Bridging Climate Change Resilience and Mitigation in the Electricity Sector Through Renewable Energy and Energy Efficiency

Emerging Climate Change and Development Topics for Energy Sector Transformation

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LIST OF ACRONYMS

CHP	combined heat and power
DG	distributed generation
DPV	distributed photovoltaics
DSM	demand-side management
EE	energy efficiency
FEMA	Federal Emergency Management Agency
GHG	greenhouse gas
IRP	integrated resource planning
IRRP	Integrated Resource and Resiliency Planning
LEDS	low emission development strategies
NAP	National Adaptation Plan
NCCAP	National Climate Change Action Plan
NDC	Nationally Determined Contribution
NREL	National Renewable Energy Laboratory
RALI	(USAID) Resources to Advance LEDS Implementation
PV	photovoltaics
RE	renewable energy

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1. INTRODUCTION

Reliable, safe, and secure electricity is essential for economic and social development and a necessary input for many sectors of the economy. However, electricity generation and associated processes make up a significant portion of global greenhouse gas (GHG) emissions contributing to climate change (IPCC 2014). Furthermore, electricity systems are vulnerable to climate change impacts—both short-term events and changes over the longer term. This vulnerability presents both near-term and chronic challenges in providing reliable, affordable, equitable, and sustainable energy services. Within this context, developing countries face a number of challenges in the energy sector, including the need to reliably meet growing electricity demand, lessen dependence on imported fuels, expand energy access, and improve stressed infrastructure for fuel supply and electricity transmission.

Energy efficiency (EE) and renewable energy (RE) technical solutions described in this paper can bridge action across climate change mitigation and resilience through reducing GHG emissions and supporting electric power sector adaptation to increasing climate risk. Integrated planning approaches, also highlighted in this paper, play an integral role in bringing together mitigation and resilience action under broader frameworks. Through supporting EE and RE deployment and integrated planning approaches, unique to specific national and local circumstances, countries can design and implement policies, strategies, and sectoral plans that unite development priorities, climate change mitigation, and resilience.

2. POWER SECTOR CLIMATE CHANGE VULNERABILITY

Climate change is currently impacting, and will continue to impact, the electricity sector globally (IPCC 2012). Both chronic climatic change and singular climate events will affect the demand, supply, production, and delivery of electricity in a multitude of ways. Table 1 presents categories of climate changes and potential impacts on power generation, transmission and distribution, and demand. EE and RE technical solutions that can support addressing these impacts are explored in Section 3.

The variability, characteristics, and severity of the impacts of climate change will also be highly localized, reflecting the particular combination of climate factors and stressors inherent to a given location. In addition to more frequent and extreme sudden-onset impacts (e.g., hurricanes, typhoons, heat waves, and extreme storms), climate change is also expected to create or exacerbate gradual-onset impacts (e.g., drought, sea level rise, and changes in precipitation patterns). Consequently, electricity sector resilience extends beyond safeguarding the integrity of power generation and grid infrastructure from short-term or immediate physical shocks to also include planning for long-term changes in climatic conditions. For the purposes of this paper, a definition of resilient power systems is included in Box 1.

For every situation, short-term and chronic vulnerabilities of the electric power sector to climate change will vary depending on the nature of the risk faced as well as the unique characteristics of the local power systems. For example, countries

Table 1. Potential Climate Change Impacts to Power Technologies and Sectors

Climate changes	Technologies/sectors	Potential impacts
Temperature change	Generation • Biopower • Hydropower • Solar PV • Thermal technologies (coal, geothermal, natural gas, nuclear, concentrated solar power) Transmission and distribution Demand	• Crop damage and increased irrigation demand • Reduced generation capacity and operational changes • Reduced generation capacity • Reduced generation efficiency and capacity • Reduced transmission efficiency and capacity • Increased demand for cooling
Water availability and temperature	Generation • Biopower • Hydropower • Thermal technologies	• Decreased crop production • Reduced generation capacity and operational changes • Reduced generation capacity
Wind speed changes	Generation • Wind	• Reduced generation capacity
Flooding and sea level rise	Generation • Bioenergy • Hydropower • Solar PV • Thermal technologies • Wind Transmission and distribution	• Physical damage and power disruption/loss—all generation technologies • Physical damage
Extreme climatic events (e.g., storms, short-term extreme heat events, other disasters)	Generation • Bioenergy • Hydropower • Solar PV • Thermal technologies • Wind Transmission and distribution Demand	• Physical damage and power disruption/loss—all generation technologies • Physical damage and reduced transmission capacity • Increased peak electricity demand

Sources: EPSA (2015); WBCSD (2014).

with installed hydropower where peak loads tend to occur in the dry season may benefit from a more diversified electricity portfolio as highlighted in Box 2. Alternatively, countries with large rural populations, dispersed load centers, and few generation sources may improve system resiliency and reduce emissions through renewable-based islanded distributed generation (DG) systems that mitigate risks to vulnerable transmission infrastructure (Cox et. al. 2016). DG solutions are explored in Section 3. These and another clean energy technical solutions are explored in sections below.

Reliable and secure access to electricity has significant implications across many economic sectors, including water treatment and distribution, manufacturing, and agricultural processing, among others. Vulnerabilities in the electricity sector have the potential to magnify vulnerabilities in other sectors, producing cascading effects across economies and local communities.[1] Resilient power systems are therefore critical in supporting cross-sectoral development goals around the world.

Box 3 provides a detailed look at water constraints in the context of climate change and possible impacts on the power sector. It presents some EE and RE technical solutions to enable power system resilience, with more highlighted in Section 3.

Box 1. Resilient Power Systems Defined

Resilient power systems bring together diverse technical solutions and integrated planning processes to allow systems to provide reliable, safe, and secure electricity during short-term disasters and events and as longer-term climate changes occur. Resilient power systems also support GHG emission reductions to mitigate further climate impacts in the future. Resilient power systems are critical in protecting and ensuring cross-sectoral economic and social development.

Box 2. Technology Innovation to Support Climate Resilience

In addition to the technical solutions highlighted in this paper, several innovative renewable energy technology design features are being researched and developed to support more resilient power systems. Example technologies include improved variable wind speed turbines, taller wind turbines to reduce wind speed variability challenges, and solar cells designed for higher temperatures, among others (WBCSD 2014).

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[1] http://www.iea.org/topics/electricity. Accessed March 2017.

Box 3. Water and Electricity in the Context of Climate Change

In 2015, more than 700 million people globally lived in water-scarce areas. Global climate change models project that this number will increase more than four-fold by 2035, with an estimated 3 billion people experiencing extreme water scarcity and stress.

Thermal electricity generation involves using a fuel source to produce steam that turns a turbine. This type of electricity production is water intensive, primarily due to cooling requirements. Other processes along the supply chain—such as fuel extraction, transportation, processing and, in some cases, emission scrubbing—can also consume significant amounts of water (IEA 2012a; IEA 2016c). As another consideration, water temperature also impacts thermal plant efficiency. Within this context, droughts and heat waves, expected to increase as a result of climate change, will significantly impact the efficiency and economics of electricity systems dependent on thermal power (DOE 2013). Further, hydropower systems, dependent on water resources for electricity generation, are expected to be impacted by changing weather patterns associated with climate change.

Building on this point, the figure below presents water use and consumption across electricity generating technologies. As shown, certain renewable energy technologies, notably solar PV and wind, use and consume less water than thermal technologies (Macknick et al. 2011). Water-saving attributes of these technologies, combined with emission reduction potential, can allow countries to pursue development pathways aligned with both climate change mitigation and adaptation. The method used for cooling a given technology can also significantly increase or decrease the water intensity of that generation technology. For example, concentrating solar power can be either a very water-intensive or water-efficient generation technology depending on the cooling process employed at the site.

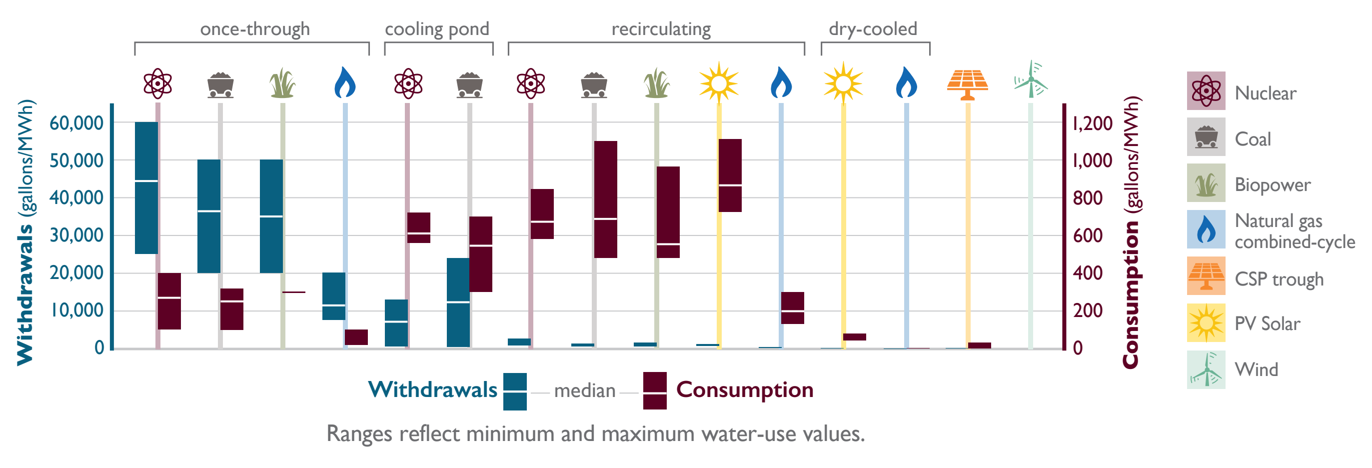

Figure 1. Water withdrawal and consumption of power generation technologies. *Source: Adapted from Averyt et al. (2011) and DOE (2013)*

At the global level, increased renewable energy deployment could result in significant water savings. Under the International Energy Agency's 450 Scenario, 48% of electricity generation would be derived from renewable energy by 2035 (IEA 2012b). Bringing this scenario to fruition could result in a water-use reduction of 200 billion cubic meters globally as compared to a business-as-usual scenario (IRENA 2015). This analysis underscores the potential for renewable energy to play an important role in supporting climate-resilient electricity generation around the world. Importantly, for an individual country, these water savings could also allow for more optimal use of scarce resources for other critical adaptation priorities, such as food security.

Another consideration of the link between energy and water is that energy is typically required to treat and transport clean water. Water treatment facilities, both potable and waste water, require energy to run pumps and motors, aerate water ponds, and to send and receive water in pipes. Energy efficiency strategies, such as using gravity-fed systems to reduce the need to pump water, high-efficiency pumps and motors, or designing natural, biological systems, reduce the energy being consumed within water treatment and delivery processes. Addressing energy needs in water treatment, as well as water needs in energy production, is prudent for achieving larger goals.

3. TECHNICAL SOLUTIONS: ENERGY EFFICIENCY AND RENEWABLE ENERGY TO SUPPORT RESILIENT POWER SYSTEMS

Resilient power systems bridge development and climate goals and can simultaneously support climate resilience, GHG emissions mitigation, and cost-effective access to electricity. While the literature on the potential for EE and RE to reduce GHG emissions (IPCC 2012; IEA 2015a; IRENA 2016) as well as other co-benefits (IPCC 2009; IEA 2014; World Future Council 2016) is extensive, there has been less emphasis on the important climate resilience benefits that can be supported through EE and RE deployment.

The following sections focus on potential resiliency benefits of key low carbon EE and RE technical solutions. Solutions highlighted include: (1) scaling up EE (integrated EE planning, demand-side management (DSM), and EE building codes); (2) diversifying generation portfolios; (3) deploying distributed generation; (4) enabling storage solutions; and (5) developing smart grids. Section 4 then highlights how these technical solutions can be brought together under integrated planning processes and in relation to unique individual country and jurisdictional circumstances and development goals (e.g., expanding energy access, improving energy security, job creation, etc.).

3.1 Scaling Up Demand-Side Energy Efficiency

Demand-side EE measures, when implemented at scale, can support both short- and long-term climate resilience solutions. During short-term extreme events, EE measures can reduce peak loads and the potential for system instability and stress. EE can also reduce the need for increased electricity supply over time as load profiles change and potential temperature increases impact durations of consumer electricity use. In addition, EE is very important when paired with battery systems, as it can expand the operating life of critical loads. Reducing the need for electricity overall can also be beneficial for daily operation of a grid system. Integrated EE planning, demand-side management, and EE building codes are three key areas to support cost-effective investment planning and responsiveness of power systems to changing load profiles over the near and long term.

Integrated Energy Efficiency Planning

Policymakers and system planners can integrate EE with electricity planning to inform new investments and policies and to support resilient power systems. Temperature changes are expected to increase demand for electricity (especially for cooling) (IEA 2013), and integrated electricity planning can allow for a portion of that demand to be met through EE rather than expanded electricity generation investments. Further, integrated EE planning can allow for prioritization of EE measures, such as DSM, highlighted below, that support responsiveness of power systems to changes in demand during short-term extreme weather events and over the longer term.

One common EE planning approach is for EE to be considered as a resource along with other generation resources within electricity expansion and integrated resource plans. EE potential studies can inform levels of demand-side resources to be considered in integrated planning processes, and these levels can align with broader EE targets or energy savings goals. However, in most cases EE is not yet considered equal to supply side resources within integrated resource planning (IRP) modeling processes. This often leads to an underestimation of EE potential and thus a greater focus on new supply side investments than may be required (Lamont and Gerhard 2013). Addressing this issue within resource planning processes could enable more cost-effective investments and reduce the need for expanded supply as electricity demand increases.

Demand-Side Management

DSM is a key EE measure and a mechanism for aligning peak demand with times of peak generation that distinctly focuses on reducing consumers' energy demand and shifting patterns of energy use. DSM improves responsiveness of the power system to shifts in electricity supply and demand, improving overall system stability and resilience to short-term extreme heat events and more chronic, long-term changes in load profiles and temperatures (IEA 2015b).

Several approaches can be implemented to support power system resilience through DSM. Power systems integrating DSM can be most responsive when utilities have the ability to shed demand-side load automatically through mechanisms such as direct load control or interruptible load. For example, utilities might develop agreements with high energy use industrial consumers to reduce electricity consumption automatically (e.g., through turning off industrial equipment) during times of highest demand. Utilities can also use incentives such as electricity tariff increases during times of peak demand, which provide a price signal to consumers to decrease electricity use. Rebates or other compensation mechanisms can also be given to commercial and industrial consumers for a commitment to reduce power when the electricity system is experiencing highest demand. Smart metering programs are another voluntary DSM approach that allows consumers to monitor their energy use and prices in real time, thus providing an incentive to reduce power use during peak demand or as prices increase (Salami and Farsi 2015; IEEE 2011).

During times of acute stress on the electricity system, e.g., extreme heat events, DSM control systems will be most effective at enabling responsiveness as adjustments can be made automatically through the utility, usually within minutes or even seconds (Sullivan et al. 2013; RMI 2006). DSM approaches that rely on voluntary consumer behavior adjustments, such as smart metering, will play a much smaller role in supporting power system resilience in these extreme circumstances. However, to address gradual climate changes over the longer term, pricing incentives and smart metering programs can be critical in enabling consumers to support more resilient power systems (EIA 2012).

Demand-side management can also reduce the need to build additional electricity generation capacity, which can in turn reduce water use needs required for certain electricity generating technologies. Water use considerations are explored further in Section 3.2. DSM programs are often implemented by utilities and include a number of incentives and other mechanisms (e.g., electricity pricing related to time of day energy usage) to reduce and shift energy consumption. Box 4 provides examples of utility-led DSM and EE programs in the United States.

Box 4. Utility-Led Demand-Side Management and Energy Efficiency Programs in the United States

Energy efficiency and demand management are increasingly prominent approaches in energy planning strategies. New data compiled by Navigant Research suggests global expenditures on integrated DSM are expected to increase from approximately $39.8 million in 2016 to $1.2 billion in 2025, with the largest increase in the United States (Navigant 2016). Several utilities across the country have already instituted DSM programs. Consolidated Edison of New York (Con Edison), one of the largest investor-owned utilities in the United States, initiated the Brooklyn Queens Demand Management (BQDM) project in 2016 in an effort to offset the construction of a new substation (Tweed 2016). The project targets specific neighborhoods with a goal of reducing demand by 52 MW through a combination of EE and DSM projects, as well as distributed generation and energy storage. Several other utilities of varying sizes have also instituted EE and demand response programs. As examples of the range of program offerings, Baltimore Gas and Electric (BGE 2016) and Hawaiian Electric (Hawaiian Electric 2016) have both implemented voluntary DSM programs. Under BGE's Smart Energy Rewards program, subscribers are credited for every kWh of energy saved (compared to the customer's typical usage) on projected high energy use days, whereas under Hawaii Electric's Fast DR Pilot Program, the utility will notify users to reduce load in real time. In evaluating the potential impact of EE and DSM programs Xcel Energy, an IOU in the United States, offers an illustrative example. Looking at combined totals through 2014 for the entire utility, which covers eight states, Xcel estimates that customers have offset the need for a total of 4,250 MW of energy production since it started tracking results from energy efficiency programs in 1992 (Xcel 2015).

Energy-Efficient Building Codes

Building codes typically cover a wide range of topic areas, including building construction and design, electrical, mechanical, lighting and plumbing components, material selection, and EE. Codes can be tailored to specific environmental contexts to address the unique hazard profiles of individual areas. For example, heavy concrete structures may not be appropriate in mountainous, landslide-prone parts of the world, and areas at heightened risk for earthquakes can benefit from adopting specific seismic codes.

In addition to structural elements to support climate resilience noted above, building codes can be designed to address various EE needs related to the building envelope, heating and air conditioning needs, installed appliances and equipment, and RE integration, among others (IEA 2008). Assessing the local current and future building stock in relation to projected climate conditions and energy supply and demand is an important first step in informing EE building codes aligned with climate resilience.

Codes that require the construction or renovation of existing buildings to become more energy efficient can assist with reducing the need for power during grid outages and enhance the passive survivability. Passive survivability is the concept of maintaining comfortable indoor environments without the need for power, such as during a power outage. Passive survivability design principles include development of low height, energy efficient, storm-resistant buildings, provision of passive solar heating and natural lighting and ventilation, and incorporation of solar water heating and other RE technologies, where possible, among others (Rutgers 2011).

Passive survivability has been demonstrated in the field to be an effective strategy in supporting climate resilience and is an area with great potential for further scaling at the household and community level. Box 5 highlights a passive survivability community in the state of Maine in the United States where home design features allowed households to better withstand extreme weather conditions.

Developing energy efficient building codes can also support utilities in directing power needs from residences and office buildings to more critical infrastructure, such as hospitals or water treatment facilities.

Several countries and jurisdictions are supporting the design and implementation of energy efficient building codes to enable climate resilience. Box 6 presents activities in Vietnam to develop green building codes to support climate resilience and GHG mitigation, and Box 7 highlights Antigua and Barbuda's planned climate-resilient energy codes based on a climate vulnerability assessment and presented in the country's Nationally Determined Contributions (NDCs).

Box 5. Passive Survivability in Maine

An ice storm in Maine, USA, in 2013 left numerous residents without power for five days with below-freezing temperatures and no heat. The homes in Belfast, Maine's Cohousing and Ecovillage were able to maintain livable indoor conditions due to passive survivability principles. The super-efficient homes have a southerly orientation and generous south-facing glazing to maximize passive solar gain, triple-paned windows and doors, super-insulation, and airtight construction to reduce loss of heat in the winter, as well as on-site PV panels to provide electricity. The home designs have resulted in a 90% reduction in energy use for space heating compared to the average house. While neighbors lost heat within 24 hours and faced subzero temperatures, the residents in the Belfast Cohousing and Ecovillage were able to maintain comfortable temperatures and stay in their homes.

To learn more about the Belfast Cohousing and Ecovillage, see Lozanova (2015).

Box 6. Building Codes to Support Climate Resilience and Mitigation in Vietnam

To support technical solutions that enable climate resilience and mitigation, USAID's Vietnam Clean Energy Program partnered with the Government of Vietnam to update the country's Green Building Code and promote high-performance, energy efficient buildings throughout Vietnam's major cities. The program creates a road map for low emission development in the electricity sector, builds capacity to strengthen the foundation for low emission energy systems, and contributes to the country's climate resilience and low emission development goals in the construction sector.

The Vietnam Clean Energy Program defines high-performance buildings as 30%–50% more efficient than current building standards. Through the project, an inventory of building stock was created to measure the energy performance of large buildings (those greater than 2,500 m^2) in Vietnam's five major cities: Hanoi, Hai Phong, Da Nang, Ho Chi Minh, and Can Tho. The project then demonstrated the potential of high-performance, energy efficient buildings, using model buildings to showcase proven energy savings and efficiency. These and other measures are playing a critical role in supporting climate resilience and mitigation in Vietnam.

Source: USAID (2014)

Box 7. Antigua and Barbuda NDCs Goal to Create Climate-Resilient Building Codes

Antigua and Barbuda has put forth a specific goal in its NDCs to update the country's building codes to also address specific climate change impacts by 2020. A "Vulnerability Impact and Adaptation Analysis for Antigua and Barbuda" will inform the building code updates to be developed by 2020.

Source: UNFCCC (2015)

3.2 Diversifying Generation Portfolios

Resilient power systems can bring together a diverse portfolio of electricity generation technologies to increase reliability, and allow for service disruptions to be mitigated and resolved quickly. Resources can be diversified in relation to geography, fuel use needs, and water use needs to support a more climate-resilient power system. As part of a portfolio diversification strategy, RE technologies can play unique and important roles relative to traditional technologies.

Geography: RE can maximize the inherent characteristics of spatial diversity. Expanding the incorporation of geographically dispersed RE and other resources with power portfolios can allow localized short-term or chronic climate impacts to be managed more effectively (REN21 2015).[2] As an example, a wind farm is spread out to maximize available wind resources, making it more spatially diverse than a coal fired power plant.[3] From a bigger picture perspective, RE resources can also add significant diversity across an electricity portfolio. Using diverse RE resources within an electricity balancing area can support a smoothing effect that facilitates the integration of variable RE with the grid and decreases vulnerability to disasters.

Fuel use: Extreme weather events (e.g., flooding, wildfires, and landslides) that impact fuel supply infrastructure (e.g., gas lines and/or road, rail, barge access) place conventional generation facilities reliant on these fuel supplies at greater risk than those generation facilities with an on-site fuel supply like wind or solar. Therefore, "all of the above" power sector portfolios diversified to incorporate RE technologies (with on-site fuel) can enable resilience and power provision when fuel supplies for traditional technologies are impacted by extreme weather events.

Water use: Diversifying power portfolios to include technologies less dependent on water will also be critical in certain areas that are expected to be impacted by water availability and/or water temperature changes. As presented in Section 2, Box 3, hydropower and thermal power technologies are highly dependent on water for power production, cooling, and other processes. Diversifying power portfolios to include technologies with low water use needs, such as solar photovoltaics (PV) and wind, could offer an important technical solution for countries and jurisdictions that are highly dependent on hydro and thermal technologies and may face water challenges related to climate change currently or in the future.

Bringing each of these areas together, Box 8 highlights electricity portfolio diversity as a key area of focus to address electricity sector vulnerabilities in Ho Chi Minh City, Vietnam.

Box 8. Addressing Climate Risks in Ho Chi Minh City

Ho Chi Minh City, with support from the Asian Development Bank, undertook a climate vulnerability study in 2010 that identified a number of vulnerabilities in the electricity sector. In particular, several power plants, electricity substations, and transmission infrastructure are in identified flood areas and could be severely impacted by floods by 2050. Compounding these issues, temperature increases are expected to increase energy demand and decrease efficiency of power generation and transmission.

To address these challenges, several options were put forth in the study, including retrofitting and relocating vulnerable infrastructure, making structural changes to a critical hydropower basin, diversifying the electricity portfolio to include decentralized RE, and integrating planning across climate change mitigation and resilience at the local level.

Source: ADB (2012)

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[2] A forthcoming and complementary paper produced through the USAID Resources to Advance LEDS Implementation (RALI) program provides further details on the vulnerability of renewables to potential climate impacts.

[3] It should be noted that the average land coverage of wind farms has not been specified, as discussed in "Land-Use Requirements of Modern Wind Power Plants in the United States," http://www.nrel.gov/docs/fy09osti/45834.pdf.

3.3 Deploying Distributed Generation: Distributed PV, Microgrids, and Minigrids

Distributed RE generation occurs near the point of electricity use and is generated within a modular system. Modularity allows for locational flexibility and for new generation systems to be put in place at a faster pace than large-scale systems as electricity demand grows and understanding of climate risks improves (REN21 2015). DG strategies can increase the relative speed of DG deployment (including the expansion of existing generation units), which may allow countries to more quickly respond to changes in load profiles or location of load centers. However, in cases where DG is connected to the grid, it is critical that robust interconnection plans are developed to support effective integration with the existing network and system.[4] Therefore, speed of DG deployment must be balanced with the time required to develop appropriate interconnection plans. Distributed power can be an important solution in addressing growing electricity needs in the wake of urbanization and climate change.

Distributed generation can support critical loads in the event of short-term climate-related disasters in rural off-grid areas as well as grid-connected areas. In both cases, distributed solar or wind must be accompanied by a battery back-up system. In the case of a grid-connected system, the batteries and inverter must be configured to operate in the event of a grid outage. If planned for, DG can provide power for telecommunications and emergency response, as well as other key services such as water treatment, healthcare, etc., during a disaster. Use of renewable-based DG systems in conjunction with diesel generators can also reduce challenges associated with fuel transport after a disaster by prolonging the need to refuel.

Distributed PV

Distributed PV (DPV) or "rooftop PV" is the most common distributed RE technology in the residential sector. DPV can support short-term and long-term climate resilience with certain design specifications. In relation to short-term climate events and disasters, currently, most DPV systems are not designed to operate independently during a grid outage. However, DPV does provide a significant opportunity for back-up power during disasters in the future if paired with battery storage and configured to operate during a grid outage. Other complementary technologies, such as supplementary generators and/or microgrids, can also be integrated with DPV systems to provide power during a grid outage (NREL 2014). Microgrids and storage are presented in detail in sections below. Box 10 presents modeling approaches to support optimal system planning across various DG technology and storage scenarios to support resilience during a grid outage.

For longer-term climate-related changes, DPV could be an important resource to support power portfolio diversification and the related climate resilience benefits highlighted above. In addition, and as noted above, DPV systems can be deployed more rapidly than traditional utility-scale power systems allowing for faster response to changing climate conditions and load profile changes over time.

Minigrids and Microgrids

Minigrids and microgrids, with appropriate design strategies,[5] are two common types of DG technologies that can support climate resiliency. Minigrids are energy systems with a localized distribution network connected to a single community or a cluster of communities that are not connected to the grid. A microgrid is often defined as a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid. If designed to do so, a microgrid can connect and disconnect from the grid to enable it to operate in grid-connected mode or independently from the grid (i.e., islanded mode). Systems that are designed to operate in islanded mode can be isolated from a larger grid, allowing the system to generate and distribute energy in the event of a power outage or disaster, behind the control switch that is connected to the larger grid. The capability of microgrids to operate in islanded mode can be critical in supporting grid resiliency by providing a back-up resource during a grid outage, while also building in the safety features needed to secure the larger grid. An additional benefit of microgrids is they can be rerouted to provide power to critical loads, such as healthcare facilities, during a grid outage—if designed to do so. Box 9 highlights Wesleyan University's microgrid that was designed to support power system resiliency in the aftermath of Hurricane Sandy in the United States. Another common feature of microgrids is the capability of two-way communication whereby data is sent directly from meters back to the energy provider, which can support faster response time during disasters (further information on smart grid technologies is provided in Section 3.5). Box 9 highlights the use of smart meters following Hurricane Sandy.

A complementary white paper titled *Distributed Generation to Support Development-focused Climate Action* (Cox et al. 2016) builds on the information in this paper to provide a more extensive presentation of DG's role in supporting climate resilience.

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[4] The importance of robust DG interconnection and grid integration plans cannot be underestimated. This is especially important for smaller islanded grids and larger grids that may lack stability (e.g., in certain developing countries). For more information on DG interconnection planning and policies, visit https://www.nrel.gov/dgic/.

[5] Please see Mini-Grids Quality Assurance Framework: https://cleanenergysolutions.org/training/mini-grids-quality-assurance-framework.

3.4 Enabling Storage Solutions

Integrating storage into electricity grid systems can help smooth variation in wind and solar generation and add back-up capabilities to the grid in the event of power outages. When DG systems with battery storage are connected to the larger grid, they can be designed, through interconnection agreements with a utility provider, to include islanding controls and energy storage to allow for grid disconnection that enables operation behind the meter or without supplying power to the larger grid. This configuration allows for independent operation during grid outages and the provision of low emission power when the grid is operating normally or when the grid is down. Storage methods may include flywheels, compressed air energy storage, batteries, and pumped-hydro storage, among others. Energy storage is an important component of RE integration for resiliency and will improve stability and reliability and allow for a faster rate of response and recovery to a disaster than a conventional system, which is not necessarily adaptable or flexible. While RE systems can be incorporated without energy storage, adding the flexibility of energy storage technologies allows for operation without grid connection. Box 10 highlights an approach to analyze technology solutions that integrates storage to support climate resilience.

Box 9. Supporting Resiliency Before and After Hurricane Sandy

In the wake of Hurricane Sandy in 2012, smart-metering programs that were already functional in Philadelphia and Washington, D.C., allowed utilities to pinpoint the exact locations of outages as they were occurring, rather than relying on people calling in to notify the utility of outages. In Philadelphia, where approximately 186,000 smart meters had been installed prior to Hurricane Sandy, an estimated 50,000 customers experienced shorter outage times due to the smart metering.

In 2013, in response to a 77-hour outage during Hurricane Sandy, Wesleyan University began a microgrid project with support from a state-wide microgrid pilot program. The initial phase of the microgrid was completed in 2014 and consisted of the campus combined heat and power (CHP) plant as well as dynamic controls to island the system from the main grid. In 2015, a 750-kW solar array was added to the microgrid to add greater flexibility to the fuel supply in the event of fuel shortages or grid outages. This hybrid system of natural gas CHP and solar maximizes fuel economy through renewable generation while at the same time providing 24-hour power through conventional power generation.

The current 3.1-MW microgrid can supply approximately 99% of the university's energy needs and is designed to avoid outages. Additionally, the microgrid system is supporting energy cost savings over time. The university is also now designated by the Federal Emergency Management Agency (FEMA) as an emergency center for the area and a distribution point.

For more information on the Wesleyan Microgrid, see Rubenstein (2016) and Cohn (2015).

3.5 Developing Smart Grids

A smart grid brings together two-way communication and other digital technologies within an electricity network to support reliability, flexibility, efficiency, and resilience. In many ways, smart grids can bring all of the technical solutions highlighted above together under a broader climate-resilient electricity system. Through automation technology, technologies or devices within a smart grid collect data in real time that can be analyzed by utilities and system operators. Grid technologies or "nodes" can then be controlled and altered based on the data received and analysis of the situation.[6] In the context of climate resilience, smart grids can support several positive outcomes. For example, because of real-time communication on changing needs and circumstances associated with short-term climate-related events (e.g., storms and other disasters), responses and decisions regarding new power needs and power diversion can be made quickly. If a generation source is impacted by a storm, other generation sources can be accessed more quickly and power can also be diverted to critical facilities such as hospitals. As highlighted in Section 3.3, smart meters can allow for this type of responsiveness by sending data directly from electricity meters to energy providers and can enable islandable DG to support resilience during climate-related disasters.

In both the near and short term, smart grids can also enable EE. For example, demand response and dynamic electricity pricing, supported by smart grid

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[6] https://energy.gov/oe/services/technology-development/smart-grid.

technologies and two-way information, can allow utilities to reduce load during peak hours, resulting in a more efficient power system. Smart grid technologies can also empower consumers to reduce peak loads by providing real-time information (through in home displays, etc.) on energy use, pricing, etc.[7] As highlighted above, reducing peak loads can lessen system instability and stress during short-term extreme climate events and, more broadly, EE measures can also reduce the need for increased electricity supply over time.

Smart grid technologies are also critical for RE integration to enable climate resilience and GHG mitigation outcomes. In particular, smart grid technologies can support management of variability and continual system balancing with supply and demand fluctuations. This is especially important in times of electricity generation scarcity that may be associated with extreme weather events, but is also necessary as penetration levels of variable renewables increase over the longer term. Key smart grid technologies and measures to support variability management and balanced systems include smart meters to enable demand response, smart inverters for two-way communication, storage technologies, computer models to support improved forecasting, and other real-time system management equipment integrated across transmission and distribution networks to support informed system operator decisions. These technologies will be critical in incorporating higher penetrations of renewables that can enable climate benefits highlighted in this paper, as well as other co-benefits (Speer 2015).

Box 10. Assessing Technology Scenarios for Climate Resilience Using System Optimization Modeling

System optimization tools support energy planning through assessing potential technology portfolios (including renewable energy and fossil fuels) to support various objectives. For example, a system optimization model was used to evaluate the technical and economic viability of PV, storage, and diesel generators for cost savings and increased resiliency of critical infrastructure in New York City. The analysis included four separate scenarios comparing the costs and operability of system designs for a five-day grid outage. The scenario with PV and batteries, combined with diesel generators, allowed for the greatest rate of survivability during a grid outage. While the analysis focused on options for greatest resilience, the added value of operating PV systems with batteries to reduce energy costs on a daily basis is another consideration.

This and other studies are showing the importance of moving beyond the status quo to integrate renewable energy sources and energy storage into resource plans to mitigate the impacts of climate change, achieve national goals, and increase resiliency. Frameworks for incorporating climate change planning into the electricity sector are discussed in Section 4.

Table 2. Technology Scenarios to Support Resilience During an Electricity Outage

Scenario Number	1	2	3	4
Scenario Description	**PV and Battery:** no resiliency required	**PV and Battery:** 5-day outage	**PV Battery, Diesel:** 5-day outage	**Diesel Only:** 5-day outage
PV Size	0	10 kW	2 kW	0
Battery Size	26 kWh/ 9kW	2,781 kWh/ 37 kW	36 kWh/ 11 kW	0
Diesel Generator Size	0	0 kW	27 kW	39 kW
Total Capital Cost	$22,520	$1,515,120	$76,620	$58,500
Base Case Life Cycle Cost	$371,141	$371,141	$371,141	$371,141
PV/Battery/ Diesel Case Life Cycle Cost	$348,594	$1,928,617	$387,608	$434,379
Net Present Value	$22,547	-$1,557,476	-$16,467	-$63,239

Source: Anderson et al. (2016)

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[7] http://web.mit.edu/energy-efficiency/docs/EESP_ArchSmartGridForEE.pdf.

4. INTEGRATED PLANNING PROCESSES: BRINGING TOGETHER TECHNICAL SOLUTIONS TO ACHIEVE GOALS ACROSS MITIGATION AND RESILIENCE

4.1 Climate Planning for the Electric Sector

To enable EE and RE technologies to support both climate change mitigation and resilience goals, one should plan with both of these targets in mind, while also acknowledging potential tradeoffs. To support climate change mitigation and resilience in the electricity sector, the EE and RE technical solutions presented in the previous sections can be evaluated and integrated under various frameworks. Three common examples of relevant planning frameworks to support climate resilience and mitigation in the electricity sector include low emission climate-resilient development strategies, integrated electricity planning approaches, and local climate action plans. These planning processes, strategies, and best practices are highlighted below.

In many countries, electricity sector planning has largely fallen under the domain of electric utilities and the commissions that regulate them (Scott 2013). However, policy frameworks to address climate change, reduce GHG emissions, and enhance resilience require coordinated and integrated planning efforts across multiple sectors and levels of government. Box 11 elaborates on the potential relationships across different levels of government and emphasizes the role of local actors in adopting location-specific solutions within the context of resilience planning in Colorado.

Box 11. Multi-Level and Sectoral Stakeholder Engagement to Enable Resiliency Planning in Colorado, in the United States

The Colorado Resiliency Framework was born out of the state's desire to rebuild in a more resilient manner following major flooding events in 2013. The Framework takes an "all hazards" approach—considering all potential hazards present in the state—and evaluates both direct vulnerability (linked to acute shocks) and indirect vulnerability (linked to chronic stresses). Despite being a state-level effort, the Framework emphasizes the need to develop local resiliency strategies. The Framework, coordinated through the Colorado Resiliency and Recovery Office, engaged more than 150 state, federal, and nongovernmental entities, including the National Renewable Energy Laboratory (NREL), and focused on six overarching sectors: infrastructure (which included energy); economic; community, health and social; housing (which included energy efficiency); and watersheds and natural resources. The stakeholder engagement process was critical to implementation because many of the state-level goals and strategies rely on measures being fulfilled at the local level. The process also resulted in joint identification of priority actions and an outline of state and local roles to support implementation.

Source: Colorado United (2013)

4.2 Low Emission Climate-Resilient Development Strategies

Low emission development strategies (LEDS) are plans that enable sustainable development while reducing GHG emissions over the medium to long term (EC-LEDS 2016). LEDS can provide a useful framework to support both climate resilience and GHG emission mitigation in the electricity sector. As of 2015, more than 100 countries were developing and implementing LEDS. Further solidifying the role of LEDS in catalyzing climate action, the Paris Agreement "invites Parties to communicate, by 2020, to the secretariat mid-century, long-term low greenhouse gas emission development strategies…" (United Nations 2015). Many countries have integrated climate resilience as a key component of their LEDS and are assessing and prioritizing electricity sector actions in relation to both mitigation and resilience criteria.

Design and implementation of a robust LEDS begins with bringing together key stakeholders across sectors of the economy. This is especially important in linking mitigation and resilience, as critical measures often require buy-in and leadership across ministries and agencies at the national and subnational level. As an example, ministries of energy and water are crucial in the planning and implementation of climate-resilient electricity systems. However, activities across these ministries and related technical agencies are often not well coordinated. Bringing these and other key stakeholders together is essential to supporting analysis and ensuring institutional buy-in and the allocation of budgets for implementation of linked climate actions and policies in the power sector (UNDP 2011).

National development goals provide the critical foundation for LEDS development and implementation. They are often articulated within an overall LEDS vision and objectives, and frame all related analyses to identify and prioritize actions.

Climate information, data, and scenarios can allow policymakers and planners to assess electricity sector vulnerabilities and risks. In some cases, studies and information that present potential climate vulnerabilities and risks over time for a particular country or region may be available. In other cases, planners may choose to use climate data available in global climate models and then improve the granularity for the national and subnational levels. Various methodologies can be used to support this process using historical temperature and precipitation information. In each case, the information can then allow planners to analyze both current and potential future vulnerabilities in the context of broader development goals (UNDP 2011). National and subnational vulnerability assessments (including quantification and ranking of vulnerabilities) can be used to bring the information together and comprehensively identify vulnerabilities and resilience/response opportunities across sectors, geographies, and populations (UNDP 2010, USAID 2016, NCA 2016). Box 12 presents the approach taken in the United States to assess climate impacts and responses.

Based on identification of climate vulnerabilities, analysts and policymakers can evaluate the mitigation potential of possible actions to address vulnerabilities. For instance, a policymaker may find that droughts are expected in a certain region of a country based on climate scenarios. This information could be used to assess potential electricity sector options to reduce water use and emissions in that region. Development of robust GHG inventories and business-as-usual scenarios is critical in supporting this broader assessment across mitigation and resilience goals.

Box 12. Climate Assessment in the United States

The U.S. government undertook a National Climate Assessment to identify the impacts of climate change on the country presently and in the future. The study was undertaken by more than 300 diverse experts from multiple sectors under the guidance of a cross-sectoral federal advisory committee and with review and input from many stakeholders.

The report summarizes impacts at the regional level and in relation to various climate events. Impacts assessed in the report are as follows: human health, infrastructure, water supply, agriculture, indigenous people, ecosystems, and oceans. The report also puts forth potential responses to address projected impacts and a robust decision-making framework to support action, highlighted below.

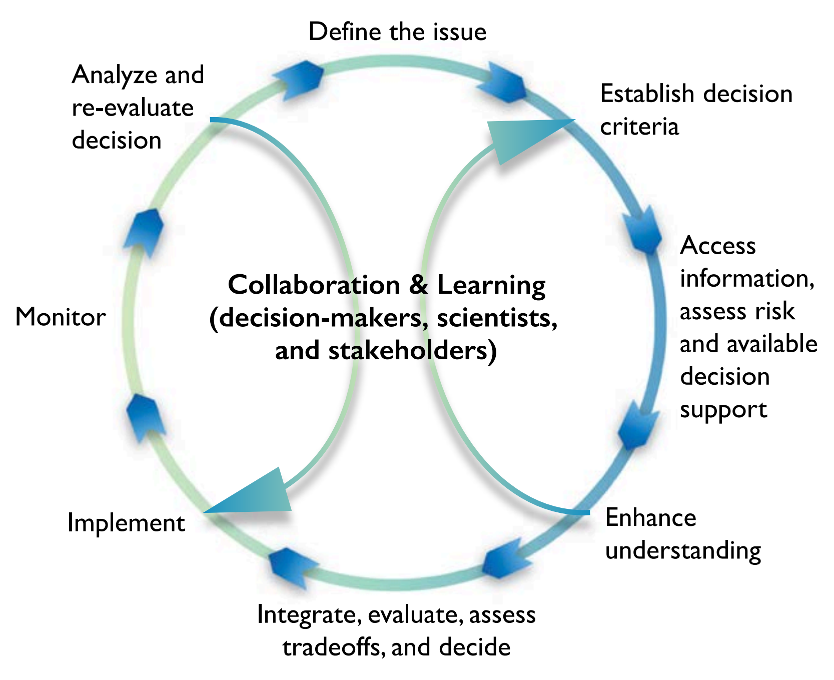

Figure 2. Decision-making framework to enable risk assessment and response.

Source: National Climate Assessment (2016)

Box 13. Low Carbon Climate-Resilient Development in Kenya

Kenya's National Climate Change Action Plan (NCCAP) provides a notable example of an approach to bridge climate mitigation and resilience under a broader national strategy. Key elements of the action plan that link mitigation and adaptation are highlighted below.

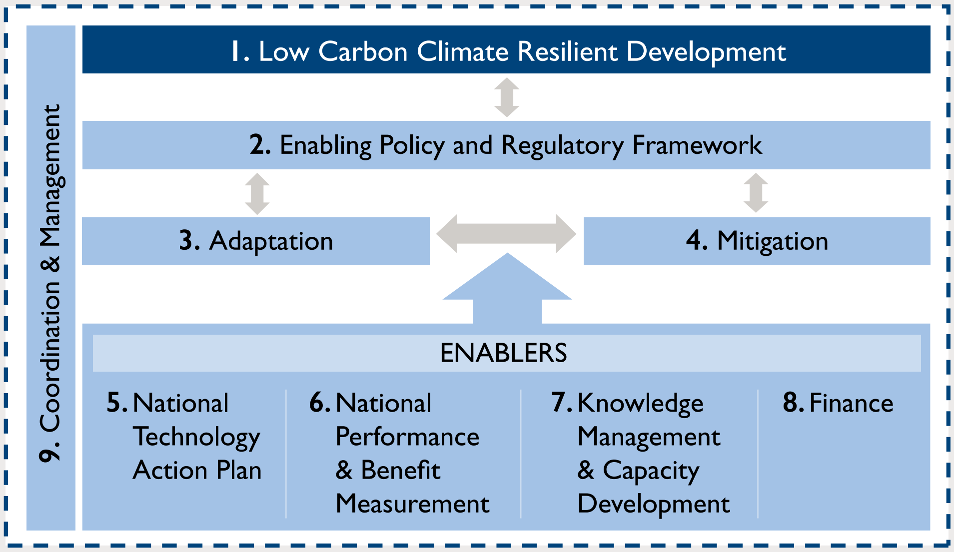

Figure 3. Kenya's National Climate Change Action Plan framework

In particular, to bridge climate mitigation and resilience in the electricity sector, the technical team supporting the NCCAP undertook a multi-criteria impact assessment of electricity sector options that included impacts related to mitigation, adaptation, and various other sustainable development objectives, as presented in Table 3. The assessment used the DIA framework developed through the LEDS Global Partnership and USAID EC-LEDS program.

Table 3. Multi-Criteria Impact Assessment to Inform Linked Adaptation, Mitigation, and Development-Focused Action in Kenya's Electricity Sector

● High Positive ⌓ Positive — Neutral/Minor impact ◡ Negative ◓ Uncertain	**Climate**			**Sustainable Development**				
	Abatement potential in 2030 ($MtCO_2$)	Abatement cost 2030 (USD/tCO_2)	Adaptation impact	Energy security	GDP growth	Employment	Improved waste management	Environmental impact
Expanding geothermal power	14.1	-19.9	●	●	●	—	—	—
Expanding wind power	1.4	-36.7	⌓	⌓	⌓	—	—	—
Expanding hydropower	1.1	-13.2	◡	⌓	⌓	—	—	◓
Clean coal (USC)	1.1	-11.1	⌓	—	⌓	—	—	◡
Distributed solar PV	1.0	13.3	⌓	⌓	⌓	⌓	—	—
Landfill gas generation	0.5	-12.4	⌓	⌓	⌓	—	●	⌓

For details on the use of the framework to support climate planning, please see https://www.ec-leds.org/tools-page/development-impact-assessment-tools. For a case study on Kenya's effort, see Cox et al. (2014).

Evaluating the broader social and economic development impacts—such as job creation and improvements to health—of potential mitigation and resilience actions identified through the assessments highlighted above is critical in aligning with development goals. Countries and jurisdictions can use multi-criteria impact assessments to evaluate economic, social, and environmental impacts across actions. An example multi-criteria impact assessment that was undertaken to inform low emission climate-resilient electricity sector action in Kenya is presented in Box 13.

Ultimately, a robust set of analyses will feed into the development of low emission climate-resilient development scenarios that provide a portfolio of priority actions governments can take to support integrated, development-focused climate action. Many EE and RE actions that could be included in these portfolios were described in earlier sections of this report.

4.3 Integrated Electricity Planning Approaches

As previously described, electricity grid systems are facing increasing climate resiliency challenges, including destructive weather events and climatic changes such as increases in average temperatures, short-term heat events of greater duration, and changes in precipitation patterns. Additionally, it is anticipated that many developing country grids will be integrating a significant amount of new, variable RE generation. In response, electricity grids need to both meet increasing electricity demand and be more reliable, resilient, and capable of integrating large amounts of clean energy generation. Integrated electricity planning approaches and grid modernization efforts can enable electric grid system operators to meet this diverse set of challenges.

Integrated electricity planning approaches can allow policymakers to evaluate and plan for electricity sector expansion from a more comprehensive perspective that brings together key social, economic, and environmental criteria. In particular, these approaches can build on traditional least-cost planning methods to ensure the resiliency of the electricity system under future climate conditions and in relation to shifting and extreme weather patterns and events. Further, integrated electricity planning approaches can also evaluate the GHG emission reduction potential of electricity sector options supporting a strong link between mitigation and resiliency in the electricity sector. Robust integrated electricity planning approaches can support improved understanding of future demand and changes in load profiles, and the new generation required to meet this demand can provide a useful framework to address emerging topics such as climate-driven risks to the electricity system. If appropriately understood and quantified, these risks may further inform the decision-making process regarding cost-effective, efficient, and sustainable generation options available, particularly when those decisions are informing infrastructure investments that will be in place for decades to come. USAID has put forward an approach called Integrated Resource and Resiliency Planning (IRRP) to enable comprehensive electricity sector planning across multiple technologies and criteria, including climate change mitigation and resilience. This approach is highlighted in Box 14.

Integrated electricity planning is considered a best practice for "meeting forecasted annual peak and energy demand, plus some established reserve margin, through a combination of supply-side and demand-side resources over a specified future period" (Wilson and Biewald 2013). Integrated electricity planning can consider RE resources available now and in the future, and strives for reliable and resilient grid planning that serves stakeholders and paying customers. An integrated electricity planning process can be an effective starting point for connecting GHG emissions mitigation strategies through RE integration with grid resiliency and reliability planning.

In the first stage of an integrated electricity planning process, goals and metrics can be developed to determine the impact of proposed electricity investment options.

Box 14. USAID's Integrated Resource and Resiliency Planning

USAID, in partnership with International Development Consulting (ICF), is building on traditional Integrated Resource Planning (IRP)—a participatory planning process used to identify energy options that serve the highest possible public good to maximize benefits (e.g., enhancing energy security, reducing sector inefficiencies, reducing electricity costs) by incorporating risks and reliability concerns (including climate change related risks) throughout the power value chain. Known as Integrated Resource and Resiliency Planning, this adapted planning process allows energy planners and investors to identify strategies and a mix of investments from a system-wide, long-term perspective that meet their objectives, including GHG mitigation, while considering climate change and other risks (e.g., risks associated with fuel price volatility). USAID is working with ICF to pilot this approach in Tanzania and Ghana. For more information on how USAID and ICF are applying IRRP to enhance power system resilience while meeting growing demands in Tanzania, see RALI (2017).

LEDS, as well as other national strategies and commitments such as NDCs grid reliability, or electrification goals, can provide an important starting point for integrated electricity planning goal-setting and support a consistent methodology for electricity planning across national and subnational actors. Once goals have been established, metrics can be designed in relation to desired outcomes and provide a way to measure successful implementation. Prioritizing goals and desired outcomes is the first step in designing integrated electricity planning processes.

Following the process to prioritize goals and establish metrics for success, various electricity scenarios can be developed that meet a forecast for energy demand plus provide a reserve margin through electricity supply and demand actions over a certain time frame. Time frames can align with GHG emission reduction and climate resilience targets identified in the country's LEDS or NDCs. Scenarios and related outputs are often evaluated by a diverse set of stakeholders to determine an optimal electricity sector pathway for the future. Stakeholders play an important role throughout this integrated electricity planning process by providing input to the overall approach, goals, metrics, and outputs. South Africa's stakeholder-led integrated electricity planning process is highlighted in Box 15.

Building on integrated electricity planning approaches and based on optimal scenarios, grid planners and operators can develop detailed plans to support integration of variable RE, often called grid-integration planning. Box 16 highlights USAID's efforts to support grid integration planning and implementation. While integrated resource plans can provide an important tool to address certain climate challenges at the subnational or regional level, community-level planning is also critical in supporting effective action based on unique

Box 15. Integrated Electricity Planning in South Africa

As the 29th-driest country in the world and with significant rainfall variation across seasons, South Africa considers water scarcity an issue of great importance. In particular, increasing electricity demand coupled with climate change is expected to place increasing pressure on scarce water resources and could have significant implications for the electricity sector. The government of South Africa is thus tackling water-electricity challenges from multiple fronts.

The South African Department of Energy developed an IRP in 2010 that brought together multiple stakeholders to evaluate development and climate-related impacts associated with various electricity supply scenarios forcasted to 2030. The IRP incorporated a multi-criteria impact assessment process that built upon a least-cost optimization model for electricity supply to balance development and environmental objectives. Specifically, water use, GHG emissions, and regional development, among other impacts, were assessed across electricity supply scenarios. The assessment occurred over a 13-month period to ensure strong stakeholder input and iteration. In 2015, the IRP was being updated with new data, information, and assumptions to better reflect South Africa's evolving electricity sector and demand forecasts. South Africa's IRP is a key tool linking climate change mitigation and resilience priorities (associated with water use) in the country's electricity sector.

Further efforts are also being made to link electricity and water planning at the national policy level. Notably, an analytical exercise monetizing economic costs associated with water use in the electricity sector was developed by the Energy Research Center and fed into a "Draft Policy Framework for Efficient Use of Water in Energy Production." The policy framework was submitted to the South African Water Research Commission for consideration and possible adoption at the national level.

As a whole, South Africa provides a strong example of a country bridging key stakeholders, analyses, and policies across the electricity and water sectors to support a low emission, climate-resilient future.

Sources: Madhlopa (2014); Energy Department: South Africa (2016a, b).

Box 16. Grid Integration Planning and Implementation

Grid integration for renewable energy is the practice of power system planning, interconnection, and operation that enables efficient and cost-effective use of renewable energy while maintaining the stability and reliability of electricity delivery.

USAID, in partnership with NREL, has developed Greening the Grid, which provides developing countries access to best practices and technical assistance to cost-effectively incorporate variable renewable energy into the electricity grid.

Source: Greening the Grid 2016.

local circumstances. Important aspects of these local climate change preparedness plans are highlighted in Section 4.4.

4.4 Local Climate Strategies

Building on LEDS, NDCs, National Adaptation Plans (NAPs), and other climate actions and strategies, subnational climate strategies can support low emission, climate-resilient electricity systems within cities, municipalities, and communities.

Local economic and social development goals provide the foundation and essential framing for considering climate actions across mitigation and resilience, and for developing subnational climate strategies. In the context of these broader development goals, communities can set local emission reduction and resiliency goals and targets based on unique local circumstances. Emission-reduction goals are often based on city or community-level GHG emission inventories. Resiliency goals are based on assessment of local vulnerabilities, threats, and opportunities, and often emphasize energy and water security (New York State 2016; EPA 2016).

Whole community planning processes with diverse stakeholders can support the successful design and implementation of local climate strategies. Identifying the essential stakeholders and subject matter experts, as well as those who have jurisdictional control or can influence policies, budget allocations, and actions, is a critical component of the planning process. Stakeholder engagement often requires multiple workshops and discussions over a long period of time to communicate and evaluate challenges and solutions across the community to develop a plan for action. Local climate action planning should be an iterative work-in-progress to support improvements and identification of new challenges and opportunities over time.

Climate resiliency is a key pillar of a local climate change strategy. As resiliency can have various definitions, it is important for a community to define resiliency from a local context, so projects and goals resonate with stakeholders and provide them with a sense of ownership and buy-in. Many examples exist; however, a community may wish to take an approach similar to the Rockefeller Foundation's 100 Resilient Cities, which defines urban resilience as "the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience" (100 Resilient Cities 2017).

To support low emission, climate-resilient electricity systems at the local level, communities can assess options that enable both GHG emission mitigation and climate resilience goals while also aligning with broader development objectives. Actions to support climate resilience can be identified through assessing threats and vulnerabilities to a community, often with a focus on grid and water infrastructure. Vulnerabilities are identified using past experience, forecasting, and subject matter experts, or a combination of many resources. Threats or hazards are further evaluated in the context of potential impacts to the community, as well as the likelihood of those threats occurring (based on statistical analysis and forecasting). The nature of threats and vulnerabilities, unique to specific communities, will inform prioritization of projects, sectors, and geographies to support climate resilience. Similar to the national LEDS process noted above, metrics can be developed to assess electricity sector actions relative to the climate vulnerabilities described above as well as GHG emission mitigation and development goals.

As outlined in previous sections, several electricity sector actions can support both climate resilience and mitigation at the local level. While large-scale electricity procurement decisions may be informed by national strategies such as LEDS and articulated in integrated electricity plans (often developed by utilities), local climate action plans can be critical in supporting smaller-scale electricity generation. For example, local climate action plans are often best suited to reflect potential DG opportunities given the decentralized and local nature of the technologies. Local climate plans can also incorporate specific goals or targets related to smaller-scale technologies and climate action.

Local climate action plans can also provide a critical mechanism to implement and monitor LEDS activities identified at the national level. For instance, a country's LEDS may put forth a goal to support climate resilience through a certain percentage of DG deployment; however, this deployment will actually occur within communities. Local climate action processes can also bring together stakeholders to build support for community action and potentially harness municipal-level funding to implement smaller-scale projects. At the same time, national-level funding, via LEDS or other strategies, could also be directed to municipal governments to implement distributed electricity projects or policies that enable islanding, storage, and other approaches to harden existing and new electricity infrastructure.[8] Finally, local communities can also play an important role in tracking climate and development impacts of smaller-scale electricity actions that can feed into monitoring and evaluation processes at the national level. Box 17 highlights climate-resilient planning efforts that link climate change resilience and mitigation at the local level in Oscarville, Alaska.

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[8] However, such budget allocations are context-specific and are dependent upon the level of decentralization and the capacity or ability of municipalities to access central funds.

Box 17. Oscarville, Alaska, Initiates Resilient Planning

Oscarville is a small village located on the north bank of the Kuskokwim River in western Alaska. This climate-threatened community relies on the Kuskokwim as the primary source for transporting goods and people and has a single power line that provides power from the power plant to the town of Bethel. In 2016, the village initiated a strategic planning process to increase the community's resilience while also bolstering sustainability goals. Oscarville is in the process of implementing the following to make the community more resilient in dealing with power outages, climate change, and transportation disruptions:

- Reduce electricity consumption rates by 2% per year through 2026. This is to be accomplished through a system of both energy education and the adoption of energy efficient technologies, including smart controls and LED lighting.
- Generate enough DG power to offset 50% of the village's consumption. This will largely be accomplished through solar PV and possibly DG wind turbines.
- Reduce dependence on fuel oil for heating. A waste heat recovery project will be implemented using the school's generator and a marine jacket system. The village will also explore waste-to-heat options to help reduce the amount of solid waste sent to the local landfill.

5. CONCLUSION

EE and RE can play an essential role in bridging climate change mitigation and resilience goals in the electricity sector. As more communities and nations consider these objectives in parallel through integrated planning processes, an increasing number of practical examples and case studies are emerging. These experiences provide insights to planners in both the developing and developed world and begin to provide model pathways for effectively deploying EE and RE in ways that not only reduce the carbon intensity of one's power system but also strengthen the resiliency of that system and the critical services it provides to those communities.

Several EE and RE technical solutions to link climate change mitigation and resilience goals were described in this paper, but as the scale and pace of EE and RE deployment continue to grow around the world, it is anticipated that many new lessons and innovative solutions will emerge as both energy demand and climate risks increase. It will be crucial to evaluate and bring these technical solutions together under integrated climate planning frameworks that connect stakeholders and unique considerations at the national, subnational, and local levels. Nations and actors are working to explore and make these connections on the ground, but there is still much work to be done to support mutually beneficial climate outcomes in the electricity sector through integrated planning and robust technical solutions.

GLOSSARY

Balancing area. The collection of generation, transmission, and loads within certain boundaries.

Demand-side management. Demand-side management and demand response enable consumers to participate in load control based on price signals.

Islandable. The ability to use distributed generation to provide power when storms or other events have knocked out the utility's ability to provide power.

Low emission development strategies. Plans that enable sustainable development while reducing greenhouse gas emission over the medium to long term.

Minigrids. Energy systems with a localized distribution network to a single community or a cluster of communities and are not connected to the grid.

Microgrid. A group of interconnected loads and distributed energy resources within a clearly defined electrical boundary that acts as a single controllable entity with respect to the grid.

Resilient power system. Resilient power systems bring together diverse technical solutions and integrated planning processes to allow systems to provide reliable, safe, and secure electricity during short-term disasters and events and as longer-term climate changes occur.

Smart grid. A nickname for the utility power distribution grid enabled with computer technology and two-way digital communications networking. The term encompasses the ever-widening palate of utility applications that enhance and automate the monitoring and control of electrical distribution networks for added reliability, efficiency, and cost effective operations.

Variability. The changes in power demand and/or the output of a generator due to underlying fluctuations in resource or load.

For additional definitions, see Greening the Grid's glossary at https://www.naed.org/naed/NAED/Research/Energy_and_Sustainability_Sub/Smart_Grid_Glossary.aspx.

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