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.

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.