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Disaster Preparedness Offers Big Payoffs for Utilities

THE BOTTOM LINE

Achieving the right balance between resilience and the cost of electricity poses a challenge. Technical solutions are available to mitigate the risks posed by most hazards, but they affect the prices customers pay for power and may be difficult to justify to regulators. Because power system assets are long-lived, they cannot be easily replaced to take advantage of advances in technology. This is where good planning comes in: depreciated, obsolete, or damaged equipment can be replaced with hazard-hardy components. Operators must plan to "build back better."

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Why is this issue important?

The cost of preventable power outages—in lives and lost production—is unnecessarily high

When Superstorm Sandy hit the United States, 8.5 million people were left without power for days or weeks. The storm claimed 72 lives; 87 more died from its consequences (CEA 2013). In developing countries, the impact of such natural hazards can be far worse, and the specific effects on power systems are generally not well documented. Asia and the Pacific are particularly vulnerable—87.6 percent of all those affected by disasters over the period between 1970 and 2014 lived in this region (UNESCAP 2015). Tropical cyclone Nargis affected nearly 2.4 million people in Myanmar in 2008 and took some 84,000 lives, with another 54,000 people counted as missing (World Bank 2013). The South India floods of 2015 resulted in 500 lost lives both during and after the flood. Just four hours into the second round of intense rains on December 1, 60 percent of city locations were without power, and several hospitals stopped functioning. Fourteen patients died after power and oxygen supplies failed on December 4, days after the initial flooding.[1] Cyclone Sidr swept through Bangladesh in December 2007 and resulted in a countrywide blackout that took more than 16 hours to restore. In Haiti after the earthquake of 2010, it took six weeks to restore the first power station and nine months to restore billing. The outages in the Caribbean following Irma (Barbuda; St. John, U.S. Virgin Islands) and Maria (Dominica, Puerto Rico) may well be worse, although official reports have yet to be issued.

Like all other infrastructure, power systems are threatened by extreme weather events and natural disasters, including hurricanes and tornadoes, flooding and rises in sea level, mudslides, earthquakes and ensuing tsunamis, severe wildfires, droughts and heatwaves, and severe winter storms. Damage to power infrastructure goes on to affect telecommunications, transportation, logistics, health facilities, and other sectors. Yet most utilities give insufficient attention to such threats. Fortunately, well-documented technical and fiscal instruments are available to help utilities and the public cope with disasters. Some simple measures, if planned for, can help alleviate the impact of disasters. For example, when informed about a disaster in advance, industries, schools, and hospitals can adjust their operations to minimize damage and even maintain operations at levels close to normal.

How prepared are utilities to handle disasters?

Not nearly as well prepared as they should be

Standard engineering practice is to design a power system to withstand the hazards—seismic events, floods, lightning—that prevail in a region. For example, pylons should have footings or foundations built to withstand flooding. Dams should be designed for predefined flood levels. Power plants and substations should be equipped with fire-protection systems. Sea defense walls, greenbelts, and coastal dykes are other measures recommended to protect key infrastructure.

Such standard preparations are often not made, however, even where outages can have severe effects on people's lives. This is especially true in developing countries, where informal settlements and unplanned land use are common. And although it may be

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[1] http://indianexpress.com/article/india/india-news-india/heavy-rains-lash-parts-of-tamil-nadu-puducherry-normal-life-hit/; http://indianexpress.com/article/india/india-news-india/live-chennai-hit-by-heaviest-rains-in-a-century-normal-life-thrown-out-of-gear/.

financially infeasible to build entire systems with enough resilience to meet all anticipated disasters, a good emergency preparedness plan accompanied by strategic investments can shorten restoration time and limit the impact of disasters. But even these require a framework to assess and address hazards.

The major components of the power system are subject to different types of hazards. For example, drought poses a greater threat to generation facilities than to transmission systems, while the latter, because of their geographic extent, are more vulnerable to hurricanes and wildfires. The reach of transmission lines also means that a localized incident will affect the transmission system less than it would a power plant.

Thermal plants that need water for cooling are vulnerable to droughts and heat waves because plants must compete for scarce water with other uses such as agriculture and domestic consumption (EPRI 2016). In South Asia, where hydropower is an important source of electricity, changes in hydrological patterns can be extremely disruptive (World Bank 2013).

Interdependence with other infrastructure further exposes power systems to vulnerabilities. For example, an incident that affects gas supplies can cripple a power plant even though the plant itself may be unaffected. Similarly, when road networks are destroyed during a disaster, efforts to repair and restore the fuel supply system may be hampered (IET 2014).

Given their geographic extent and long life, power systems may be hit multiple times, with each incident causing fluctuations in supply and demand and affecting the utility's revenue stream, even if infrastructure is not directly damaged. Hazard incidents are often followed by sharp fluctuations in demand that may affect system conditions (frequency, voltage oscillations) and possibly overload certain transmission lines. The reduced demand may also increase the average cost of production, compounding revenue losses owing to volume reductions.

The growing share of solar and wind generation introduces yet another type of risk. Wind turbines will shut down during strong winds, and solar panels are useless under cloudy skies, eliminating these sources of generation during a storm (EPRI 2016). Solar farms are also susceptible to strong winds and falling debris.

Well-documented technical and fiscal instruments are available to help utilities and the public cope with disasters. When informed about a disaster in advance, industries, schools, and hospitals can adjust their operations to minimize damage and even maintain operations at levels close to normal.

What are the options for incorporating disaster resilience in power systems?

Building resilience into power systems is a systemic, multi-step process

Resilience starts with understanding risks, devising a strategic framework to mitigate those risks, and identifying critical nodes. A risk assessment will identify the system's exposure to extreme events, the frequency of those events, and their impact on system operations. Some options for incorporating disaster resilience apply at the system level, and others are specific to components of the network (generation, transmission, or distribution). This section starts with measures that are applicable at the system level and then takes a look at measures applicable to subsystems.

Before any capital investment is made, it is important to prepare a strategic framework for resilient disaster management. Preparedness is the key. Having a well prepared and widely shared emergency management plan with periodic trainings and simulation exercises (drills) is essential if the benefits of resilience measures are to be realized. As the plan is implemented, the resilience of the system should progressively increase.

Critical nodes are major points in the interconnected power network that may spread blackouts to a larger area or exert critical loads under strained conditions. Various methods can be used to identify critical nodes—for example, the multi-hazard risk framework devised by the U.S. Office of Technology Assessment (OTA 1990) and the method presented by Li and others (2015) in their discussion of network control theory. In large systems with cross-border interconnections, utilities from the participating countries should join together in this exercise (GridWise Alliance 2013).

Building resilience can't be improvised. Resilience measures provide early warnings, minimize the immediate impact of the event, and enable quick recovery after the event. As shown in figure 1, four features characterize a resilient system: robustness (the ability to absorb shocks, which includes reinforcement and substitute or redundant systems), resourcefulness (the ability to manage a disaster as it unfolds, which includes identifying options and prioritizing actions to control damage), rapid recovery (the ability to restore systems quickly), and adaptability (the ability to incorporate lessons from a disaster to "build back better") (NIAC 2010).

> Even where it is financially infeasible to build entire systems with enough resilience to meet all anticipated disasters, a good emergency preparedness plan accompanied by strategic investments can shorten restoration time and limit the impact of disasters.

A disaster-resilience framework is necessarily incremental (OTA 1990; EPRI 2016; CEA 2013). Because of the long lifespan and high replacement costs of much power infrastructure, it is typically not feasible to replace all equipment at once, leaving parts of the power system vulnerable until they can be upgraded or replaced. Some components, such as wooden distribution poles, grow weaker with age, making them more susceptible to collapse under extreme events. New facilities can be designed to meet known climatic conditions that have a high probability of occurrence, such as floods, storms, and droughts.

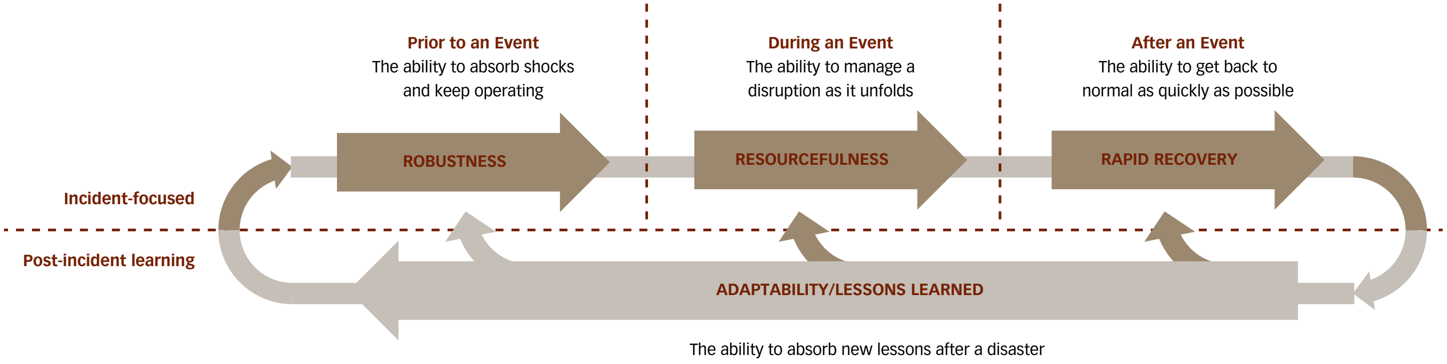
A number of "soft" measures can increase resilience, as well—key among them operational procedures for utility staff. System operators need to know precisely what to do at the onset of and during a catastrophe. The operational procedures need to be kept up to date, and staff training should include frequent drills on handling such events.

Specific measures to increase power system resilience are discussed below. These fall into three categories: (a) incorporating hazard risks into system planning; (b) standardizing equipment and improving inventory management; and (c) investing in resilient infrastructure such as smart grids, stronger towers and poles, and robust technologies.

Hazard risks should be taken into account in system planning. Until recently, little work had been done on including climate considerations in planning. Although these issues are well understood in qualitative terms and practiced in the field, only recently have their trade-offs been expressed quantitatively in power system plans that achieve a good balance between cost and risks.

An ongoing study by the World Bank, for example, uses a two-stage stochastic planning model to analyze the impact of climate risks on the power system expansion plan for Bangladesh, which

Figure 1. Building resilience at every step



Source: NIAC (2010).

is highly vulnerable to climate change. The analysis concludes that modeling the relationship between climate and generation-system parameters increases capital requirements by $560 million (for additional flood protection)—but could save up to $1.6 billion.

Similar considerations of natural hazards can be included in transmission and distribution system planning. In more advanced systems, contingency planning can be extended to include demand-side management. For example, a predetermined amount of load can be disconnected during an event so as to preserve grid stability and prevent widespread outages.

The output of the planning process also feeds into postdisaster needs assessment. By taking into consideration the risk of natural hazards, proper planning can help identify segments of the power system that can and should be "built back better," the costs of which can then be included in needs assessments.

System operators need to know precisely what to do at the onset of and during a catastrophe.

Standardized equipment and better inventory management are part of the resilience chain. Standardizing major equipment improves system resilience, since standardized equipment can be used interchangeably and shrinks the inventory of spares required for both routine operations and post-disaster recovery. One of the most unwelcome incidents during a disaster is losing the spares that are needed for system restoration. For that reason, a systemwide approach to maintaining the stock of spares may be required in countries that are vulnerable to catastrophic events. In transmission systems, for example, it is not uncommon for different areas of the grid to manage individual stocks (with the equipment in stock available on request for use in other parts of the network).

An even better approach would involve central management of the stock of spares in close collaboration with the operating areas. The equipment in question need not be centrally located. On the contrary, geographic dispersal of warehouses reduces the risk of losing critical quantities of spares to catastrophic events. However, the stocking of warehouses can benefit from central oversight to ensure that stock levels remain adequate and can be shared across locations. Independent power producers might even share some common vital spares. The location of warehouses will have to be carefully selected, and warehouse structures must be resilient to natural hazards.

The database of assets should be regularly updated so that the utility can quickly determine capital requirements to replace damaged equipment following a disaster. Many utilities in developing countries maintain only fragmented information on their power systems across units—this will hamper system recovery.

Some items, such as high-voltage transformers, are too expensive to permit backups to be kept in stock, and the time between placement and fulfillment of an order for a replacement may be up to two years. Some utilities solve this problem by replacing damaged transformers with others from less-critical sections of the network, giving the utility time to order replacements.

Investment should emphasize resilient infrastructure. Examples include smart grids, backup control centers, stronger components (such as poles and towers), underground cables, mobile substations, and emergency restoration systems.

Smart grids improve situational awareness. "Smart" electronics on transmission and distribution networks have helped many utilities improve grid performance by providing up-to-the-minute information on the state of the power system. These devices also help improve resilience on the grid (GridWise Alliance 2013; CEA 2013). For example, phasor measurement units that rapidly assess and report on the state of the transmission network have averted widespread blackouts even during normal operations. They can be employed in wide-area monitoring systems to automatically react to changes in the network and avoid outages. The two-way communication capability of advanced metering infrastructure, implemented at the level of individual consumers or groups of consumers, can aid in restoration. For example, AMI allowed the Potomac Electric Power Company that serves the Washington, DC, metropolitan area to rapidly restore power after Superstorm Sandy. The utility received "no power" signals from meters that enabled them to pinpoint outages and dispatch teams to specific areas instead of scouting wider areas to locate problems (CEA 2013).

Backup control centers improve resilience. Utilities in developing countries exposed to natural hazards can follow the example of the industrialized world by installing backup control centers from which to resume system operations following a failure at the main control

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center. The backup control center should be located some distance from the main center to reduce the risk of losing both facilities.

Mobile substations and emergency restoration systems significantly reduce restoration time. Mobile substations are truck-mounted "plug-and-play" substations that can be used to bypass damaged substations to meet demand. Emergency restoration systems are structures that can be rapidly erected to divert collapsed lines.

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Different sets of measures are appropriate for generation and for transmission/distribution.

Generation plants are exposed to droughts, fires, earthquakes, floods, tsunamis, and heat waves, as well as events that affect fuel supplies and transmission interconnections.[2] Among the aspects of plant design that can increase resilience are higher embankments, alternative forms of cooling, alternate fuel storage, and distributed generation.

Enhanced embankments and elevation can help protect against floods and landslides. Alternate forms of cooling meriting consideration are air- or hybrid-cooled generators. The Thermosyphon Cooler Hybrid Cooling System, for example, uses evaporators and an air-cooled condenser (or open cooling tower) to cool convection-driven refrigerants (EPRI 2016). Similarly, with gas turbines, the cooling system requires only a small amount of water, which is cooled by a fin-fan cooler or air-cooled heat exchanger. Alternative forms of fuel storage include the use (presently the subject of research) of active carbon membranes to store natural gas at a fraction of the pressure typically used in cylinders (EPRI 2016). Distributed generation and mobile generators can be deployed to power critical loads during disasters (box 1). However, enhanced supervisory and control systems will be required to effectively dispatch such units, which may require telecommunication infrastructure (GridWise Alliance 2013).

Because transmission systems extend over a wide area, it is possible to distribute critical nodes, lowering risk to the system as a whole. However, geographic distribution also means transmission systems are more exposed to multiple hazards. Overhead transmission and distribution grids are particularly prone to strong wind events, such as the tropical cyclone that struck Fiji in 2015 (box 2).

Building redundancy into the network raises flexibility and resilience. Increasing the number of electrical paths improves resilience because power can be rerouted around faulty segments (CEA 2013).

Towers, poles, and foundations can be designed to withstand strong winds. Installing more dead-end towers and poles (which are stronger than suspension towers) between spans reduces the risk of cascades of collapse, which increase the time required to restore service.

Underground cables can forestall and limit outages during storms. On the other hand, they are 2–15 times more expensive to install than overhead conductors, cost more to repair, and take longer to restore in the event of a fault. Aerial bundled conductors resist winds and growing trees better than conventional aerial conductors at lower costs than underground cables.

Box 1. Distributed systems improve resilience: Lessons from Tropical Cyclone Pam in Vanuatu

Electricity was hit hard by Tropical Cyclone Pam. The records of UNELCO, a Vanuatu utility, show that Efate and Tanna islands were the hardest hit of its concession areas: 65 kilometers of transmission and distribution lines were damaged or destroyed. An estimated 12,000 customers were affected, representing approximately 5 percent of UNELCO's base load.

The off-grid portion of the electricity sector suffered minimal damage and losses. Owners of individual solar home systems prepared before the cyclone by dismantling and storing the systems.

Disaster recovery recommendations included the provision of backup generators for critical infrastructure, such as hospitals, pharmaceutical storage sites, airports, and wharves, together with distributed systems for camps and water and sanitation facilities.

Source: Government of Vanuatu (2015).

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[2] Catastrophes at nuclear power plants are a much larger and complex subject that is not dealt with here.

MAKE FURTHER CONNECTIONS

Live Wire 2015/43. “Integrating Climate Model Data into Power System Planning,” by Debabrata Chattopadhyay and Rhonda L. Jordan.

Live Wire 2015/44. “Mapping Smart-Grid Modernization in Power Distribution Systems,” by Samuel Oguah and Debabrata Chattopadhyay.

Live Wire 2016/59. “Are Power Utilities in Tonga and New Zealand Resilient? Human and Organizational Factors in Disaster Response,” by Ray Brown, Xiaoping Wang, and Christopher Page.

Live Wire 2016/60. “Toward Climate-Resilient Hydropower in South Asia,” by Pravin Karki, Laura Bonzanigo, Haruhisa Ohtsuka, and Sanjay Pahuja.

Live Wire 2016/66. “Can Utilities Realize the Benefits of Advanced Metering Infrastructure? Lessons from the World Bank’s Portfolio” by Varun Nangia, Samuel Oguah, and Kwawu Gaba.

Box 2. The vulnerabilities of Fiji’s distribution system during Tropical Cyclone Winston

On February 20, 2016, Tropical Cyclone Winston caused all of the customers of the Fiji Electricity Authority (FEA) to lose power. This was primarily because of extensive damage to the distribution grid (with lower levels of damage to power generation and transmission infrastructure). Damage to the rural power generation assets of Fiji’s department of energy was significant, with approximately 54 diesel mini-grids and 609 solar home systems affected.

Emergency repairs were completed and full generation capacity restored within one week of the cyclone, except at the Nadarivatu Power Station, which was switched on after four weeks. All transmission assets were operational by March 20, 2016, although some works were temporary and some customers remained without power. An estimated 4,000 km (41 percent of FEA’s total distribution assets) were damaged in the storm.

An estimated 1,500 residential customers whose homes were destroyed were projected to be reconnected gradually over the next 12 months, as reconstruction proceeded. For customers whose houses were not destroyed, full restoration and connection was not projected to occur until 4–5 months after the cyclone, highlighting the fact that resilience is important throughout the supply chain.

Recommendations for recovery included using more underground cables and installing power plants at higher altitudes.

Source: Government of Fiji (2016).

Where do we start?

Appreciating the need to incorporate disaster resilience in planning, design, and operations is the biggest challenge

There are many ways to build the resilience of power systems. Some are very capital intensive—others less so. The first priority is to assess the vulnerabilities of the power sector. Platforms like the World Bank’s Climate Change Knowledge Portal (http://sdwebx.worldbank.org/climateportal/) can help countries understand some of the hazards their systems face. The Global Facility for Disaster Reduction and Recovery (http://www.gfdrr.org) also offers a set of thematic programs dedicated to specialists and clients at the country level (ThinkHazard, Understanding Risk, Resilient Infrastructure, Resilient Cities, Resilience to Climate Change, Hydromet services, Resilient Recovery, etc.).

The risks of natural hazards, as gauged in risk assessments, should be incorporated into power system planning to better understand the costs and benefits of hazard-proofing power system infrastructure. Planning can also help identify those components that need to be “built back better.”

Investments in infrastructure must be made in tandem with investments in human capital. System operators should be well trained to react appropriately to disasters.

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MAKE FURTHER CONNECTIONS

Live Wire 2016/67. "Managing the Grids of the Future in Developing Countries: Recent World Bank Support for SCADA/EMS and SCADA/DMS Systems," by Varun Nangia, Samuel Oguah, and Kwawu Gaba.

Live Wire 2016/68. "Distribution Automation: An Opportunity to Improve Reliability and Quality," by Samuel Oguah, Varun Nangia, and Kwawu Gaba.

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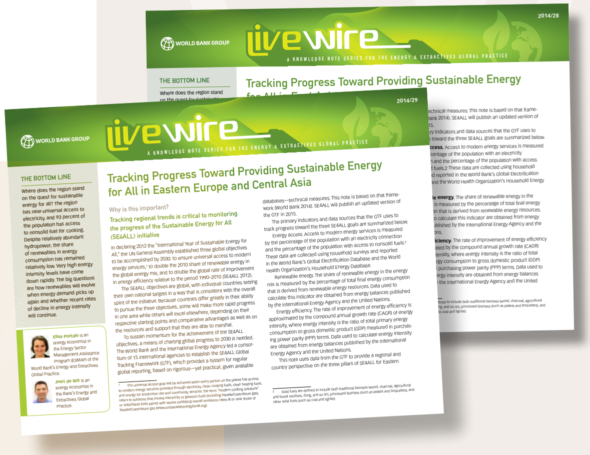

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THE BOTTOM LINE

Where does the region stand

Tracking Progress Toward Providing Sustainable Energy

2014/29

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THE BOTTOM LINE

Where does the region stand on the quest for sustainable energy for all? The region has near-universal access to electricity, and 93 percent of the population has access to nonsolid fuel for cooking. Despite relatively abundant hydropower, the share of renewables in energy consumption has remained relatively low. Very high energy intensity levels have come down rapidly. The big questions are how renewables will evolve when energy demand picks up again and whether recent rates of decline in energy intensity will continue.

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Tracking Progress Toward Providing Sustainable Energy for All in Eastern Europe and Central Asia

Why is this important?

Tracking regional trends is critical to monitoring the progress of the Sustainable Energy for All (SE4ALL) initiative

In declaring 2012 the "International Year of Sustainable Energy for All," the UN General Assembly established three global objectives to be accomplished by 2030: to ensure universal access to modern energy services,[1] to double the 2010 share of renewable energy in the global energy mix, and to double the global rate of improvement in energy efficiency relative to the period 1990–2010 (SE4ALL 2012).

The SE4ALL objectives are global, with individual countries setting their own national targets in a way that is consistent with the overall spirit of the initiative. Because countries differ greatly in their ability to pursue the three objectives, some will make more rapid progress in one area while others will excel elsewhere, depending on their respective starting points and comparative advantages as well as on the resources and support that they are able to marshal.

To sustain momentum for the achievement of the SE4ALL objectives, a means of charting global progress to 2030 is needed. The World Bank and the International Energy Agency led a consortium of 15 international agencies to establish the SE4ALL Global Tracking Framework (GTF), which provides a system for regular global reporting, based on rigorous—yet practical, given available databases—technical measures. This note is based on that framework (World Bank 2014). SE4ALL will publish an updated version of the GTF in 2015.

The primary indicators and data sources that the GTF uses to track progress toward the three SE4ALL goals are summarized below.

Energy access. Access to modern energy services is measured by the percentage of the population with an electricity connection and the percentage of the population with access to nonsolid fuels.[2] These data are collected using household surveys and reported in the World Bank's Global Electrification Database and the World Health Organization's Household Energy Database.

Renewable energy. The share of renewable energy in the energy mix is measured by the percentage of total final energy consumption that is derived from renewable energy resources. Data used to calculate this indicator are obtained from energy balances published by the International Energy Agency and the United Nations.

Energy efficiency. The rate of improvement of energy efficiency is approximated by the compound annual growth rate (CAGR) of energy intensity, where energy intensity is the ratio of total primary energy consumption to gross domestic product (GDP) measured in purchasing power parity (PPP) terms. Data used to calculate energy intensity are obtained from energy balances published by the International Energy Agency and the United Nations.

This note uses data from the GTF to provide a regional and country perspective on the three pillars of SE4ALL for Eastern

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[1] The universal access goal will be achieved when every person on the planet has access to modern energy services provided through electricity, clean cooking fuels, clean heating fuels, and energy for productive use and community services. The term "modern cooking solutions" refers to solutions that involve electricity or gaseous fuels (including liquefied petroleum gas), or solid/liquid fuels paired with stoves exhibiting overall emissions rates at or near those of liquefied petroleum gas (www.sustainableenergyforall.org).

[2] Solid fuels are defined to include both traditional biomass (wood, charcoal, agricultural and forest residues, dung, and so on), processed biomass (such as pellets and briquettes), and other solid fuels (such as coal and lignite).