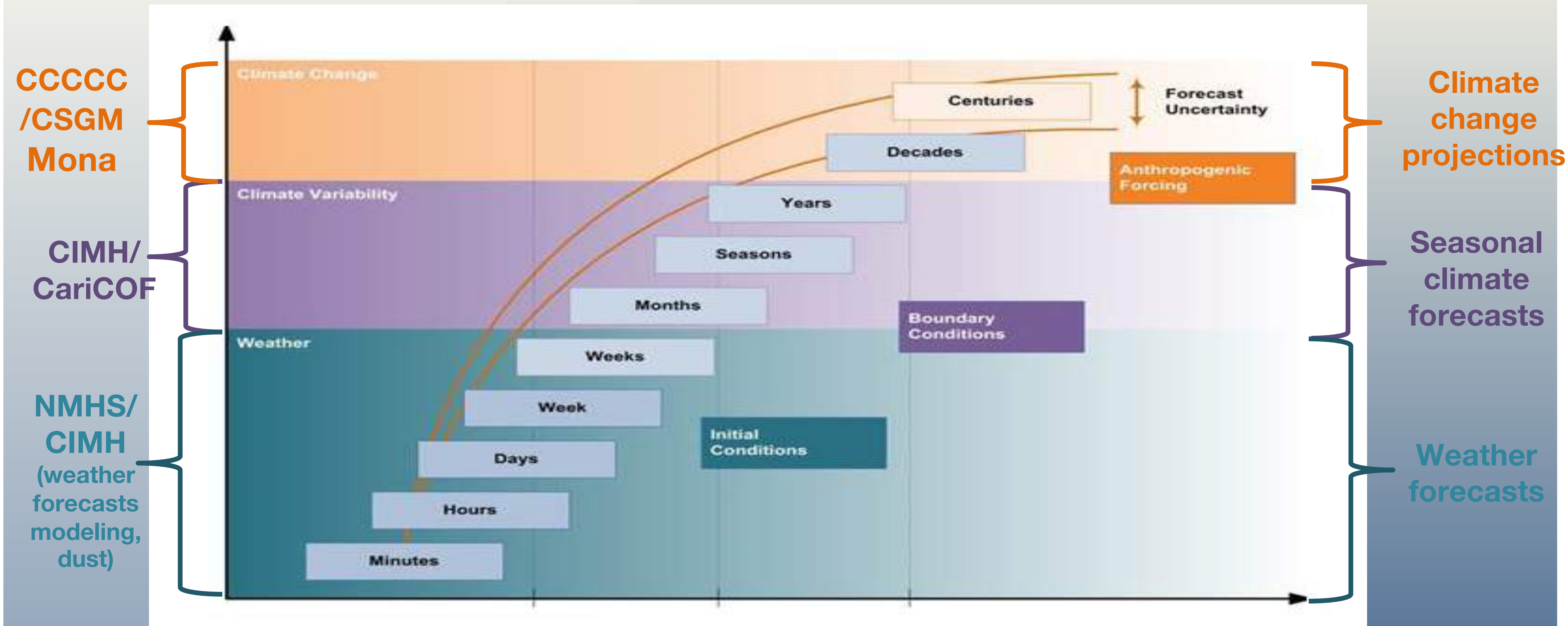
Definitions and Concepts...cont'd

What is meant by climate?

- *Climate describes the average weather conditions for a particular location and over a long period of time.*
- *Weather describes the short-term conditions of the atmosphere*

Source: WMO

Definitions and Concepts…cont'd



Weather and climate information support decision-making across varying timescales

Definitions and Concepts…cont'd

What is meant by climate vulnerability?

- *The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of climate variability and/or climate change*

Climate Risk

Climate risk and the energy sector:

- Risk related to generation
- Risk related to transmission and distribution
- Risk related to demand

Climate Risk…cont'd

Risk related to generation – Hydropower potential

- *The number of consecutive dry days is increasing, as well as the amount of rainfall during rainfall events.*
- *The Caribbean as a whole will gradually dry through to the end of the century.*
- *Drying is expected to be less in the far north Caribbean and more in the south and southeast.*

Source: The State of the Caribbean Climate Report

Drier conditions will impact hydropower potential and the availability of water for cooling

Climate Risk…cont'd

Risk related to generation – Solar potential

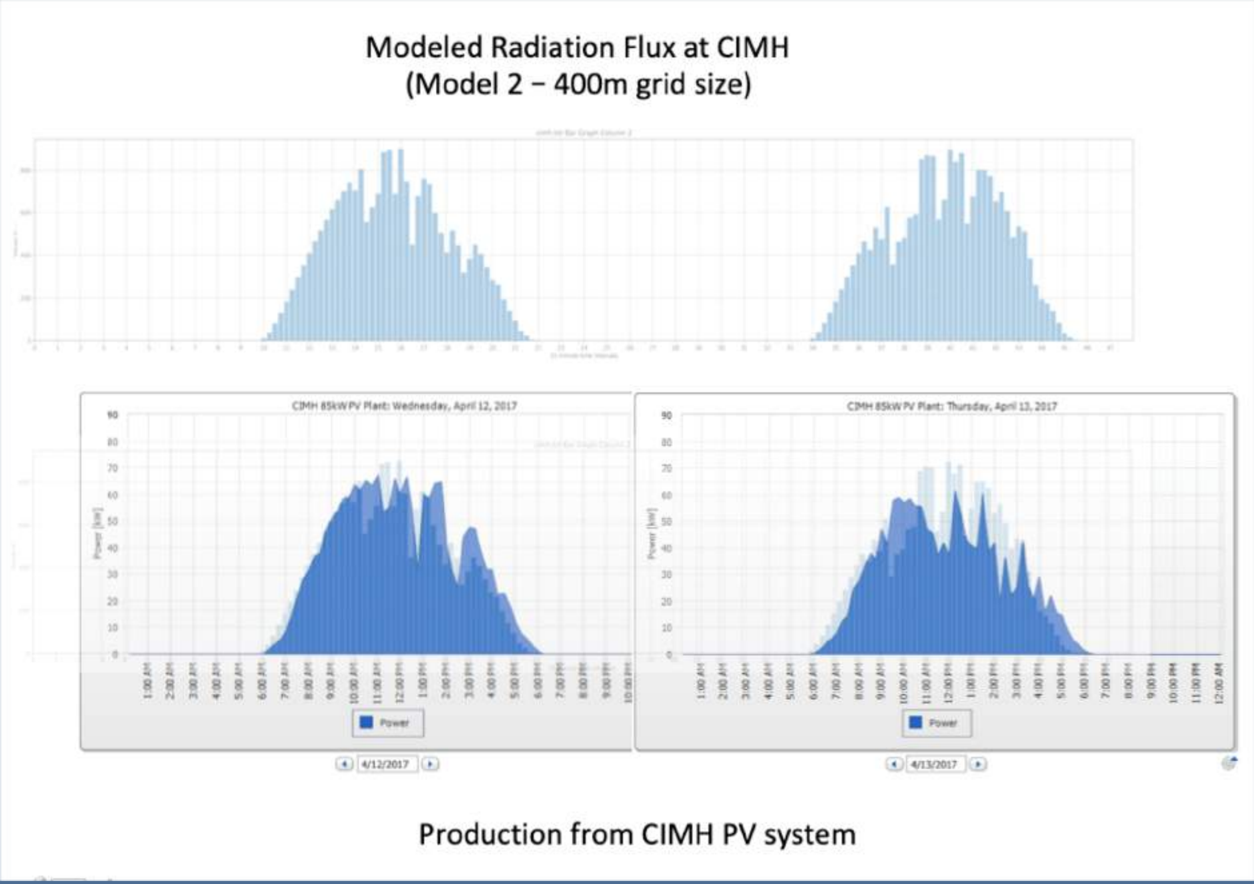
- *Increase in temperature in Caribbean is consistent with global warming trend.*
- *The Caribbean as a whole will gradually warm through to the end of the century.*
- *Minimum, maximum and mean temperatures increase irrespective of scenario through the end of the century.*

Source: The State of the Caribbean Climate Report

Increased air temperatures lower solar PV efficiency and energy output. Dry conditions increase dust events

Climate Risk…cont'd

Suite of nowcasting and forecasting products being developed for the energy sector that will involve opportunities for innovation.



Renewable Energy Production and Modelling @ CIMH

Climate Risk…cont'd

Risk related to generation – Wind potential

- *Increase in temperature in Caribbean is consistent with global warming trend.*
- *The Caribbean as a whole will gradually warm through to the end of the century.*
- *Minimum, maximum and mean temperatures increase irrespective of scenario through the end of the century.*

Source: The State of the Caribbean Climate Report

Changes in wind climatology can alter wind potential. Increase air temperatures lowers wind potential

Climate Risk…cont'd

Subdivided region into zones based on wind resource potential.
Generally, excellent wind resource across the region with good prospect for utility-scale wind power.

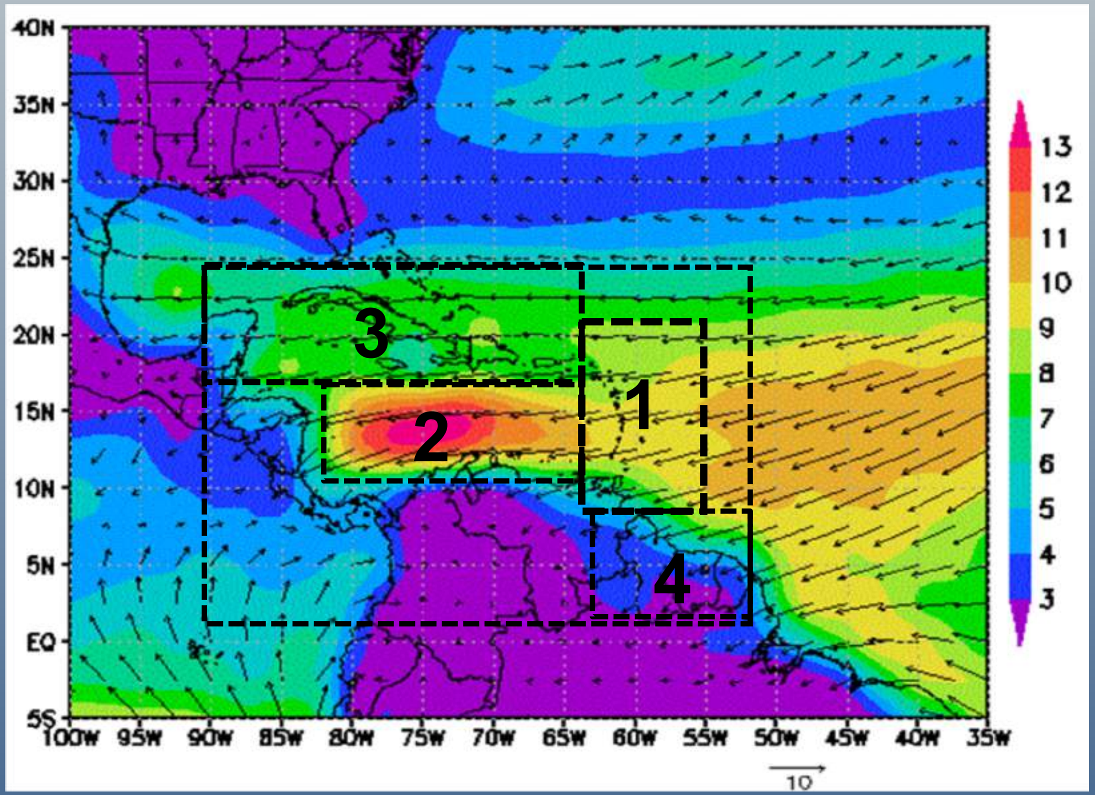
Zone 4: Minimum in the wind resource; varies from poor to fair; mean wind speeds are 3 to 4 ms^{-1} but increase to 5 to 7 ms^{-1} along the coast.

Zone 2: The maximum in the wind resource (CLLJ) ~over 13 ms^{-1} (class 7, superb).

Zone 1: The Eastern Caribbean, has a good to superb wind power resource with mean wind speeds ranging from 7 to 11 ms^{-1}.

Zone 3: The Greater Antilles, good to excellent resource (5 to 9 ms^{-1}).

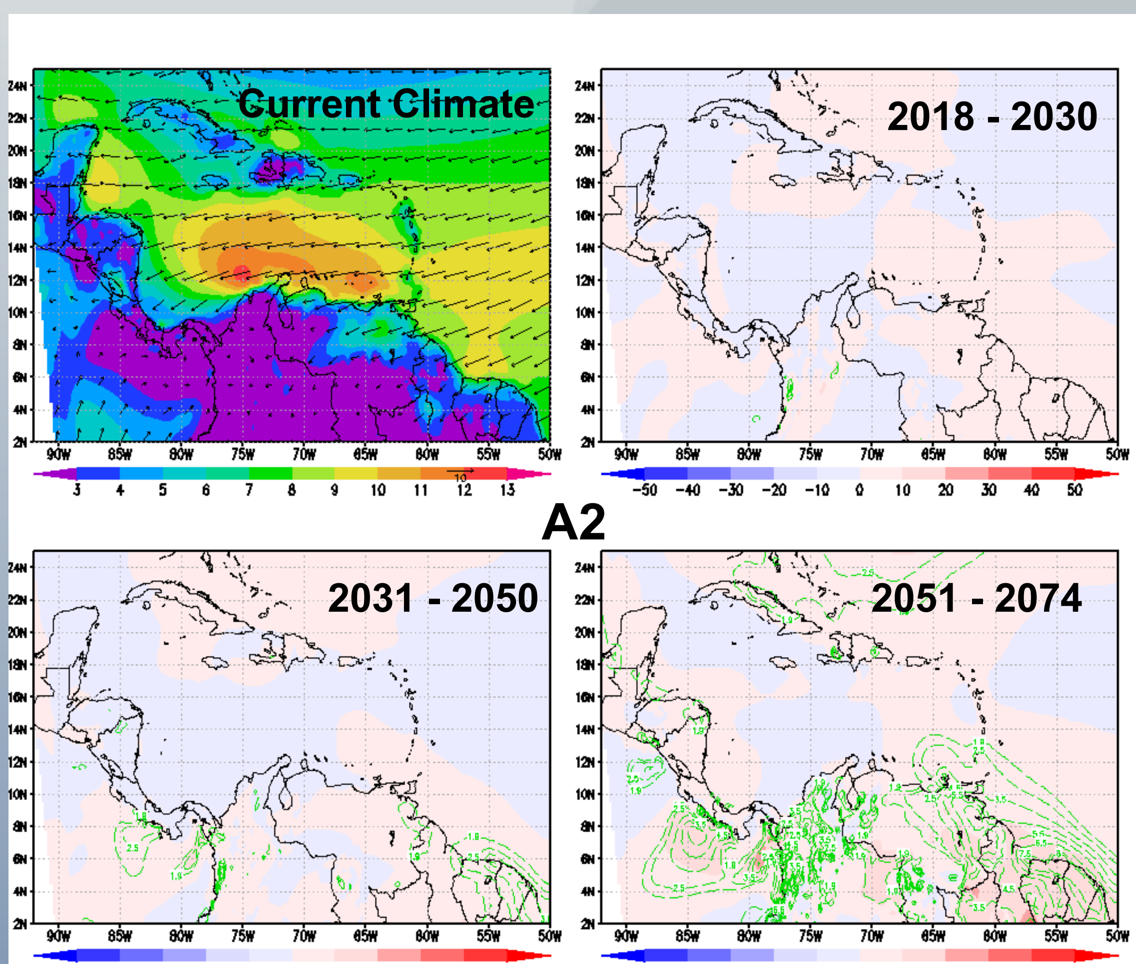
Zone 1 (E Caribbean)
Zone 2 (SW Caribbean…CLLJ)
Zone 3 (NW Caribbean)
Zone 4 (Guianas)

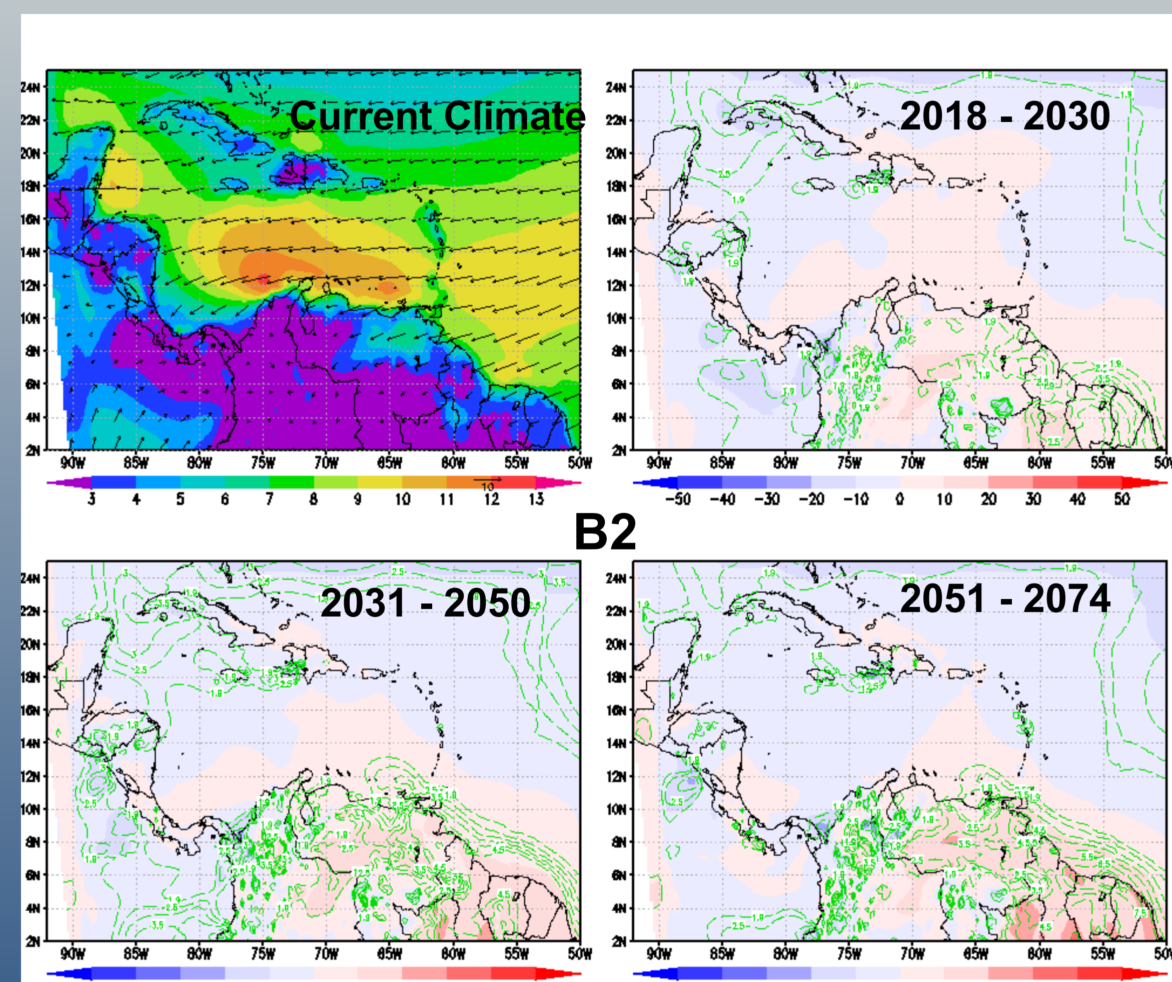


Potential Impact of Future Climate Change on Wind Resource – Study Region and Wind Climatology (1949 – 2015) at 50m

Climate Risk…cont'd

Agreement in trends for both scenarios over the central and southern EC, southward through to the Guianas (increasing winds); the CLLJ and the western Caribbean (decreasing winds).





Potential Impact of Future Climate Change on Wind Resource - Results

Climate Risk…cont'd

Risk related to generation – Infrastructure

- *Significant increase in frequency and duration of Atlantic hurricanes since 1995.*
- *Shift toward stronger storms by the end of the century as measured by maximum wind speed increases*
- *+20% to +30% increase in rainfall rates for the model hurricane's inner core.*

Source: The State of the Caribbean Climate Report

More intense storms and extreme precipitation are expected to damage generation infrastructure

Climate Risk...cont'd

Risk related to transmission and distribution

- *Increased temperatures reduced efficiency*
- *More intense storms, severe convection and coastal inundation are expected to damage transmission and distribution infrastructure*
- *Increased wild fire activity can directly damage transmission and distribution infrastructure.*

Source: The State of the Caribbean Climate Report

Climate Risk…cont'd

Power Plant and Distribution Systems

Station locations exposed to hydro-meteorological hazards. Intake structures impacted by debris flows

Flood impact VinLec hydro-electric power station resulting from Christmas Eve Flood (December, 2015) - Cumberland River nr Spring Village.

Climate Risk…cont'd

Power Plant and Distribution Systems

Largely centralized systems with overhead and underground lines for distribution exposed to wind, landslide and flood impacts

Damage to distribution system in Dominica due to Hurricane Maria (September, 2017)

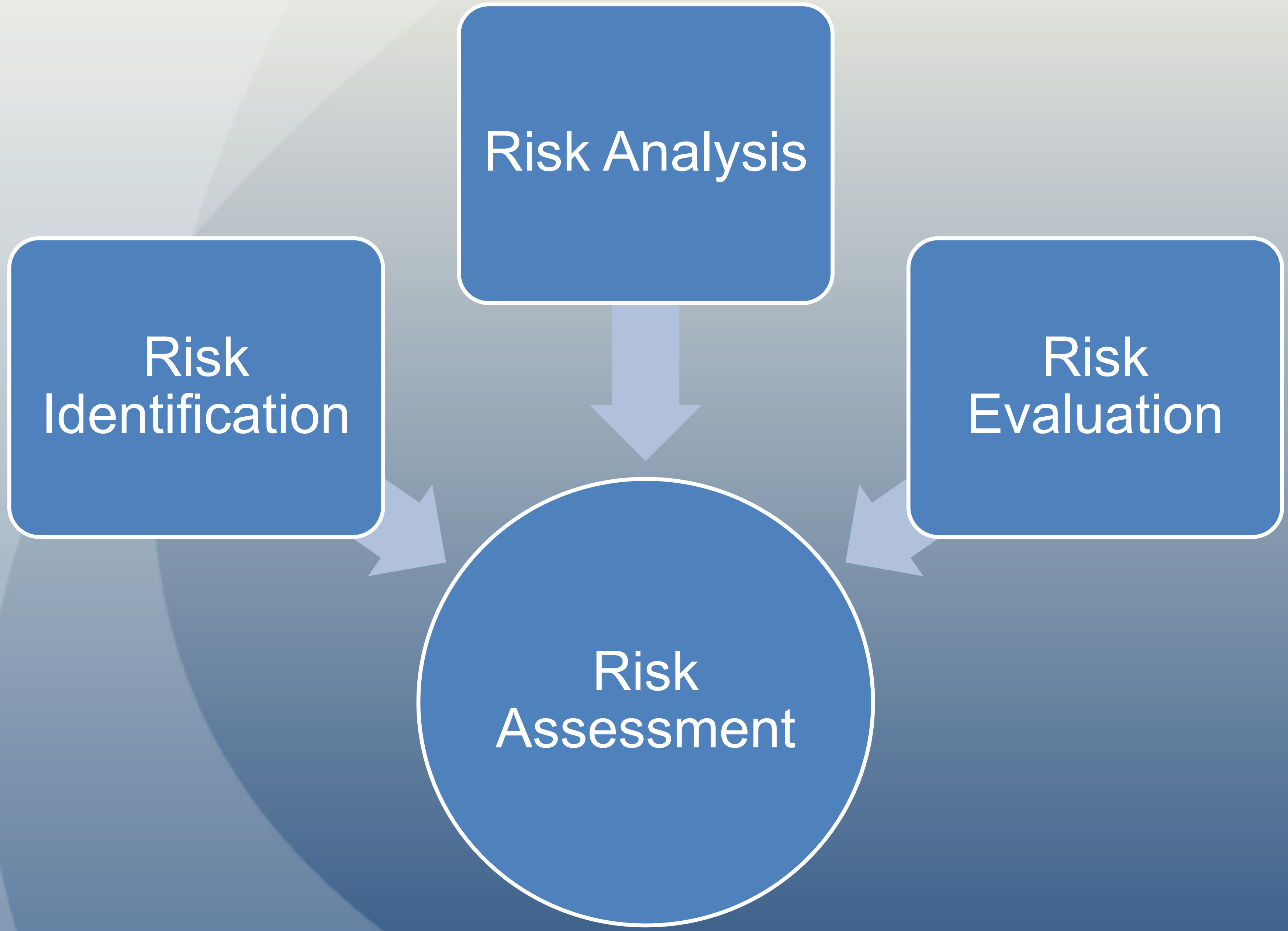
Climate Risk…cont'd

Risk related to demand

- *Increased temperatures increase energy demand for cooling and may stress capacity*
- *Decreased precipitation and increasing dry days will increase irrigation and potable water demand*

Source: The State of the Caribbean Climate Report

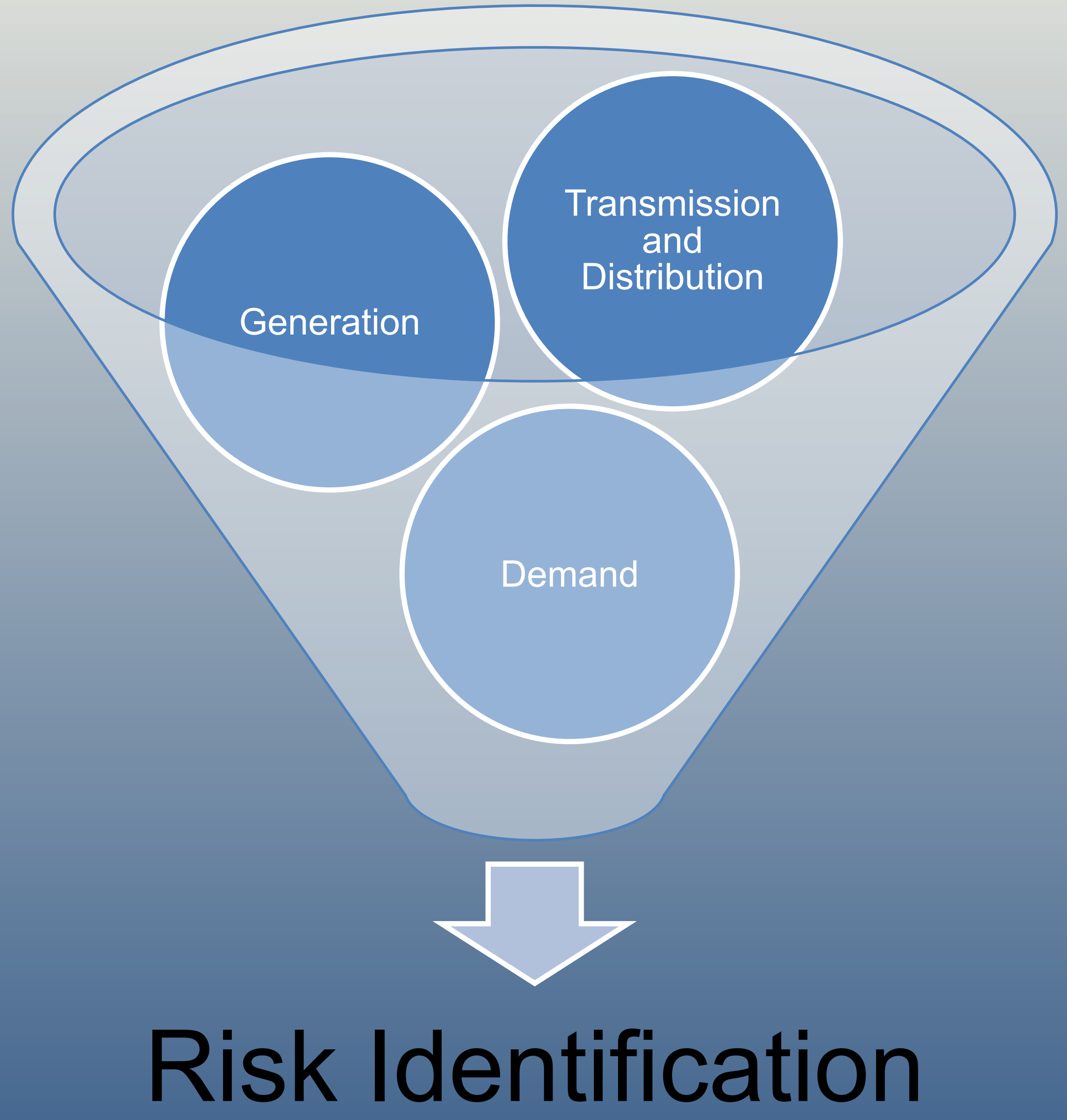
Risk Assessment



Risk Assessment...cont'd

Risk Identification

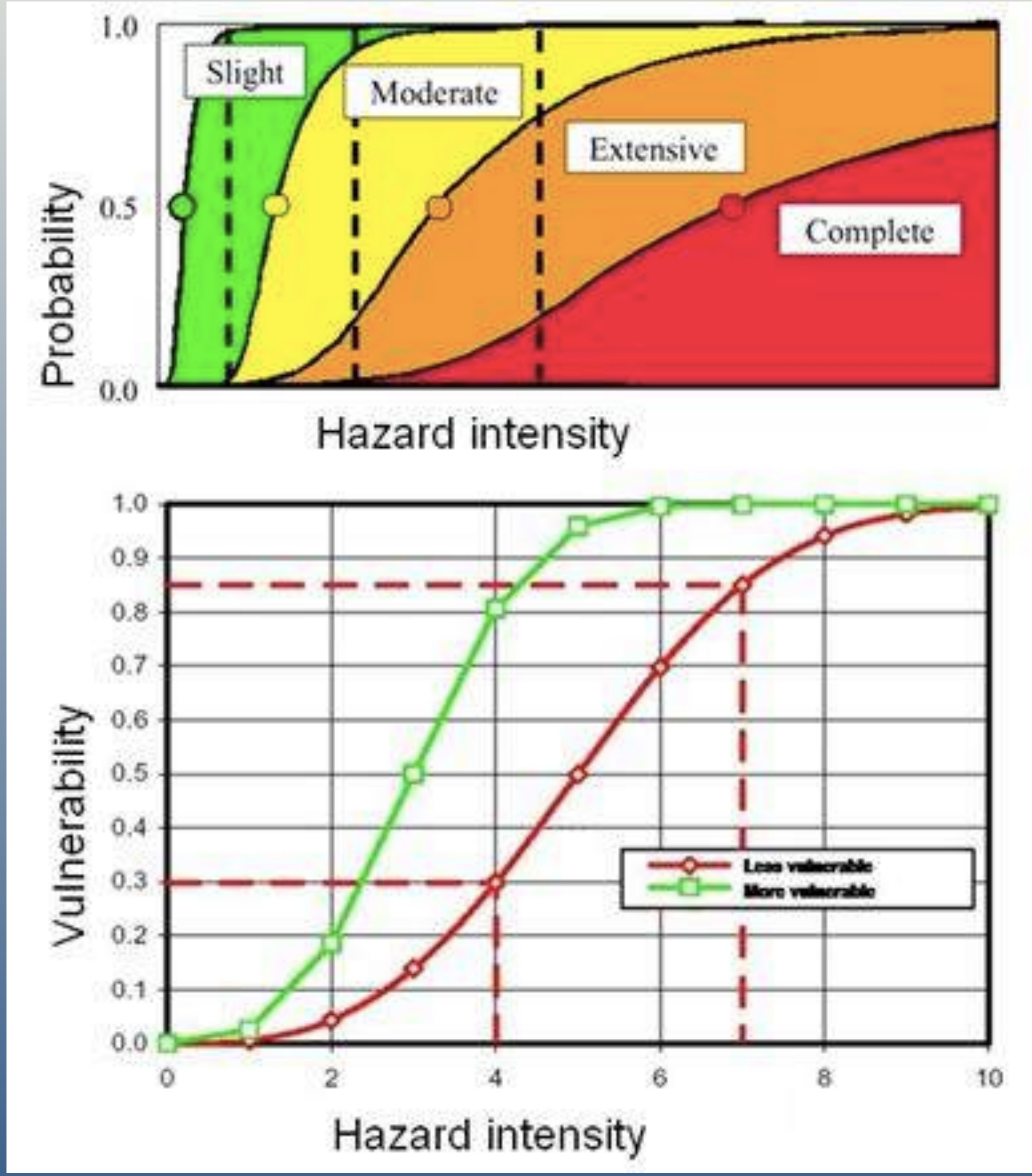
- *Risk identification aims to describe risks that may help or prevent objectives from being achieved.*



Risk Assessment...cont'd

Risk Analysis

- *Risk analysis aims to understand the nature and level of risk. It considers uncertainties, sources, consequences, likelihood and capacity.*
- *Analysis techniques can be qualitative, quantitative or a combination of both.*



Source: CDEMA

Risk Assessment...cont'd

Risk Evaluation

- *Risk evaluation aims to support the decision making process*
- *Results of the risk analysis compared with risk criteria*
- *Determine action to be taken in consideration of the actual and perceived consequences*

Risk and Response Matrix: Severe Convection

Risk Matrix					
Likelihood	High				
	Medium				
	Low				
	Very Low				
		Minimal	Minor	Significant	Severe
		Potential Impacts			

Risk Level	Response
High	Take Action
Medium	Be Prepared
Low	Be Aware
Very Low	No Action

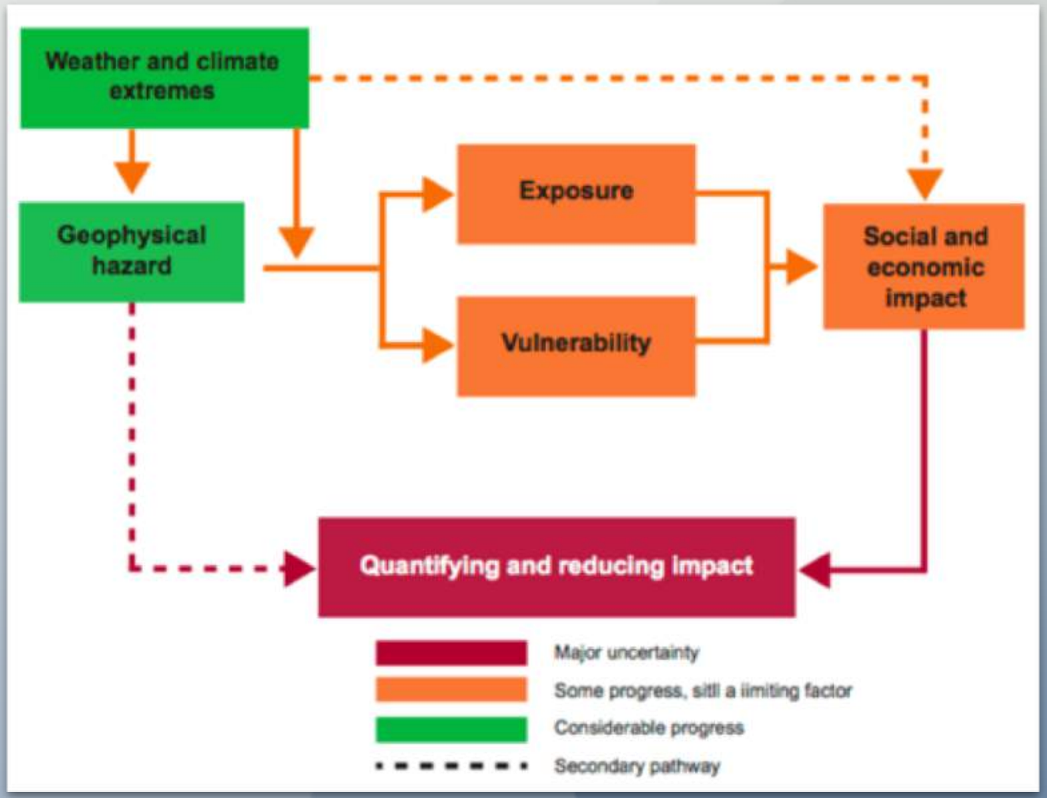
Response Matrix:
Severe Convection

Very Low - Business as usual	Low - Be Aware	Medium - Be Prepared	High - Take Action
Monitor for changing weather conditions.	Seek shelter if lightning is near. Beware of possible impacts to aviation and marine activities, isolated power and communications disruptions and possible traffic delays.	Seek shelter if lightning is near. Be prepared for possible delays at airport and to seek shelter for small watercraft for severe convection and/or lightning. Prepare for traffic delays, cancelation of school activities and closures and regional power outages are all possible.	Seek shelter if lightning is near. Check with airlines for flight delay cancellation. Seek shelter for small watercraft and avoid or delay driving until after the severe weather; expect long delays and traffic congestion. Secure students in sheltered locations until event passed and students can return to class or leave for school

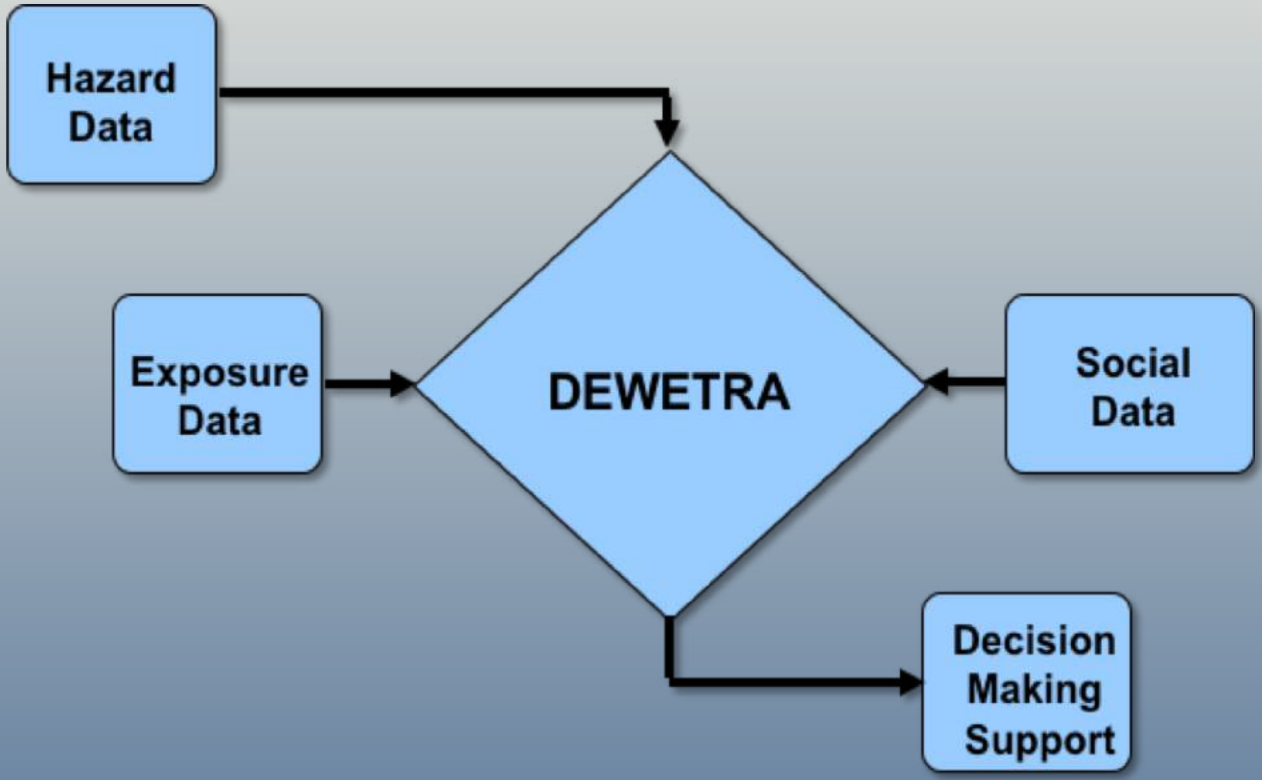
WRNs Barbados

Source: WCRN

Risk Assessment Applications

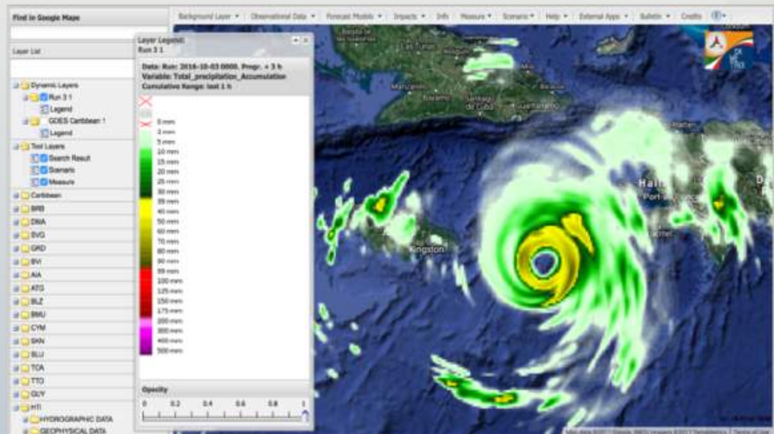


Impact-based Forecasting System
(source: WMO 1150)

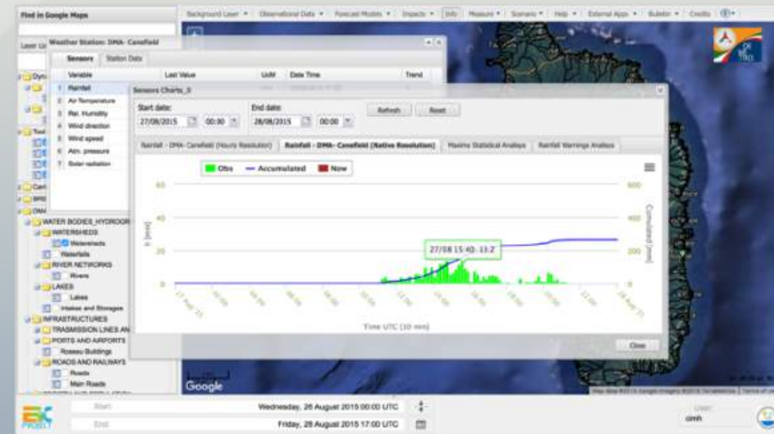


Caribbean Dewetra Platform
Qualitative Risk Assessment

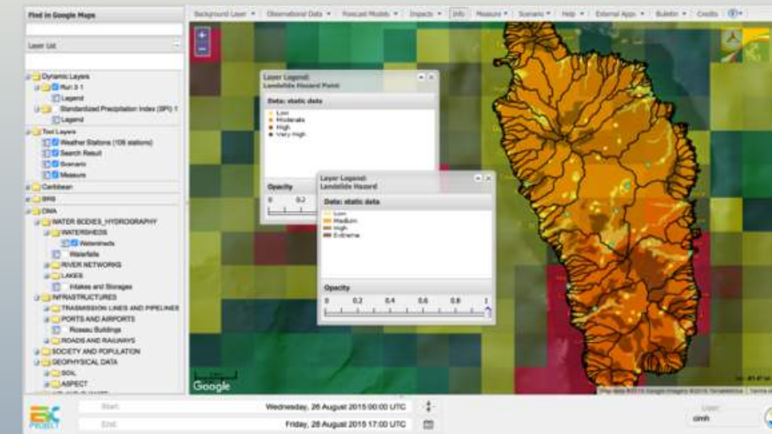
Risk Assessment Applications...cont'd



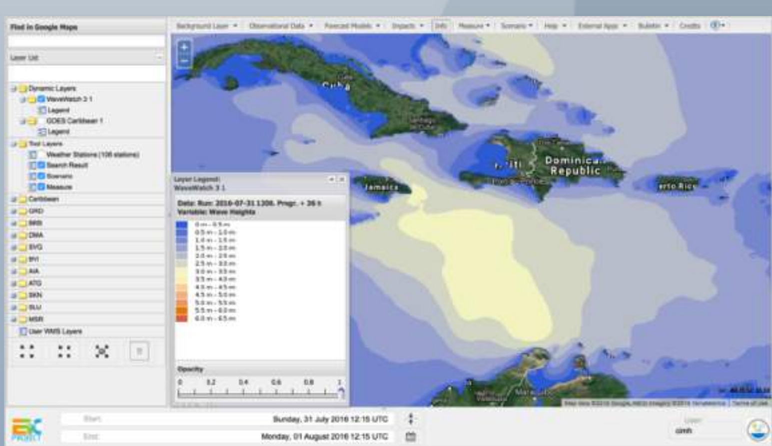
Numerical Weather Prediction



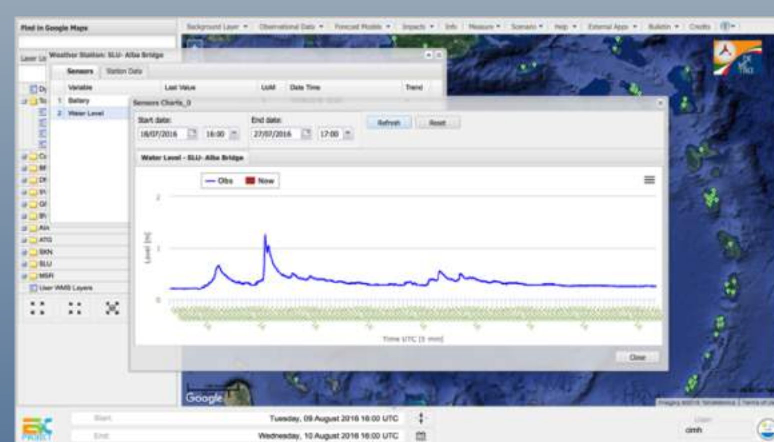
Automatic Weather Station



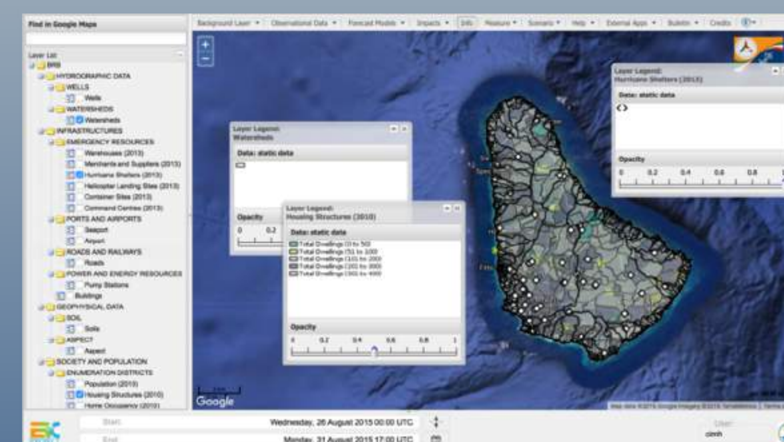
Hazard/Risk Exposure



Wave Height Prediction



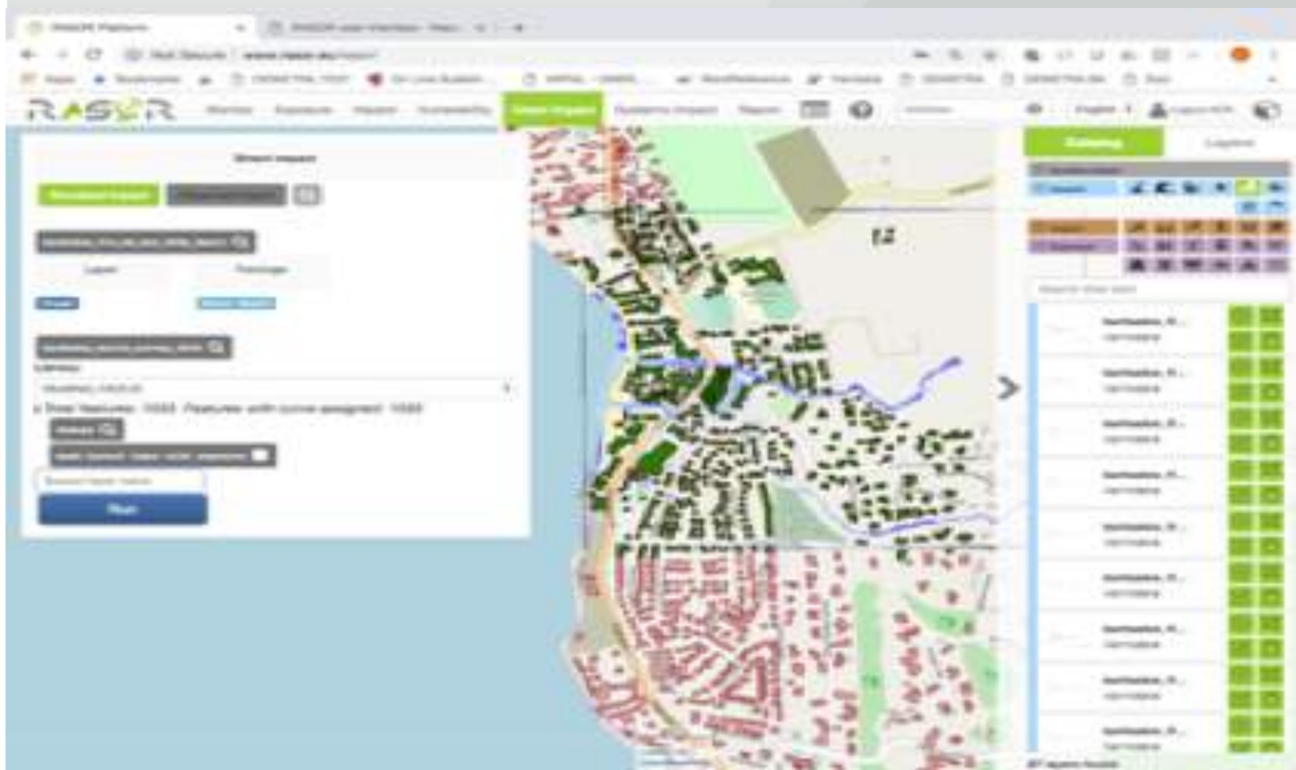
Automatic Water Level Station



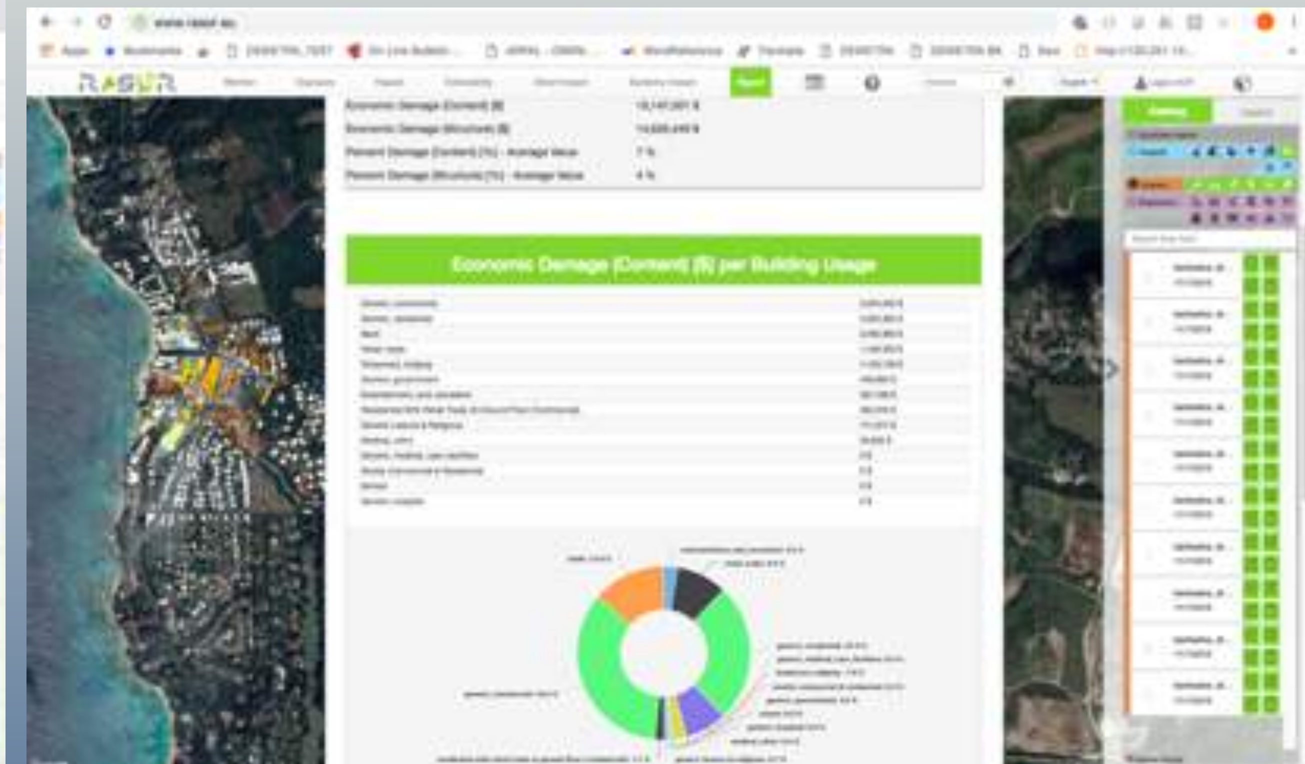
Population Vulnerability

$$Risk \propto \frac{Hazard \times Exposure}{Coping\ Capacity}$$

Risk Assessment Applications…cont'd



Flood impact analysis at building scale



Flood impact computation at building scale

RASOR Platform

Quantitative Risk Assessment

Thank You

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Case Study: Climate Resilience Assessment of Mini-Grids in Ghana

Integrated Resource and Resilience Planning (IRRP) Project

03/09/2021

Mason Fried
Managing Consultant, Climate Scientist

Climate Resilience Assessment of Mini-Grids in Ghana

A collaborative team of experts:

Dr. Molly Hellmuth (Africa Climate and Energy Sector Resilience Lead, USAID/IRRP)

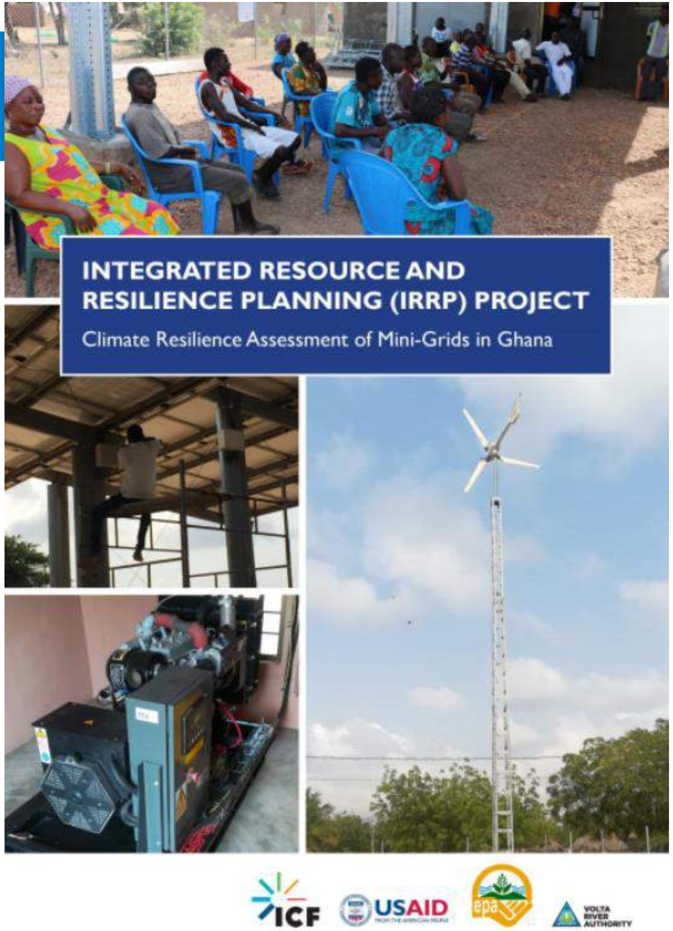
Dr. Abdul-Razak Saeed (Climate Resilience Specialist, USAID/IRRP)

Mark Summerton (Senior Climate Resilience Expert, USAID/IRRP)

Sanjay Chandra (Director – Energy Markets, USAID/IRRP)

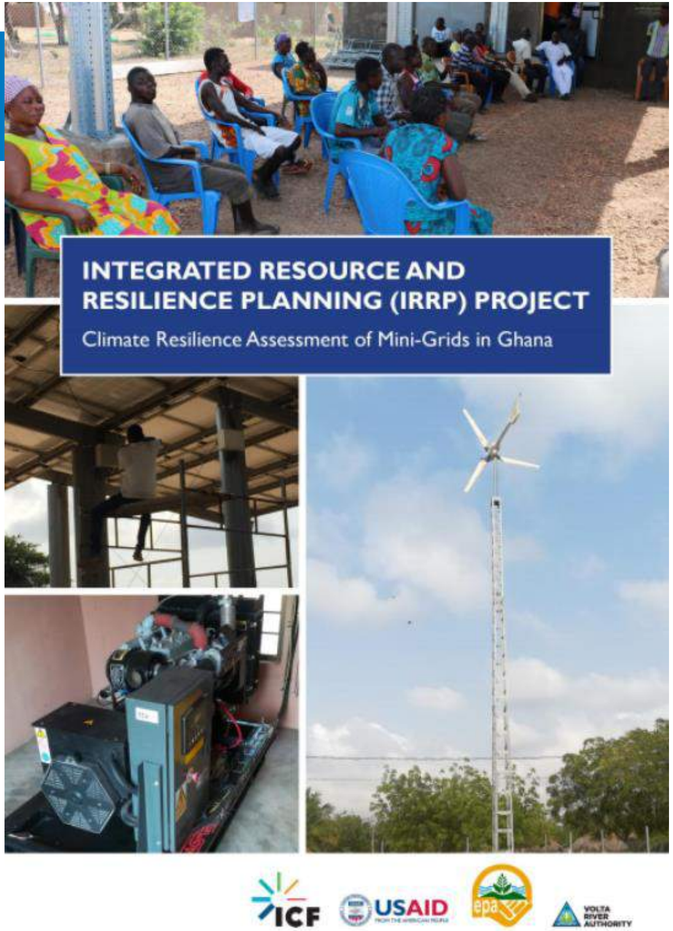
Dr. Mason Fried (Climate Scientist, USAID/IRRP)

Maame Tabuah Ankoh (Renewable Energy Specialist, USAID/IRRP)



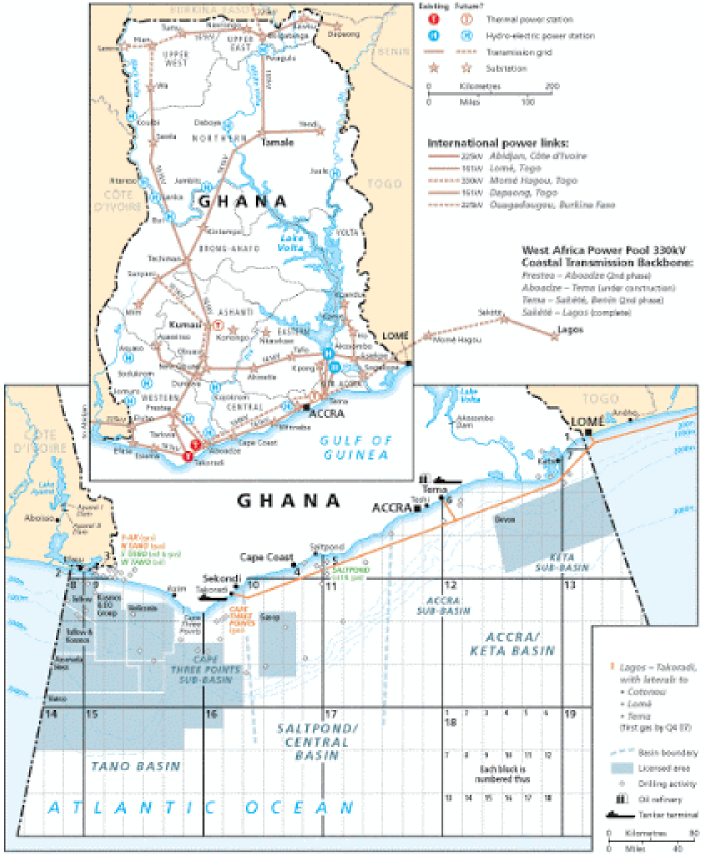
Climate Resilience Assessment of Mini-Grids in Ghana

- USAID/IRRP climate resilience assessment to:
  - Identify current and potential future climate change and associated risks for a mini-grid pilot program in Ghana.
  - Assess the extent to which climate change was considered in the planning, design, and construction of mini-grids.
  - Identify measures for building the resilience of existing mini-grids against climate risks.



Ghana Mini-Grids: Local Context

- Ghana has one of the highest electrification rates in sub-Saharan Africa
  - Sustainable Energy for All Goal
  - Roughly two million people living in rural or remote areas
  - National grid unlikely to reach these areas within the next ten years
  - Mini-grids present a solution



Ghana Mini-Grids: Electrification Program

- The Government of Ghana plans to install 300 new renewable energy mini-grid systems by 2030 to serve small communities
- The Ghana Energy Development and Access Project with funding from the World Bank established a Mini-grid pilot program to electrify five communities on Lake Volta islands and in the Volta River delta
    - Solar and wind generation
    - Installed capacity between 30 kW and 55 kW
    - Battery stora

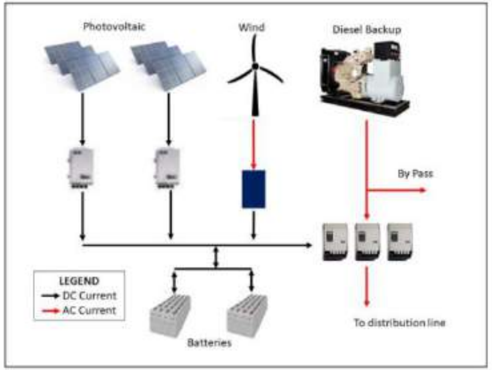
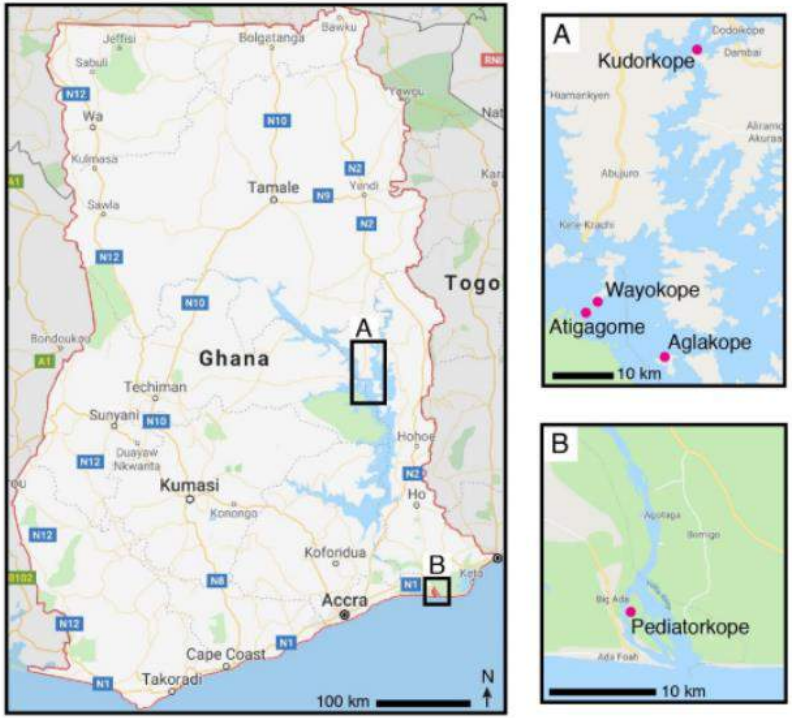


***Figure 1:** Location of the communities served by five existing mini-grids in Ghana*



Mini-Grid Benefits

- Mini-grid electrification program offers numerous benefits to remote and rural communities, including
  - Low emission solution for energy resilience
  - Improved security, health and income
  - Reduced expenditure on energy
  - High power reliability

Climate change and hazards already pose risks to mini-grid performance and lifespan in Ghana

- Temperatures – unanimous observation by community members of steadily increasing temperatures at all sites
- Severe weather – high winds during the “Easter period” and wet season, disrupting distribution lines and warping powerhouse roofing sheets
- Lake flooding – high water levels from August to November
- Sea level – corrosion of solar panel structures reported as a result of salt water
- Backup diesel generator

The resilience benefits of mini-grids are only as strong as the resilience of the mini-grids themselves




Components of the Resilience Assessment

- Identification of relevant climate hazards
- Acquisition and/or generation of data; data analytics
- Assessment of present and future climate and weather-driven risks to mini-grid systems
- Development of climate resilient strategies


Community engagement


Identification of Climate Hazards and Risks

Once planners and designers understand potential climate risks, they can prioritize responses

- Increasing temperatures – battery bank, distribution lines, solar PV output, solar PV panels, wind turbine output
- Extreme storms and high winds – distribution lines, distribution infrastructure

- Harmattan winds and dust – solar PV output

- Lightning – dispensers
- Flooding – distribution infrastructure

Many of these hazards are already disrupting Ghana’s mini-grid infrastructure. Climate change will amplify and increase the frequency of these disruptions.

Identification of Climate Hazards and Impacts: Additional Challenges

Weather and climate hazards are amplified by -

- Logistical challenges
  - Remote and isolated locations
  - Limited technical support, spare parts, maintenance capacity to address mini-grid issues/disruptions
- Changes in demand
  - Rising demand driven by increasing temperatures, changing



Climate Hazard Data and Analytics to Support Resilience

- Acquisition or generation of relevant, hazard-specific data
  - Climate data – e.g., Global Climate Model projections of solar radiation, temperature projections, sea level rise and wind; storm surge modeling, topography mapping
    - Time horizons – 2030 and 2050
    - Changes Relative to a historical baseline
  - Mini-grid system data – e.g., capacity ratings, load projections, damage functions
  - Community science
- Data analytics to understand range of potential impacts
  - Informs climate adaptation and resilience measures
  - Risk management

Figure 15: *GCM ensemble mean surface downwelling shortwave radiation under RCP 8.5 for northern Lake Volta and Volta River delta regions. Projections show decreasing solar radiation through time.*

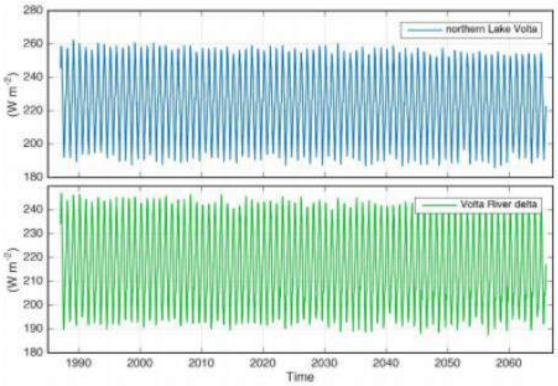
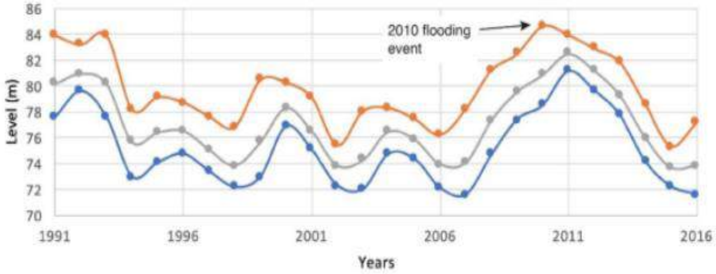


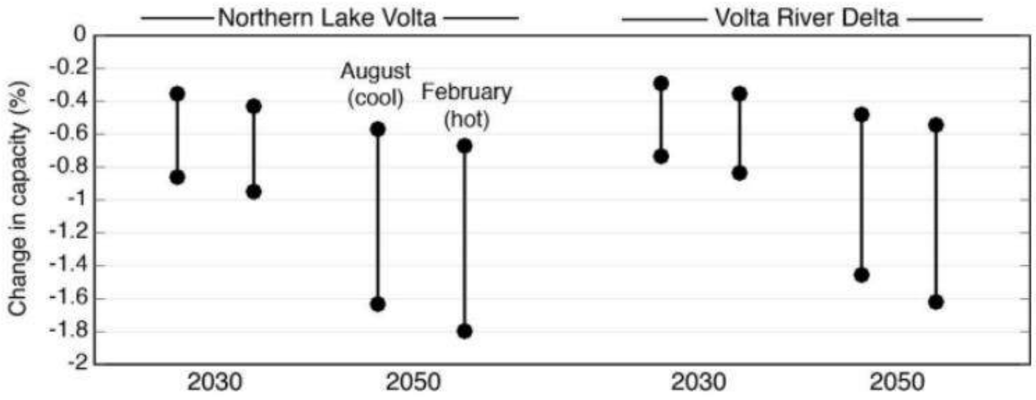
Figure 6: *Historical (1991–2016) maximum (orange), minimum (blue), and mean (grey) annual water elevations of Lake Volta* (Source: VRA)



Climate Hazard Data and Analytics to Support Resilience: Increasing Temperature

- Increasing average and extreme temperatures
- Data/analytics used to project risk:
  - Global Climate Model temperature projections
  - Load projections
  - System capacity ratings

Figure 10: *Change in distribution line capacity based on the change in maximum temperature for mini-grids in the northern Lake Volta and Volta River delta regions for 2016–2045 and 2036–2065, relative to the historical period 1987–2016. Changes are evaluated for both August (coolest month of the year) and February (warmest month of the year). The upper bounds represent RCP 4.5 projections and a 0.5 percent decrease in capacity per 1°C rise, and the lower bounds represent RCP 8.5 projections and a 1.0 percent decrease in capacity per 1°C rise.*

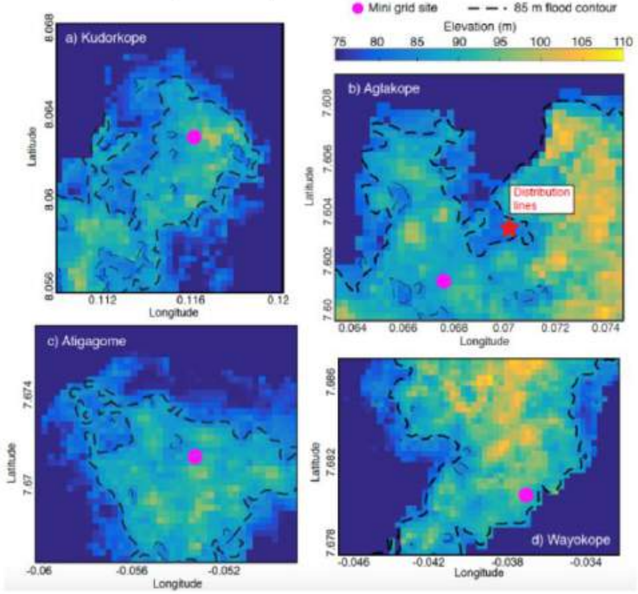


Projected temperature increases also reduce solar PV and wind turbine output, and can reduce battery capacity by up to 7%

Climate Hazard Data and Analytics to Support Resilience: Flooding

- High inflows from August through November raise lake levels
- Saltwater and freshwater delta – corrosion and sea level rise/storm surge-driven flooding
- Data/analytics used to project flood risk:
  - Digital Elevation Models (DEMs)
  - Historical flood contours
  - Sea level rise & storm surge projections

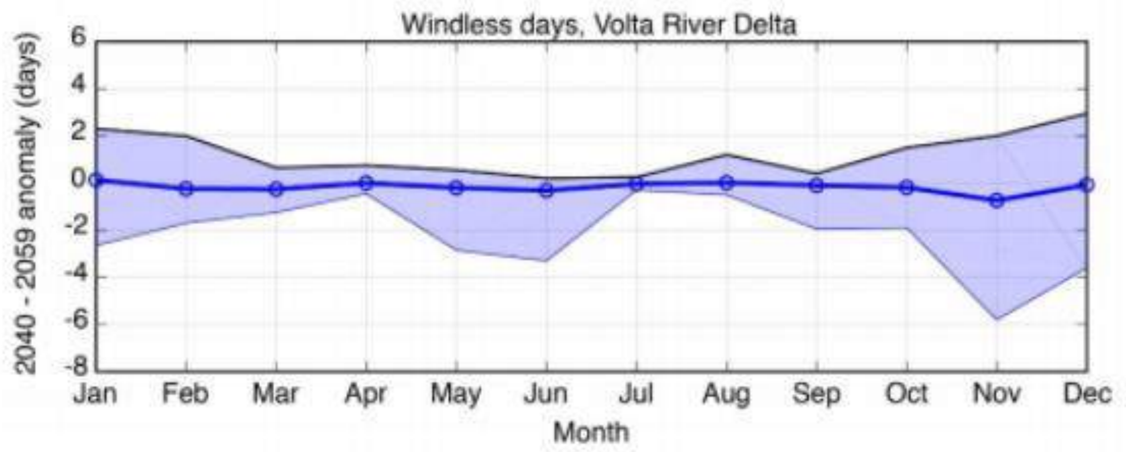
Figure 13 *ASTER GDEM Version 2 showing topography around four Lake Volta mini-grid stations (a–d) and communities. Pink circles represent mini-grid locations. Black dashed line represents 85-m flood contour. Atigagome and Wayokope are situated ~2.5 km apart on a peninsula in Lake Volta.*



Climate Hazard Data and Analytics to Support Resilience: Wind Stress

- Strong winds experienced during the “Easter Period”
- Data/analytics used to project wind risk:
  - Global Climate Model wind simulations
  - Wind generation capacity

Figure 12: *Monthly anomaly for windless days by mid-century (2040–2059), relative to the historical baseline (1986–2005) for mini-grids in the Volta River delta regions. Dark purple line shows GCM ensemble means and purple shaded region shows the range in GCM projection. Data from the World Bank Climate Change Knowledge Portal.*[37]



Summary of Identified Climate Risks

Current and Future Climate Risks and Effects on Mini-Grids	
Flooding	▪ Inundated distribution lines and other power assets located below the maximum lake water level on Lake Volta ▪ Increased risk of flooding downstream of Akosombo Dam due to the increased frequency and intensity of rainfall events
Sea-Level Rise and Storm Surge	▪ Increased risk of flooding from storm surge and sea-level rise at Pediatorkope
Temperature Stress	▪ Increased demand for cooling (fan use at night) ▪ Reduced solar generation, wind turbine output, and panel lifetimes ▪ Reduced battery efficiency and lifetimes due to higher temperatures ▪ Increased distribution line losses
Wind Stress (sustained high winds)	▪ Felled distribution lines due to high wind gusts and toppled trees ▪ Increased potential of wind-related damages to distribution, solar panels, and other infrastructure ▪ Increased operations and maintenance (O&M) costs
Solar Radiation and Cloudiness	▪ Disrupted power and reduced voltage ▪ Reduced solar generation
Extreme Weather (heavy rainfall, lightning strikes, dust)	▪ Damaged mini-grid component parts (e.g., dispensers, solar panels) and household appliances ▪ Reduced solar panel lifetimes

Adaptation Options

Resiliency measures should consider a **360 view** to mitigate risks from climate change –

- Structural measures. e.g., hardening measures for flooding and downed trees, fans or heat pumps to maintain airflow around battery banks and other critical infrastructure, lighting grounders.
- Reliability measures. e.g., extra battery banks if feasible, backup diesel, downstream efficiencies.
- Operations and community coordination. e.g., invest in necessary tools and capacity to ensure mini-grid systems are well maintained and operate as intended.
- Prioritize resilience planning. e.g., planning should proactively incorporate assessments of climate change risks.

Adaptation Options: F

- Using climate and mini-grid system data, ICF generated a suite of resilience measures that sought to
  - Improve the reliability of mini-grids in both current and future climate
  - Address a range of potential climate futures

Table 3: Recommendations for existing and planned future mini-grids

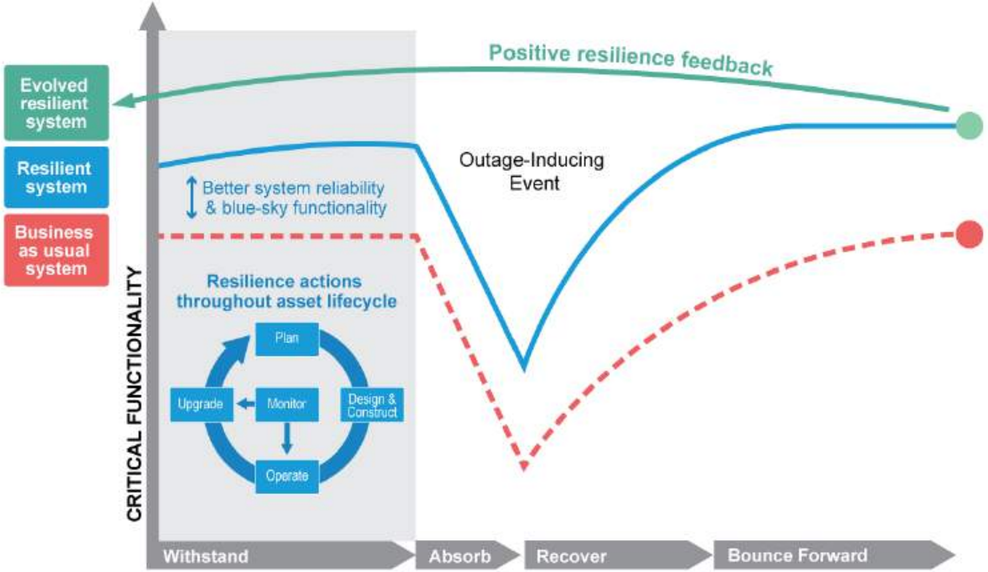
Mini-Grid Component	Impact	Measures
Battery bank	Reduced efficiency and up to 7% battery lifespan reduction by 2050	▪ Implement low-cost cooling technologies to increase the efficiency and lifetime of battery cells
Distribution lines	Damage and power disruptions from wind and debris	▪ Maintain tree corridors ▪ Strengthen line fasteners to reduce system effects from high winds
Solar PV output	Up to 20% solar PV capacity reduction due to transient dust cover; increased risk of hot spots	▪ Improved technologies for PV cleaning (considering safety and water constraints) ▪ Increased cleaning and panel maintenance
Distribution infrastructure	Inundation of low-lying distribution poles and household connections	▪ Protect distribution system infrastructure (e.g., poles) against flooding ▪ Build distribution network outside of flood risk zone
Solar PV panels	Reduced solar panel lifespan due to delamination and damage	▪ Increase system capacity to increase buffer (i.e., additional battery banks and converting street lights to stand-alone solar) ▪ Increase energy efficiency by building the capacity of consumers to identify and purchase highly efficient appliances ▪ Increase available technical support, spare parts, and maintenance capacity ▪ Incorporate lightning grounders to protect mini-grids from power surges and to increase safety ▪ Operate diesel generator (genset) to charge the batteries when solar power is not available ▪ Integrate cooling technologies into the design to reduce efficiency losses, including the use of fans, water sprayers (for panels), or enhancing ventilation.
Dispensers	Power disruptions	
Solar PV output	Low current events due to extended cloudiness and up to 1% solar PV capacity reduction through 2050	
Distribution lines	Up to 1.8% distribution line capacity reduction through 2050	
Solar PV output	Up to 0.7% solar PV capacity reduction through 2050	
Wind turbine output	Up to 0.6% wind turbine capacity reduction through 2050	

Applications for Solar Photovoltaic Systems; hurricanes and extreme weather

- Recent storms have highlighted modes of survivability and failure
  - Implications for design, construction and operations decisions

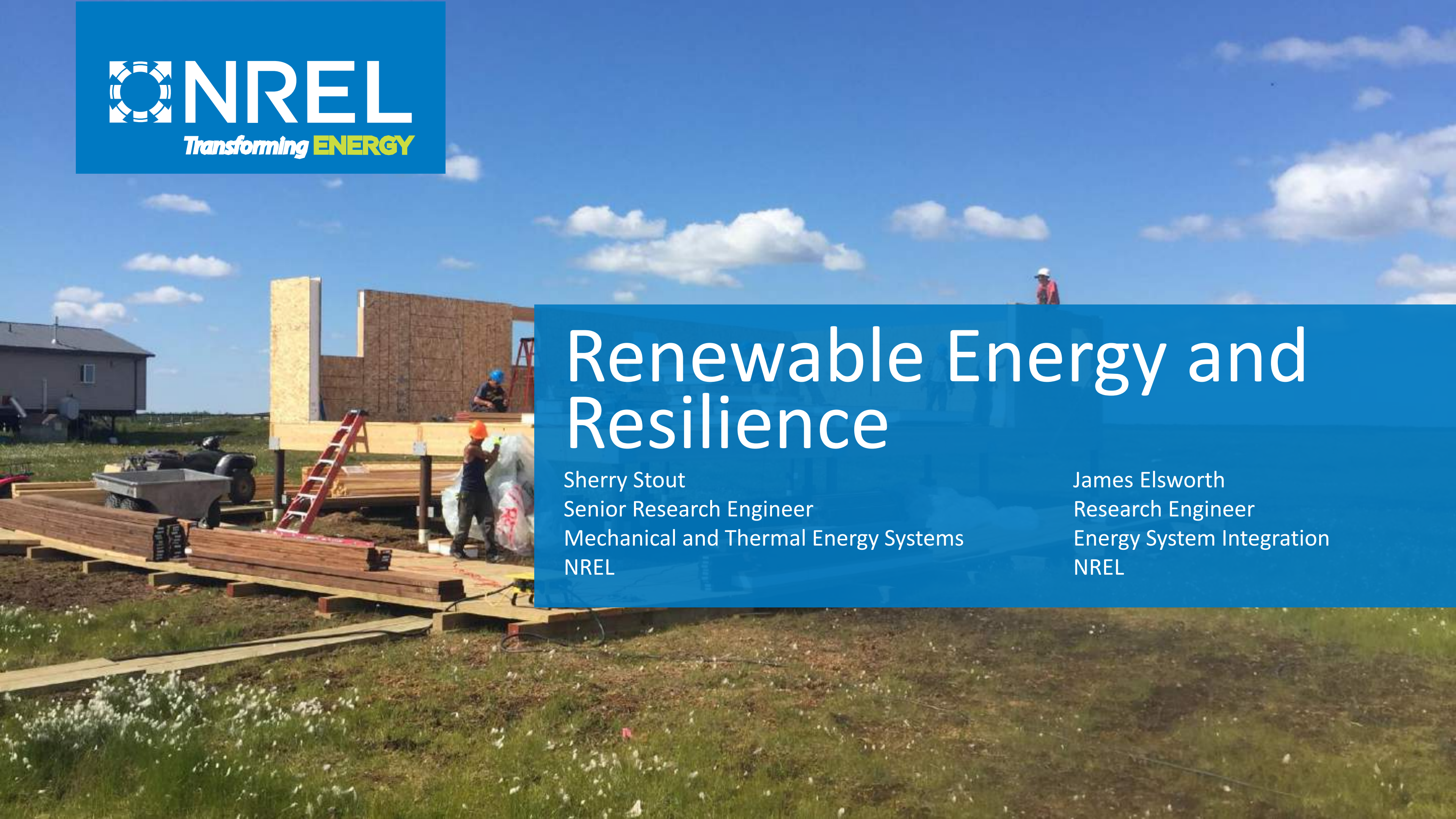
- Updated design specifications; Fasteners, materials, storm water drainage

- Resilience framework
  - Planning encompasses
  - Multiple considerations



Con Edison, 2019

Questions?



Renewable Energy and Resilience

Sherry Stout
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Mechanical and Thermal Energy Systems
NREL

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Research Engineer
Energy System Integration
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Energy in Context

Empowering Women and Youth

Economic Opportunity

Educational Attainment

Health and Sanitation

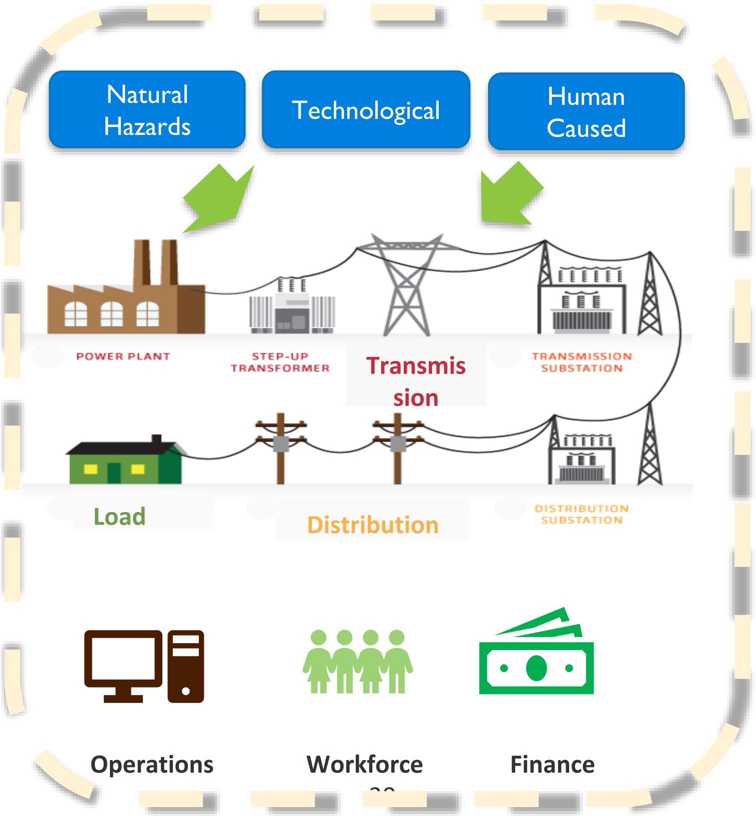
What is Resilience

At its most basic level, resilience refers to the ability to recover after the application of stress

Resilience is the ability to prepare for and adapt to changing conditions and withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents

Motivation for Power Sector Resilience

- The power system is essential to providing reliable, secure, and affordable electricity and to driving growth and development in the country.
- The power system faces potential risk from natural, technological, and human-caused hazards that could disrupt the power supply.
- A resilient power system could thrive under changing conditions and withstand, respond to, and recover rapidly from disruptions.



Island Specific Considerations

Vulnerabilities to island power systems include

Increased frequency and intensity of weather-related threats to power infrastructure

Price volatility of generation fuel supplies

Availability of fuel in post-disaster situations

Variability of renewable resources

Challenging logistics in post-disaster scenarios

Community vulnerabilities related to power-supply include

Outages for critical facilities

Health impacts of power outages

Social and financial impacts of power outages

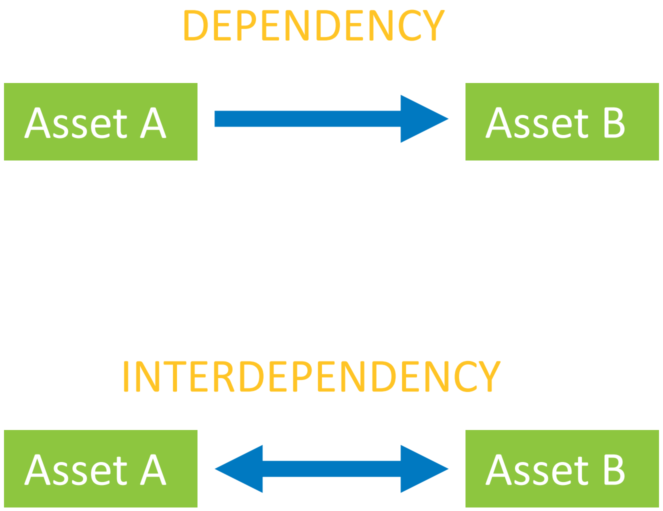
Effective Resilience Planning

Power sector resilience planning should:

- Be part of existing planning process.
- Include engagement with non-utility entities for incorporation into broader community resilience and adaptation planning
- Be part of an iterative process and updated periodically
- Be linked to implementation and financing
- Include understanding of dependencies and interdependencies of the power sector assets

Effective Resilience Planning: Understanding Interdependencies

- **Dependency:** A "unidirectional relationship between two assets (e.g., critical infrastructure, firm, organization, or facility) where the operations of Asset A affect the operations of Asset B."
- **Interdependency:** A "bidirectional relationship between two assets where the operations of Asset A affect the operations of Asset B, and the operations of Asset B then affect the operations of Asset A."



SOURCE: PETIT, ET AL. (2015). ANALYSIS OF CRITICAL INFRASTRUCTURE DEPENDENCIES AND INTERDEPENDENCIES. ARGONNE NATIONAL LABORATORY. HTTPS://PUBLICATIONS.ANL.GOV/ANLPUBS/2015/06/111906.PDF

Resilience Attributes

CHARACTERISTIC	EXAMPLES
Robustness *Are systems physically secure?*	• Active performance monitoring and maintenance • Critical equipment and facilities physically secured and cybersecured • Resilient building and infrastructure design (drainage, underground lines, elevation) • Temporary or permanent relocation of critical missions
Redundancy *Are there single points of failure?*	• Backup power (i.e., generators or microgrids) and modular assets • Redundant electric, water, wastewater, transportation, and communications systems • Mesh or loop networks to route power from multiple directions • Mission capability duplicated at other sites and multiple staff trained in critical skills
Resourcefulness *Do we have diverse options?*	• Diversified generation and fuel sources (generators, renewable energy, storage) • Diversified water, wastewater, transportation, and communication sources • Load shedding • Community mutual aid agreements and diversified supply chains
Response *Are systems automated and self-healing?*	• Training and exercises for outage scenarios, documented procedures • Fault tolerance (controlled cooldown for safe recovery) • Inclement weather response plans • Smart control systems
Recovery *Can systems recover?*	• Spare parts inventory, preferably using commercial off-the-shelf parts • Utility coordination and agreement • Development of staff support programs to institutionalize resilience and build capacity

Identify Solutions

- Policy matters
  - Long-term planning
  - Regulations and procedures
- Technical solutions
- Programs
- Capital projects.

PHOTOS BY DENNIS SCHROEDER, NREL 25930 62231

Renewable Energy for Resilience in Caribbean Islands

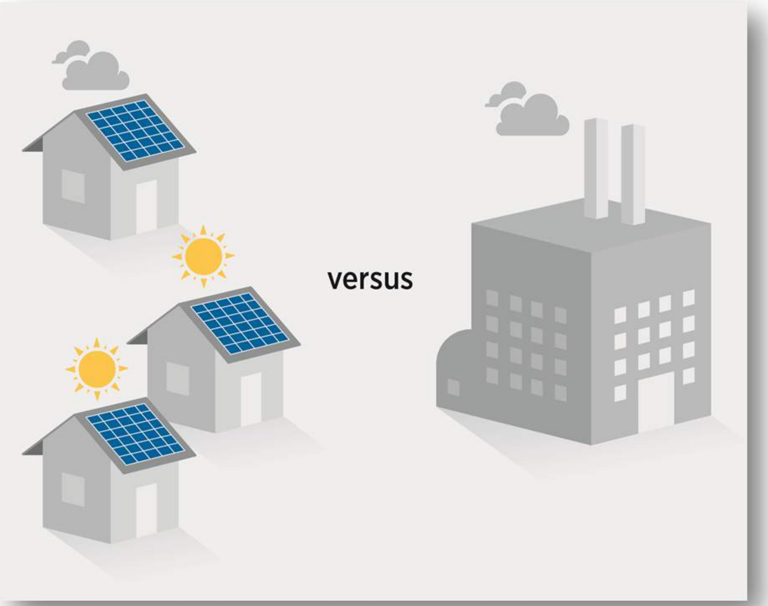

Photo: Owen Buggy Photography

Why Renewables for Island Power Sector Resilience?

- Economics
  - Utility saves on fuel cost for fuel-based plants
  - Local source of electricity allows more money to circulate the local economy rather than go to imported fuels
  - Mitigates price volatility of fuel sources
- Logistics
  - Logistics of fuel import and storage during/after major weather events
  - Modular nature of RE makes it a prime candidate for DG +storage

Renewable Energy

- **Diversifying the generation mix:**
  - Spatial diversity
  - Resource and fuel diversity.
- **Reducing water use:**
  - Reduce vulnerabilities related to drought.
- **Enabling modular and rapid deployment:**
  - Decentralized power generation
  - Locational flexibility.
- **Islanding:**
  - Reduce vulnerabilities related to broader grid outages.
- **Coupling with storage:**
  - Backup power
  - Potentially enable black start recovery.
- **Operating during normal and black-sky scenarios:**
  - Value stacking, economic resilience.
  - Demand-side management and efficiency



Solar Resilience Considerations

- On-site energy generation can be a resilience strategy, if designed and operated appropriately
- Systems designed to be more resilient should include site-specific or hazard-based design, energy storage and islanding controls, site-specific storm preparation plans to further minimize damage
- Sites should also be evaluated for readiness for major storms
  - Major storms are increasing in frequency; designs based on historical data may not be sufficient!

Resilience Considerations for Solar PV

Category	Gap/Issues	Opportunity/Solutions
On-site energy generation	Lack of codes	Review solar installation requirements to ensure that roof-mounted and ground-mounted solar technologies are designed to static wind-loading conditions as well as dynamic wind-loading conditions.
	Site inspections	Field verification could be conducted on large systems to ensure safe installation practices.
	Site characteristics	Consider conducting geotechnical studies on utility-scale array foundations located in hurricane zones.
Outreach	Workforce engagement	Workforce development strategies could enhance implementation and build knowledge of secure PV installation and building code designs and enforcement
	Outreach & education	Create a communications plan to share information about resilience programs and resilience considerations for rooftop solar
Emergency preparedness	Potential improvement	Checklists for pre-hurricane preparation could be developed to secure and prepare solar arrays for coming storms. These checklists would include items such as removal of potential debris, checks to ensure adequate weather sealing on combiner boxes and inverters, and torque checks for all connections and bolts.

Technical Solutions: Renewable Energy Continued

RE systems are only resilient if they are designed to be so!

- Hardware
- Siting
- System design
- Sizing

PHOTO BY ELIZA HOTCHKISS, NREL

PHOTO FROM JERSEY SHORE SOLAR, NREL 09440

Construction Considerations

- Ensure siting outside of known hazard zones where possible (e.g. above flood levels, in areas with lower expected storm surge, etc.)
- Ensure ground mount arrays have appropriate civil engineering including soils analysis and drainage
- Where possible, perimeter fences may be used to reduce wind loading on arrays


Photo: Strata Solar


Photo: Anonymous, Used with Permission


Photo: Dust Solutions, LLC

Solar Array Design

- Ensure that panel mounting equipment is rated for expected wind loads
- Use through-bolting where possible rather than clamp-style mounting
- Use locking fasteners
- Avoid self-tapping screws or clips for mechanical joints
- Use fixed-tilt arrays (rather than tracking) to minimize failure due to torsional forces on rotating torque tubes
- Use a three-rail racking system with thicker gauge metal
- Use a two-pier support system with shorter distance between supports
- Rooftop: Attach directly to roof

Pre-Storm Checklists

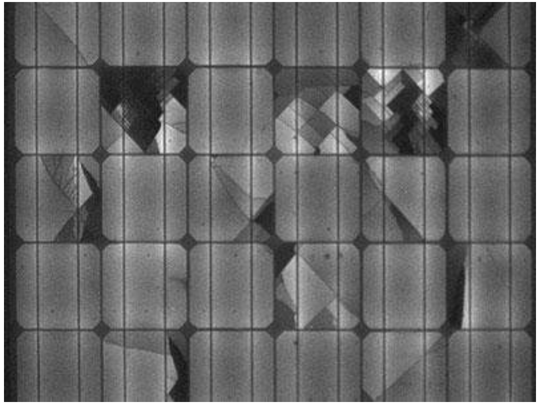
Calibrated Digital Torque Wrench

Develop pre-storm checklists to ensure readiness of arrays

- Site
  - Remove any debris from site to minimize impacts during storms
  - Ensure that flood control and drainage systems are functioning at large array sites
- Array
  - Check torque on all hardware connections
  - Check corrosion of hardware
  - Check torque on all wiring connections
  - Check weather seals and locking mechanisms on BOS systems to prevent water intrusion
  - Check for loose cables and for cable ties.
  - Power down array

Photo: Bad Wire Management

Post-Storm Checklists



Develop post-storm checklists to ensure readiness of arrays

- Site
  - Walk the site to check for damage
- Array
  - Check electrical continuity and grounding pathways
  - Check torque
  - Check for water intrusion into electrical boxes and inverters
  - Check PV cable connections
  - Conduct a damage assessment that includes EL imaging

Workforce Solutions

- Cross-trained staff
- Robust maintenance schedules and plans
- Staffing at redundant locations
- Remote capacity support for rural power system operators

Source: 60Hz Inc

Resilience Enabling Policies

- Rate structures or incentive programs
- Interconnection processes
- Government financing mechanisms
- Overarching policy/regulatory goals for resilient design and operation of infrastructure systems – both the electricity system and supporting infrastructure
- Safety, reliability, and robustness standards

Resilience Enhancing Programs

- Power System
  - Workforce development
  - IRRP creation and updates
  - Geospatial data with system assets and hazards
- Community
  - Outreach and communication on power sector goals
  - Communication on imminent threats to power service
  - Demand response
  - Trade-in or incentive programs to adopt energy efficiency measures

Photo credit: Sherry Stout, NREL

Key Takeaways

DG can play a valuable role in power sector resilience in the Caribbean

Appropriate design of both the site and the array can help ensure survival of PV during storm events

Site preparation prior to major storms can significantly reduce damage due to impacts during major storm events

Array preparation prior to storms can reduce damage due to hardware and BOS failure during major events.

Questions?

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Feedback Poll

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