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POWERING DEVELOPMENT IN CLIMATE VULNERABLE AREAS

The Role of Decentralized Solar Solutions in India

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FOREWORD

The year 2020 marked five years since the signing of the Paris Agreement, which aims to limit global temperature rise by 1.5°C through aggressive mitigation action. India has been making steady progress toward its commitment of reducing energy sector emissions and has set a 450 GW target for renewable energy by 2030. India also made significant progress in improving electricity access for more than 500 million people over the last two decades.

Despite the significant increase in electrification of homes, electricity access continues to be a challenge for the rural health, education, and livelihood sectors. In India, according to National Health Mission statistics of 2018, 36 percent of public schools and 24 percent of public health centers remain unelectrified. Several of the electrified centers get only an intermittent and unreliable supply of electricity and are therefore compelled to rely on expensive diesel generators. Inequitable access to reliable electricity supply impacts the socioeconomic development of vulnerable communities, particularly in rural areas, as it disrupts schooling, medical services, and livelihoods.

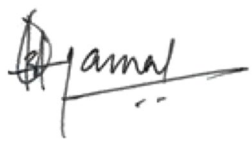
The 14 case studies in this report, "Powering Development in Climate Vulnerable Areas: The Role of Decentralized Solar Solutions in India," highlight how climate change affects electricity demand and debilitates the infrastructure that supplies electricity. The report is a timely analysis of the importance, and advantages, of deploying decentralized energy solutions to power remote and rural schools, healthcare, and livelihood facilities. The findings from this publication also indicate that effective decentralized energy solutions need to be climate proof and tailored to local conditions. For example, Assam, which is a flood-prone state, has developed unique solutions such as floating solar grids to reduce the risk to infrastructure during the monsoon. On the other hand, in lightning-prone areas of Jharkhand, implementers have installed lightning arresters to protect against such events. The localization and customization of clean energy solutions are not limited to technology but also include operational and financial processes.

This report aims to be a roadmap for designing, implementing, and managing clean energy solutions—especially in climate vulnerable areas. It describes how implementers, vendors, and policymakers can come together to build resilient infrastructure that can support the country in achieving its Sustainable Development Goals and climate targets.

As a developing country, India enjoys the unique advantage of being able to pursue cleaner trajectories for infrastructure that is yet to be built. As the Indian government works toward ensuring sustainable, affordable, and reliable electricity for all, it needs to ensure that the new infrastructure is climate resilient to secure mitigation and development gains. Decentralized renewable energy solutions crafted to meet developmental needs are essential to lift people out of poverty and stay below 1.5°C.

Andrew Steer

President
World Resources Institute



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EXECUTIVE SUMMARY

Many of India's most impoverished and underserved people live in the country's climate vulnerable regions. With limited access to healthcare, education, and livelihoods, the poor are among the least equipped to cope with the climate change threat despite being overrepresented in climate vulnerable areas (Diwakar et al. 2019).

Highlights

- In India, poor and marginalized communities face the dual challenges of low socioeconomic development and extreme vulnerability to climate change. Providing reliable access to electricity through decentralized renewable energy creates an opportunity to stimulate low-carbon socioeconomic development in climate vulnerable areas.
- India has made impressive progress in increasing the reach of its grid connectivity. Climate-related events can impact the supply of electricity, especially the distribution network of the centralized grid structure.
- Decentralized energy solutions play an essential role in supplementing grid connectivity to support basic services such as health, education, and livelihood generation during uncertain times.
- Development agencies are increasingly adopting decentralized energy solutions to provide affordable, reliable, and sustainable electricity access, which is key to building long-term adaptive capacity. Notably, these solutions can also be affected by climate-related events, thus requiring resilience planning.
- Developing climate resilient energy solutions requires working across conventional silos; incorporating climate considerations in technology, planning, and execution; and aligning organizational responsibilities and funding arrangements at each stage of the project cycle.

Energy in Climate Vulnerable Areas

Although there have been significant improvements in India's rural household electrification, electricity availability for health centers, schools, and rural enterprises is still limited.

Electricity is one of the enablers of socioeconomic development. Access to reliable electricity can improve the working hours, staff availability, water availability, and medical and diagnostic services in hospitals; improve the learning environment, school attendance, and the quality of education delivery in schools; and enhance productivity, savings, and income for rural livelihoods (Chaudhury and Hammer 2003; World Bank IEG 2008; SEforAll 2018). In climate vulnerable areas, facilities for essential services, such as healthcare, education, and livelihoods, that are functional under all conditions can help the poor improve their socioeconomic situation and cope with the existing and new threats posed by climate change.

Decentralized solar energy solutions are increasingly considered for bringing reliable electricity to community facilities, especially in climate vulnerable areas. **Although decentralized solar solutions are not entirely immune to extreme events, they are relatively more resilient than centralized electricity systems** (IEA 2015; PGCIL 2015; WBCSD 2014; OECD 2018).

About This Report

In this report, we explore the impacts of climate-related events on electricity needs, whether decentralized solar solutions consider climate change in the lifecycle of the installation, and if not, then what factors need to be considered.

Since 2015, World Resources Institute (WRI) India's work on improving energy access in India has focused on the states of Assam, Jharkhand, and Rajasthan**.** We adopt a four-pronged approach encompassing technology, data, policy, and finance as a scaling-up strategy to ensure reliable electricity for social and production loads. Our partners are development agencies such as public health departments, charitable hospitals, schools, local administrations, state government departments, and not-for-profit livelihood grassroots organizations. To further that work, through this report we explore the nexus between energy for development and climate change. We analyze

14 decentralized solar energy systems installed in community-level healthcare, education, and livelihood facilities in climate vulnerable regions across these three states. For this report's purposes, *decentralized solar energy solutions* refer to stand-alone or minigrid-sized installations that provide electricity supply to facilities such as schools, health centers, and communities.

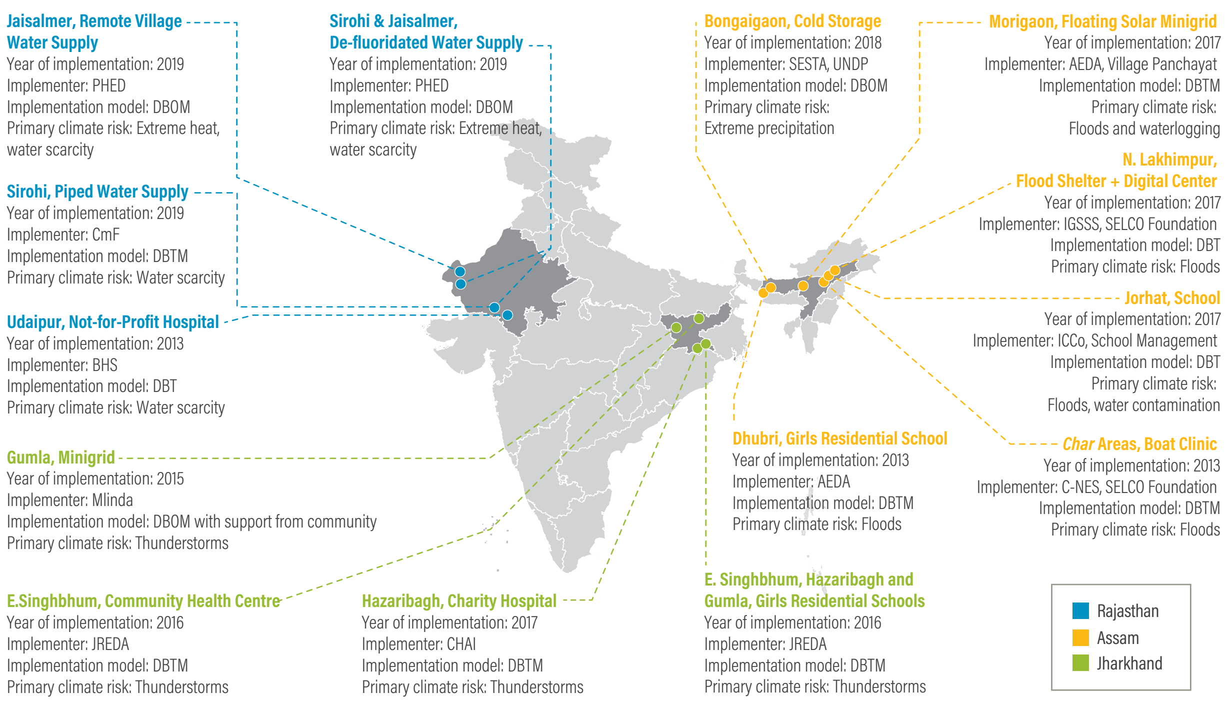
We explore whether electricity demand for healthcare, education, and livelihoods is affected by climate-related events and whether energy solutions take climate risks into account. A summary of the case studies is shown in Figure ES-1.

How to plan for energy for development in climate vulnerable areas?

Through this study we inquire about the impact of climate vulnerability on energy needs for development. By studying energy access installations, we explore how these solutions account for climate vulnerability in their design and implementation models, specifically in energy-poor states. These case studies of installations help us to arrive at the factors that should be considered for improving the sustainability of energy access solutions in climate vulnerable areas.

This study is the culmination of extensive background research, in-person interviews, state-level multi-stakeholder consultation workshops, and field visits. An initial list of decentralized renewable energy (DRE) projects was created with the help of this network. This list was then distilled to 14 case studies based on population served, location, access to the site (permission to visit), and willingness to share information. The field visits conducted between June and November 2019 document various stakeholders' experiences at the sites. During the field visits, we interviewed

Figure ES-1 | Fourteen Case Studies of Decentralized Solar Energy Systems in India



Note: AEDA = Assam Energy Development Agency; BHS = Basic Health Care Services; CHAI = Catholic Health Association of India; CmF = Centre for Micro Finance; C-NES = Centre for North East Studies and Policy Research; DBOM = Design Build Operate Maintain; DBTM = Design Build Transfer Maintain; DBT = Design Build Transfer; ICCo = Innovative Change Collaborative; IGSSS = Indo-Global Social Service Society; JREDA = Jharkhand Renewable Energy Development Agency; PHED = Public Health Engineering Department; SeSTA = Seven Sisters Development Assistance; UNDP = United Nations Development Programme.

Source: WRI authors.

implementers, donors, operators, and end users about the experience of installing and operating DRE solutions, the challenges faced, and benefits accrued. We expect our research to provide practical, usable information for government agencies, energy enterprises, financing agencies, and development organizations implementing decentralized solar energy solutions in climate vulnerable areas.

Findings

Our research indicates that electricity demand for the delivery of essential services is impacted by climate risk in three ways:

- Backup power: Electricity supply through the grid is often disconnected during thunderstorms and floods because of, or in anticipation of, damage to the grid infrastructure. As a result, the demand for backup sources of electricity, such as diesel generators, increases during these times.
- Demand surges: Electricity demand increases as people seek to cope with specific climate-change-induced events. For example, they need electricity for information and communication, medical diagnostics and treatment of diseases, or pumping and filtration of water due to contamination or scarcity.
- Service expectations: Electricity demand will increase for ongoing activities such as digital education, quality healthcare, and income and livelihood enhancements that build the long-term capacities of communities to cope with climate events.

Climate change impacts the technical, operational, and financial design of a project. Many renewable energy projects adapted their designs considering specific local conditions. For example, in Assam, to deal with waterlogging and flooding, installations are designed to withstand higher water levels, either through raised platforms or through technologies such as floating solar installations. Jharkhand is prone to thunderstorms and lightning, and a few pilot implantation projects in the state have installed lightning rods, surge protectors, and chemical earthing. In the desert state of Rajasthan, the installations are designed to withstand extreme temperatures and strong winds and include insurance of structures in project design.

However, none of the installations covered in the case studies specifically incorporate predictions of future climate change into their project design. Climate considerations are even less evident in the operational and financial design. Our research finds that only a limited number of case study installations have operational clarity on roles and responsibilities during and after a climate-related event or have funding arrangements in place to deal with the aftermath of an event. Furthermore, the clarity that some possess stems from learning through experience and not from the project design. We expect that this report will trigger more thinking and planning for climate events in the design and operations of future projects.

Implications for Decentralized Solar Solutions in Climate Vulnerable Regions

Ensuring energy systems' resilience is vital for development agencies and is a growing area of concern for renewable energy practitioners. Building on the framework from a recent report by UN Foundation and Sustainable Energy for All (SEforAll) titled *Lasting Impact: Sustainable Off-Grid Solar Delivery Models to Power Health and Education* (UN Foundation and SEforAll 2019), we identify the following additional considerations for decentralized solar energy installations in climate vulnerable regions:

- **Technical considerations** include understanding the current and future climate risks in the region, how they affect the demand for and supply of electricity, and what technology options, codes, and guidelines exist to ensure that the energy system continues to remain useful and functional. The implementing agencies and vendors should also consider whether project timelines include climate risks through the four stages of the project life cycle and whether the technical design considers the market availability of spare parts in case disruptions occur.
- **Organizational considerations** include whether the contractual and non-contractual responsibilities of all participants are laid out in the event of climate-related disruptions and whether they have adequate capacity to execute them. Users and implementing agencies should account for local capacity building, contingency communication, or response plans under contractual obligations that can

be activated during climate-related events. Energy project planning should consider the local community's expectations, including the role played by energy in the community's current and future coping mechanisms to manage climate-related risks.

- **Economic considerations** include a realistic estimate of whether finance for the project incorporates climate resilience as a critical element of project planning. Funding agencies, implementing agencies, and users should collaborate on project planning that is flexible enough to integrate innovative financing options to hedge against short- and long-term uncertainty.

Policymakers, implementing agencies, vendors, and funding agencies can build resilient structures by integrating these considerations well before the design stage. System design and operation during the lifetime of the infrastructure, when based on climate and other risk assessments, can increase the installation's lifespan and reduce downtime and avoid failures. Policies, financial instruments, and design standards can reinforce the resilient design and management of infrastructure.

CHAPTER 1

INTRODUCTION

India is already facing the impacts of climate change. Warming trends accompanied by shifting rainfall patterns and extreme weather events affect lives, livelihoods, natural resources, and built environments.

Climate change disproportionately affects the poor and marginalized (Olsson et al. 2014), and India has over 360 million people who continue to live in poverty (UNDP & OPHI 2019). Globally, India ranks 131 out of 189 countries in the Human Development Index (UNDP 2020). With limited access to health and education and low living standards, India's most impoverished population is among the least equipped to cope with the threats brought about by climate change. As the number and intensity of prolonged droughts, flash floods, riverine flooding, sea level rise, landslides, and extreme heat events increase in the near future (World Bank 2013; Dhiman et al. 2010), there is an urgent need for innovative solutions that address both India's development and climate challenges.

The electricity access gap continues to be a very real challenge. Despite improvements in rural household electrification in recent years, community facilities such as schools and hospitals remain poorly served. Thirty-six percent of government schools (MHRD 2019), 24 percent of government health subcenters, and 3 percent of Primary Health Centres (PHCs) (HMIS 2019) remain unelectrified in India. Where connections exist, the electricity supply is often unreliable and unaffordable. The 2019 Global Competitiveness Report ranks the quality of India's electricity supply at 108 among 141 countries in the world (Schwab 2019). Weather events such as cyclones, floods, storms, and extreme temperatures can exacerbate these challenges by damaging conventional electricity generation, transmission, and distribution infrastructure, leading to frequent and more prolonged power interruptions (PGCIL 2015).

Decentralized renewable energy (DRE) presents an opportunity to enhance access to electricity. India has seen rapid progress in deploying renewable energy solutions thanks to its ambitious clean energy targets. The renewable energy sector has grown at a compound annual growth rate (CAGR) of around 17 percent, attracting over USD 42 billion from 2014 to 2019 (IBEF 2019). As part of this trend, promising DRE solutions that address development needs in rural areas are also being implemented (Ashden 2020). Accessible healthcare, education, and livelihood facilities enable the poor to improve their socioeconomic situation and build their capacities to adapt to climate events (Perera et al. 2015) in rural areas. As India makes the transition to a cleaner energy future, there is an opportunity to implement energy interventions that stimulate local development, help meet climate goals, and are themselves climate resilient.

This report presents 14 case studies of such interventions, where decentralized solar energy systems have been installed to improve service delivery in the health, education, and livelihood sectors (the case studies are summarized in Tables A.1, A.2, and A.3 in Appendix A). These include systems installed in schools for lighting, WASH (water, sanitation, and hygiene), and cooking purposes; systems in health centers for lighting, running diagnostic and critical medical equipment and operating rooms; and systems installed to provide potable water to communities as part of public health services. The case studies were identified through stakeholder consultations in each state. The study found that climate change impacts the technical, operational, and financial design of decentralized solar energy projects. All the interventions studied are in climate vulnerable regions in Assam, Jharkhand, and Rajasthan. Climate vulnerable areas were identified based on future climate risk and current socioeconomic and environmental factors in the three states (see Tables 1 and 2). The case studies feature community-scale electricity access interventions in vulnerable areas, where operations commenced at least six months before the study. The case studies explore whether the electricity demand for healthcare, education, and livelihoods is affected by climate-related events, and whether energy solutions consider the risk posed by and the impact of climate events. Learnings from the case studies lead to factors that stakeholders should consider for the long-term sustainability of decentralized solar energy solutions in climate vulnerable areas. Selection criteria for the climate vulnerable areas and the overall methodology are discussed in Section 2. Section 3 presents findings from case studies and discusses the climate risks faced by the installations and the stakeholders' response mechanisms. Section 4 presents the framework for designing and operating climate resilient decentralized solar energy solutions. This framework has been developed based on a report by UN and SEforAll titled *Lasting Impact: Sustainable Off-Grid Solar Delivery Models to Power Health and Education*, which describes the three pillars of sustainability: technical, operational, and economic considerations (UN Foundation and SEforAll 2019).

Linkages between Electricity Access, Development, and Climate

Previous research by WRI finds that the relationship between electricity access and development is bidirectional (Odarno et al. 2017). Although electricity can act as an enabler for socioeconomic development, some level of socioeconomic development is necessary if electricity supply businesses are to remain profitable and continue to provide electricity (Odarno et al. 2017). As a result, there is a need to carefully study the value added by electricity access and integrate it in supply planning models to promote climate resilient socioeconomic development. In the following subsections, we review the pathways by which electricity access affects development outcomes such as health, education, and livelihood opportunities, and how climate change can affect these pathways.

Electricity Access and Health

In the health sector, access to electricity can affect working hours, staff availability, quality of services, water availability, and medical or diagnostic services.

A study in Maharashtra on electricity outage frequency and maternal health service usage found that improving electricity supply may increase institutional delivery rates and improved the overall maternal and child health outcomes (Koroglu et al. 2019). Another study exploring factors that influence women's decisions regarding their place of child delivery in Jharkhand found that good infrastructure, including electricity supply, water, and clean toilets, affects women's satisfaction with services (Bhattacharyya et al. 2016). An evaluation by the World Bank Independent Evaluation Group in 2008 found that, in Bangladesh and Kenya, electrified health clinics are open for one more hour every day on average than unelectrified health clinics (World Bank IEG 2008). Electricity access can also impact staff absenteeism in health centers (WHO and World Bank 2015).

A study of health workers in Bangladesh shows that they are less likely to be absent from a health facility if they stay in the same locality as the facility. The presence of electricity increases the attractiveness of rural living for medical professionals (Chaudhury and Hammer 2003). Health clinics with electricity access are also more likely to have piped water supply (World Bank IEG 2008), which is crucial for ensuring that routine services such as child deliveries are conducted in a safer environment (WHO and UNICEF 2015).

Electricity enhances medical care quality, providing lighting, communication, power for diagnostic devices, refrigeration for vaccines and medicines, sterilization of instruments, and safe disposal of hypodermic syringes (GEA 2012; WHO and World Bank 2015). Taking the vaccine quality example, in India, 20 percent of temperature-sensitive healthcare products, including 25 percent of vaccines, arrive damaged or degraded because of inadequate cold chain infrastructure (SEforAll 2018; WHO and PATH 2013). World Bank IEG (2008) finds that equipment such as vaccine cold storage devices is more likely to be present in electrified health clinics than in unelectrified ones. However, electrification of the health center does not guarantee the functioning of electrically powered equipment. A study of PHCs in Chhattisgarh showed that close to 36 percent of health centers faced unreliable electricity supply, despite having an electric grid connection (Ramji et al. 2017). Subsequent to this study, CREDA undertook the solarization of 900 health centers across Chhattisgarh state to improve electricity access for health facilities (Ashden 2018, 2020).

Electricity Access and Education

In the education sector, access to electricity can influence the learning environment, school attendance, and the availability and quality of educational services. Access to electricity can contribute positively to education outcomes through better living conditions for students, teachers, and school staff (World Bank 2004; World Bank IEG 2008). It can improve the likelihood that children, especially girls, will attend and complete school by enhancing access to clean water, sanitation, lighting, space heating, and cooling. Electricity can also provide opportunities to use teaching aids and equipment such as computers, projectors, and science equipment (GEA 2012; UNDESA 2014; UN Foundation and SEforAll 2019). An assessment of schools in rural Kenya showed that electrically powered educational aids play a crucial role in bridging the urban-rural divide in preparing children for competitive exams. It also found that schools with basic lighting can provide extra early morning and late evening classes for students. Solar Digital Night Schools project run

by Barefoot College and Department of Science and Technology in India have integrated 40 percent of dropouts into the secondary schools, provided vocational education for adults, and improved health-related awareness programs (DST n.d.). Increased hours help the schools cover material that they cannot cover during regular hours because of a shortage of teachers (Kirubi et al. 2009). Electricity access also affects parents' perceptions of their children's education. In a WRI study of households in India and Nepal, more than 80 percent of respondents said they thought electricity access positively impacted school enrollment rates (Rao et al. 2016).

Electricity Access and Livelihoods

Electricity access can help improve livelihood opportunities by enhancing productivity, increasing savings and income, and creating new livelihoods. Access to reliable electricity has the potential to increase India's rural incomes by as much as USD 5.5 billion a year and prevent business losses to the tune of USD 22 billion a year (Zhang 2019). The livelihood sector can be broadly categorized into farm and non-farm-based livelihoods. For farm-based livelihoods, energy is relevant to the entire value chain from production to post-harvest storage, processing, and marketing (Practical Action 2012). At the production stage, it is widely acknowledged that mechanization of activities such as sowing, irrigation, spraying, and harvesting can improve farm and labor productivity. However, only 40–45 percent of the agriculture sector is mechanized in India (Mehta et al. 2014). Estimates suggest that the untapped market potential for mechanization at the production level (not including irrigation) through clean energy is close to USD 30 billion (Waray et al. 2018). After harvest, 1.3 billion tons of food is lost or wasted each year globally (FAO 2013), while the Ministry of Food Processing Industries of India estimates a loss of 2 million tons of grains, 12 million tons of fruit, and 21 million tons of vegetables (NAAS 2019). In developing countries, most loss and waste occur near the production stage rather than at the consumption stage, as is the case in developed countries. Refrigerated storage and transport will play a significant role in solving this problem. Local access to cooling would allow smallholder farmers to produce higher-value processed products and enhance farm incomes (SEforAll 2018).

Access to reliable electricity plays a crucial role in a wide range of non-farm livelihoods such as manufacturing, space, process heating and cooling services, cooking, information and communications technology (ICT), and mechanical processing, manufacturing, and repair (Practical Action 2012). Reliable electricity is particularly crucial for small businesses, which, unlike larger establishments, cannot afford backup power generators (Grainger and Zhang 2017). A 2019 study by SELCO Foundation documenting 65 micro-enterprises' experience found that sustainable energy solutions helped them add more products and services that were otherwise unavailable to them due to lack of reliable electricity supply (SELCO Foundation 2019). Sustainable energy led to the creation of additional employment opportunities, income increases, and adoption of technologies outside the project (Terrapon-Pfaff et al. 2018; Sambodhi 2017).

Factoring in Climate Change

The linkages between electricity and development, and between climate and development, have been studied extensively. However, the interplay between electricity, development, and climate change is relatively less studied. The literature focusing on this relationship fall mainly into two categories: electricity access as an input to climate resilience and the climate resilience of the electricity infrastructure and systems per se.

Electricity access is considered to be one among many factors that contribute to community resilience. Some studies explicitly consider electricity access as an indicator of adaptive capacity and community resilience (Chen et al. 2018; Perera et al. 2015). Others argue that poor people are more likely to not have access to electricity and therefore are less equipped to cope with climate events (Scott et al. 2017), leading to enhanced vulnerability. A few studies focus specifically on how electrically powered activities, such as using ICTs for better warning systems (Sumiya 2016) or electricity-powered equipment for diversified livelihoods (Murphy and Corbyn 2013), contribute to building resilience.

Climate-related events can also change electricity demand. For example, periods of high temperatures can increase the need for cooling; erratic rainfall can affect the irrigation demand (Stuart 2017; WBCSD 2014). The electricity sector, which is affected by infrastructure vulnerabilities, unreliable fuel resource availability, and international policies, has to deal with the uncertainties arising from climate change and climate policy (Blyth et al. 2007; Santos et al. 2016). A systematic literature review of the role of electricity access in climate change adaptation finds an incomplete evidence chain linking the two. It suggests the need for country-specific studies to understand the specific causal chain (Perera et al. 2015). It is also important to note that research looking at electricity as an entry point for building resilience focuses primarily on household-level electricity access, not on the community or facility level. Access to healthcare, education, and livelihoods are considered indicators of adaptive capacity, but whether the facilities providing these services have access to electricity for functioning is not considered in some frameworks. For example, the vulnerability assessment of rural areas of the state of Madhya Pradesh in India considers economic, environmental, and social indicators for adaptive capacity. However, it does not consider factors that can affect those indicators—such as electricity services (Gosain et al. 2014).

If electricity is to power development activities, it must be available, reliable, and affordable. Electricity access solutions in climate vulnerable areas must be resilient to climate events in order to positively impact communities over the long term (Murphy and Corbyn 2013). Studies on climate resilient electricity infrastructure focus on the grid or large-scale renewable electricity plants and consider DRE as one of the options that can enhance electricity system resilience. When damaged, centralized grid systems, especially the transmission and distribution networks, require more time and effort to restore than decentralized systems (IEA 2015; OECD 2018; PGCIL 2015; WBCSD 2014). Electricity generation and distribution systems can experience long outages and huge financial losses caused by extreme events. More resilient systems would improve performance and reduce life-cycle costs (Hallegatte 2009; Hallegatte et al. 2019). However, the decentralized electricity systems must themselves be resilient enough to withstand disruptions due to climate-related events (Cox et al. 2016). In addition to building resilient structures, decentralized systems need to have better maintenance and management systems for quick recovery and rehabilitation. Climate models should be used along with local environmental and socioeconomic assessments.

In this context, our study looks at how electricity access through renewable energy sources can improve the delivery of development services and how climate events affect electricity systems and their functioning.

Developmental and Climate Context of Assam, Rajasthan, and Jharkhand

Assam, Rajasthan, and Jharkhand are states in India that rank 30th, 29th, and 34th in the Human Development Index (UNDP 2019). WRI India's work on improving India's energy access has been focused on these three states since 2015. Although household electrification has been enhanced in these states, access to reliable electricity for community-level services and enterprises remains a challenge. The development status and electrification levels in the study states (Assam, Rajasthan, and Jharkhand) are summarized in Table 1.

Whereas Assam is a flood-prone state, Rajasthan is mainly drought-affected and faces heat stress. Jharkhand faces water scarcity issues as well as increased thunderstorms and lightning. The State Action Plans on Climate Change of the three states list a few common impacts resulting from increased temperatures and uncertainty around rainfall patterns:

1. Agricultural losses due to uncertain rainfall, prolonged dry spells, and increasing temperatures; and adverse effects on associated industries
2. Increased extreme precipitation events accompanied by long dry spells, resulting in flash flooding and reduced groundwater recharge
3. Increased prevalence of vector-borne diseases for longer durations
4. Increased incidence of water-borne diseases due to floods and poor sewerage network

A summary of climate change impacts in the three states is given in Table 2.

In this context, our study looks at how electricity access through renewable energy sources can improve the delivery of development services and how climate events affect electricity systems and their functioning. It aims to study solar solutions in three states from different agroclimatic zones and varying demands. The next section discusses the research objectives and methodology applied for the selection of case studies and assessment of information.

Table 1 | Some Socioeconomic Parameters of Study States

PARAMETER/STATE	ASSAM	JHARKHAND	RAJASTHAN	ALL-INDIA AVERAGE	SOURCE
Per capita net state domestic product, INR (2017–18)	74,204	69,265	99,487	114,958	MoF 2020
Electricity consumption per capita, kWh (2016–17)	339	915	1,166	1,122	MoP 2017
Percentage literacy rate (2011)	72	66	66	73	Census 2011
School electrification rate (% of total functional schools, 2017–18)	24	47	64	63	MoHRD 2019
Life expectancy in years (2013–17)	66.2	68.6	68.5	69	MoHA 2019a
Infant mortality rate (infant deaths per 1,000 live births, 2017)	44	29	38	33	MoHA 2017
Maternal mortality ratio (maternal deaths per 100,000 live births 2015–17)	229	76	186	122	MoHA 2019b
Electrified health subcenters as % of total functional subcenters (2018–19)[a]	38	34	65	74	MoHFW 2019
Electrified Primary Health Centres (PHCs) as % of total functional centers (2018–19)[b]	93	45	96	95	MoHFW 2019

Notes: a. The list of subcenters does not include Health and Wellness Centre in subcenters. b. The list of PHCs does not include Health and Wellness Centres in PHCs. The percentages have been rounded off.

Table 2 | Climate Change Conditions in the Study States

STATE	TEMPERATURE[a]	PRECIPITATION[a]	EXTREME EVENTS[a]	IMPACTS
Rajasthan	1–1.4°C average temperature increase, extended summer days	50–100 mm increase in the southern hilly regions and northern districts	Increase in extreme precipitation events in the desert region along with an increased number of dry days; desert regions are also affected by high wind speeds Increased heat stress in the southwestern and eastern districts; sandstorms in summer	▪ Water availability to fall below 0.00045 BCM by 2050, indicating extreme scarcity compared to 2010 ▪ Deterioration of groundwater quality due to salinity, fluorides, and water scarcity ▪ Agriculture in 26 of 33 districts extremely vulnerable (Rama Rao et al. 2013) ▪ Increased risk to nutrition security in humans ▪ Adverse impacts on human health due to extreme heat conditions and longer summers
Assam	1–1.5°C average temperature increase, 1.5°C increase in high-altitude regions, extended summer days in central plain regions	50–100 mm increase in pre-monsoon rainfall with an equivalent decrease in monsoon and post-monsoon rainfall	Increased dry days in the southwestern regions and decrease in the northeastern areas. Increase in extreme rainfall events and floods	▪ 37% reduction in the irrigated areas of Brahmaputra basin ▪ 28.75% of Assam is flood-prone (NRSC 2016), increasingly erratic rainfall events and increase in the area prone to floods, riverbank, and river island erosion ▪ Increased glacial melt and forest fires during summer ▪ Increased damage to crops, loss of cattle, and reduced production of fisheries
Jharkhand	1–1.2°C average temperature increase, extension of summer by 20–35 days	State-wide 50–100 mm decrease in average annual rainfall, increase in heavy precipitation days in the central region	Extreme heat stress in southwestern districts, increased storm events with high wind speeds, most of the plains is prone to lightning	▪ Reduced production of paddy, wheat, maize, mustard, milk, and eggs. Increased mortality rate in poultry ▪ Agriculture in 11 of 24 districts is highly/extremely vulnerable (Rama Rao et al. 2013) ▪ Forests in 10 districts highly/extremely susceptible to forest fires ▪ Increased incidence of heat-related diseases and malnutrition ▪ Adverse impacts on mining due to forest fires, water scarcity, and extreme precipitation

Notes: a. Data presented are the multi-model projections for the mid-century (2021 to 2050) scenario compared to the baseline scenario (1981–2010) for the low-emission (RCP4.5) and high-emission (RCP8.5) scenarios.

Sources: WRI analysis using data from the Climate Change Information Portal, a joint effort by Ministry of Environment, Forests and Climate Change, Government of India and GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), available online at http://climatevulnerability.in/. Impacts listed in the fourth column were taken from the respective State Action Plans on Climate Change.

CHAPTER 2

RESEARCH OBJECTIVES, SCOPE, AND METHODOLOGY

As discussed in Section 1, DRE solutions are considered an adaptation measure to address the gaps in the centralized electricity supply. Although decentralized solutions fill these gaps, the systems are not always designed to be resilient to climate risks and impacts.

Climate risks and effects need to be mainstreamed in the lifecycle of energy solutions and in their associated technical, organizational, and economic aspects.

This study documents and analyzes efforts to deliver developmental outcomes through improved electrification in climate vulnerable areas to answer the following research questions:

- How does climate vulnerability affect energy needs for development?
- How do energy access solutions take climate vulnerability into account in energy-poor Indian states?
- What factors should be considered for improving the sustainability of energy access solutions in climate vulnerable areas?

As WRI India's work on improving India's energy access has focused on Assam, Jharkhand, and Rajasthan since 2015, we selected these three states for this study.

We began by collecting data on climate risks due to extreme temperatures, uncertain rainfall patterns, and cyclonic conditions along with environmental data on groundwater conditions, water quality, localized flooding, and drought conditions for the study states.

Data were supplemented with socioeconomic data on population density, livelihoods, and the Human Development Index (HDI) to identify districts within the study states facing all three challenges: impacts of climate change, poor development prospects, and unreliable electricity access.

We then identified decentralized solar energy installations through secondary research on energy interventions by energy, health, education, livelihood, skilling, welfare, and forest and agriculture departments; multilateral development institutions; energy enterprises; local development organizations; and funders working in socioeconomic and climate vulnerable areas in the three states. Based on information collected through secondary research, interviews, and stakeholder consultations, we developed an initial list of 58 case studies, spread across districts in the three states. The following selection criteria were used to identify possible case studies for in-depth study:

- **Electricity access**: The selected interventions feature an improvement in the tier of electricity access, either in terms of affordability, reliability, or sustainability (or a combination of the three), enabling the community to support increased demand.
- **Community-focused developmental interventions**: The electricity interventions focus on achieving developmental outcomes at the community level in the education, health, and livelihood sectors.
- **Time frame**: The interventions were implemented at least six months before our research, allowing enough time to observe the interventions' results.

- **Climate vulnerability**: The electricity interventions have been implemented in climate vulnerable areas. They may or may not contribute directly to building climate resilience, but they contribute to development outcomes in climate vulnerable areas. The impacts of the electricity interventions on development outcomes and climate resilience may be positive, negative, or neutral.

The list of potential case studies was further narrowed based on the project implementers' interest and responsiveness and an evaluation of travel conditions for field visits (such as support systems available in known conflict zones or remote locations).

We selected 14 interventions across the three states for case study analysis. Primary data were collected through field visits and in-person interviews with key government and nongovernmental stakeholders in each of the states, accompanied by telephone interviews with specific stakeholders for each intervention. We conducted 38 interviews over six months. The interviews were also used to identify development sector agencies and organizations working in districts affected by climate change and utilizing clean electricity installations to improve service delivery. Interview guides for these stakeholders are provided in Appendix B.

These interviews were further substantiated with three multi-stakeholder consultations conducted in the state capitals of Guwahati, Jaipur, and Ranchi and a national-level panel discussion in New Delhi to explore the links between electricity and development in climate vulnerable areas.

The 14 case studies include projects of differing scales, from single-installation projects to multiple-installation projects; projects that continue to function and projects that ran into operational difficulties; and projects with different implementation models. The case studies are summarized in Figure 1. Our research is limited to the role played by electricity in service delivery. The impacts of electricity on broader development outcomes or climate resilience are beyond this report's scope, as these impacts could become evident only over a more extended period. For this report's purpose, Decentralized Solar Energy Solutions refer to stand-alone or minigrid-sized installations that provide electricity supply to facilities and communities. Household electrification installations are not assessed in this study.

In Section 3, we discuss the case study findings categorized under education, health, and livelihoods themes. Each section explores in detail the need for decentralized solar energy solutions, the challenges faced during and after installation, and the benefits observed by end users and implementers.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CHAPTER 3

CASE STUDY FINDINGS

The case studies presented in this report cover decentralized solar energy solutions that improve the electricity supply to the health, education, and livelihood sectors in climate vulnerable areas of Assam, Jharkhand, and Rajasthan states. They have been implemented by a mix of government agencies, non-government agencies, and private sector agencies.

The case studies analyze how implementing agencies use decentralized solar energy solutions to address communities' development needs while facing erratic rainfall, floods, thunderstorms, lightning strikes, groundwater contamination, water shortages, and extreme heat. A summary of the case studies covered in this study is provided in Figure 1. Details of the case studies can be found in Appendix A.

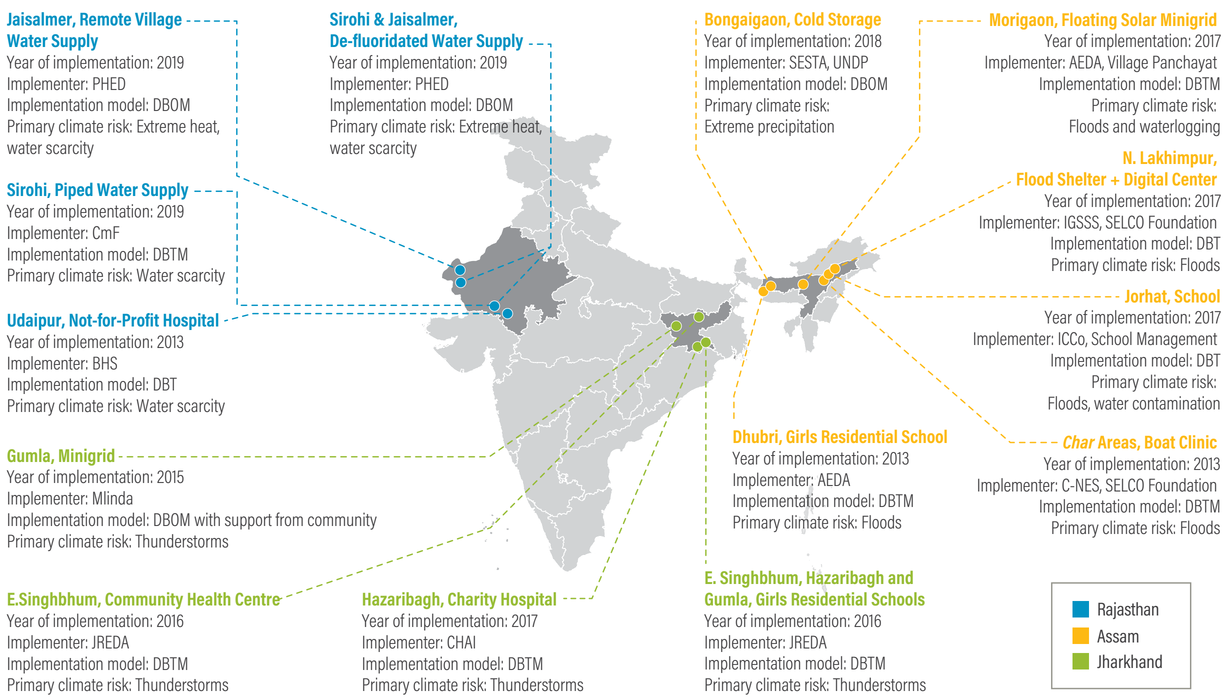
Most of the case study installations have multiple agencies working together to ensure that the energy solutions serve user needs. In this report, we name only the critical implementing agencies primarily responsible for designing, installing, or planning for the upkeep of energy projects.

The findings from our analysis are grouped into two sections. In the first section, we present our observations on how energy demand for education, health, and livelihoods is affected by climate-related events. In the second, we examine whether and to what extent the decentralized solar energy projects factor climate change into their technical, operational, and financial planning.

Energy Access for Education, Health, and Livelihoods in a Changing Climate

We find that slow-onset and sudden-onset climatic events affect access to energy in different ways. First, sudden-onset events can disrupt the existing sources of electricity supply. For example, electricity grids are often disconnected during thunderstorms and floods because of, or in anticipation of, damage to grid infrastructure and concern for residents' safety. As a result, the demand for backup sources of electricity, such as diesel generators, increases. Slow-onset events such as water scarcity arising due to changes in precipitation and poor water management can affect the production of electricity from thermal power

Figure 1 | Fourteen Case Studies of Decentralized Solar Energy Systems in India



Note: AEDA = Assam Energy Development Agency; BHS = Basic Health Care Services; CHAI = Catholic Health Association of India; CmF = Centre for Micro Finance; C-NES = Centre for North East Studies and Policy Research; DBOM = design build operate maintain; DBTM = design build transfer; ICCo = Innovative Change Collaborative; IGSSS = Indo-Global Social Service Society; JREDA = Jharkhand Renewable Energy Development Agency; PHED = Public Health Engineering Department; SeSTA = Seven Sisters Development Assistance; UNDP = United Nations Development Programme.

Source: WRI authors.

stations (Tianyi et al. 2018). Second, people rely on electricity to respond to the conditions caused or exacerbated by climate change. People need electricity to power information and communication devices during floods, cooling devices during extreme heat, diagnostic and medical appliances to treat outbreaks of disease, and equipment for pumping and filtering water in areas facing groundwater contamination or water shortage. All these activities increase electricity demand.

Finally, electricity is required for ongoing activities that can build long-term capacities to cope with the increasing incidence and severity of weather events associated with climate change. Such activities include powering infrastructure required for digital education, providing access to clean drinking water, ensuring the quality of healthcare facilities, and creating income enhancement opportunities.

Energy Demand for Education

Educational institutions most commonly use electricity for lighting, thermal comfort, pumping water from below the ground or from overhead tanks for drinking and sanitation purposes, and powering ICT-enabled teaching and learning. Table 3 summarizes the case studies where a decentralized solar installation was used to enhance service delivery for education.

Three of the four educational facilities we studied faced power outages and voltage fluctuations that worsen during extreme rainfall, thunderstorms, lightning strikes, and flooding conditions. In the fourth case, a residential girls school in Dhubri, Assam, does not have grid electricity yet and depends entirely on a solar PV system for all its electricity needs. Residential schools need energy for lighting, thermal comfort, and water supply, not just during school hours but at all hours to

Table 3 | Energy Interventions for Education

NAME OF THE CASE	INSTALLATION TYPE AND SIZE	SERVICES PROVIDED	FOCUS COMMUNITIES	CLIMATE CONTEXT (CURRENT AND FUTURE)	ENERGY CONTEXT BEFORE SOLAR
Digital education center + flood shelter in North Lakhimpur, Assam	1.5 kW off-grid roof-mounted solar PV system	Electricity for lighting and charging points for computers and mobile phones	Economically backward, rural, flood-prone communities	The region is extremely prone to flooding with intermittent flooding from June to September. Projected increase in average rainfall and extreme precipitation	The solar system was installed immediately after the construction of the center. It subsequently got a grid connection, which gets disrupted during flooding conditions
Residential girls school in Dhubri, Assam	5 kW off-grid roof-mounted solar PV system with storage (storage is currently inoperative)	Electricity for lighting, fans, one sewing machine, and water pump in school and residence	Female students from marginalized communities	The region is extremely prone to flooding and land erosion. Projected increase in average rainfall and extreme precipitation	Unreliable grid connection Kerosene lamps used at night
A primary school in Jorhat, Assam	2 kW off-grid roof-mounted solar PV	Electricity for pumping and treating water for drinking, sanitation, and mid-day meals	Students from nearby villages	Groundwater is contaminated with arsenic, and the region is prone to flooding. Projected increase in rainfall and temperature	Unreliable grid connection Use of firewood and LPG for mid-day meals
Residential girls schools in Jharkhand (multiple districts)	20 kW off-grid solar PV system	Electricity for lighting, fans, computers, and water pumps in school and residence	Female students from marginalized communities	The region is prone to thunderstorms, lightning, and high wind speeds. Projected increase in extreme heat days and erratic rainfall patterns	Unreliable grid connection Diesel generator backup

Source: WRI authors.

serve the children and staff who stay on campus. Before installing the solar PV system, the residential schools in Dhubri and Jharkhand used diesel generators as the primary and backup sources of power, respectively. The Dhubri school is in a *char* (a riverine island in the Brahmaputra river, created through sediment deposits). It is often cut off from the mainland during rains and floods, limiting diesel access for the generator. Without a functioning diesel generator, the school had to use highly inefficient and polluting kerosene lamps for lighting and could not operate fans or get running water. The Jharkhand schools used diesel generators as backup sources of power during grid outages. With the provision of off-grid solar energy, the schools have reduced their overall electricity expenses and can run additional equipment such as computers.

However, the schools' reliance on fossil-fuel-based backup power has not been entirely phased out. For example, because the Dhubri school's battery backup became inoperative after installation, it is forced to go back to kerosene lamps during evenings and nights. In Jharkhand, the solar installations have been affected by thunderstorms and lightning, which, coupled with the slow response of the vendor to maintenance, has led the schools to fall back on their diesel generators.

The primary school in Jorhat is in a region where the groundwater is contaminated with arsenic. The school is dependent on unreliable surface water sources for drinking water and preparation of mid-day meals. Surface water sources are affected by biological contamination, especially during flooding and waterlogging events. The provision of solar-based electricity enables the school to use additional water filters (reverse osmosis [RO] filters that run on electricity) to provide safe and clean drinking water to children and a water pump to ensure running water in toilets. In addition, to prepare rice for the mid-day meals, the school uses a solar thermal cooking solution to preheat the water. Solar cooking reduces the school's dependence on liquefied petroleum gas (LPG) and firewood, reducing operational expenses.

The digital education center in North Lakhimpur was initially planned as a flood shelter for nearby villages. When it was connected to the grid, it was decided to use the shelter as a digital resource center where local youth could get computer training, and households could access government benefits. During floods, the grid connectivity is disrupted. During this time, the off-grid solar solution provides lighting and mobile recharging facilities, enabling access to information such as flood levels and evacuation processes. The region regularly faces grid disruptions, but this worsens during floods, when the villages are without access for weeks.

The case studies demonstrate that these facilities employed alternative fuels such as kerosene to meet their energy needs owing to the absence of reliable grid connectivity, incurring avoidable costs. Climate-related events affected physical access to these alternative fuels, and grid connectivity (where available) worsened further during such events. The installations, where adopted and implemented, successfully reduced the use of alternative fuels and reduced operational costs for the schools.

Energy Demand for Health

The absence of a reliable supply of electricity affects health centers' daily operations and community-level public health initiatives such as the provision of potable water. Installation of off-grid solar PV in the six locations described in Table 4 has resulted in reliable electricity supply for primary health care services, running much-needed medical equipment, refrigeration for vaccines and medication, and providing safe drinking water to remote communities. Diesel-powered generators have conventionally played a crucial role in providing electricity to remote public health centers and clinics. However, the fuel and maintenance costs in such remote locations make the use of diesel generators an expensive and polluting alternative.

The grid-connected Community Health Centres (CHCs) and nonprofit hospitals in Jharkhand experience worse power outages during thunderstorms when falling trees and lightning strikes damage grid infrastructure. Backup electricity from diesel-powered generators is not cost-effective. Moreover, diesel availability is affected by extreme weather conditions as road connectivity to nearby towns is disrupted. When everything fails, healthcare professionals had to work by torchlight. With the arrival of the off-grid solar PV systems, critical procedures such as deliveries could be conducted under proper lighting.

The nonprofit health clinic in Udaipur, Rajasthan, operates under similar conditions. The clinic is located away from Udaipur city in an area prone to frequent power outages and grid failures. The

Table 4 | Energy Interventions for Health

NAME OF THE CASE	INSTALLATION TYPE AND SIZE	SERVICES PROVIDED	FOCUS COMMUNITIES	CLIMATE CONTEXT (CURRENT AND FUTURE)	ENERGY CONTEXT BEFORE SOLAR
Boat clinic in Majuli, Assam	3 kW off-grid system on a boat	Run lights, fans, and medical equipment and refrigeration	Serving Mising tribes in *char* areas. One boat clinic serves seven villages during each trip. Focus on women and child health	Island prone to extreme flooding, waterlogging, and rising temperatures	Petrol-based generator for basic needs of the boat clinic Ice pack for vaccine storage
Community Health Centre in Gamharia, Jharkhand	10 kW off-grid system	24/7 electricity for all equipment, lighting, and refrigeration	Health care services for the rural population	The region is prone to thunderstorms, lightning, and high wind speeds. Projected increase in extreme heat days	Unreliable grid connection Diesel generator backup
Nonprofit hospitals in Jharkhand (multiple districts)	7–10 kW off-grid systems in different locations	Patient wards, operation rooms, lab equipment, refrigeration, water supply	Health care for marginalized and poor rural communities	Remote area is prone to thunderstorms and lightning. Increase in the number of extreme heat days	Grid connection with 3- to 12-hour outages Diesel generator backup
Nonprofit health clinic in Rajasthan	1 kW off-grid roof-mounted solar system	Essential lighting and equipment: autoclave, centrifuge, baby warmer, spotlights, fridge, and platform weighing scale	Health care with a focus on tuberculosis (TB) and malnutrition in tribal communities	Projected increase in extreme precipitation events with long dry spells	Single-phase unreliable grid supply
Piped water supply in Sirohi, Rajasthan	3.2 kW off-grid roof-mounted solar system	Piped water supply for 70 households	Tribal communities in remote locations	Hilly terrain in a dry climatic region. The annual average rainfall of 600 mm. Increasing extreme rainfall patterns	Single-phase unreliable grid supply
De-fluoridated water supply in Rajasthan (multiple districts)	1.5 to 2 kW off-grid steel-mounted solar system	De-fluoridated water supply in designated spaces	Communities residing in fluoride-affected areas	Prolonged droughts and water shortages in Jaisalmer. Reduced number of rainy days with extreme rainfall patterns	Single-phase unreliable grid supply

Source: WRI authors.

off-grid solar system helps the clinic offer diagnostic facilities and medical support for ailments such as vector-borne diseases, which are projected to rise in the region with climate change.

Assam's *char* areas are disconnected from the mainland and extremely prone to flooding events, making primary health care or electricity supply challenging to build. A boat clinic is one of the few viable options for ensuring regular health-care access for the 95 *char* villages in Jorhat and nearby districts. A boat clinic requires a decentralized energy source to power medical appliances, vaccine cold storage, and necessary facilities such as lights, fans, and mobile chargers for the staff who stay on the boat. Using solar power instead of a petrol or diesel generator allows the boat clinic to make longer trips and reach remote villages. Refueling is required only to run the boat and not for medical equipment. Solar power also reduces indoor air and noise pollution, runs more medical equipment, and enables refrigeration facilities for vaccines. The clinic is functional year-round and acts as a first response for health care in flood-affected communities, helping prevent post-flood disease outbreaks.

Because electricity is essential for operating health facilities, diesel generator sets have been the electricity solution of first and last resort in the absence of reliable grid connectivity at health centers. Diesel generators are not cost-effective for health facilities, which face challenges in accessing diesel during extreme rainfall, flooding,

and storms. Solar PV installations in these health centers have reduced diesel expenses and allowed for uninterrupted services and better working conditions for staff. They have also allowed access to adequate drinking water, which requires electric pumps.

In Sirohi and Jaisalmer in Rajasthan, groundwater is fluoride-affected, and surface water sources are nonexistent. Groundwater recharge is expected to be reduced due to changing climate patterns, resulting in an increased fluoride concentration in the water supply. Solar-powered water supply and treatment systems improve community health and reduce the burden on women, who take responsibility for fetching potable water. The reduced groundwater recharge can result in resource extraction at further depths, which will increase electricity demand.

Energy Demand for Livelihoods

These case studies cover interventions that improve productivity and income and reduce the risk level in economically backward or marginalized communities that are mostly dependent on agricultural livelihoods. The case studies include regions that are not connected to the grid or that experience unreliable or insufficient single-phase electricity. A summary of the case studies is presented in Table 5.

Solutions such as the floating solar minigrid in Morigaon and the minigrid in Gumla were implemented before the region was grid-connected. They remain relevant because weather events such as floods and thunderstorms disrupt grid electricity. In flood-prone Morigaon, the flood-resilient floating minigrid provides electricity to 21 households. However, it supports only one household's livelihood by powering a fishpond aerator and a solar irrigation pump. In Gumla, the minigrid supports home-based poultry farmers and agribusinesses running cereal and pulse mills, grinders, and mustard oil expellers, as well as non-farm enterprises running vending machines and banking kiosks. These productive loads account for 60 percent of the plant utilization. Gumla is prone to thunderstorms and lightning strikes that cause regular power outages on the grid. Moreover, the single-phase electricity provided to households is insufficient for running small businesses, making a decentralized solution such as solar a crucial enabler for livelihood activities.

Table 5 | Energy Interventions for Livelihoods

NAME OF THE CASE	INSTALLATION TYPE AND SIZE	SERVICES PROVIDED	FOCUS COMMUNITIES	CLIMATE CONTEXT (CURRENT AND FUTURE)	ENERGY CONTEXT BEFORE SOLAR
Floating minigrid in Morigaon, Assam	10 kW off-grid floating solar panels structure on a backyard pond	Electricity provision to 25 households and small enterprises (pond aerator for increasing fish production) in village	Marginalized section of the community that is dependent on small-scale agriculture, fisheries, and livestock for their livelihoods	The village experiences annual flooding and waterlogging from the Brahmaputra river. 70% of the district is flood-prone, with 33% at high risk	Unelectrified
Cold storage in Bongaigaon, Assam	4.5 kW solar PV array system with in-built electricity storage	5 MT cold storage by Ecofrost, which can store seeds and farm produce in temperature ranges between 4 and 10°C	Farmer Producer Organization (FPO) comprises only women farmers	Reduction in annual average rainfall with erratic rainfall patterns, an increasing number of heat days. Also, 24.11% of the district is flood-prone, with 9% being at high risk of flooding	Unreliable grid supply. Due to unreliable grid electricity, cold storages were not viable in that region
Minigrid in Gumla, Jharkhand	35 minigrids of 20–25 kW each	Powers households and village entrepreneurs who have poultry farms, oil expellers, and grain mills	Economically backward communities belonging to the lowest quintiles of the National Family Health Survey (NFHS) wealth index	Thunderstorms with lightning strikes and strong winds and seasonal water shortages, projected increase in the number of days with high temperatures	Unelectrified
Water supply for livestock in Jaisalmer, Rajasthan	Seven installations of 45–60 kW each	Pumps groundwater to ground level reservoirs for human consumption and into troughs for consumption by livestock and wild animals in water-stressed areas	Economically backward, livestock-rearing communities living in extremely remote desert regions	Extreme heat, water shortage, strong winds, and sparse vegetation (desert ecology)	Single-phase electricity connection in the village, hence use of diesel pump sets for pumping water

Source: WRI authors

In Jaisalmer's remote and arid deserts, rearing livestock is the primary livelihood. The region faces severe water shortages, making crop cultivation next to impossible and survival tough for people and their livestock. Although the region is connected to the grid, the electricity supply is unreliable. The remoteness also makes it difficult for any disruptions to be solved on time. Decentralized solar energy systems help in pumping drinking water for use by both communities and their animals.

In Bongaigaon in Assam, members of an all-women Farmer Producer Company (FPC) face erratic and unseasonal rainfall that affects their livelihood by increasing crop and seed rots' risk, among other hazards. With the help of solar-PV-powered cold storage, they can extend the storage time for seeds and other farm produce and reduce losses due to damage and rot. With reliable electricity, farmers can spread their risks by diversifying their livelihoods to include post-harvest processing such as cold storages, milling and grinding, and irrigating fields when rainfall is inadequate.

Electricity plays an essential role in improving the productivity and sustainability of livelihoods dependent on natural resources—agriculture and allied activities—and other market-based enterprises. Solar PV installations, especially in remote and backward areas, allow for productive livelihoods despite challenges that make grid extension unviable.

Planning for Energy Supply: Design Considerations in the Context of Climate Risks

This section discusses how stakeholders in each case planned the implementation of a decentralized solar energy solution and whether climate risks were factored into the projects' technical, operational, and financial design.

Summary of Planning in the Context of Climate Risks

Of our 14 case studies, few installations have factored in the environment and local climate conditions in some form or the other while developing the technical design and operational and financial models. Most of these projects may be responsive to some climatic impacts. They considered recent climatic changes and local knowledge of the environment and weather, such as wind speeds and floodwater levels. Only three installations—the minigrid in Gumla (Jharkhand) and de-fluoridation and remote water supply in Rajasthan—considered current climate patterns from all three aspects: technical, operational, and financial. The minigrid in Gumla added lightning arrestors and surge protectors in response to regular thunderstorm activity. The water supply projects in Rajasthan designed the systems to be resistant to historic high wind speeds. Although the minigrid project in Gumla has started looking at climate projections, none of the other interventions look at future climate risks instead of focusing on historical and current experiences.

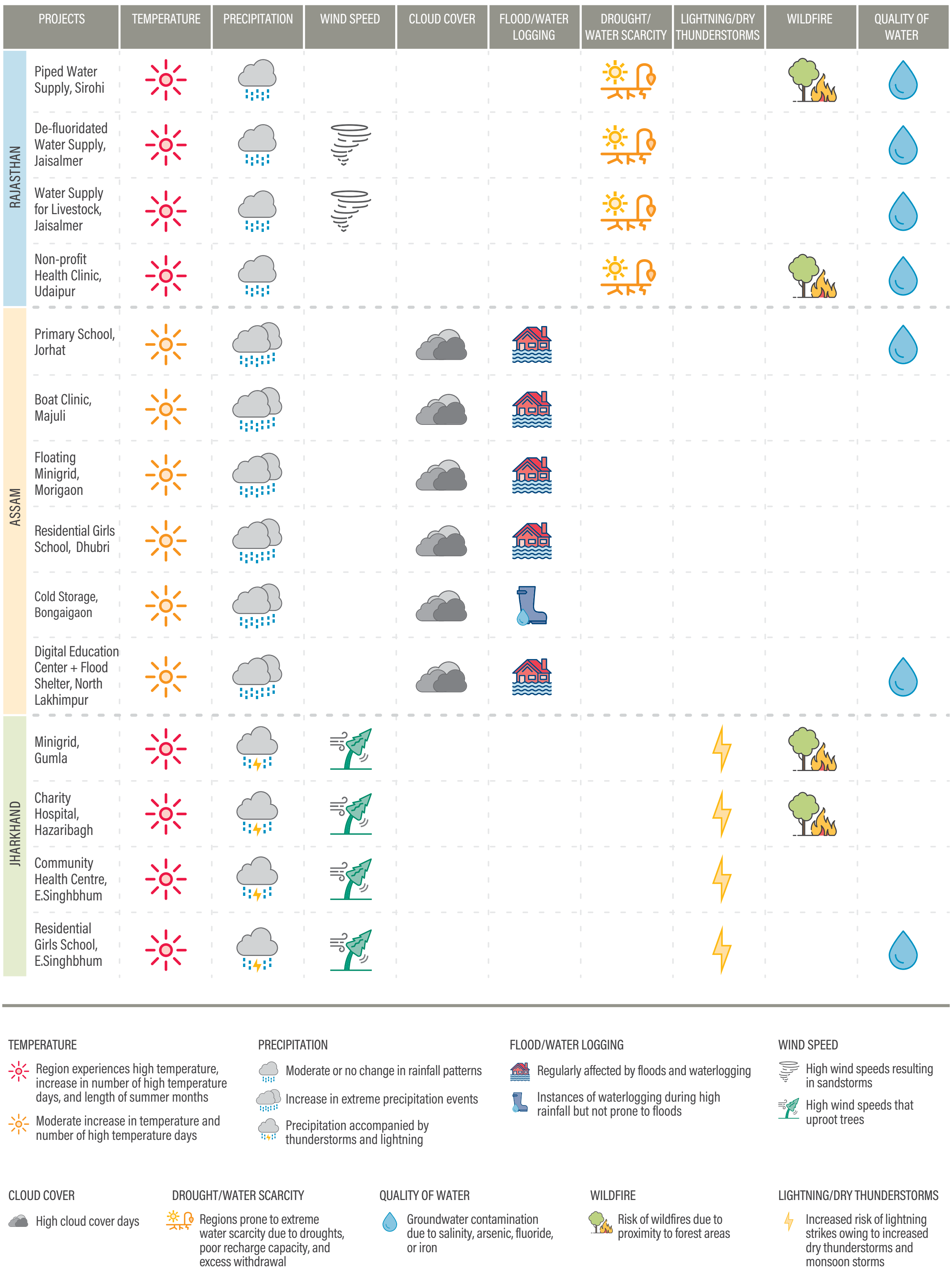
Figure 2 shows the type of climate risks most relevant in each case study as perceived by project beneficiaries and implementers interviewed. The design of the projects considered some of the following current environmental and climate factors. Only one project considered climate projections while designing the project.

Technical Aspects

As the figure shows, different locations in the same state face varied climate risks. In Assam, the significant risk is that of flooding and waterlogging. Some case study installations have designed their systems to mitigate this risk. For example, the floating solar minigrid in Morigaon can function even with a 5 ft water level rise. Here, a ground-mounted solar PV is not ideal as the region is prone to waterlogging, and any available space is needed for crop and fish farming. Most of the houses in this village (as in most parts of Assam) are made of tin and can only support a limited load. A 10.5 KW system would require significant roof space, which is not viable in this case. Given this context, a floating solar solution with adequate battery storage offers a better alternative, as it overcomes the challenges associated with ground/roof-mounted solar. In another case, while selecting the site for the cold storage unit in Bongaigaon, an area not prone to regular floods was chosen, and the solar system was mounted on the roof of the cold storage unit. In North Lakhimpur, the digital education center cum flood shelter is similarly on higher ground and raised further above the current flood levels. The solar panels have been mounted on the roof to reduce the risk further, as is the case with the residential girls' school in Dhubri and Jorhat's primary school. Batteries in all the instances in Assam are stored in raised platforms at heights above current water levels. In addition, Jorhat's primary school has oversized the system to make up for losses during cloudy days.

In Jharkhand, the lightning and temperature variation followed by high wind speeds are the key climate risks that affect the energy installations. The implementing agencies have taken steps to reduce the impact. For example, the minigrid in Gumla has lightning rods, surge protectors, and chemical earthing as precautions against lightning strikes. The minigrid operators keep spare meters in stock to replace the ones affected by lightning strikes at any point in time. They are also actively engaged in research to develop better, innovative solutions to protect their minigrids from lightning damage. In addition to the lightning rods and surge protectors, the community health center in Gamharia and the residential girls schools in multiple locations in Jharkhand are connected to a remote monitoring system to report malfunctions to the implementing agency as well as the energy vendor. These specifications were incorporated at the tendering stage. However, despite precautionary measures, there are also cases of damage being reported, such as in a nonprofit hospital in Hazaribagh. In this case, although there was a lightning arrestor, faulty earthing resulted in damage to the system. Similarly, lightning struck the solar PV installation at one of the residential girls' schools, making it dysfunctional ever since.

Figure 2 | Climate Risks Faced by Each of the Case Study Projects



Note: All the regions must factor in cloud cover, but the ones highlighted in the tables are regions with dense cloud cover for a higher number of days.

Source: WRI authors.

In Rajasthan, extreme heat can reduce the efficiency of solar panels and batteries. The solar projects for the health facilities and water supply and purification systems have been installed with 30 percent excess capacity to allow optimum output due to efficiency loss and cloud cover on rainy days. The water supply projects by the Public Health Engineering Department (PHED) in Rajasthan have been designed based on human and livestock population growth for seven years, as reflected in the tank capacity. Because Jaisalmer faces sandstorms and high wind speeds, the solar de-fluoridation unit's steel structure is designed to weather high wind speeds of up to 200 kmph and a wide range of temperatures. The unit structure is a 20 ft mild steel (MS) frame structure on a concrete base. The other challenge in states such as Rajasthan is water shortage. All installations in Jaisalmer are planned as interim measures for a fixed term of seven years, assuming that groundwater withdrawal will no longer be sustainable due to geological and climatic conditions. At the end of seven years, these projects are expected to be decommissioned and replaced with more sustainable options available at the time.

Although climate risks have been considered while designing the systems, factoring of risk is conspicuously absent post installation. For example, in water-stressed areas, the project's sustainability depends on the sustainability of the water source. In such cases, when groundwater recharge is currently not part of the design, as in the case of installations in Rajasthan, it can affect the performance of the system in the future.

Operational Aspects

In several of our case studies, the implementing agency is an energy expert; for example, the state nodal agencies for renewable energy such as Assam Energy Development Agency (AEDA), the Jharkhand Renewable Energy Development Agency (JREDA), and energy enterprises such as Mlinda in Jharkhand.

None of the nonprofit implementing agencies have a sole focus on energy as part of their operations. These agencies include the Seven Sisters Development Assistance (SeSTA), Indo-Global Social Service Society (IGSSS), Innovative Change Collaborative (ICCo) & Reaching and Educating At-risk Children (REACH) India, Centre for North East Studies and Policy Research (C-NES), Basic Healthcare, and Centre for Micro Finance (CmF). Of these, IGSSS and C-NES worked closely with a partner with energy expertise (SELCO Foundation) through all the implementation stages. The remaining implementing agencies relied on internal technical expertise or vendors' expertise in the open market for implementing their solutions (see Figure 1 for a summary of the agencies and the interventions they implemented).

Where implementing agencies are energy experts, precautions were taken to incorporate climate risks in the technical design, but this did not necessarily ensure operational clarity in terms of roles and responsibilities. Operational clarity enhances coordination among multiple stakeholders, which is essential for building climate resilience. For example, in the case of a residential girls school in Jharkhand, when the solar system broke down, the school administrators were not clear regarding whether it was their responsibility or JREDA's to arrange for repair and pay for it. In the case of the floating solar minigrid in Morigaon, installed by AEDA, community members declined to use or pay for electricity from the minigrid once grid electrification reached the village. Interventions that integrate design considerations while also clarifying roles and responsibilities and ensuring local buy-in are functional and better equipped to respond to developmental needs and climatic impacts.

Decentralized solar energy installations have the flexibility of being installed, maintained, and operated by either centralized agencies such as state-level nodal agencies or decentralized models of community management. JREDA, Catholic Health Association of India (CHAI), PHED, and C-NES projects provide examples of centralized ownership structures. In JREDA schools and hospitals, the vendor contracts directly with JREDA and not with the individual schools or hospitals. The same is the case with CHAI hospitals. As a result, even though the schools and hospitals are encouraged to contact the vendor directly to resolve problems, the vendor is not obliged to respond, causing delays and service disruptions. This is particularly important when weather events directly damage the systems (e.g., lightning strikes in Jharkhand). In the case of PHED and C-NES, although the contracts are centralized, the facility-level operations are co-managed with the energy vendor, which reduces the burden of coordinating between different agencies for ongoing operations and maintenance (O&M). At the residential girls school in Dhubri, the primary school in Jorhat, and the nonprofit health clinic in Udaipur, the energy installations are owned and managed at the facility level. In such cases, stakeholders involved do not have the capacities or bargaining power to ensure that the project meets local needs, has adequate maintenance provisions, or incorporates climate considerations beyond what is offered by the solar vendor.

Community members play critical roles in 5 of the 14 case studies. The solar installations to supply piped water in Sirohi and the floating solar installation in Morigaon are owned and managed by a village committee. In these cases, the energy vendors agree with the village representatives to provide maintenance services, usually for a fixed term funded by user fees. Beyond that term, it becomes the village committee's responsibility to ensure that the energy system remains functional and in use. The village committee also sets up mechanisms to collect user fees from energy consumers to pay for ongoing maintenance. In Bongaigaon's cold storage, the FPC owns and is primarily responsible for the solar installation. The minigrid in Gumla is run by a social enterprise that follows a slightly different approach. It draws up a service agreement with the village representatives, under which it selects the site for minigrids and pays rent for the lease of land where the solar panel arrays and operating house with battery backup are set up. The minigrid installation includes transmission and distribution wires for villages and meters for each user who pays for the electricity. Community engagement in these case studies has made implementing agencies and vendors more accountable and empowered the community to make decisions regarding their energy needs. This equips them to respond better to climate-related events.

Many of the case study installations have locally hired or trained operators. These operators may or may not work for the energy vendor. The minigrid in Gumla and the remote water supply and de-fluoridation projects in Jaisalmer and Sirohi recruit and train local operators to handle operations and conduct preventive maintenance as part of the energy services provision. With this, lead times reduce significantly for responding to operational challenges and disruptions that arise from unexpected weather events. In the remaining installations, local operators are usually residents or staff of the facility where the energy system is installed. In these installations, although the operators may know how to maintain the system functions on an ongoing basis, they receive little to no training on extensive

troubleshooting. They are dependent on the vendor for diagnostics and resolution of every issue. In the case of the cold storage in Bongaigaon, this is partially resolved by proactive remote monitoring by the energy vendor.

Financing Aspects

The financing models for the interventions studied were either grant-based or publicly funded, which sometimes included user fees. Three of the installations (the floating solar minigrid in Morigaon, a primary school in Jorhat, and piped water supply in Sirohi) used a community's financial or workforce contribution during installation. Stakeholders in these interventions feel that such payments from the community are instrumental in garnering long-term commitment from the beneficiaries by creating a sense of ownership and interest in ensuring the system's upkeep. In addition, accountable arrangements to track contributions and utilization of funds are also essential to building trust in the implementation agency.

Financing for maintenance of installations varies among the case studies. The O&M costs of three projects (the floating solar minigrid in Morigaon, a primary school in Jorhat, and piped water supply in Sirohi) are funded entirely or partially by the beneficiaries' contributions. The minigrid in Gumla covers its O&M costs from its service charges. Three other projects (the boat clinic in Jorhat, flood shelter cum digital resource center in N. Lakhimpur, and nonprofit hospitals in Jharkhand) included fixed five-year O&M contracts in their installation grants. By contrast, four other projects (de-fluoridation in Sirohi, water supply for livestock in Jaisalmer and community health center in Gamharia, and the residential girls schools in Jharkhand) have fixed-tenure O&M contracts serviced by public sources of funding. The remaining four projects studied did not have O&M arrangements and had to meet these costs by themselves. Even when funds were kept aside for O&M contracts, they were often nominal, as with the floating solar minigrid in

Morigaon. Morigaon did not have funds to replace batteries at the end of their three- to five-year lifespan. Large-scale interventions, such as those involving nonprofit and government hospitals in Jharkhand, leave O&M to be covered by the facility budgets, which can be onerous, especially when damaged parts need replacement.

An interesting model deployed by PHED in Rajasthan utilized a staggered payment schedule that released 65 percent of the total contract amount to the vendor as initial capital and allocated the remaining 35 percent to O&M. The latter was released in annual installments over seven years. This model does not require annual maintenance contracts, which are typical of other projects. In addition, the agreement designed by the PHED includes a sunset clause, stipulating an end to the project period. After seven years, when the O&M tenure expires, the contract is either extended by the PHED, or the vendor is asked to remove the installations and return the use of the allocated space to the PHED. Although the average life of solar installations is more than seven years, this arrangement gives the PHED the option of exploring other electricity sources after the contract expires. Furthermore, because the installation's practical ownership remains with the vendor throughout the contract, there is an implicit commitment from the vendor to maintain and ensure the security of the structures. Note that such arrangements could potentially exclude small-scale energy enterprises from participating in such contracts because of the higher costs.

Even though these interventions are in climate vulnerable areas, many did not consider insurance for losses due to wind, lightning, or flood damage, or cover supply delays caused by loss of road connectivity. Only a few case study installations considered insurance, specifically those with water pumping as the primary intervention because pump insurance already exists as a market product. Because there are no specific products for solar PV insurance, our installations also did not procure such coverage. However, some of them did face challenges and risks that insurance could cover. Overall, only five installations allocated a separate budget for regular upkeep from the beginning. Four of these five installations allocated money for the potential damage caused by extreme weather events.

The case studies have demonstrated that climate-related events impact electricity provision in grid-connected areas and that RE interventions have proved beneficial in reducing the cost of electricity access, improving the service provision at schools and health centers, and increasing the short-term productivity and long-term sustainability of livelihoods. On delving further, we see that there are considerations related to sizing, siting, and designing the installations that are important to ensure the sustainability of the structure in the face of climate change. During the life of the installation, clarity on roles and responsibilities, capacity development of the stakeholders involved, and community engagement are essential for the smooth operation of the installations. Financial arrangements to cover the costs of operations, maintenance, and troubleshooting either in the form of budget outlays, O&M contracts, and user fees are essential for sustaining the installations. There is scope for innovative business models with various partnership models, as has been demonstrated by some case studies.

CHAPTER 4

IMPLICATIONS FOR DECENTRALIZED SOLAR SOLUTIONS IN CLIMATE VULNERABLE REGIONS

Ensuring the sustainability of energy systems is an area of concern for decentralized solar energy practitioners. Decentralized solar energy systems are expected to have a long usable lifetime, but often fail to meet expectations because of technical, financial, operational, and logistical problems.

Ensuring the Sustainability of Installations

A recent report, *Lasting Impact: Sustainable Off-Grid Solar Delivery Models to Power Health and Education* (UN Foundation and SEforAll 2019), explores this issue in depth for health and education facilities in South Asia and sub-Saharan Africa. The report identifies critical insights to be kept in mind by stakeholders wishing to undertake off-grid solar projects for community facilities. The insights relate to projects' technical, organizational, and economic aspects and span four stages of project life cycles: inception, design, build, and O&M. We borrow this framework to support additional considerations that stakeholders need to keep in mind while working in climate vulnerable areas, based on our observations from the case studies.

Technical Considerations

Technical considerations include the interactions between the electricity infrastructure and the environment in which it operates, as shown in Table 6. They include the current and future climate risks in the region, how they affect the demand for and supply of electricity, and what technology options, codes, and guidelines exist to ensure that the energy system remains useful and functional. It also looks at whether climate risks are included in project timelines during implementation and whether the technical design considers the market availability of spare parts in the event of any disruptions.

Different climate-related events can affect decentralized solar-powered systems differently depending on the type of event and its intensity. We have not identified any comprehensive guidelines on how decentralized solar systems should be designed to mitigate the risk of different climate events. However, we summarize some standard practices noted from the case studies and recommendations on resilient infrastructure from the literature in Table 7. This table discusses the potential impacts of climate-related events on decentralized solar installations and the technical design considerations for mitigating the risks. Box 1 discusses ongoing mapping initiatives on climate and energy by WRI that can support design considerations.

Table 6 | Technical Considerations at Various Stages in a Project

INCEPTION AND DESIGN PHASE	▪ What climate risks does the location currently face? ▪ What climate risks will the location face during the lifetime of the energy project? ▪ How is the energy demand affected by climate risks? Is this effect factored into the design of the energy system? ▪ How will various climate risks, individually or combined, affect the energy infrastructure? ▪ What electrical, structural, and product design standards should the project follow to factor in the climate risks? ▪ Are there technology options to proactively monitor and respond to climate risks?
IMPLEMENTATION PHASE	▪ Are all the required electrical, civil, and product design codes being followed? ▪ Have the climate risks been factored into the project life cycle?
O&M PHASE	▪ Are there local markets for components that are specifically affected by or required to respond to climate risks? Is there a need to procure and stock essential spare parts? ▪ Are the operational guidelines for taking care of the energy system during extreme weather events specified?

Note: O&M = operations & maintenance.

Source: WRI analysis, based on recommendations for resilient infrastructure by Williamson et al. (2009), OECD (2018), Hallegatte et al. (2019), and UN Foundation and SE4All (2019).

Table 7 | Impact of Climate Change on Off-Grid Solar Infrastructure

CLIMATE CHANGE, UNCERTAINTIES, AND HAZARDS	DIRECT POTENTIAL IMPACT ON INFRASTRUCTURE	DESIGN CONSIDERATIONS TO MITIGATE RISK
Temperature	Increased temperature can reduce solar cell efficiency Extremely high temperature can reduce the carrying capacity of lines depending on the transmission distance Extreme heat and cold can affect battery life and efficiency	Include efficiency loss in energy demand calculations Where possible, use components that can withstand high temperatures Improve air circulation below and in between the panels Factor in replacement costs for components and batteries whose life can be affected by extreme temperatures
Precipitation	Increased precipitation days can reduce productivity Increased precipitation intensity can damage parts of the system Heavy downpour and persistent rainfall can damage the distribution lines	Limit exposure of wiring and distribution cables to rainfall
Wind speed	High/cyclonic wind speeds can damage the infrastructure Winds can damage distribution lines by affecting connecting points	Follow structural design codes to design wind-resilient structures
Cloud cover	Reduced array output due to reduction in insolation	Include efficiency loss in energy demand calculations
Lightning	Direct strikes can damage parts of the system and transmission lines	Add lightning and electrical surge arrestors at source and the consumer level
Flood/waterlogging	Can damage the system and transmission lines	Elevate the system above ground based on historical flooding/waterlogging, soil data, and flooding projections
Drought	Reduced availability of water can result in dust accumulation, leading to reduced efficiency of panels If the water supply is dependent on solar energy, the problem is exacerbated, and the usability of the energy system is compromised	Design dust removers that are not dependent on water in drought-prone regions Use recycled water
Wildfire	Increased dry periods can lead to wildfires that can damage the infrastructure	Choose fire-resistant modules
Landslides	Precipitation-induced (or earthquake-induced) landslides can damage the infrastructure	Assess local topographical and geological conditions for selecting an appropriate site and follow structural design codes to avoid damage
Quality of water	Turbidity and salinity can result in scouring of the panels pH levels and other contaminants such as iron in water can have a corrosive effect on mounting structures and foundation	If dust removal is via washing, add water filter/softener as required and where feasible Follow structural design codes for foundations in contaminated water table regions Use anti-corrosive modules and structure
Indirect impacts—Increased precipitation, high wind speeds, and flooding can affect the response time of the maintenance crew and availability of parts		

Source: WRI analysis, based on recommendations for resilient infrastructure by Williamson et al. (2009), OECD (2018), and Hallegatte et al. (2019).

Box 1 | Using Geospatial Information for Location-Specific Decision-Making

Climate change is a global challenge, but adaptation planning occurs at various levels: local, regional, national, and international. "Planned adaptation to climate change means using information about the present and future climate change to review the suitability of current and planned practices, policies, and infrastructure" (Fussel 2007). In addition, adaptation planning requires human development and environmental indicators to assess the current situation and project future requirements.

Location-specific planning for development and adaptation needs can be supported by geospatial analytics, which can help planners understand existing local conditions, trends, and probable future climatic events using multiple indicators. The Partnership for Resilience and Preparedness (PREP) and the Energy Access Explorer (EAE) are examples of geospatial data analytics for planners to support decision-making.

Climate Information Services are used widely. One of the significant benefits of converting climate data to spatial visualization is that it enables users to analyze and add value to data (Giuliani et al. 2017) and supports informed decision-making. PREPdata (www.prepdata.org) is a free, open-source data platform that provides accessible, curated data that decision-makers need to analyze vulnerability and build climate resilience. It allows users to easily access highly credible climate, physical, and socioeconomic datasets from multiple sources, including the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, United States Geological Survey, European Space Agency, and Indian Institute of Tropical Meteorology. Users can visualize a specific region's vulnerability; track the indicators most relevant to their work on customizable dashboards; request that data providers add new tools or datasets to PREPdata; and share their analyses with adaptation practitioners worldwide. The platform's wide-ranging datasets include extreme weather events, precipitation, drought and flood risks, social vulnerability, coastal energy facilities, landslides, sea level rise, global urban heat island effect, reservoirs and dams, global cropland extent, and more. Details on the accuracy, granularity, and source of each dataset are available on the website.

GIS-based modeling helps decision-makers develop electrification policies, identify technologies, and design location-specific cost-effective electricity supply systems for diverse users (Mentis et al. 2016). WRI India's EAE (https://www.energyaccessexplorer.org/) is an interactive online platform that compiles and analyzes several spatial datasets across the development and electricity sectors. It is a significant effort that helps visualize energy access gaps, focusing on unmet and undermet electricity needs for social and institutional facilities such as hospitals and schools. These maps will provide both a state of play and establish benchmarks for future decision-making in the sector.

Organizational Considerations

Organizational considerations for factoring in climate risks related to the roles, responsibilities, and expectations of all the stakeholders involved in or affected by the energy project are shown in Table 8. Considerations include whether the contractual and non-contractual responsibilities of all the participating organizations are laid out if a climate-related event were to occur, and whether they have adequate capacity and flexible internal mechanisms to execute their roles and responsibilities. An essential component of organizational aspects is a careful examination of the community's expectations and how they will be affected by the energy project, including energy's role in their current and future coping mechanisms to address climate risks.

Economic Considerations

Economic considerations for energy projects in climate vulnerable areas relate to the financial resources available to plan for, implement, and maintain a climate resilient system. As discussed in Table 9, they involve a realistic estimation of whether the funding plan regards climate resilience as a key priority and has addressed the integration of financing options to hedge against the uncertainty caused by climate risks in the short and long term.

Our analysis of the case studies suggests that although energy projects largely consider the technical aspects of planning for climate resilient systems, they often fall short when planning for economic and organizational sustainability in the face of climate risks. Although currently there are no customized insurance products for challenges

Table 8 | Operational Considerations at Various Stages in a Project

INCEPTION AND DESIGN PHASE	▪ How do communities cope with extreme weather events, and will the energy project help or hinder their coping mechanisms? Is there a plan to set expectations and seek feedback from the community about the project? Will this process include the voices of all affected groups, including marginalized groups in the community? ▪ How will the performance of the energy project be measured? Will this consider the climate change impacts? ▪ Are contractual and non-contractual roles and responsibilities of each participating organization (at headquarters or the local level) laid out? Does this cover situations arising from climate-related risks?
IMPLEMENTATION PHASE	▪ Do all affected members of the community have adequate information about the project? Are there formal mechanisms to incorporate their concerns, if any, into the design and implementation of the project? ▪ Do all the participating organizations have adequate capacities to execute their contractual or non-contractual roles and responsibilities before, during, and after extreme weather events? Is there a need to recruit additional capacity? ▪ Are any local community members being trained in operating and conducting necessary repairs in the aftermath of extreme weather events, as per guidelines?
O&M PHASE	▪ Is there locally available capacity for operating a climate resilient system and conducting basic repairs/replacement in the aftermath of weather events? ▪ Is there a communication/response plan in place to address unexpected problems caused by weather events?

Note: O&M = operations and management.

Source: WRI analysis, based on recommendations for resilient infrastructure by Williamson et al. (2009), OECD (2018), Hallegatte 2019, and UN Foundation and SE4All (2019).

Table 9 | Economic Considerations at Various Stages in a Project

INCEPTION AND DESIGN PHASE	▪ Does the funding allow for the design of a climate resilient system? ▪ Has the funding plan considered options such as staggered payments, insurance, sunset clauses, or contingency funds for hedging against climate risks? ▪ Has the funding plan considered existing or extended warranty coverage for the effects of climate-related events on the system? Is this factored into procurement plans? ▪ Does the funding plan specify financial responsibility in the event of climate-related events?
IMPLEMENTATION PHASE	▪ Has finance considered the potential implications of climate risks throughout the project life cycle?
O&M PHASE	▪ Is there a funding plan for ongoing and future O&M? Does this consider unexpected problems caused by extreme weather events? ▪ How is the financial performance of the energy project measured? Does this consider the risk of climate-related events?

Note: O&M = operations and management.

Source: WRI analysis, based on recommendations for resilient infrastructure by Williamson et al. (2009), OECD (2018), Hallegatte et al. (2019), and UN Foundation and SE4All (2019).

to solar PV installations from weather impacts, business interruptions, property damage, and so on, financing and implementing agencies must allocate some resources to avail themselves of such coverage as and when these products are developed. Energy projects are designed and implemented in silos by the implementing agency, with other stakeholders unclear about their roles and responsibilities. A coordinated effort must integrate all three aspects of project design to ensure energy projects' sustainability in climate vulnerable areas.

Key Messages

Climate change can affect the level and type of demand for electricity for development service delivery. Extreme events associated with climate change can disrupt the existing electricity supply, leading to demand for alternate or backup electricity sources. Communities rely on electrically powered activities to respond to conditions caused or exacerbated by climate change. Finally, electricity is required for ongoing activities that can potentially build long-term capacities to cope with climate-related events.

Effective decentralized solar solutions in climate vulnerable regions must be tailored to local conditions. Energy systems must be designed to meet context-specific electricity demand, based on local geography, the availability of supportive infrastructure, and end-use requirements. For example, planning for the design, installation, and maintenance of a decentralized solar energy system in a flood-prone *char* island school is very different from that in a lightning-prone mainland school, even if both schools fall under the same government program.

Decentralized solar energy systems are not entirely climate proof. Components of decentralized solar solutions are vulnerable to climate-related events such as floods, lightning, extreme temperature, and rainfall. Understanding and planning for the climate risks in advance can help reduce downtime, loss of assets, and build resilience.

Resilience planning starts before the design stage and continues thereafter. Project implementers, policymakers, and donors need to realize that building resilient structures and communities begins well before the design stage. System design and operation and maintenance planning should be based on climate-risk data and models, local socioeconomic and ecosystem assessments, policies, and design standards that promote and enforce resilient infrastructure and support community resilience.

Technology is just one component of a climate resilient decentralized solar installation. Organizational arrangements need to incorporate climate considerations while setting expectations and assigning roles and responsibilities. Climate resilient design needs to also translate into the funding plan, with innovative financing and risk hedging models.

There is a need to go beyond conventional implementation models. Traditional implementation models have specific, often siloed responsibilities. The uncertainty created by climate change requires all stakeholders to be more flexible and responsive and demands more innovative implementation, operation, and maintenance models. Examples include energy and development partners working together from the start, active participation and capacity building of end users and community members, and innovative financing models.

Conclusion

India faces the dual challenge of meeting its development goals while also reducing climate change impacts. DRE can contribute to both goals by providing opportunities to power healthcare, education, and livelihoods in communities most at risk from climate-related effects. DRE is often cited as a climate resilient electricity solution compared to centralized electricity generation, transmission, and distribution infrastructure. However, for sustainable, affordable, and reliable energy, the off-grid and grid-connected solar PV solutions need to be designed, implemented, operated, and maintained with future climate change impacts and energy demand in mind.

This report presents 14 case studies of decentralized solar installations in climate vulnerable areas that help facilities provide healthcare and education services and livelihood opportunities to communities. In our analysis, we examine how climate-related events affect the energy demand for development, ask whether climate risks are considered in the design of the installations, and explore the factors that affect the long-term sustainability of these solutions. Decision-makers for the development sector in government, NGOs, and private sector entities can benefit from recognizing vulnerabilities to climate change and the role that electricity plays in addressing developmental challenges and overcoming these vulnerabilities. While acknowledging these vulnerabilities, keeping technological, organizational, and economic considerations at the center of the design, implementation, and operations would also ensure the sustainability of the energy solution in the face of climate change. Enterprises offering energy solutions can consider the current and future impacts of climate change and improve system design tailored to implementation. Agencies working on the ground could ensure the sustainability of these energy solutions by choosing implementation models that integrate adaptation to climate change with affordable, reliable, and sustainable electricity supply.

APPENDIX A: CASE STUDY INFORMATION

Source for climate impacts: Data from Climate Change Information Portal, a joint effort by Ministry of Environment, Forests and Climate Change, Government of India and GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), available online at http://climatevulnerability.in/

Data presented are the multi-model projections for the mid-century (2021–2050) scenario compared to the baseline scenario (1981–2010) for the low-emission (RCP4.5) scenario.

Table A.1 | Livelihoods

SOLAR MINIGRID FOR AGRIBUSINESSES IN GUMLA, JHARKHAND	
Climate impacts	The location of the minigrid faces thunderstorms, lightning strikes, and strong winds, especially in the pre-monsoon and monsoon seasons. The area also faces a water shortage. Compared to the baseline (1981–2010), the annual rainfall by mid-century (2021–2050) in Gumla is not expected to change much. However, the average temperature is projected to increase by 1.3°C with a 25% increase in the number of days with high temperatures. The region is also prone to high wind speeds and lightning strikes.
Developmental challenges	Village enterprises need electricity to operate. During thunderstorms, high wind speeds and lightning strikes affect the grid and the minigrid operations. Lightning strikes are common in the region and can damage the minigrid, the meters, and any connected appliance in households or in enterprises.
Energy situation at site (before intervention)	Before the minigrids provided reliable electricity access, poultry farmers relied on kerosene lamps for the growth of chicks; farmers relied on rain-fed mono-cropping as they did not have reliable electricity for irrigation facilities, which in turn was necessary for cultivating crops more often than once a year, and village entrepreneurs relied on diesel for operating their mills. Most villages in the area were unelectrified before Mlinda started operating. Households have been connected to the electricity grid recently through single-phase connections. The households use both sources of electricity, depending on their reliability. Productive loads are run on the minigrid supply.
Energy intervention features	Intervention includes 35 minigrids of 20–30 kW size in Gumla district providing a three-phase connection at 240 V. They are being used to power two types of loads: (1) household loads such as lights, fans, mobile chargers, and household appliances and (2) livelihood loads such as high-wattage lights in poultry farms, water pumps, rice and wheat hullers, oil expellers, welding machines, flour milling machines, and pulverizers. Lightning arrestors were added to the installation after the loss of assets due to multiple lightning strikes.

SOLAR-PV-POWERED DRINKING WATER SUPPLY FOR LIVESTOCK IN JAISALMER, RAJASTHAN	
Climate impacts	The region is an arid desert with 200 mm annual rainfall and extreme heat conditions, with the temperature reaching 45–50°C in the summer months. The region has sparse desert vegetation, which serves as fodder for livestock. The region also experiences high winds, and shifting sand dunes are part of the changing landscape. Compared to the baseline (1981–2010), the annual rainfall by mid-century (2021–2050) in Jaisalmer is not expected to change much (a yearly increase of 10 mm). However, the number of extreme precipitation days is set to increase by a day every year. The district's average temperature is also set to increase by 1.3°C, with extreme heat days increasing by 20%.
Developmental challenges	The Public Health Engineering Department (PHED) is responsible for the supply of water to every household in Rajasthan. In remote desert regions, which face extreme heat and where water availability is generally low, PHED's water supply is the only source of sustenance for humans and their livestock. The provision of water by PHED in these remote areas has been through water tankers or drawing of water from open wells or using diesel pump sets to pump water from borewells. Most open dug wells have dried up, and groundwater pumped through borewells is the only local solution. The quality of groundwater is potable with slightly higher TDS, which does not require advanced filtration methods.
Energy situation at site (before intervention)	A single-phase grid supply has been provided to the village habitations recently. The supply is unreliable due to power cuts and the frequent inability of grid infrastructure to withstand the high wind speeds common in the region. Due to the remote location of these areas, the repair and maintenance of electricity infrastructure is expensive and time-consuming. As a result, habitations faced power cuts, which lasted for days, and water supply using electric pumps was stalled. Alternatively, water was pumped from borewells using diesel pumps, and the PHED bore the cost of diesel transport. Fuel was often pilfered during transport, and supply was delayed due to the harsh conditions. Further, if diesel generator sets needed repairs, the supply of water was stalled. The transport of water via tankers was very costly for the department. To overcome this, it was essential to install a distributed energy generation source that is reliable and meets the water needs of the habitations.
Energy intervention features	The intervention is solar-PV-powered submersible water pumps ranging from 12.5 to 17.5 hp. The pumped water is stored in ground level reservoirs (GLRs), ranging from 10,000 to 20,000 L (liter) capacity adjoining habitations. The GLRs have two dispenser taps for human consumption and are connected to open water troughs for livestock consumption. Each location has a switch room containing a battery backup of 1,250 Ah, which can run one fan, one light, one exhaust, and the drive to operate the pumping system. Borewell depth ranges between 300 and 400 ft, and water levels range between 135 and 250 ft.

FLOATING SOLAR FOR RURAL LIVELIHOODS IN MORIGAON, ASSAM	
Climate impacts	Morigaon district is located along the Brahmaputra river and is therefore affected by its annual floods. Thanagorha village is situated slightly away from the Brahmaputra, making it relatively less vulnerable to massive flooding. As a result, the village is prone to waterlogging every year during the monsoon season from July to September and floods every few years when the rains are extreme. Compared to the baseline (1981–2010), the annual rainfall by mid-century (2021–2050) is set to increase by an average of 115 mm. The district will see an increase in pre-monsoon rainfall with a rise in extreme precipitation events. The district's average temperature is also set to increase by 1.1°C, with intense heat days increasing from 34 days in 2020 to 69 in 2050. Almost 70% of the district is flood-prone with 33% at high risk.
Developmental challenges	During the monsoons, water fills up in all the ponds and fields. Houses, which are usually constructed on higher ground, do not get affected much. However, extreme events do occur, as in 2004, when the water levels increase drastically. During this time, families take their belongings, move to higher ground, and return after the waters recede. Households faced difficulties in accessing supplies such as kerosene and diesel during floods and rains.
Energy situation at site (before intervention)	Thanagorha village was unelectrified before installation of the solar solution. Communities living here need access to electricity for basic lighting and mobile charging for safety and uninterrupted communication, especially during floods and waterlogging. They also had limited livelihood options such as fisheries and paddy cultivation. The more affluent community members used diesel pumps for irrigation, while households used kerosene for lighting. During floods, communities would be plunged in darkness, making it difficult—especially for women and children—to go out. Community members would not be able to charge mobile phones to get access to information.
Energy intervention features	The intervention is installing 10 kW off-grid solar panels mounted on large PVC pipes that rise along with water levels, allowing the panels to float on the water body, preventing contact between metal and water. The panels are tethered to the pipes, leaving enough space for movement to repair and maintain the panels. The system is located on a private pond and is connected to two 5 kVA inverters, and 21 VRLA batteries (12 V 150 Ah) kept in a battery house building 7–8 feet above current water levels. Wires that are in contact with water are well insulated. At the time of installation, electricity from this system was to power three lights, a fan, and one cell phone charging point for 21 houses in the village. When we visited the site, the intervention was powering one fishpond aerator, one centralized mobile charging station attached to the battery building, and 30 streetlights.

SOLAR COLD STORAGE FOR WOMEN'S FARMER PRODUCER ORGANIZATION (FPO) IN BONGAIGAON, ASSAM	
Climate impacts	Compared to the baseline (1981–2010), the annual rainfall by mid-century (2021–2050) is set to decrease by an average of 70 mm. The district will see a decline in pre-monsoon and monsoon rains with increasing dry spells that adversely affect crop planning and productivity. The district's average temperature is also set to increase by 1°C, with extreme heat days increasing from 36 days in 2020 to 74 in 2050. Extreme heat can lead to seed, crop, and harvest losses. Crops are susceptible to new and increased pest attacks due to increasing temperatures. Moreover, 24.11% of the district is flood-prone, with 9% being at high risk of flooding.
Developmental challenges	The district faces erratic rainfall and gets waterlogged during the rainy season. Waterlogging does not affect agricultural activities, especially paddy; however, civil structures do get affected. Uncertain rain in the region has resulted in input losses, a decline in crop productivity, and post-harvest damages. Such losses adversely impact the income of the farmers. To avoid post-harvest losses, farmers need to save and store the produce to sell in the markets, hopefully at competitive prices. Farmers also keep their seeds for the next season in the absence of any other storage facility.
Energy situation at the site (before intervention)	The region faces unreliable power supply, with power cuts lasting several days in the summer and monsoon months. When it rains, the grid is shut off to avoid damage to the grid infrastructure and as a precaution against electrocution. This limits the opportunities for the FPO to invest in grid-electricity-based post-harvesting processes to diversify livelihood options and enhance incomes.
Energy intervention features	The intervention is a 5 MT cold storage by Ecofrost that can store farm produce in temperature ranges between 4 and 10°C. It is powered by a 4.5 kW solar PV array system with in-built electricity storage. The installation is adjustable, and mobile-app-controlled temperature settings allow the storage of a wide range of fruits and vegetables. When we visited the site, the facility stored approximately 1,000 kg of potatoes from the harvest in January 2019. The farmers procured 2,100 kg of seeds in the off-season, with a total saving of approximately INR 150,000 (or INR 70 per kg) on the seed costs. The cold storage facility allows member farmers to save some of their seeds, which would otherwise get spoiled. Farmers who are not members of the Farmer Producer Company (FPC) also use the cold storage for a fee (INR 60 per 100 kg of produce stored for one season), resulting in additional income for the FPC.

Table A.2 | Health

SOLAR PV FOR BOAT CLINICS IN MAJULI, ASSAM	
Climate impacts	Compared to the baseline (1981–2010), the annual rainfall by mid-century (2021–2050) in Majuli is set to increase by an average of 106 mm. The district will see an increase in pre-monsoon rainfall with a rise in extreme precipitation events. The average temperature of the district is also set to increase by 1.1°C, with extreme heat days increasing from 36 days in 2020 to 70 in 2050. The resulting vulnerabilities include flooding after extreme precipitation events, and days with high heat and humidity.
Developmental challenges	Floods and waterlogging lead to a higher incidence of water-borne and vector-borne diseases. Gastrointestinal disorders, injuries, infections, and skin diseases increase during and after floods. Due to flooding, the *char* areas get disconnected from other regions. These boat clinics are the only medical facilities accessible to them. Boat clinics must be stocked up with fuel (petrol/kerosene) to power the boat and all medical equipment. The areas they serve are very remote, so the boat must make occasional halts to refuel. Massive floods force them to halt operations as the river becomes dangerous. Boat clinics continue to function during floods until extremely heavy flooding makes it dangerous for the boats to operate.
Energy situation at site [before intervention]	The boat was dependent on a petrol generator for powering lights, fans, and medical appliances. Ice packs were used for storing vaccines in the absence of a vaccine storage unit. The generator would be run only when there was an immediate need for electricity and would be switched off during the night to save fuel—leading to poor living conditions without lights and fans—for the staff on board. They had to stop occasionally for petrol and ice packs for vaccines; as a result, they used to take a longer time to cover all villages.
Energy intervention features	The boat has a 3 kW off-grid system to power lights, fans, medical equipment and mobile chargers, with eight 12 V 200 Ah batteries, a 5,000 VA inverter, and a 500 W solar-powered 46 L Godrej GVR 50 DC vaccine refrigerator, with in-built technology to last for 7 days with no electricity, maintaining 2–8°C temperature.

SOLAR PV FOR CHCs IN E. SINGHBHUM, JHARKHAND	
Climate impacts	Compared to the baseline (1981–2010) the annual rainfall by mid-century (2021–2050) in E. Singhbhum is not expected to change much. However, pre-monsoon rain is set to decrease with a subsequent increase in monsoon months, and the total number of extreme precipitation days is projected to increase by 1.2. The district's average temperature is also set to increase by 1.3°C, with extreme heat days increasing by 24%. The resulting vulnerabilities include rains with high wind speeds, thunderstorms, and lightning strikes, and extreme heat days in summer.
Developmental challenges	The region is moderately prone to lightning in the pre-monsoon season. During thunderstorms, the electricity grid fails due to impacts on the grid with high wind speeds and tree crashes. At times, the grid is shut down as a precautionary measure. The CHC does not have a critical care unit and has not been able to treat patients struck by lightning.
Energy situation at site [before intervention]	The facility has a grid connection that faced numerous power cuts in the earlier years. However, the power situation has improved since the augmentation of power supply from a nearby power plant. Power cuts range from 0.5–1 h daily. In the pre-monsoon, monsoon, and festival season, power cuts extend to daylong durations and beyond owing to extraneous circumstances. The facility used a diesel generator set regularly to run medical appliances. However, general electrical appliances such as lights and fans for waiting areas and wards were not connected to the generator. Monthly expenses for diesel were approximately INR 33 lakh.
Energy intervention features	The CHC has installed an off-grid 10 kW system with 2V 400 Ah HBL tubular gel batteries. After installation of the above system, the monthly diesel expense reduced to INR 17 lakh, and uninterrupted power became available 24/7 for use by patients and staff for medical services and staff quarters.

SOLAR PV FOR CHARITY HOSPITALS IN HAZARIBAGH, JHARKHAND	
Climate impacts	Compared to the baseline (1981–2010), the annual rainfall by mid-century (2021–2050) in Hazaribagh is not expected to change much. However, the number of extreme precipitation days is set to increase by 1.5. The average temperature of the district is also set to increase by 1.3°C, with extreme heat days increasing by 23%. The resulting vulnerabilities include strong winds, thunderstorms, and lightning during the monsoon season and an increase in temperature.
Developmental challenges	The region is prone to thunderstorms and lightning. The hospitals are situated in remote locations surrounded by forest areas. High-speed winds and thunderstorms lead to trees falling on the grid infrastructure, causing prolonged electricity outages of 3–4 days.
Energy situation at site [before intervention]	The facilities are connected to the grid, but face extensive power outages ranging from 3 to 12 hours a day in different locations. During the monsoon season, the number of hours of grid outage increases. The hospitals have been provided with diesel generators and small-sized battery backups. The diesel generators were used during power cuts, and the hospitals incurred very high costs to operate them. The battery backup was used for office operations.
Energy intervention features	The Jamshedpur facility has installed 32 panels of 335 W, each with 60 2V 500 Ah tubular gel batteries. The Hazaribagh facility has installed a system with a total capacity of 7 kW with 24 lead-acid batteries. After installation, diesel expenses have almost halved in both the facilities. In Jamshedpur, solar PV powers patient wards (a 50-bed hospital), OPD (lights, fans, OT/consultation lights), pharmacy (lights and fans), and offices (lights, fans, computers). The lab equipment is powered by grid power. Solar PV does not power the staff quarters. In Hazaribagh, solar installation powers lights, fans, one aquarium, one water cooler, and the chapel's audio system.

SOLAR PV FOR PIPED WATER SUPPLY IN SIROHI, RAJASTHAN	
Climate impacts	This region is characterized by arid geography and a hilly terrain with granite and marble rocks, making access to water difficult. Compared to the baseline (1981–2010), mid-century annual rainfall (2021– 2050) in Sirohi is set to decrease by 22 mm. The district will see a uniform decrease from June to December. Extreme precipitation events of >20 mm rainfall per day are set to increase by a couple of days. The average temperature of the district is also set to increase by 1.2°C, with extreme heat days increasing by 23% by 2050. High temperatures combined with erratic rainfall and low groundwater recharge levels can affect the water security of the region.
Developmental challenges	The primary source of water for these villages has been hand pumps installed by the government. With the groundwater table receding over the past few years, most hand pumps have run dry. There are no perennial rivers in the area, and there are little mountain streams over which check dams have been created to provide water for agricultural use. Women and children have had to fetch water from surface water sources farther away. Several borewells have been constructed in the area to pump groundwater; however, the electricity supply is only single-phase at the household level, which cannot power high-capacity water pumps.
Energy situation at site [before intervention]	Grid connectivity was provided to the villages a few months ago. The Centre for Micro Finance (CmF), which has been working with these communities for several years, considered applying for a separate electricity connection to pump water. However, the application process for approval would take several months.
Energy intervention features	The intervention is an off-grid 3.2 kW solar PV system connected to 3 HP motors for pumping water from the borewell and storing it in a 5,000 liter overhead tank. Water levels in the borewell vary from 120 ft to 280 ft. The tank is connected to a pipeline running to each household where a multi-purpose dispenser tap is fixed. The solution is reliable and suffices for the needs of the villages. There is no need for electricity storage.

SOLAR DE-FLUORIDATION FOR WATER SUPPLY IN RAJASTHAN	
Climate impacts	Site visits were conducted in two districts: Jaisalmer and Sirohi. Jaisalmer district in Western Rajasthan is part of the Thar desert. The region is characterized by uncertain rain, prolonged droughts, extreme heat, and water contaminated with fluoride, which can increase due to drought conditions. Geological conditions do not allow groundwater recharge, and even a few showers of rain can flood the area. Groundwater in several pockets in the district is fluoride affected. Sirohi district in southern Rajasthan has a dry and hilly terrain with an average annual rainfall of 620 mm. It has been observed that the overall number of rainy days has reduced, and extreme rainfall events have increased. Groundwater in the region is fluoride affected in some pockets, and the water depth is currently at 120 to 250 ft. Climate information is the same as mentioned above for other case studies from Jaisalmer and Sirohi.
Developmental challenges	Hilly regions, as in Sirohi district, need deeper bores and have fewer aquifers to tap into. Here, the main source of livelihood is agriculture, which is rain-fed or irrigated by borewells, which stresses the groundwater aquifers and can affect drinking water supply too. Some places have check dams that support surface irrigation and groundwater recharge. Compared to Jaisalmer, villages in Sirohi are densely populated. As in Jaisalmer district, extreme heat conditions in summer months coincide with water scarcity. In Jaisalmer and Sirohi, there are operational challenges, such as leakages, higher maintenance costs, and high need for human resources, in supplying water to remote households through centralized pumping stations. The only water source was hand pumps (when water is available, at max. 30–35 ft) or tankers provided by the Public Health Engineering Department (PHED). Many such areas also face groundwater contamination by fluoride. With the groundwater table receding, electricity is required to pump groundwater.
Energy situation at site [before intervention]	Almost all households in Jaisalmer and Sirohi have a single-phase electricity connection, but most do not yet have piped water supply. Households use traditional water storage methods at the household level, unlike large tanks in urban areas. To avoid long-distance piped water supply and tanker supply challenges, the PHED developed off-grid units to filter and supply water near the habitations.
Energy intervention features	The intervention consists of off-grid solar-PV-powered pumps combined with an overhead tank to store water. The tank is connected to a bio-media gravity-based filtration system that dispenses water through faucets. The solution also provides raw untreated water through clearly marked taps. The pumping system is automated and functional during the daytime. It is remotely monitored and controlled by the implementing agencies. Locations in Jaisalmer also have water troughs for animals, whereas those in Sirohi do not have water troughs. As the water level dips below a level in the overhead tank, the pump automatically starts, and the tank is filled. Some locations have added small solar-powered lights at the unit.

Table A.3 | Education

SOLAR PV FOR RESIDENTIAL GIRLS SCHOOLS IN JHARKHAND	
Climate impacts	Jharkhand state faces intense thunderstorms, with heavy rains, strong winds, and lightning strikes. For climate projections, refer to other case studies from E. Singhbhum, Hazaribagh, and Gumla.
Developmental challenges	Kasturba Gandhi Balika Vidyalayas (KGBVs) are in areas with a large population of tribal and other marginalized communities, including minority communities that have low levels of female literacy and are in remote habitations with sparse populations that do not qualify for a regular school. They are residential schools offering girl students free education from the upper primary level to higher secondary levels.
Energy situation at site [before intervention]	All the KGBV schools under the program are connected to the electric grid but face erratic electricity supply. Power outages can last from a few hours to days at a time. These outages worsen during thunderstorms, as uprooted trees and winds can damage the electricity grid infrastructure. To help them cope with outages, KGBV schools have backup diesel generators. However, when the grid outages last a long time, running diesel generators is not economical, so they must often go without electricity. During this time, the students and staff find it difficult to maintain good living conditions, such as lighting, water supply, and thermal comfort. They also have to compromise on learning activities like computer classes.
Energy intervention features	To help address the unpredictable and unaffordable electricity situation, the Jharkhand Renewable Energy Development Agency (JREDA) facilitated the installation of 20 kW off-grid solar systems with battery backup in KGBV schools. The solar system is connected to 50–60 fans and lights, 10–12 computers, 1–2 water pumps, 1–2 reverse osmosis (RO) water purifiers, and 1 refrigerator in each school. During a power outage, a trained staff member turns on the solar system, which allows the school to continue its normal functions. With the coming of solar PV, the schools report several benefits: over 50% reduction in the use of diesel, with some schools eliminating diesel usage; the presence of constant running water supply and fans improving living conditions, especially during the evenings and in summers, respectively; lights improving the perception of safety and enabling students to study late into the evening; uninterrupted functioning of facilities such as computer labs, water purifiers, refrigerators, and recreational and educational devices like televisions.

SOLAR PV FOR DIGITAL-EDUCATION-CUM-FLOOD-RELIEF CENTRE IN NORTH LAKHIMPUR, ASSAM	
Climate impacts	Compared to the baseline (1981–2010), the annual rainfall by mid-century (2021–2050) in the district will increase by an average of 72 mm. The district will see an increase in pre-monsoon and monsoon rainfall with a rise in extreme precipitation events. The district's average temperature is also set to increase by 1.2°C, with extreme heat days increasing from 36 days in 2020 to 69 in 2050. An increase in overall rainfall and extreme precipitation events are set to exacerbate the existing flooding situation. The villages get intermittently flooded every year between July and September. The flood levels rise 2–4 ft above the ground level. However, with increasing rainfall, the level of inundation may increase. Various tributaries of the Brahmaputra cut across the district, making 67.5% of the area flood-prone.
Developmental challenges	The older houses constructed in the region get inundated with floodwaters almost every year. New homes have been built on stilts and are less affected. During floods, the electricity grid connections are shut off, and the relief shelters are the only places with electricity supply powered by solar panels. Due to the lack of electricity and public lighting, there are safety and security concerns, especially for women and children.
Energy situation at site [before intervention]	The relief shelter is connected to the grid and doubles up as a digital resource center for villagers, conducting computer classes for students when there are no floods. The shelter has five computers and one printer and is managed by the village committee for printing certificates, filing applications online, and booking train tickets. During floods, because the grid is disconnected, solar power and battery backup are used for lighting and mobile charging at the shelter.
Energy intervention features	The shelters have each have a 1.5 kW off-grid solar PV system with 12 V 200 Ah lead-acid battery backup to power DC lights and a mobile charger in addition to the grid connectivity.

Table A.3 | Education (Cont.)

SOLAR PV FOR RESIDENTIAL GIRLS SCHOOL IN DHUBRI, ASSAM	
Climate impacts	Compared to the baseline (1981–2010), the annual rainfall by mid-century (2021–2050) in Dhubri is set to increase by an average of 116 mm. The district will see an increase in pre-monsoon rainfall, but no monsoon rainfall change with a rise in extreme precipitation events. The district's average temperature is also set to increase by 0.9°C, with extreme heat days increasing from 36 days in 2020 to 67 in 2050. In addition, an increase in cumulative rainfall and extreme precipitation events is set to exacerbate the existing flooding situation, which may increase the school's risk of being inundated in the future. Moreover, river islands are also subject to land erosion, which can result in landmass loss. Increased incidence of floods can result in high levels of erosion; 24% of the district is at high risk of riverine flooding.
Developmental challenges	The school is located on a *char* island—the riverine islands in the Brahmaputra prone to heavy flooding—although the school itself is situated on elevated land. During flooding, classes get interrupted as many teachers find it challenging to reach the school. Only 3 out of 10 staff members stay on the school premises. These islands have limited access to basic education and health facilities. The communities must go to the mainland for most necessities. The literacy rate is very low, especially among girls. Dropouts and early marriages are common. Most of the students are from economically backward families.
Energy situation at site [before intervention]	The *char* regions are not connected to the grid. Before this intervention, the school did not have any electricity supply. The school was given a diesel generator in 2008, and it stopped functioning in two years. After that, the school started using kerosene lamps. The school had 22 lights, 9 fans, 1 TV, 1 electric sewing machine, and 1 water pump, although it had no electricity to power these. Classrooms were dark, hot, and humid, and students did not have any access to digital literacy resources. There were no lights and fans in the student hostels, posing comfort and safety issues. There was no running water in toilets, and water had to be carried from tanks.
Energy intervention features	The Assam Energy Development Agency (AEDA) has installed a 5 kW solar PV system with 48 2 V 500 Ah lead-acid batteries with a 5 kVA power conditioning unit (PCU). Solar PV provides electricity in the daytime, and the school uses kerosene lamps in the evening. Only lights and fans are connected to the solar panels, so essentials like computers and water pumps remain unused. They still have the same number of appliances, although many are not powered. Teaching and learning conditions have seen some improvement because fans operate during the afternoon. However, solar and battery backup do not function at all times, because of which kerosene lamps are used at night. Living conditions have not improved. Monthly expenses have reduced by approximately 50% because of the reduction in diesel use.

SOLAR PV AND HEATER FOR WASH AND MID-DAY MEALS IN SCHOOLS IN JORHAT, ASSAM	
Climate impacts	Compared to the baseline (1981–2010), the annual rainfall by mid-century (2021–2050) is set to increase by an average of 106 mm. The district will see an increase in pre-monsoon rainfall with a rise in extreme precipitation events. The district's average temperature is also set to increase by 1.1°C, with extreme heat days increasing from 36 days in 2020 to 70 in 2050. With increasing rainfall, dependence on groundwater can be reduced by managing surface water better. Furthermore, the Brahmaputra river cuts across the district, making it prone to floods and inundation; 42.5% of the district is flood-prone, with 10% under high risk.
Developmental challenges	Jorhat district has a high incidence of arsenic contamination in groundwater. According to the 2018 Ministry of Water Resources database, 79% of the district's habitations are affected by arsenic. According to WHO, drinking arsenic-contaminated water can induce several short-term effects like diarrhea, vomiting, abdominal pain, and long-term effects like skin problems, including cancer. Hence, the district encourages decontamination of groundwater before use or dependence on surface water sources. Until recently, the school administration and the communities nearby did not realize that their groundwater was contaminated with arsenic. The school used to draw water for drinking and sanitation from hand pumps. A few years ago, the school administration started getting more and more complaints of abdominal pain in children. Upon testing the water, they realized that it was contaminated with trace quantities of arsenic.
Energy situation at site [before intervention]	The school is connected to the electricity grid, but receives erratic supply, especially during the monsoon, when the grid is shut down to avoid electrocution in waterlogged areas. Accessing water requires electricity, either to pump groundwater or to pump surface water from nearby ponds into the overhead tanks of the school building. The school provides mid-day meals to its students. The cooking, done within the school premises, required energy sources like firewood or LPG. Firewood is difficult to procure during the rainy season as it becomes damp and unusable, and alternative sources of energy for cooking were required during this time.
Energy intervention features	The electricity solution is an off-grid 2 kW solar PV with a 650 VA inverter and two 75 Ah batteries. It is used for powering a water pump to supply water from a rainwater-harvesting structure and a pond nearby, to an overhead tank and a solar water heating system. The overhead tank supplies the water to a drinking water reverse osmosis (RO) plant (which is also powered through solar) and to the toilets. An additional solar water heater pre-heats the water for cooking, and from there, the water gets stored in an overhead tank for the kitchen. The solution provides reliable electricity all day for pumping and filtering water, and the electricity generated can also be used for powering lights, fans, and charging mobile phones.

APPENDIX B: INTERVIEW GUIDES

This section provides questionnaires developed for interviewing implementation agencies, funding agencies, vendors, and beneficiaries. Implementation agencies coordinated the installation of the solar systems and were responsible for their operation and maintenance in many cases. Beneficiaries are communities (and representatives of the beneficiary communities). Vendors here also include energy enterprises that designed and installed the decentralized solar system.

INTERVIEW GUIDE FOR IMPLEMENTING ORGANIZATION

Informed consent script:

I am ____ from the Energy Program/ Climate-Resilience Practice at WRI India. We are conducting a study on how energy access solutions address energy needs and contribute to health/education/livelihood outcomes in energy poor, climate vulnerable areas. We would like to ask you a few questions regarding the energy solution in this locality. This interview will take around 1 hour. The information we capture will be used for research purposes only. The information will be treated as confidential and any individual-identifying details will be anonymized before publication. May we have your consent to proceed?

(Record verbal consent)

Interview details

1. Project name:
2. Interviewed by:
3. Date:
4. Name of the interviewee(s), organization(s) and role(s)
5. Contact details
6. Location of implementation
7. Village:
8. Block:
9. District:
10. Geo-location:
11. Landmarks (if any)

FOR INTERVIEWER'S REFERENCE

Objective of these interviews

- To understand whether the *energy solutions are resilient* to any climate events/conditions in the region, *address the energy needs, and contribute to development outcomes* (such as health, education, livelihood)
- Capture communication stories

Stakeholder categories

1. Implementing organization: Responsible for coordinating various activities for implementation of the energy solution in/not in the climate vulnerable areas and bringing different stakeholders together. *Questionnaires may need to be administered at both the headquarters and the field level*.
2. Funding agency: Organization that partially or fully funds the implementation and/or bears the financial risk.
3. Vendor: Organization responsible for design, installation, and O&M, if applicable.
4. Beneficiary: Those who benefit from the facility.

Context

1. Tell us about your organization and the work that it does.
2. What are your geographies of interest?
3. Is the health/education/livelihood facility where the energy interventions have been installed owned and operated by you? If not, please mention who owns and operates the facility.
4. What natural calamities or conditions are faced by the **state in general and your facility in particular** *(Probe: like floods, droughts, extreme rainfall/temperature, soil or water contamination, land erosion): [TO BE ASKED AT LOCATION]*
    a. Which months in a year?
    b. What changes have you been experiencing in the past years in terms of frequency and/or severity of the climate events?
    c. How are the communities affected and how do they cope?
    d. How do your facilities get affected and how do they cope?
5. What is the electricity situation in regions where you work *(probe on grid connection, backup power, voltage situation)*?
6. Do the climate event/conditions affect the electricity situation? If yes, how?
7. Does the electricity situation affect service delivery in your facilities? If yes, how?

About the energy need and solution

8. What form of technology are you using in your facilities to solve the electricity issues?
9. Who conceptualized the idea of installing the energy access solutions and what were the reasons for doing so? *(Probe: accessibility, affordability, reliability, sustainability, other reasons)*
    a. Access to electricity
    b. Reduction in power cuts
    c. Reduction in voltage fluctuations
    d. Reduction in cost
    e. Others
10. Where is the solution installed? Who owns the space where it is installed?
11. On an average, what is the system specification for the energy solutions you have implemented in your facilities?

Capacity in kW (range, average)	
Space occupied	
Module cost	
Is there a battery? Battery type	
Battery capacity in Ah	
Battery cost	
Inverter specs	
Inverter cost	
Total system cost	

Sustainability in the climate context (impact of natural calamities during and after installation)

12. What precautions have you taken to ensure that your energy solutions are not affected by natural calamities or conditions? *(Probe: Is the system robust—ability to withstand events, resourceful—ability to manage stresses during the event, and recoverable-ability to restore operations after the event)*
13. What was the impact of climate vulnerabilities, natural calamities on design of the system?
14. What was the impact during the installation period?
15. How did you deal with the same and bring the project back on track after the disruptions (if any)?
16. Have you seen any impact of the climate vulnerabilities, natural calamities on O&M of the system?
17. How do you deal with the same and ensure the system performs as planned?

Financial sustainability of the system

18. What is the average cost of the installation and how was it funded? *(Probe: grant, loan, self-funded and their breakdown by source)*
19. What convinced you/funders to invest in this energy solution?
20. Who funds the O&M of the system?
21. Who will fund post completion of the AMC tenure?

Operational sustainability of the system

22. Which stakeholders came together to design the project (organization/individual/community/government)?
23. What role (if any) did you play during the installation process?
24. Who takes care of the O&M (human resource)?

25. Please answer the following questions regarding your experiences with maintenance of the systems:
    a. Have the systems been performing as expected?
    b. How prompt are the maintenance services?
    c. Has there been a situation where you had to halt operations as the system was not working? Elaborate on the experience.
    d. How do you track the efficiency of the system—performing as vendor had promised?
    e. What are the challenges you have faced to date?
26. Do you have an AMC in place for the systems?
27. What is the average duration of the AMC?
28. After the AMC ends, who will ensure operation of the systems?
29. Did you/do you do local capacity building for day to day troubleshooting?
30. Is there remote monitoring of the system—its performance and disruptions caused by climate vulnerabilities or natural calamities?
31. Do you have plans to scale up this model? *(Probe: in other geographies you work, increase system capacity in existing geographies, with other partners, etc.)* Why/Why not?
32. If similar projects come up in such locations, would you be willing to take them on? If not, why?

Impact of the energy intervention in the context of climate vulnerabilities and natural calamities

33. How has the electricity access situation improved after installation across your facilities?
    a. What improvements do you see in the electricity situation during the time when climatic events/conditions affect your facility?
34. How has the improved electricity access situation impacted service delivery/helped communities nearby?
    b. What improvements do you see in the service delivery during the time when climatic events/conditions affect your facility?
35. Did these implementations bring about the changes you expected to see when you began this project? Please explain how.
36. What were your broad experiences with the following when you think about your operation in exacerbated climate stress and more frequent/severe climatic events? *(Probe: what went well, what was difficult)*
    c. Space for installation:
    d. Approvals/ permissions from the Government:
    e. Funding:
    f. Civil work:
    g. Energy vendors, including O&M support:
    h. Logistics like transportation of system components:
    i. Natural calamities or conditions:
    j. Other:
37. Have you conducted an impact assessment of the energy solution installation? If so, can you share the findings/report?
    k. Do these assessments include the climate vulnerability angle—how electricity/ service delivery is affected during climate events/conditions?
38. Do you or other stakeholders involved have plans to scale up this model *(Probe: in other geographies you work, increase system capacity in existing geographies, with other partners, in areas with similar climate stress, etc.)*
39. If you have already scaled up—please share more about how you scaled this up and who are the partners

Learnings from the implementation

40. Are there any broad learnings for you and your organizations from this implementation?

INTERVIEW GUIDE FOR BENEFICIARY

Informed consent script:

I am ____ from the Energy Program/Climate-Resilience Practice at WRI India. We are conducting a study on how energy access solutions address energy needs and contribute to health/education/livelihood outcomes in energy poor, climate vulnerable areas. We would like to ask you a few questions regarding the energy solution in this locality. This interview will take around 1 hour. The information we capture will be used for research purposes only. The information will be treated as confidential and any individual-identifying details will be anonymized before publication. May we have your consent to proceed?

(Record verbal consent)

Interview details

1. Project name
2. Interviewed by
3. Date
4. Name of the interviewee(s)
5. Occupation(s)
6. Age(s)
7. Hold a SC/ST certificate?
8. Contact details
9. Gender(s)
10. BPL card?

FOR INTERVIEWER'S REFERENCE

Objective of these interviews

- To understand whether the *energy solutions are resilient* to any climate events/conditions in the region, *address the energy needs and contribute to development outcomes* (like health, education, livelihood)
- Capture communication stories

Stakeholder categories

1. Implementing organization: Responsible for coordinating various activities for implementation of the energy solution in/not in the climate vulnerable areas and bringing different stakeholders together. Questionnaires may need to be administered at both the headquarters and the field level.
2. Funding agency: Organization that partially or fully funds the implementation and/or bears the financial risk.
3. Vendor: Organization responsible for design, installation, and O&M, if applicable.
4. Beneficiary: Those who benefit from the facility.

Interview questions

About climate vulnerability

1. Name of the district, block, village
2. Climate vulnerabilities or natural calamities faced by this region and by beneficiary/communities being interviewed here *(Probe: like floods, droughts, extreme rainfall/temperature, soil or water contamination, land erosion, increasing temperatures)?*
    a. Which months in a year?
    b. How are you affected?
    c. How do you cope?

About electricity access situation

3. Is your village connected to the grid?
    a. Since when?
    b. How many households are connected?
    c. Do other buildings in the village like schools, hospitals, panchayat buildings, *anganwadi* have access to electricity?
        i. Do they have grid/alternate electricity connection?
        ii. If no electricity access, what challenges do they face?
        iii. If any of them recently got electricity access, have you noticed any changes in services?

4. Is there an electricity connection in your house?
    a. Are you connected to grid?
        i. What phase connection?
        ii. How many hours of power cut?
        iii. What electrical appliances do you have at home?
        iv. How much is your average bill?
    b. Are you connected to any other electricity source?
        i. What is the electricity source?
        ii. How many hours of power supply?
        iii. What electrical appliances do you have at home?
        iv. How much is your average bill?
5. What energy source do you use for cooking in your house?

About the facility

6. What services do you avail from the (health/education/livelihood) facility?
7. To your knowledge, who all avails services from this facility (*to understand if there is a segment of the population who uses this facility*)?
8. Do you know what kind of energy solution is installed in this facility?
9. Do you know when the energy solution was installed? Were you using the facility then?
10. Have you noticed any changes in the services offered by the facility after the coming of the energy solution?
    a. Is there any change in operating hours?
    b. Is there any change in the number of staff living here/available when needed?
    c. Is there increase in services offered like vaccinations/deliveries for health, computer education for education?
    d. Is there any change in facilities like lights, fans, drinking water?
    e. Any other changes?
11. Do you use the electricity from the facility? If yes, please explain what it is used for and how it helps you.
12. Do you think the electricity solution in this facility is the best solution? Why/why not? *(probe into why they think any other solution like grid itself would not work in this context)*

Sustainability in the climatic context

13. Does this facility function during natural calamities—extreme heat days, extreme rains, floods, droughts?
14. Have you seen the system breaking down during natural calamities? How frequently does this happen? *(Probe for specifics)*

Financial sustainability of the system

15. Do you know who funded the installation?
16. Was the community involved in the funding?
17. Do you know who funds the O&M of the system?
18. Is there any money collection from the community for O&M?

Operational sustainability of the system

19. Were you or anyone from the community involved/consulted in any way during the implementation process *(Probe: land procurement, village decision-making, construction job, capacity building, etc.)?*
20. Are you happy with the services provided by the facility? What more is required? *(Probe: a greater number of facilities, more services, etc.)*

INTERVIEW GUIDE FOR FUNDING ORGANIZATIONS

Informed consent script:

I am ____ from the Energy Program/ Climate-Resilience Practice at WRI India. We are conducting a study on how energy access solutions address energy needs and contribute to health/education/livelihood outcomes in energy poor, climate vulnerable areas. We would like to ask you a few questions regarding the energy solution in this locality. This interview will take around 1 hour. The information we capture will be used for research purposes only. The information will be treated as confidential and any individual-identifying details will be anonymized before publication. May we have your consent to proceed?

(Record verbal consent)

Interview details

1. Project/program/site name
2. Project/program/site details (number of sites, locations, duration of this project/program)
3. Interviewed by
4. Date
5. Name(s) of the interviewee(s), organization(s) and role(s)
6. Contact details

About the location

1. What are the climate vulnerabilities or natural calamities faced by the communities and institutions living here *(Probe: like floods, droughts, extreme rainfall/temperature, soil or water contamination, land erosion)?*
2. What energy issues are faced by the areas covered by this project/program?

FOR INTERVIEWER'S REFERENCE

Objective of these interviews

- To understand whether the *energy solutions are resilient* to any climate events/conditions in the region, *address the energy needs and contribute to development outcomes* (like health, education, livelihood)
- Capture communication stories

Stakeholder categories

1. Implementing organization: Responsible for coordinating various activities for implementation of the energy solution in/not in the climate vulnerable areas and bringing different stakeholders together. Questionnaires may need to be administered at both the headquarters and the field level.
2. Funding agency: Organization that partially or fully funds the implementation and/or bears the financial risk.
3. Vendor: Organization responsible for design, installation and O&M, if applicable.
4. Beneficiary: Those who benefit from the facility.

Motivation/context for implementation

3. Tell us about your organization and its work in the energy-development space
4. How do you perceive your role in the implementation—as a funder of energy access, as a funder of a development project, monitoring and evaluation role, ecosystem support, etc.?
5. Why did you decide to invest in this?
   a. Geography
   b. Implementation model
   c. Implementation organization
   d. Energy solution
6. How and when did you decide on funding this project/program/site?
7. Is this part of your long-term strategy to invest in the upliftment of the area?
8. What financial and non-financial returns do you expect out of this investment ?
9. What is the time frame for returns you are looking at for making these kinds of investments?
10. When are these decisions taken (specific times in a year, frequency)?

Financial sustainability of the system

11. Are you contributing to the one-time CAPEX or CAPEX + on-going O&M or to O&M only?
12. If you are contributing to one-time CAPEX:
    a. What was the one-time CAPEX for this project/program/site (as applicable)?
    b. What was/is your contribution to the CAPEX for this project/program/site? *(what % of the cost was borne by this funder?)*
    c. For the one-time CAPEX, did you provide a grant/loan/equity investment/other like revolving fund?
13. Who apart from you contributed to the funding of this project/program/site?
14. Was this the funding model for other partners—same or different from your model?
15. Why do you think this is the best-suited model for this implementation?
16. Who is taking care of the O&M (finance element) of the system?
    a. If no one is taking care of O&M expenses, how do you ensure the long-term sustainability of the project?

Sustainability in the climate context (impact of natural calamities during and after installation)

17. Do you know if the vendor has taken any precautions to ensure the project/program/site is not affected by natural calamities or conditions?
18. Did you see any negative impact of climate vulnerabilities, natural calamities on project/program/site post installation or during installation? (*probe further*)
19. Did that have any impact on the financial returns from the project/program/site?

Impact in the context of climate vulnerabilities and natural calamities

20. What do you think is the impact of this project/program on the facilities/communities?
21. How do you assess the impact of this project/program? Are you happy with the same? If not, why?
22. Do you see any changes in impacts during (a) chronic climate events/conditions (b) climate-related disruptions? (Please explain)
23. Based on your experience, have other organization like yours expressed interest in learning about this intervention and contributing to this or other similar interventions?
24. Do you currently have plans to scale this up/invest further in similar?
    a. Geography
    b. Implementation model
    c. Implementation organization
    d. Energy solution
    e. Why/Why not?
25. What are the overall learnings for you from this investment? *(Probe: what worked, what didn't work, what needs to be changed)*
26. Have you taken/plan to take any measures to reduce the risks of climate events/conditions in your projects/investments?
27. Are you interested in investing in similar projects in these areas/other areas?

INTERVIEW GUIDE FOR VENDORS

Informed consent script:

I am ____ from the Energy Program/Climate-Resilience Practice at WRI India. We are conducting a study on how energy access solutions address energy needs and contribute to health/education/livelihood outcomes in energy poor, climate vulnerable areas. We would like to ask you a few questions regarding the energy solution in this locality. This interview will take around 1 hour. The information we capture will be used for research purposes only. The information will be treated as confidential and any individual-identifying details will be anonymized before publication. May we have your consent to proceed?

(Record verbal consent)

Interview details

1. Project name
2. Interviewed by
3. Date
4. Name of the interviewee(s), organization(s) and role(s)
5. Contact details

About the location

1. Name of the district, block, village
2. Climate vulnerabilities or natural calamities faced by the communities and institutions living here *(Probe: like floods, droughts, extreme rainfall/temperature, soil or water contamination, land erosion)?*
3. What energy issues were faced by the site?
4. In the context of these vulnerabilities and energy issues, what challenges was the client facing in delivering services?

FOR INTERVIEWER'S REFERENCE

Objective of these interviews

- To understand whether the *energy solutions are resilient* to any climate events/conditions in the region, *address the energy needs and contribute to development outcomes* (like health, education, livelihood)
- Capture communication stories

Stakeholder categories

1. Implementing organization: responsible for coordinating various activities for implementation of the energy solution in/not in the climate vulnerable areas and bringing different stakeholders together. Questionnaires may need to be administered at both the headquarters and the field level.
2. Funding agency: Organization that partially or fully funds the implementation and/or bears the financial risk.
3. Vendor: Organization which has installed the energy intervention. The same may be an integrator, distributor, developer of the technology. The vendor may/may not be the organization doing the O&M of the system.
4. Beneficiary: who benefits from the facility

ISSUE	INTENSITY	COMMENT
Not connected to grid		
Connected but no power	(hours of outage)	
Connected but no power and depending on DG set	(hours of outage) (hours of DG set operation)	
Voltage fluctuations	(frequency and range)	

About the solution

5. What is the energy solution?
6. When was it installed?
7. Why was it installed? To solve what problem (according to vendor)

8. What was the motivation for you to take this project?
9. Where is it installed (what type of institution)? Who owns the space where it is installed?
10. Technical specs of the energy solution—please fill in the table below:

COMPONENT	CAPACITY	MAXIMUM AMBIENT TEMPERATURE	MAXIMUM AMBIENT WIND SPEED	OTHER VULNERABILITIES (E.G., AMBIENT HUMIDITY)
Solar panels				
Battery				
Inverter				
Balance of system (electrical wire/panels)				
Power backups if any				
Any other specs				

11. Are you empaneled by MNRE or any other agency?
12. What energy demand did you take into consideration while designing the system?
13. If there is an increase in energy demand in the future, how will your system respond/change?
14. Civil engineering specifications
    a. Where is the system installed—on rooftop/ground/other
    b. Space occupied
    c. Please fill in the table below:

COMPONENT	HEIGHT FROM GROUND	MATERIAL	MAXIMUM WEIGHT SUPPORTED	MAXIMUM AMBIENT WIND SPEED
Mounting structure				
Any other component of civil structure				

Sustainability in the climate context (impact of natural calamities during and after installation)

15. What precautions have you taken to ensure that your project is not affected by natural calamities or conditions?
16. What was the impact of climate vulnerabilities, natural calamities on design of the system?
17. What was the impact during the installation period?
18. How did you deal with the same and bring the project back on track after the disruptions (if any)?
19. Have you seen any impact of the climate vulnerabilities, natural calamities on O&M of the system?
20. How do you deal with the same and ensure the system performs as planned?

Financial sustainability of the system

21. What was the total cost of the installation and how was it funded? *(Probe: grant, loan, self-funded and their breakdown by source)*
22. Who funds the O&M of the system?
23. Who will fund post completion of the AMC tenure?

Operational sustainability of the system

24. Which stakeholders came together to design the project?
25. Who takes care of the O&M (human resource)?
26. Do you have an AMC in place for this system?
27. Until when is the AMC valid?
28. After AMC ends, who will ensure operation of the system?
29. Did you do local capacity building for day-to-day trouble shooting
30. Is there remote monitoring of the system—its performance and disruptions caused by climate vulnerabilities or natural calamities?
31. Do you have plans to scale up this model? *(Probe: in other geographies you work, increase system capacity in existing geographies, with other partners, etc.)* Why/Why not?
32. If similar projects come up in such locations, would you be willing to take them on? If not, why?

Impact in the context of climate vulnerabilities and natural calamities

33. How do you think the working of the facility changed after the installation?
    a. Increased no. of working hours
    b. Staff living on site
    c. Staff retention going up
    d. Increased number of footfalls (hospital), retention rates (schools)
    e. New services added
    f. New equipment purchased
    g. More of the same equipment purchased
    h. Increased no. of hours spent on equipment
    i. Income increased
    j. Expenditure reduced
    k. Improved living conditions
    l. Other
34. Have you conducted an impact assessment of the energy solution installation? If so, can you share the findings?
35. What are the overall learnings for you from this implementation? *(Probe: what worked, what didn't work, what needs to be changed)*

Installation process

36. Please describe the process of installation of the system (Probe: site assessments, system design, procurement of panels, transport and logistics, civil work, etc.)

Motivation/ context for implementation

37. What services do you offer? *(Probe: focus on household, productive, social, minigrid loads, what technologies—solar PV, water heater, biomass, biogas etc.)*
38. What are your geographies of interest?
39. How did you come to know of this project?
40. What convinced you to take this project on?

Impacts/learnings from the implementation

41. Are you monitoring the performance of the system? How?
42. How many hours of electricity supply does the facility get now?
43. Does the voltage fluctuate?
44. Does the facility currently use backup power? *(Probe: if there is backup, what backup, fuel availability, cost on backup, hours of usage)*
45. How do you think the working of the facility changed after the installation?
    a. Increased no. of working hours
    b. New equipment purchased/new services added
    c. More of the same equipment purchased/services added
    d. Increased no. of hours spent on equipment
    e. Income increased
    f. Expenditure reduced
    g. Improved living conditions
    h. Other
46. Do you think the installation of the energy solution has impacted community members in any way? If so, please explain how.
47. Has energy access solution helped the facility address community needs better during natural calamities or conditions? *(Probe: like floods, droughts, extreme rainfall/temperature, soil or water contamination, land erosion)*
48. Have you conducted an impact assessment of the energy solution installation? If so, can you share the findings?
49. What are the overall learnings for you from this implementation? Would you be willing to take up another similar project with the same partners? *(Probe: what worked, what didn't work, what needs to be changed)*

GLOSSARY OF TERMS

Char areas: Commonly used term in Assam and West Bengal. These areas can be described as tracts of land surrounded by the waters of a river, ocean, sea, lake, or stream; it usually means any accretion in a river course or estuary.

Extreme heat days: Number of days with maximum temperature above the 90th percentile calculated for a five-day period centered on each calendar day between 1981 and 2000.

Extreme precipitation: Measures the relative amount of annual rainfall delivered by large, single-day precipitation events; shows change over time. Extreme precipitation events are defined as days with precipitation in the top 1 percent of all days with precipitation.

Hazard: The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources (IPCC 2015).

Impacts: The consequences of realized risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability. Impacts generally refer to effects on lives; livelihoods; health and well-being; ecosystems and species; economic, social, and cultural assets; services and infrastructure. Impacts may be referred to as consequences or outcomes and can be adverse or beneficial (IPCC 2015).

Risk: The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the context of the assessment of climate impacts, the term *risk* is often used to refer to the potential for adverse consequences of a climate-related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods; health and well-being; ecosystems and species; economic, social,and cultural assets; services (including ecosystem services); and infrastructure. Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence (IPCC 2015).

Uncertainty: A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, incomplete understanding of critical processes, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (IPCC 2015).

Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC 2015).

ABBREVIATIONS

AEDA	Assam Energy Development Agency
BHS	Basic Health Care Services
CHAI	Catholic Health Association of India
CHC	Community Health Centre
CmF	Centre for Micro Finance
C-NES	Centre for North East Studies and Policy Research
CAGR	compound annual growth rate
CSR	corporate social responsibility
DBT	design build transfer
DBOM	design build operate maintain
DBTM	design build transfer maintain
DFID	Department for International Development
DRE	decentralized renewable energy
FPC	Farmer Producer Company
FPO	Farmer Producer Organization
GW	gigawatt
HDI	Human Development Index
IGSSS	Indo-Global Social Service Society
ICCo	Innovative Change Collaborative
ICT	Information and communications technology
INR	Indian rupee
JREDA	Jharkhand Renewable Energy Development Agency
kW	kilowatt
LPG	liquefied petroleum gas
MT	metric ton
NFHS	National Family Health Survey
O&M	operations & maintenance
OECD	Organisation for Economic Co-operation and Development
PHC	Primary Health Centre
PV	photovoltaic
PHED	Public Health Engineering Department
REACH	Reaching & Educating At-risk Children
SRS	Sample Registration System
SeSTA	Seven Sisters Development Assistance
TB	tuberculosis
UN	United Nations
UNDP	United Nations Development Programme
USD	United States dollars

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ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

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