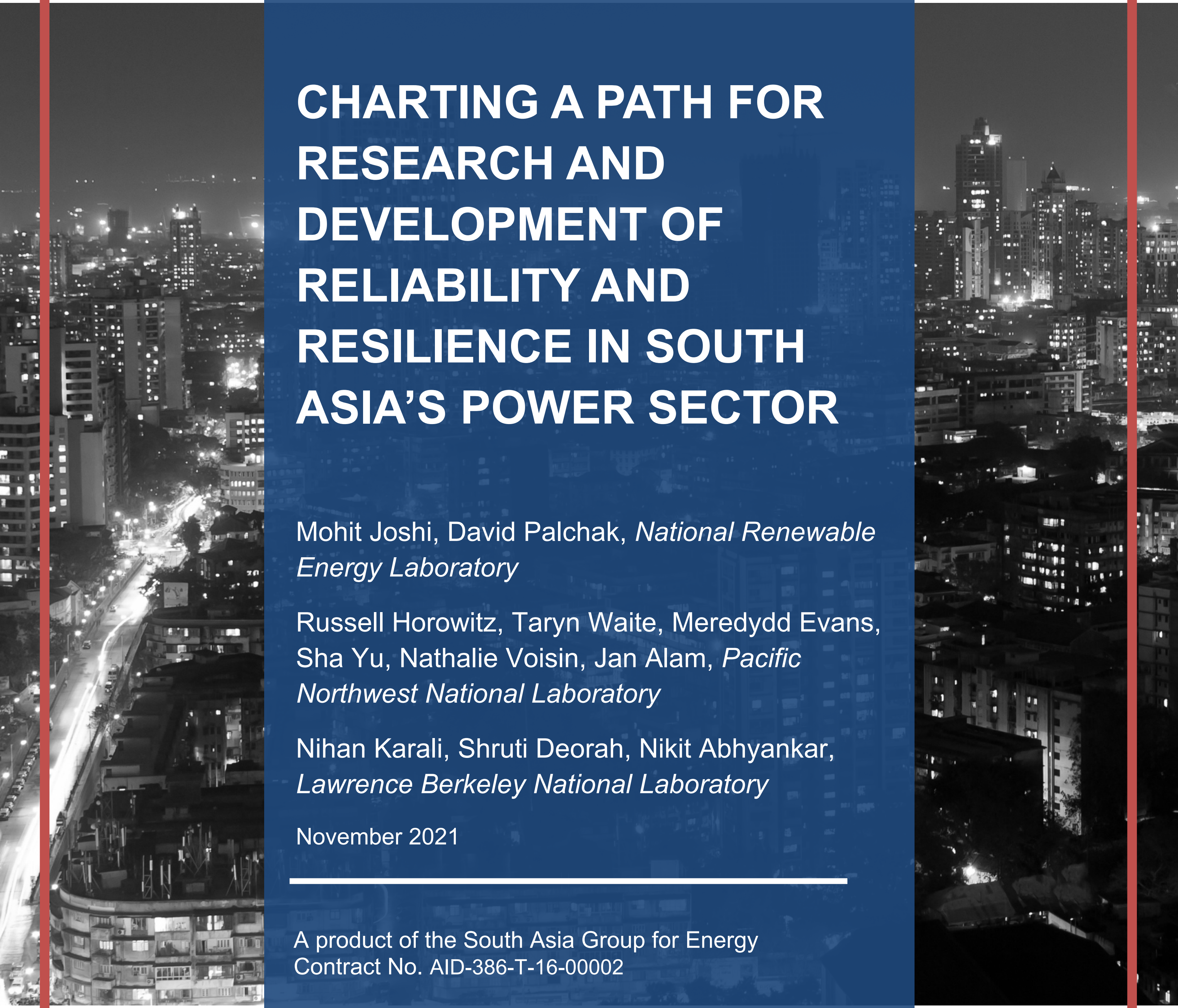
CHARTING A PATH FOR RESEARCH AND DEVELOPMENT OF RELIABILITY AND RESILIENCE IN SOUTH ASIA'S POWER SECTOR



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NOTICE

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Abstract

The power sector in South Asia faces several trends that have the potential to impact reliability and resilience. Rapidly increasing demand, coupled with an increasing reliance on variable renewable resources and the circular linkages with climate change, points to an increasing need to understand the extent of climate impacts on both electricity load and generation. These larger shifts are also coupled with opportunities near the grid edge that could have a large impact on system planning and operations, such as electrification of the transport sector, increased reliance on buildings to serve a broader set of loads and be flexible resources for utilities, more efficient use of industrial and agricultural loads, and growth in distributed energy resources such as rooftop solar and batteries. It is critical that, as this transformation takes place, expectations for reliability and resilience of the grid continue to increase in the region. The South Asia Group for Energy (SAGE), composed of the U.S. Agency for International Development (USAID), the U.S. Department of Energy, and three national laboratories, has been tasked with providing an overview of the research and development resources necessary to understanding the upcoming challenges for the power system as it pertains to reliability and resilience. This discussion paper identifies some of the key trends and connections that are important for power sector reliability and resilience and provides a starting point for eliciting feedback from power sector stakeholders about their experiences and needs.

List of Acronyms

NAREM	North American Energy Resilience Model
NREL	National Renewable Energy Laboratory
SAGE	South Asia Group for Energy
USAID	U.S. Agency for International Development

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1 Introduction

Power systems in South Asia are rapidly evolving to increase reliability and resilience in the face of climate change impacts, continued demand growth, emerging technologies, and increased renewable energy generation. Demand for electricity across the region has grown rapidly in recent history, in step with rising incomes, with a continued growth of roughly 5% per year expected in coming years (SLME 2021; IEA 2021; ADB 2017). New opportunities are developing for energy storage, distributed energy resources, and electrification of new sectors. By 2030, Bangladesh envisions up to 9 GW of additional solar energy capacity (Chowdhury 2020), and India has a target to achieve 450 GW of renewable energy capacity by the same year. Additionally, Nepal hopes to increase its renewable energy capacity by a factor of 10 (Government of Nepal 2020), and Sri Lanka looks to achieve a 70% renewable energy share in electricity generation (SLME 2021). These trends will alter the magnitude and profile of electricity consumption and generation. As consumers rely on electricity for more of their energy needs and expect a constant supply, stakeholders will need to ensure that the power system is reliable, resilient, and sustainable.

Demand is expected to continue its rapid expansion in the region as incomes rise, with climate change adding to the trend, particularly in peak demand, through its effect on cooling appliance ownership and use. Extreme weather events such as heat waves, flooding, and droughts are predicted to occur more frequently in South Asia (Seneviratne et al. 2021), and the availability of water resources may vary from historical trends. As both droughts and downpours become more common, countries particularly dependent on hydropower for electricity generation, such as Bhutan and Nepal, will have increasingly variable generation. Nations with more coastal exposure, such as Maldives and Sri Lanka, will face greater threats to infrastructure, production capability, and supply chains from rising sea levels and tropical storms.

Box 1: Key Areas for Stakeholder Input:

- Challenges for maintaining reliability and resilience of future power system
- Incorporation of climate change into operations and planning
- Forecasting demand with changing load profiles
- Need for Integrated Resilience and Resource Planning.

All of these challenges require a holistic approach toward the planning and operation of power systems in South Asia. This has motivated the South Asia Group for Energy (SAGE), composed of the U.S. Agency for International Development (USAID), the U.S. Department of Energy, and three national laboratories, to identify key power sector opportunities for further research and development of innovative solutions to meet the needs of future power systems. The first phase of this project is to initiate stakeholder engagement across South Asia to discuss, identify, and prioritize the key issues most relevant to them. This discussion paper is meant to identify various power system challenges to initiate the conversation with power sector stakeholders about how to build a reliable and resilient power system. Box 1 indicates a few key areas where we hope to receive input from stakeholders. The second phase of this project will focus on finding solutions to the key challenges prioritized by stakeholders in the first phase.

2 Challenges to Grid Reliability and Resilience in South Asia

2.1 Reliability

Reliability is the most important aspect of a power system, comprising operational reliability and resource adequacy (NERC 2007). **Operational reliability** is the ability of the electric system to maintain service to customers despite sudden disturbances such as electric short circuits or unanticipated loss of system components. **Resource adequacy** is defined as the ability of the electric system to continuously supply the aggregate electric power requirements of electricity consumers (NERC 2007).

To ensure that South Asia's power sector will be able to reliably meet the region's rapidly growing demand, stakeholders must consider threats to the power sector from climate change. Integrated resource planning is needed to guarantee that generation additions keep pace with increasing electricity demand to enable round-the-clock reliable power supply to all consumers. This is already a challenge, but will become more so as changes to the climate affect resource availability. Planning will be more difficult if there is greater uncertainty about generation and demand response to trends in the climate and extreme weather.

Steady economic growth, expanded electricity access, and rising urbanization have led to rising electricity demand, particularly peak loads. Figure 1 shows the increase in peak loads in Delhi in July over recent years. The highest hourly load increased by 48% between 2010 and 2018. In the next decade, India's peak load is expected to almost double, from 180 GW in 2020 to 340 GW in 2030, while the total energy demand is projected to increase by 75% over the same period (Abhyankar et al. 2021). Higher peak loads imply more expensive electricity costs because of lower system utilization factors. This is even more important in a decarbonized power system where load profiles will determine the amount of storage and flexible resources needed in the system. Load profiles will change due to the electrification of industrial applications, agricultural activities, and vehicles, as well as the climate impacts on weather-dependent loads such as air conditioning.

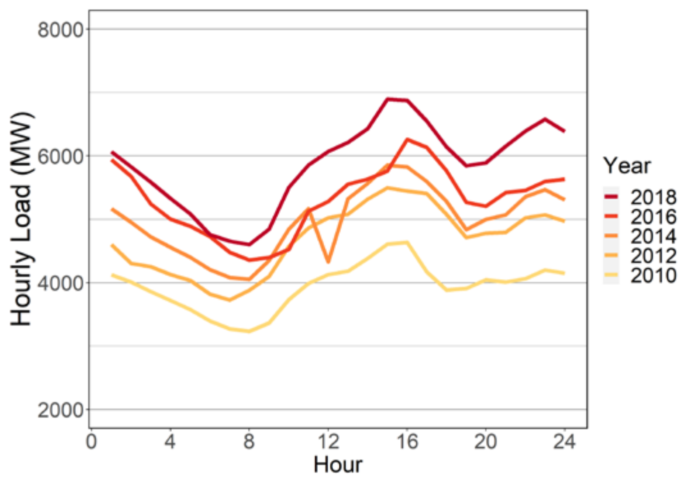

Figure 1. Hourly load from a peak load day in July in Delhi, 2010–2018

Source: (Abhyankar et al. 2021)

Climate change will add to the uncertainty in supplying enough power to meet demand. Changes to precipitation, temperature, sea level, wind, and solar radiation patterns can all impact the availability of generation resources. Droughts may provide a particular challenge for South Asia, particularly in regions more dependent on hydropower or with high competition on scarce water resources for water-dependent thermal plants. While average annual rainfall is expected to increase throughout most of South Asia due to greater summer monsoon precipitation, increased total rainfall will be accompanied by a rise in seasonal and annual variability, leading to more extreme dry and extreme wet conditions (Vinke et al. 2017; Gupta et al. 2020). In March and April of 2019, Sri Lanka faced power cuts as droughts brought about water shortages that cut hydropower output by half (Aneez 2019). For hydropower plants in mountainous regions, glacial retreat represents another threat (Pathak 2010). A study on river flow regimes in Bhutan projects that hydropower plants in some catchments could lose up to 14% of river discharge available for hydropower production annually due to decreasing snowmelt and receding glaciers (Beldring and Voksø 2012). Thermal plants, which rely on water for cooling, may face increasing competition for water during dry spells, potentially increasing costs or constraining production (Zhou et al. 2018).

To holistically approach and plan for a reliable power system, updates may be required to existing regulations, standards, analysis tools, and technologies. As high penetrations of renewable energy and energy storage are reached, planners will need to consider the grid effects of new sources of variability, weather dependence, and system inertia. We have identified some key questions to start engaging stakeholders to discuss these challenges and decipher the future needs for a reliable and resource-adequate power grid. These questions are only meant to start the discussion and are not representative of all possible stakeholder concerns:

Stakeholder Discussion Questions: Reliability
• What measures need to be taken to ensure power system resource adequacy and reliability as the resource mix evolves and the climate changes? • What measures need to be prioritized in the near term? Which are more important for the long term? • How will climate change impact regional power generation, demand, delivery, and overall reliability? • How much additional load will new connections, economic growth, electrification of transportation and industry, and appliance growth add to the grid? How will this further affect the diurnal and seasonal profile? • How can demand response be leveraged to manage a growing load and a renewable energy-heavy grid?

2.2 Resilience

Resilience is the ability of the power system to withstand and reduce the magnitude and/or duration of disruptive events. This includes the capability to anticipate, absorb, adapt to, and/or rapidly recover from such events (National Infrastructure Advisory Council 2009). Resilience will rise in importance as consumers depend more on electricity and extreme events (heat waves, droughts, heavy precipitation, tropical storms) increase in intensity, frequency, and duration. This combined growth of demand and weather variability raises the potential for power system difficulties and failures. The historical increase in such events in South Asia is shown in Figure 2, with particularly stark increases in flooding and storms occurring in recent decades. Addressing the greater frequency and intensity of such events requires risk assessment, advance planning, and emergency preparedness, and post-event recovery procedures. Below, we highlight the potential impacts of high precipitation events and heat waves, as they are predicted to have widespread effects across geographies and sectors (ADB 2012).

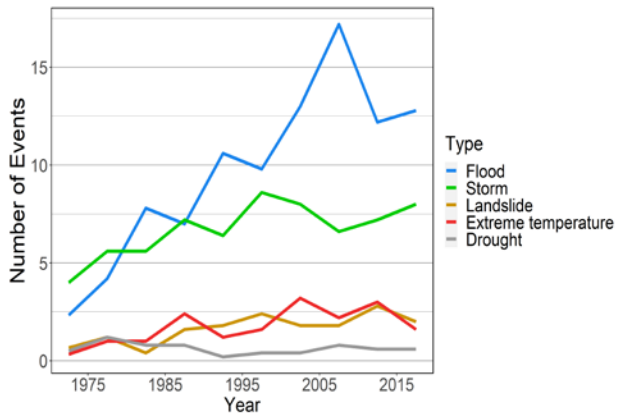

Figure 2. Extreme events from 1970–2020, totaled across all countries in South Asia

Source: (EM-DAT)

Stronger monsoon season rains are hazardous for the power system due to more frequent and destructive extreme precipitation events in South Asia (Gupta et al. 2020; Huo and Peltier 2020). The resulting increase in floods and landslides can damage energy sector infrastructure and supply chains, limiting both production and delivery. In August 2014, nearly 10% of Nepal's hydropower supply was disconnected due to damage from a landslide caused by heavy rainfall (Bhatt 2017). The powerful wind and rains from storms present yet another growing threat; tropical cyclone SIDR in 2007 caused failures at all major power plants in Bangladesh, severe damage to wind power infrastructure, and destruction of electricity transmission lines (Shahid 2012).

Heat waves can create periods of high stress on both the demand and supply side of the power sector. In South Asia, the frequency and severity of heat waves is projected to increase, with an extra 12–18 days of extreme heat per year possible between 2020 and 2064 (Rohini et al., 2019). On the demand side, heat waves are projected to lead to higher peak loads as more and more customers seek protection from extreme temperatures. Although peak loads in South Asia are already greater in the summer, a relatively small proportion of the population currently owns air conditioners. In 2016 and 2018 only 5% of residential buildings in India and 10% in Sri Lanka had central or room air conditioners, respectively (Abhyankar et al. 2017; Frost and Sullivan 2018). In July 2021, India's instantaneous power demand hit a historic high of 200 GW, following increased use of air conditioners due to the high temperatures reached in northern India (Shah and Lolla 2021). On the supply side, elevated air and water temperatures during heat waves may deteriorate the performance of power plants and transmission and distribution systems (Añel et al. 2017). This coincident peak in demand and stress on supply can ultimately lead to power shortfalls, which is a major health concern during heat waves (Stone et al. 2021).

Regardless of the specific region being discussed, climate change is a growing source of uncertainty, risk, and potential deviation from business-as-usual operation. Operational and investment decisions will need to work towards building a power system resilient to a changing, and often more destructive, climate. With this in mind, we have developed the following questions to engage with stakeholders:

Stakeholder Discussion Questions: Resilience
• How are power systems currently prepared to withstand and recover quickly from extreme events? • What new measures need to be taken to ensure grid resiliency as demand and extreme event intensity increase? • How will a high renewable energy share affect grid vulnerability and ability to withstand extreme events?

3 Planning for the Future

To improve the resilience and reliability of the future power system, stakeholders need integrated planning processes capable of accounting for all the factors that will affect their operations. The continued growth of renewable energy and demand entail a massive expansion of investment, infrastructure, and generation capacity. More variable energy sources and loads will create new operational challenges, while climate change adds uncertainty to resource availability, electricity demand, and infrastructural security. This new environment necessitates holistic and coordinated planning processes by stakeholders across South Asia.

Demand forecasting is critical to ensure cost-effective system planning and reliable grid operation. Accurate forecasting allows grid operators and planners to achieve higher efficiency and reliability in system planning and grid operations. It is also key to keep consumer costs low by ensuring that utilities procure a least cost mix of resources to meet the demand reliably. There are many factors that can drive uncertainty in demand growth, such as appliance ownership and usage, new sectoral loads, changing weather patterns, and demand response. While some of these factors already impact demand profiles, others such as electric vehicle adoption, industrial electrification, climate change, and renewable energy penetration will increasingly alter the load in the future.

An additional challenge for planners is that the trends facing the power system in South Asia do not act in isolation, but rather must be viewed as a connected set of drivers acting on the system. To maintain grid reliability and resilience, it will be crucial for demand and supply forecasts to be synchronous. Power generation infrastructure decisions must consider demand projections, renewable energy targets, availability of fuels, and protection against damage and performance deterioration from climate impacts. A schematic representation of these interconnections is shown in Figure 3, where various forces challenge the ability to create a reliable and resilient power system.

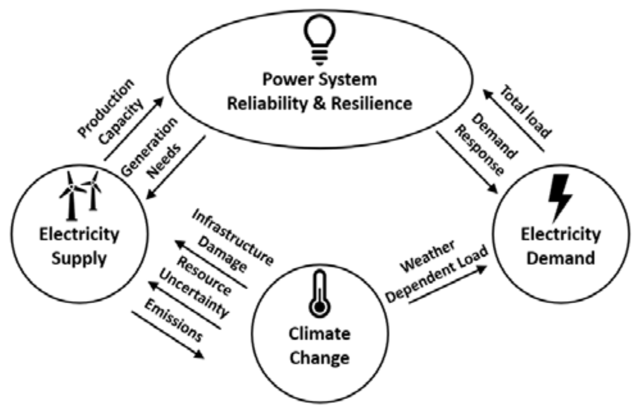

Figure 3. Forces and feedbacks acting on power system reliability and resilience

One planning approach for dealing with this complexity, Integrated Resource and Resilience Planning creates a long-term investment plan that considers various uncertainties and risks, as well as policy, social, and environmental factors. It attempts to engage all relevant stakeholders to create a least-cost plan that can be regularly updated (Boyer et al. 2020). Regardless of the specific planning strategy utilized, it is important that stakeholders are armed with best-available data and projections to make evidence-based decisions. This may require addressing systemic challenges to data usage; for example, lack of consumer metering and unreliable metering, better load research and surveys by utilities and third parties, appliance-level consumption analysis, and availability of feeder and sub-feeder-level metering data.

In addition to approaches to improve forecasting, cooperation and communication can be beneficial across nations, states, sectors, and stakeholders. A wide footprint of power grids with regional diversity in climate, resources, and load can provide a buffer of reliability and resiliency to a power system. Knowledge sharing, cross-border electricity trade, regional grid connection, and standardized procurement and planning practices are all options that could result in a more reliable, resilient, and consistent system. We want to understand and discuss the opportunities and needs in South Asia to improve interconnections for sharing resources, coordinating operations, and cooperating in crises. Below are questions aimed at better understanding stakeholder planning processes and need:

Stakeholder Discussion Questions: Planning
• What approaches can be taken to better incorporate emerging challenges into an integrated planning process, both across sectors and geographies? • Does long-term planning currently account for climate change? • In what ways can the existing load forecasts be improved? How can they be redesigned to better account for uncertainties in load? How can demand response be incorporated in load forecasting? • What methods of cooperation or coordination, within or between countries, would be most beneficial to stakeholders?

4 Next Steps for Research and Development

The application of SAGE capabilities to address power sector challenges will depend on the needs of stakeholders. The national laboratories comprising SAGE have a wealth of experience and knowledge developing and applying tools to improve planning and decision-making. These tools include power system-specific models that provide a detailed understanding of grid operations, as well as broader energy-economic models that capture interactions between the power system and energy, climate, land use, and water systems. They can be used to assess existing infrastructure operational stress, energy system transitions, and the resilience of the grid to extreme events, among other capabilities.

Based on stakeholder feedback, SAGE can assess which solutions can answer unresolved questions and support decision-making. This may involve repurposing tools to capture regional specificities, combining models to link different types and levels of system representation, collaborating with country-specific stakeholders to take advantage of their existing data/models, and/or developing new tools for stakeholders. An example project to provide inspiration for SAGE is the North American Energy Resilience Model. This is an effort in the United States among multiple national laboratories to develop a modeling system for planning and real-time analysis of the energy system's response to extreme events and energy disruptions. Another effort across multiple national laboratories and universities is Integrated Multisector Multiscale Modeling, where capabilities are being developed to understand the co-vulnerabilities and co-resilience of the energy-water-land systems to climate, technological, and socio-economics changes in the 21st century. Tools and lessons resulting from these projects may inform power sector work in the South Asian context.

Next steps will include meetings to understand the perspectives and experiences of those working directly in the power sector. Using the feedback from those meetings and this discussion paper, the national laboratories and selected partners will write three more detailed reports related to the power sector in South Asia: on the resiliency of the power sector, climate impacts, and electricity demand. The findings from those works and meetings with stakeholders will guide the creation of a research plan to be conducted by the SAGE laboratories in collaboration with stakeholders.

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