## 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<br>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<br>▪ Deterioration of groundwater quality due to salinity, fluorides, and water scarcity<br>▪ Agriculture in 26 of 33 districts extremely vulnerable (Rama Rao et al. 2013)<br>▪ Increased risk to nutrition security in humans<br>▪ 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<br>▪ 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<br>▪ Increased glacial melt and forest fires during summer<br>▪ 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<br>▪ Agriculture in 11 of 24 districts is highly/extremely vulnerable (Rama Rao et al. 2013)<br>▪ Forests in 10 districts highly/extremely susceptible to forest fires<br>▪ Increased incidence of heat-related diseases and malnutrition<br>▪ 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.