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Powering through the Storm: Climate Resilience for Energy Systems

THE BOTTOM LINE

Climate change and its impacts on power systems often mean more frequent power outages and repairs, which raise maintenance costs and pose other challenges. Yet proactive modifications in project design, maintenance, and operation can enhance system resilience at lower costs than reactive adaptation. This Live Wire considers the implications of climate resilience in the power sector and highlights ongoing World Bank work and best practice, with a focus on Africa.

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Why is resilience important for energy projects?

Resilience is important in all networked infrastructure projects—especially those that deliver critical services

In the context of a power system—and electricity services specifically—resilient service delivery means that end users (businesses, homes, community infrastructure) see minimal disruptions to electricity services even if certain aspects of the system suffer damages or failures. Resilient energy projects are designed to continue delivering services even in the face of natural hazards (e.g., floods, landslides, cyclones, storms) and other stressors. If not accounted for in project design and operation, the impacts of such events may result in the loss of electricity, revenue, and costly repairs. Ultimately, integrating resilience early in project design and implementation protects investments and delivers lasting benefits.

The threat to infrastructure assets from natural hazards and climate change (which will increase the frequency and magnitude of natural hazards) is widely recognized.[1] The direct costs from reduced power utilization and lost sales—not to mention lost lives and livelihoods—are estimated at $120 billion annually in low- and middle- income countries. In many parts of Africa, losses from reduced utilization of disrupted infrastructure exceed 0.8 percent—higher than most other regions globally. Unreliable power systems also require backup options, including diesel generators that have high financial and environmental costs. Once parts of a system are damaged, especially transmission and distribution assets, coordination across other infrastructure sectors, such as telecommunication and transportation, is required to access and repair the damaged assets. The coordination and activation of supply chains, expertise, and emergency response planning must already be in place for timely repairs to occur. Taken together, the detrimental effects of hazards and climate change on power systems can disrupt progress toward the Sustainable Development Goals, including those related to health care, education, service provision, and economic growth. These challenges are particularly acute in Africa.

Fortunately, opportunities abound to incorporate resilience in new infrastructure projects. In most cases, engineering and systems-level solutions are available to reduce the vulnerability of power assets to stressors and increase the overall reliability of service. For example, assets within a system can be built to withstand hazard conditions (a process known as "hardening"), or a system can be designed to quickly re-route power or include backup options such as batteries, diesel generators, or other technologies ("redundancy"). When damages exceed operational levels, repairs can be accelerated if disaster-management plans include pre-stockpiling of parts, access to trained personnel, and secure access to sites ("repairs and recovery"). All of these measures increase the resilience of critical power assets and systems.

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[1] This section draws on the following works: Albert, Albert, and Nakarado (2004); Cervigni et al. (2015); CIMA Research Foundation (2019); Comes and de Walle (2014); Fekete, Hufschmidt, and Kruse (2014); Hallegatte, Rentschler, and Rozenberg (2019); Karagiannis et al. (2017); Loggins et al. (2019); Murphy et al. (2020); New York Power Authority et al. (2017); Nicolas et al. (2019); Oguah and Khosla (2017); Panteli and Mancarella (2015); Schweikert and Deinert (2021); and Sebastian et al. (2017).

The recognition that proactive resilience planning and investments can have positive impacts across project lifetimes in terms of both financial return and delivery of services motivated the creation and deployment of the Resilience Rating System at the World Bank.

Energy systems are central to the operation of many other connected systems. The reliable supply of electricity is essential for financial and banking operations, water and wastewater treatment, transportation, telecommunications, health services, and educational facilities. A power system encompasses transmission and distribution infrastructure (a complex, networked system in itself), and generation facilities that can include everything from standalone solar and wind to large nuclear power facilities. Depending on fuel type, natural gas and pipeline infrastructure can also be considered part of the broader power system, as can mining facilities, waste disposal, and regulatory and oversight bodies.

For each of these elements, it is important to understand not only the asset-specific vulnerabilities but how a failure, or even a delay, in the operation of one subsystem can affect others. For example, the failure of a pipeline delivering fuel to a generation facility not only delays the transportation of fuel but can also reduce generation capacity, limit output to the grid, and ultimately affect prices, electricity supply, and other important factors. These cascading failures are complex and are best understood using systems analysis, as is often done to plan generation and transmission.

The recognition that proactive resilience planning and investments can have positive impacts across project lifetimes in terms of both financial return and delivery of services motivated the creation and deployment of the Resilience Rating System[2] at the World Bank. Two sides of resilience are considered. The first is the resilience of a project—that is, how a project performs under stress from discrete events like a cyclone or flood, as well as ongoing stresses from climate change. The second is the resilience created by a project—that is, the additional resilience of the sector or beneficiaries brought about by the project. In the energy sector, projects that add resilience include those designed to increase electricity access and reliability, to build capacity, and to improve maintenance and emergency procedures. Strengthening a project's resilience, meanwhile, might include asset hardening, siting considerations, emergency planning, supply chain considerations, and more.

Is increased resilience worth the costs? Careful planning can inform how, when, and if resilience-enhancing investments make sense based on current and future conditions. A recent World Bank report (Hallegatte, Rentschler, and Rozenberg 2019) assessed thousands of scenarios of future socioeconomic and climate trends in an effort to quantify how various patterns of investment in resilient infrastructure would fare financially. The report found that in 96 percent of scenarios, investing in more resilient infrastructure was beneficial. On average, every $1 invested returned $4 in lifetime benefits, a net savings in low- and middle-income countries of $4.2 trillion. The savings were nearly doubled when climate change scenarios were included in the calculations.

When available, probabilistic risk analyses enable robust assessments of life-cycle costs to inform appropriate investment strategies. These cover routine construction and maintenance costs, repair costs from hazard events, and the expected probabilities of damages from different natural hazard and climate change events. However, such analyses may be difficult to conduct where data on infrastructure performance, key risks, and costs are lacking.

How do you build resilience into an energy-system project?

Asset hardening, operations and maintenance, and efficient disaster response and recovery plans can all be used to increase resilience

After identifying the greatest threats and gathering information on the local context (including institutional capacity and resources), one can proceed with investment planning.[3] For energy infrastructure, resilient investments can be classified into four categories:

- Those that reduce asset vulnerability
- Those that reduce liabilities and hazardous conditions created by infrastructure
- Those that enhance the reliability and service delivery of the electricity network
- Those that reduce the response time and increase the capacity to respond when natural hazards occur.

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[2] The Resilience Rating System methodology is detailed in World Bank Group (2021). Many of the projects described in this Live Wire are part of pilots applying these concepts.

[3] This section draws on the following works: Balaraman (2020); DELWP (2020); Engie Impact (2021a); Hirabayashi et al. (2013); Liu, Stanturf, and Goodrick (2010); Nicolas et al. (2019); Schweikert and Deinert (2021); and Smith et al. (2017).

Each type of investment can occur at various times in the planning, construction, and operation of an energy system. Some investments are small, while others entail high up-front costs or ongoing maintenance requirements.

Assets can be made less vulnerable by siting them outside the highest-risk regions and by hardening infrastructure—for example, designing it with specifications that ensure it can sustain natural hazards of greater intensity than historical conditions may indicate. Geospatial analysis is one way to identify high-risk regions. Systematic assessment of proposed infrastructure locations can help identify the expected historical stressors and projected climate change impacts by location. This is particularly important in the face of climate change, as many design standards are based on historical conditions that may not encompass the range of extreme events expected. In many locations, climate change is expected to exacerbate the frequency or severity of flooding, for example, and may increase the expected damages to infrastructure. Several adaptation and mitigation strategies may be employed. If possible, not siting assets in high-risk regions may be the most cost-effective approach. If this is not possible, adaptation options might include elevating photovoltaic panels and other infrastructure assets, building flood walls, or waterproofing key components. It is also important to assess the direction and speed of strong wind events, especially for rooftop-mounted photovoltaic systems. Inevitably, some assets cannot fully avoid high-risk locations. In this case, identifying the expected stress from natural hazards and climate change can inform design decisions.

Increasing resilience is about finding the right balance of redundancy, hardening, and readiness to respond and rebuild rapidly when a disaster hits.

Reducing the liability or risks that infrastructure poses to the environment and communities it serves is an important aspect of resilient siting, design, and operation. Transmission and distribution systems can pose a risk of wildfires, especially during hot, dry periods. This can occur in several ways, but it typically involves the arcing, or contact, of transmission or distribution wires with very dry vegetation. For example, Pacific Gas and Electric Company in the United States filed for bankruptcy in January 2019 owing to an estimated liability of $30 billion from wildfires caused by power lines it owned and operated. The fires killed over 100 people, burned thousands of acres, and required compensation of billions of dollars. Designing lines with aerial bundled cable and conductors in high-risk regions could reduce the likelihood of such risks but requires an additional investment of up to 60 percent of construction costs. Less expensive options include vigilant vegetation management and turning the lines off at times of extreme risk (e.g., during periods of high winds and drought).

The reliability of service delivery can be enhanced through routine maintenance, emergency backup generation options, and redundant systems. For photovoltaic panels, regular maintenance—including inspection for damages and dirt—can ensure that the arrays are delivering their full generation potential. This requires access to the infrastructure and therefore raises the question of panel placement (e.g., rooftops can be difficult to access). For battery storage, ensuring that ventilation systems are clean, free of debris, and adequate for cooling during times of high demand ensures proper system operation and minimizes damages. This is particularly true as elevated temperatures can increase the rate of battery degradation.

Completely avoiding all damages from climate change and natural hazards is not possible—and trying to achieve it would be extremely costly. Increasing resilience is instead about finding the right balance of redundancy, hardening, and readiness to respond and rebuild rapidly when a disaster hits.

The final component of a resilient power system is **an emergency response plan**. This should consider trained personnel, access to infrastructure, communication, available supplies, and broader system capacity. In regions that contain critical assets, the siting of a warehouse stocked with supplies can help ensure that parts are available when needed. Equally important are trained personnel to implement the needed repairs. Their successful deployment in turn relies on access to damaged regions (requiring functional roads and equipment) as well as telecommunication and other services. An emergency response and preparedness plan that includes these considerations can enhance system resilience and broader institutional capacity. Many of the power projects in Sub-Saharan African countries include specific components for institutional capacity building, including a disaster risk management plan.

How have these concepts been applied?

Several World Bank energy projects in Africa recently incorporated resilience in their preparation, design, and operations

A recent study in **Benin** included a cost-benefit analysis of various backup and redundancy options for electricity generation, storage, and distribution.[4] This allowed for a life-cycle comparison of the costs of implementation of each strategy alongside a cost assessment of the likelihood of outages and the resulting impacts from loss of service. For backup diesel generators, the capital cost was estimated at $800 per kilowatt installed and an operating cost of $20 per kilowatt installed for maintenance and $0.25 per kilowatt-hour for fuel. Additional considerations included the looping of lines to create redundancy, estimated at an additional construction cost of $30,000 per kilometer. Where mini- or micro-grid resources exist, resilient design could include the ability of a system to decouple and operate as a standalone resource for emergency backup power.

Several low-cost investments to reduce assets' vulnerability to natural hazards were identified across multiple projects. These included simple maintenance activities, such as regular vegetation management (at approximately $800 per kilometer) and turning off the lines during periods of high wind and drought.

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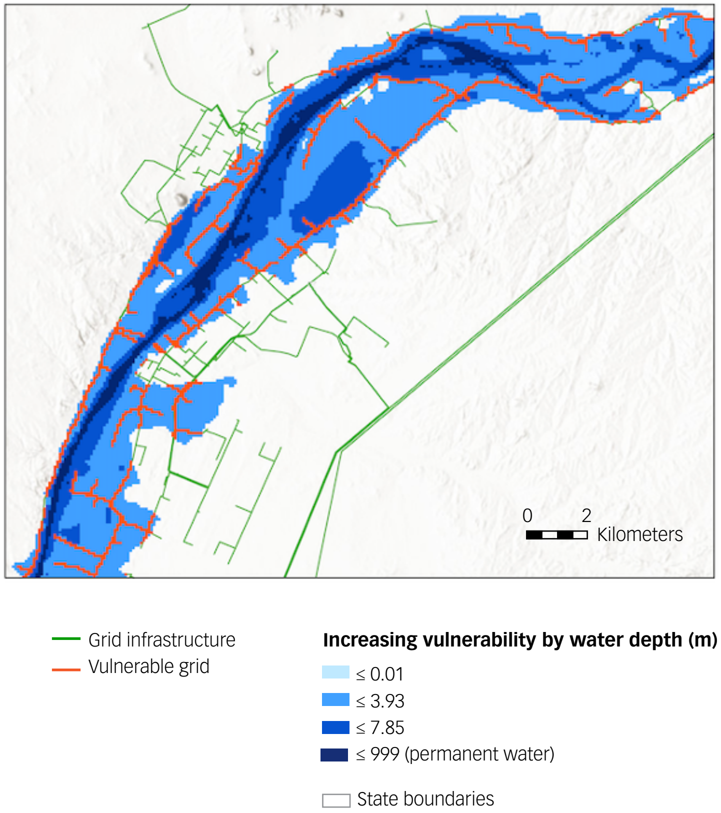
In **Cabo Verde**, a multi-island assessment of projects looked at how siting, design, and infrastructure affected the resilience of renewable energy. One project that expanded rooftop solar to local health care clinics had to consider strong island winds, requiring additional mounting and bracketing to ensure the solar panels were firmly attached. In many cases, the existing roof structure was not designed to accommodate these requirements, requiring additional investment.

A resilience assessment of a grid extension project in **Mozambique** found that planned distribution infrastructure in certain locations would have high exposure to fires and cyclones. In these locations, changing the distribution poles from wood to steel increased overall project resilience and reduced the need for ongoing maintenance. For the entire project, a cost increase of just over 2 percent was estimated to reduce damages in these high-risk regions by up to 90 percent.

In **Sudan**, geospatial risk analysis was used to identify current and planned assets at risk from flooding. A sample risk analysis based on that project appears as figure 1.

Figure 1. Sample hazard assessment highlighting grid assets vulnerable to flooding



Source: World Bank Group.

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[4] This section draws on the following works: DELWP (2020); Engie Impact (2021b); Karagiannis et al. (2017); and Thacker et al. (2018).

For substations, elevating the cabin at the time of construction does increase the initial construction cost. However, the action is recommended because it is likely to reduce lifetime operational exposure to flood events that can result in costly repairs and extended network downtime.

In **Tanzania**, a recent project increased the number of household grid connections and rehabilitated and expanded distribution infrastructure. Some of the locations considered were prone to frequent flooding at depths of 0.5 meters or more, the standard height for installation. For new household connections, ensuring that the installation is above the expected flood depths can be done at little to no cost. Similarly, ensuring that pole-mounted transformers sit at least 2–3 meters above expected flood depths can reduce exposure and damage. For substations, elevating the cabin at the time of construction does increase the initial construction cost. A study of UK substation hardening suggested that elevating substations to 1.2 meters represents a 7 percent increase over base costs. However, the action is recommended because it is likely to reduce lifetime operational exposure to flood events that can result in costly repairs and extended network downtime. This and other simple measures to protect assets from flooding appear in the photos below.

Examples of adaptation measures to protect infrastructure assets from flooding

a. Elevated PV array using concrete blocks

b. Elevated substation

c. Ventilation units raised above the battery energy storage system

d. Elevated battery energy storage system

a. https://en.wikipedia.org/wiki/Photovoltaic_mounting_system. Licensed for free use under by CC 2.0

b. https://side.developpement-durable.gouv.fr/NORM/doc/SYRACUSE/6934/reduire-la-vulnerabilite-des-reseaux-urbains-aux-inondations.

c and d. https://www.blackshieldshvac.com/applications/climate-control-solutions-for-bess/

Many of the interventions listed above do incur some initial costs, although these vary widely by intervention type. Each reduces damage and life-cycle costs, including for repairs. Whether a solution is appropriate can be assessed based upon the life-cycle risk of damage, the costs of repairs, and the indirect costs of lost power to consumers. Similar adaptations have been considered for projects in Tanzania, Benin, and the Democratic Republic of Congo.

Considering resilience early in project conceptualization—in siting, design, maintenance, operations, disaster risk management, and response plans—can increase the resilience of important infrastructure assets.

What can policy makers do to move toward a more robust, resilient system?

They can make sure resilience is considered from the start, and that adequate policy, budget, and staffing are in place to enhance resilience

Considering resilience early in project conceptualization—in siting, design, maintenance, operations, disaster risk management, and response plans—can increase the resilience of important infrastructure assets. Engagement with stakeholders on the ground throughout the design and building processes can ensure that lessons learned in other projects are integrated appropriately. While many tools are available to support specific aspects of project resilience, challenges remain. These include funding for up-front resilience studies and efforts to raise awareness, as well as regulations to incentivize related investments and ongoing work to identify better quantitative toolkits and approaches for understanding resilience within and across sectors.

To perform a resilience analysis, knowing what information is available and how to integrate it into ongoing projects is important. In many locations, data on the performance of assets under stress, as well as simple tools with which to assess the economics of associated damages, are unavailable. But where specific information is available, it must be integrated with existing feasibility studies and projects. Clearly defining who is responsible for these tasks is another challenge. Finally, in many cases, adaptation and mitigation efforts to increase resilience may impose additional up-front costs that may strain initial budgets.

Ongoing efforts to develop and maintain a resource base of resilience expertise, and to fill data and funding gaps, are crucial to improving future projects. Several resources developed by the World Bank for its ongoing resilience work include Think Hazard.org (https://thinkhazard.org/en/), the Climate Change Knowledge Portal for Development Practitioners and Policy Makers (https://climateknowledgeportal.worldbank.org), the Resilience Booster Tool (https://resiliencetool.worldbank.org/#/home), and Eskedar (2021). New ones are being continuously improved as lessons are learned.

This Live Wire was peer reviewed by Debabrata Chattopadhyay, senior energy specialist at the World Bank.

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