CLIMATE RESILIENCE AND POWERING HEALTHCARE IN THE GLOBAL SOUTH

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SUSTAINABLE ENERGY FOR ALL

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ABBREVIATIONS

CAPEX	Capital expenditure
CEEW	Council on Energy, Environment and Water
GCF	Green Climate Fund
GHG	Greenhouse gas
GoI	Government of India
IEA	International Energy Agency
KGMU	King George's Medical University
KWh	Kilowatt hour
LED	Light-emitting diode
MNRE	Ministry of New and Renewable Energy
MW	Megawatt
NCDC	National Centre for Disease Control
NGCP	National Grid Corporation of the Philippines
OPEX	Operating expenditure
PV	Photovoltaic
SDD	Solar direct drive
SEforALL	Sustainable Energy for All
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNICEF	United Nations Children's Fund
UNOPS	United Nations Office for Project Services
USAID	United States Agency for International Development
USD	United States Dollar
WHO	World Health Organization
WRI	World Resources Institute

GLOSSARY

Adaptive capacity: The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences of climate change (IPCC 2018).

Air pollution: The degradation of air quality with negative effects on human health or the natural or built environment due to the introduction, by natural processes or human activity, into the atmosphere of substances (gases, aerosols) which have a direct (primary pollutants) or indirect (secondary pollutants) harmful effect (IPCC 2018).

Climate change: A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (IPCC 2018).

Extreme weather event: A weather event, such as storm, heavy or reduced rainfall, high or low temperatures, that is rare for that location and time of year. This can also be called a climate "shock".

Climate stress: Slow-onset hazards, events or changes, such as changes in temperature, rainfall and sea level, that unfold gradually over time.

Resilience to climate change: The ability of systems, communities or individuals to withstand and recover from the environmental, social, economic or health-related adverse impacts of climate change (SEforALL and OPM 2023).

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EXECUTIVE SUMMARY

One of the varied ways that climate change poses a risk to public health systems in the Global South is the impact of climate and weather events on the energy infrastructure of healthcare facilities. This is the first known study to explore how different climate impacts disrupt the supply of energy to healthcare facilities and affect their demand for energy, and what actions facilities and governments can take to make healthcare facility energy infrastructure more resilient to climate risks.

The impacts of climate shocks and stress on the energy infrastructure of healthcare facilities can occur in two ways. Firstly, a climate shock (flood, storm etc.) can physically damage the source of energy and cause a power outage (or reduced volume of power supply). Secondly, a climate shock or stress (extreme heat, erratic rainfall etc.) can increase the energy needed by facilities, for example for indoor cooling or providing emergency services. As a result of these two impacts, there are permanent or temporary unmet energy needs and therefore a reduced volume and quality of healthcare services.

This study uses data from Kenya, India and Barbados to illustrate the scale of the climate impacts facing these three diverse countries and the corresponding strain on energy systems in health facilities.

There are proven and available resilience solutions that will help ensure healthcare facilities have a secure and sustainable supply of energy in the face of climate risks. This includes resilience measures for grid-supplied electricity, diversified and decentralized clean energy sources, energy efficiency technologies and practices, resilience measures for on-site energy systems, and health facility energy planning and operations. However, the relevance of a specific resilience solution depends on the specific risks facing the energy infrastructure of each country and facility.

There is limited uptake of the identified resilience solutions in Kenya, India and Barbados, due to financial, regulatory, capacity and technical constraints. The study ends with three suggestions to partners working on powering healthcare in the Global South.

Firstly, to enable collaboration between health, clean energy, and climate stakeholders. This means bringing together the three different communities of practice that are looking at this issue from the perspectives of clean energy for healthcare, climate resilient healthcare and resilient energy systems.

Secondly, to pursue co-benefits for resilience from powering healthcare initiatives. For example, ensuring that programmes underway that are installing solar energy systems for public healthcare facilities are incorporating risk reduction measures in the design, placement and management of the systems.

Thirdly, to proactively promote a set of resilience solutions that most facilities will benefit from. For example, three such solutions could be energy efficient fans, solar direct drive (SDD) vaccine refrigerators, and cool roofs. If all the healthcare facilities that require such solutions in Kenya, India and Barbados were to adopt them the total investment that governments and partners would need to mobilize in each country would be United States Dollars (USD) 5.8 million, 54 million and 0.2 million, respectively.

CHAPTER ONE

INTRODUCTION

Public healthcare facilities in the Global South are at the frontline of dealing with the health impacts of the climate crisis. Over 5 million deaths each year globally are tied to climate impacts (The Commonwealth Fund 2024). Healthcare facilities require a reliable and clean source of electricity to respond to the increase in vector-borne diseases, air pollution, heat stress, malnutrition and other impacts of climate change (Health & Climate Network 2021; United Nations Environment Programme (UNEP) 2021). However, nearly 1 billion people in low- and lower middle-income countries are served by healthcare facilities that do not have reliable electricity access or have no electricity access at all (World Health Organization (WHO) et al. 2023).

Climate change will continue to add to the demand for health services from healthcare facilities, while further disrupting the sources of energy they use to power these services. Climate and weather events are already, and will increasingly in the future, impact the supply of electricity to healthcare facilities, from the grid and from on-site solar systems. At the same time, the demand for energy by healthcare facilities for indoor cooling/heating and emergency services will increase due to climate change. In this sense, climate change presents a double threat to energy infrastructure for healthcare facilities: it will increase facilities' energy needs for dealing with climate-related impacts on public health and it will disrupt the supply of energy to facilities.

This study is the first known exploration of how climate change will impact the energy infrastructure of healthcare facilities and how the risks can be reduced and/or managed. It aims to add a resilience lens to Sustainable Energy for All's (SEforALL's) Powering Healthcare programme, which provides data, best practices, support and leadership for the electrification of healthcare facilities in energy-deficit countries in the Global South.

The study starts, in Chapter Two, by laying out how climate change impacts the energy infrastructure of healthcare facilities, including effects on both the supply of and demand for energy. Chapter Four then unpacks what is meant by climate resilience and identifies a set of possible resilience solutions for healthcare facility energy infrastructure. Chapter Four looks at the current level of adoption of the resilience solutions in three countries – Kenya, India and Barbados – and the barriers to, and opportunities for, scaling their uptake. The report ends, in Chapter Five, with some recommended actions for the healthcare electrification sector.

The analysis is based on insights provided by national and international experts, published literature and publicly available data. The study focuses on three countries – Kenya, India and Barbados – although many of the findings are applicable across the Global South. These countries were selected on the basis of their diverse contexts, relevance to ongoing SEforALL work, and the availability of both experts and data.

CHAPTER TWO

CLIMATE RISKS TO POWERING HEALTHCARE

2.1 The risk of climate change for healthcare facilities in the Global South

Climate change is an acute health emergency, and health systems in the Global South are at the frontline of addressing climate-related health impacts while also being impacted by climate shocks and stresses. Between 2026 and 2050, the number of climate-induced health cases in low- and middle-income countries is projected to rise to up to 5.2 billion (with associated economic costs of up to USD 20.8 trillion, or 1.3 percent of gross domestic product) with Sub-Saharan Africa expected to account for 71 percent of cases and nearly half of all deaths (World Bank 2024b).

Some of the ways in which climate change impacts public health and health systems include the following:

Immediate and long-term health impacts of extreme weather events: Floods, heat waves, tropical storms and other climate shocks are increasing in frequency and intensity, resulting in deaths, injuries, and long-term mental and physical health conditions. Heat-related deaths have risen by 70 percent in two decades (WHO 2023b).

Increases in diseases, and in food and water insecurity, due to climate stress: Erratic temperature and rainfall are changing the patterns of malaria, dengue, chikungunya and other arboviruses, presenting a complex challenge to infectious disease control; this Is projected to cause 250,000 additional deaths yearly by 2030 (WHO 2009, p. 20, 2023b). Climate stressors are also intensifying existing risks to food and water security – hunger affected 770 million people in 2020, predominantly in Africa and Asia (WHO 2023b). Air pollutants, including indoor pollution from cooking with biomass and ambient pollution from transport and industrial sources (that are also contributing to climate change) are leading causes of respiratory and cardiovascular diseases and cancers (WHO, 2024a, 2024b).

Direct impacts on health sector infrastructure and services: Climate shocks (floods, storms, etc.) are causing damage to health facilities (buildings, medical equipment, electricity- and water-critical services) and disrupting supply chains. For example, the damage caused by Hurricane Maria in Puerto Rico on manufactures who produce 10 percent of drugs in the United States caused prolonged shortages of critical products like saline solution (Lawrence et al. 2020). The demand on health services is also increasing due to climate change, not just during periods of emergency but also due to climate change-related migration, which is altering the profiles of infectious diseases and increasing stress on local health facilities (Locke 2009; McMichael 2015; Musuka and Dzinamarira 2023; Shahverdi et al. 2020).

This chapter focuses on how healthcare facilities in the Global South are at risk from climate change, which can be explained in terms of three aspects: weather and climate events; exposure; and vulnerability (IPCC 2012).

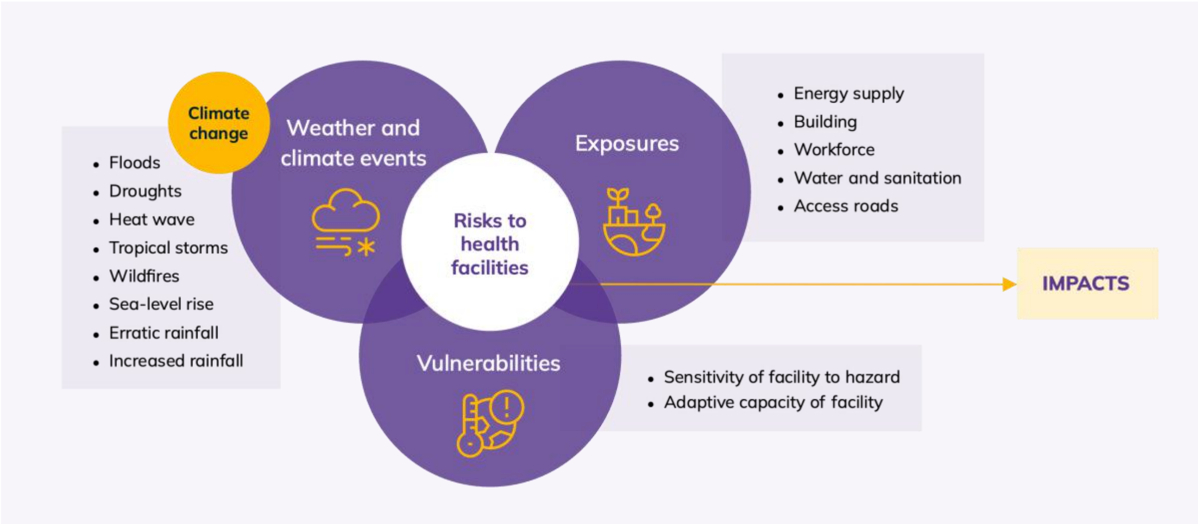
Weather and climate events = The potential occurrence of a climate-related or extreme weather-related physical event in that location, i.e. the area where the facility is located has experienced a flood, drought, etc. in the past and/or it is projected to in the future.

Exposure = Healthcare facilities and associated infrastructure are located in places and settings that could be adversely affected, i.e. the building, access roads and water and energy supply systems, etc. would be affected by climate shocks or stress.

Vulnerability = The degree to which the healthcare facility would be affected by the hazard ("sensitivity") and the ability of the facility to adjust to potential damages ("adaptive capacity").

As the figure below indicates, these three components determine the level of climate risk for healthcare facilities and therefore the likelihood that they will face climate change impacts. The table below the figure provides some examples of the potential impacts of different weather and climate events, although whether a health facility actually faces such impacts is determined by their level of exposure and vulnerability.

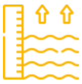
FIGURE 1: Impacts of climate-related risks on healthcare facilities



Source: Authors' own, adapted from WHO, 2021a

TABLE 1: Examples of climate impacts on healthcare facilities

EVENT	POTENTIAL CLIMATE IMPACTS ON FACILITIES	EXAMPLE
Flood	Flood inundation of facilities; damage to buildings, access roads and equipment; disruption to power, water supply and communications systems; increased demand on emergency health services.	Floods in Pakistan in 2022 were caused by a heatwave melting glaciers in the mountains, with 13 percent of health facilities damaged or destroyed (costing USD 188 million for reconstruction) (MOPDSI, Govt of Pakistan 2022).
Drought	Shortage of water availability for facility services; increased demand for health services due to diarrheal and vector-borne diseases.	Kenya's severe drought in 2022 triggered widespread migration as people searched for water, food and pasture, significantly impacting healthcare access and services. In Turkana, hospital-based births declined sharply from 411 to just 100 per month. Additionally, the drought severely affected hydropower generation, leading to power shortages and daily power rationing. This disruption indirectly increased the pressure on healthcare facilities by limiting access to essential electricity and water resources, both of which are critical for providing effective medical procedures (UN 2022; Ambani 2023).
Heatwave	High indoor temperature of facility causing increased morbidity and mortality and/or increased demand for indoor cooling services; disruption to power supply due to increased demand; increased demand on health services due to extreme heat impacts.	During the 2024 heatwave, Pakistan reported power outages of up to 16 hours a day, leading to an increase in patients in health emergency facilities and creating pressure on the already stressed health systems (ur-Rehman 2024).
Tropical storm	Damage from high winds to buildings (roofs, windows, etc.); coastal storm surges causing inundation and	In 2019, an extremely severe cyclonic storm in Odisha, India, caused several healthcare facilities to rely on 24-hour generator use to

EVENT	POTENTIAL CLIMATE IMPACTS ON FACILITIES	EXAMPLE
	damaging buildings and critical equipment; disruption to power, water supply and communications systems; increased demand for emergency health services.	power critical care only, with all non-emergency services closed. Roads also saw waterlogging and fallen tress due to high winds, presenting challenges for patients seeking to access services (Krishnan 2019; Mohanty et al. 2020).
Sea level rise 	Permanent flooding and land erosion causing permanent destruction to buildings and/or access roads.	In Pacific Island countries approximately 62 percent of healthcare infrastructure is located within 500 metres of the coast, making these facilities highly vulnerable to sea level rise and associated events like storm surges and high tides (Taylor 2021).

2.2. The impact of climate change on healthcare facility energy infrastructure

One of the most significant ways that climate change impacts healthcare facilities is by disrupting the supply of energy to facilities and affecting the demand for energy by facilities. This study focuses on how to manage the impact of climate change on healthcare facility energy infrastructure, which can be divided into different types of energy sources and uses (see table below, which draws on WHO et al., 2023).[1]

TABLE 2: Summary of healthcare facility energy infrastructure types

DIMENSION	COVERAGE
Energy supply configuration	**Evidence on percentage of facilities using each source**
No source of electricity	An estimated 12 percent of facilities in South Asia and 15 percent in Sub-Saharan Africa do not have access to electricity.
Utility grid electricity supply	The percentage of electrified facilities using the central grid as the primary source of electricity in a sample of seven countries ranges from 24 percent (Liberia) and 31 percent (Burkina Faso) to 96 percent (Sri Lanka). Not Including Liberia and Burkina Faso, more than 75 percent of electrified facilities across the five other countries rely mainly on the grid.[2]

[1] This study does not consider the full lifecycle of healthcare facility energy infrastructure, although how healthcare facilities dispose of their solar photovoltaic (PV) panels, batteries and electronic waste can impact levels of pollution, environmental degradation and ultimately the resilience of the facility.

[2] The percentage of electrified healthcare facilities with the central grid as the primary energy source for a sample of seven countries is: Bangladesh (79 percent), Burkina Faso (31 percent), Liberia (24 percent), Nepal (86 percent), Senegal (77 percent), Sri Lanka (96 percent) and Zimbabwe (92 percent).

DIMENSION	COVERAGE
Off-grid/decentralized electricity supply: Mini-grids, standalone solar (or other) systems (grid-tied/hybrid/off-grid)	The percentage of electrified facilities using solar as the primary source of electricity in a sample of seven countries ranges from 0 percent in Sri Lanka to around 20 percent in Senegal and Bangladesh to 68 percent in Burkina Faso (although 30 percent of the solar systems in Burkina Faso facilities are reportedly not functioning).[3]
Standalone electricity supply for appliances: Solar lanterns, SDD refrigerators etc.	SDD refrigerators have been promoted across the Global South, including via procurement of 41,000 units by Gavi, the Vaccine Alliance.
Direct combustion of fossil fuels: Diesel/petrol generator, cooking, heating water and sterilization using biomass, coal or liquefied petroleum gas etc.	The percentage of facilities across a sample of seven countries with an operational generator ranges from 7 percent to 53 percent (median of 21 percent).[4]
Types of energy use	**Evidence on energy consumption by facilities**
Electricity needs: Medical equipment, lighting, immunization and cold chain; telemedicine; facility operations/ administration and communication; air conditioning/heating	In sample of three countries: electricity was used for all electrical needs in 58 percent of facilities in Liberia, 91 percent in Sri Lanka and 84 percent in Zimbabwe. Electricity was used for only standalone devices (e.g. refrigerators) in 19 percent of facilities in Liberia, 2 percent in Sri Lanka and 2 percent in Zimbabwe. 20 percent of healthcare facilities in the Global South do not have access to cold chain equipment (SEforALL 2022).
Other thermal energy needs: Cooking and water heating; sterilization and medical waste handling powered through direct combustion of diesel, gas, coal, biomass using on-site boilers (WHO 2014).	56 percent of healthcare facilities in 21 low-income countries had access to adequate sterilization equipment in 2014. 58 percent of facilities in 24 of these countries had a disposal system for hazardous waste (WHO 2014).
Transport: Ambulances.	A review of studies in the Global South found that only a small proportion of patients travelled to the hospital by ambulance, with rates ranging from 5.9 percent in Zambia to 58 percent in India (Bhattarai et al. 2023).

The impacts from climate shocks and stresses on the energy infrastructure of healthcare facilities can occur in two ways:

Firstly, from disrupting the supply of energy to healthcare facilities. A climate shock (flood, tropical storm etc.) can physically damage the grid and off-grid source of energy for the facility. Depending on the severity of the hazard, this could cause a permanent power failure or a

[3] The percentage of electrified healthcare facilities with solar as the primary energy source for a sample of seven countries is: Bangladesh (19 percent), Burkina Faso (68 percent), Liberia (52 percent), Nepal (13 percent), Senegal (21 percent), Sri Lanka (0 percent) and Zimbabwe (2 percent).

[4] The percent of all healthcare facilities with an operational generator (functional and fueled) in six countries is: Bangladesh (7 percent), Nepal (12 percent), Senegal (15 percent), Zimbabwe (26 percent), Liberia (32 percent) and Sri Lanka (53 percent).

temporary interruption, or a reduced volume of power supply. The impact of a climate shock depends on how energy is supplied to the healthcare facility (see the table below). Off-grid and decentralized sources of clean energy are suggested as a resilience solution in section 3.2.

The impact also depends on the generation source for energy. For thermal energy production, which currently accounts for about 80 percent of global electricity, rising ambient temperatures can reduce the efficiency of thermal conversion processes, while decreasing water availability for cooling, and increasing water temperatures can force plants to operate at reduced capacity (ECF et al. 2014; IPCC 2014). Wind energy experiences high variability due to changes in wind speeds and patterns, as well as due to physical damage from extreme weather events. Hydropower is influenced by changes in precipitation, runoff, and streamflow patterns. Severe rainfall, extended droughts, and upstream water flow alterations lead to uncertainty in water resource availability, impacting production capacity (Russo et al. 2022; Osman et al. 2023). Solar power is comparably less affected by climate and weather events, although increased temperatures can slightly reduce PV panel efficiency, and cloud coverage and dust accumulation can contribute to marginally lower outputs.

Secondly, the level and nature of demand for energy by healthcare facilities can change. A climate shock or stress (extreme heat, erratic rainfall etc.) can increase or change the pattern of energy demand in a healthcare facility. Depending on the type of hazard, this can happen incrementally or immediately (following an extreme weather event) and as a result can put more pressure on the source of energy supply.

The table below provides some examples of the impacts of climate hazards on different sources of energy for healthcare facilities.

TABLE 3: Examples of climate impacts for different healthcare facility energy sources

ENERGY SUPPLY CONFIGURATION	IMPACTS ON SUPPLY OF ENERGY	IMPACTS ON DEMAND FOR ENERGY
Utility grid electricity supply	• Physical damage from floods/sea level rise/storms etc. to power plant and/or grid network. • Increased temperature reduces cooling efficiency and output at power plants.	• Slow-onset changes in temperature and heatwaves increase national demand for energy for cooling/heating, which puts pressure on the generation capacity of grid.
Off-gird/ decentralized electricity supply	• Physical damage from floods/sea level rise/storms etc. and incremental damage from heat and humidity to solar panels, wires and batteries. • Increased temperature reduces output capacity from PV cells and efficiency and operability of batteries, particularly li-ion and lead–acid batteries).	• Slow-onset changes, and sudden spikes/dips, in indoor temperature in healthcare facilities increase demand for cooling and heating. • Surges in emergency health services during droughts, storms, floods etc. increase demand for energy. • Additional energy required for cooling of batteries to manage risk of increased temperatures.
Standalone electricity supply for appliances	• Physical damage from floods, storms etc. to appliances and batteries, and incremental damage from heat and humidity to solar-powered appliances. • Droughts create water shortages and reduce supply of frozen water packs for SDD refrigerators. • Physical damage from floods, storms etc. to fossil fuel-powered generators, ambulances and fuel supply routes.	• Surges in emergency health services during droughts, storms, floods, etc. increase demand for energy during non-sunlight hours. • Due to disruptions to primary energy sources (see above), increased pressure on fossil fuel-powered back-up generators.
Direct combustion of fossil fuels	• Physical damage from floods, storms etc. to generators, ambulances. • Disruption to fuel supply, including firewood, LPG, diesel/petrol etc.	• Due to disruptions in primary energy source (see above), increased pressure on back-up energy sources.

The disruption to the supply of energy to healthcare facilities, and the increased demand for energy by facilities, results in permanent or temporary unmet energy needs of healthcare facilities. A staggeringly large proportion of healthcare facilities face unreliable electricity supply (an estimated 68,350 facilities in Sub-Saharan Africa) although it is difficult to distinguish the contributing role of climate change shocks and stresses, relative to wider energy access issues. For example, due to a variety of climate and non-climate reasons, in South Asia, there are on average over 25 power outages per month. The duration of power outages varies by region, lasting up to 8 hours in Latin America and the Caribbean and around 7.5 hours in Sub-Saharan Africa, compared to 2.5 hours in East Asia (Casey et al. 2020).

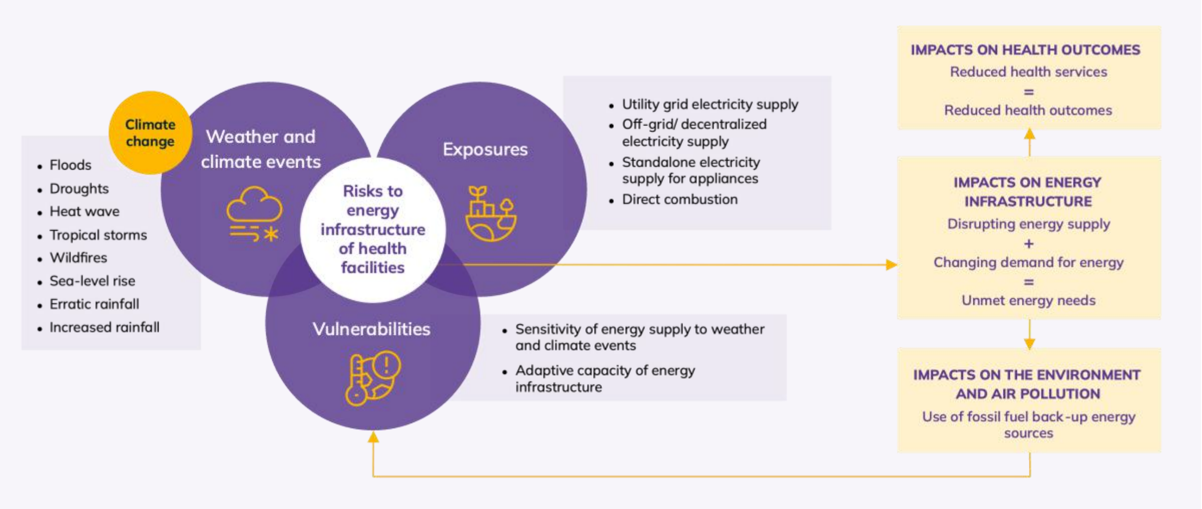
The wider literature on healthcare electrification gives a clear picture of the health and environmental implications of the unmet energy needs of health facilities, regardless of the cause of the problem. In particular:

Reduced health services affecting health outcomes: When the supply of energy is temporarily disrupted or under ongoing pressure, basic healthcare facility services (lighting, communications, clean water etc.) and medical equipment (to power surgeries, immunizations etc.) are affected. As the report *Energizing Health: Accelerating Electricity Access In Health-Care Facilities* makes clear, an unreliable supply of electricity is a major barrier to universal health coverage and can make the difference between life and death (WHO et.al, 2023). For example, it has been estimated using modelling that for one hospital in Islamabad, Pakistan, with 545 beds, approximately nine patients of productive working age are at risk of mortality due to power shortages every year. Considering the estimated social value these lives lost, this represents an economic cost to the country of USD 4,781,710 per year (WHO, 2023a). A study in Ghana calculated that power outages of more than two hours increased the risk of hospital mortality by 43 percent (Apenteng et al. 2018).

Increased use of fossil fuel as a back-up source of energy further worsens climate change: Diesel- or petrol-powered generators are the most common form of back-up energy supply for healthcare facilities. As disruptions to and pressure on the primary energy supply of facilities increases, the use of such generators is likely to increase. As described in the table above, this source of energy is itself at risk from climate change, but it is also a contributor to climate change and health-affecting air pollutants (WHO and World Bank 2015; CCAC 2024). An SEforALL study estimated that across South Asia and Sub-Saharan Africa there is the potential to save 0.33–0.54 metric tons of carbon dioxide (MtCO2) and 0.35–0.43 MtCO2 of annual emissions, respectively, if healthcare facilities switched from fossil fuel generators to standalone solar PV systems (SEforALL and OPM 2023).

The figure below presents the full impact pathway of climate change on the energy infrastructure of healthcare facilities**.**

FIGURE 2: Summary of impact pathway of climate change on energy infrastructure of healthcare facilities



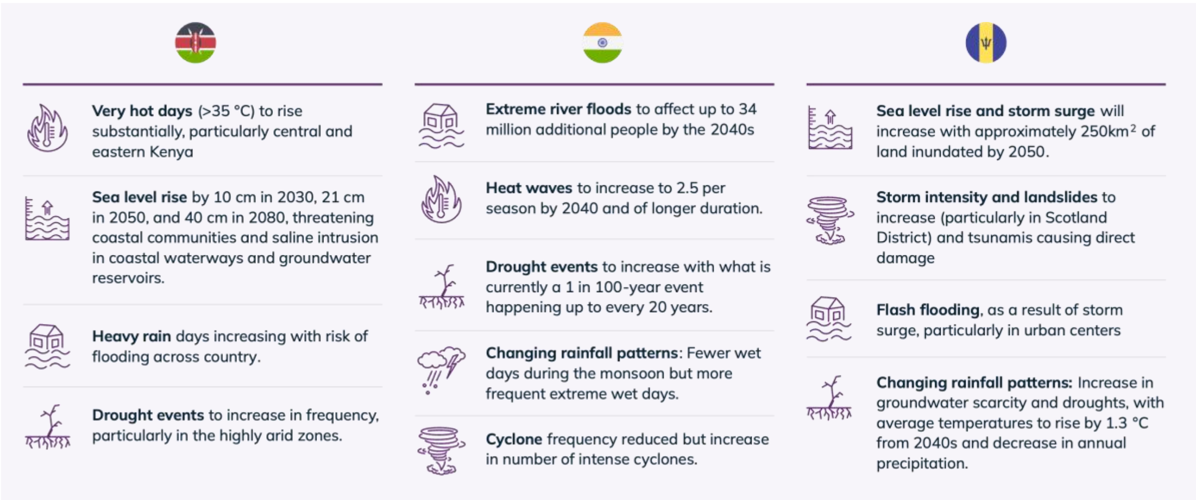
Source: Authors' own.

2.3. Climate impact pathways for Kenya, India and Barbados

The exact scale and nature of the current and potential future impacts of climate change on healthcare facilities' energy infrastructure depends on the level of exposure of a facility to weather and climate events and its vulnerability to such events. A facility-level climate risk and vulnerability assessment would be the most accurate method to assess this, and there are various tools available to support facilities in this regard, which include some focus on energy infrastructure: in particular, WHO's Guidance to Assess Vulnerabilities in Health Care Facilities (WHO 2021a). However, given the current lack of such facility-level assessments, this section uses available data and expert interviews to give a picture of the level of risk facing the energy infrastructure of healthcare facilities in Kenya, India and Barbados.

The climate change risk profile of each of these countries differs, with healthcare facilities in each country facing a diverse set of climate shocks and stresses. The figure below summarizes some of the most significant weather and climate events in each of the countries, and their projections.

FIGURE 3: Summary of climate change projections in Kenya, India and Barbados



Source: Martyr-Koller et al., 2019; USAID, 2021; World Bank, 2021b, 2021a; UNDP, 2022.

The number of healthcare facilities that are exposed to these weather and climate events depends on their exact location. For example, in Kenya the northern regions and the southern tip of the coastal strip are the areas most affected by climate change, particularly in terms of recurrent floods and droughts (UNICEF 2023b). The main hospital in Barbados, Queen Elizabeth Hospital, was built on a flood plain, leaving it vulnerable if a major storm hits the island (Buckholtz 2023). This section presents estimates of the number of healthcare facilities that are at risk from particular hazards, using available information from published climate risk profiles of each country and government data on the number of healthcare facilities in each location.[5] The multi-dimensional nature of the climate risks facing health facilities is striking, showing that facilities need to be prepared for a range of very different potential impacts.

In Kenya, approximately 64 percent of all public healthcare facilities (910 facilities) are at high or very high risk of water scarcity and/or drought, heatwaves and/or floods. Of these, 81 percent face risks of water scarcity and/or drought (every couple of years), 78 percent face risks of heatwaves and 31 percent face risks of annual flooding. 67 percent of facilities are at risk of two types of climate or weather event risks and 12 percent are at risk of three.

In India, approximately 19 percent of all public healthcare facilities (36,446 facilities) are at high or very high risk of drought, flood and/or cyclone. Of these, 75 percent face a risk of drought, 63 percent face a risk of flood and 24 percent face a risk of cyclone. 35 percent of facilities are at risk of two types of climate or weather event risk and 3 percent are at risk of three. Using a separate data source, approximately 3 percent of all public healthcare facilities are at high or very high risk of heatwaves.

In Barbados, of the 15 public and private healthcare facilities of different tiers in the country, all are considered at high or very high risk of flood and storm and 50 percent are at risk of sea level rise. Given the small land area of the country, it is estimated that all facilities would be at risk of such an extreme weather event, while half are in low-lying coastal areas and therefore at risk of inundation.

[5] In India, the Council on Energy, Environment and Water's (CEEW's) Climate Vulnerability Index was used to identify districts at high or very high risk of one or more of the three weather events the report modelled: drought, cyclone and floods. Using the government's report on the health dynamics of India, a total of 1,56,674 public healthcare facilities (including five types of health centres and hospitals) were mapped to each district to identify the total number of facilities potentially exposed to such risks. However, a vulnerability assessment of healthcare facilities in India (CEEW 2024), provides an estimate of the proportion of healthcare facilities that are likely to be actually exposed in any high-risk location (70 percent), which has been applied for both India and Kenya. CEEW's Index did not model the risk of extreme heat, but the expert consultations identified this as a crucial risk facing healthcare facilities. Therefore, using separate modelling estimates (IMD's Climate Hazards and Vulnerability Atlas of India) the proportion of districts at high and very high risk of heatwaves (4 percent) was applied to the total number of healthcare facilities in the country (using the same 70 percent exposure rating as for other risks) to estimate the number of facilities at risk of heat waves (IMD 2022; MoHFW 2024). In Barbados, given the small number of facilities and geographic size of the country, the authors used a manual process of locating each healthcare facility on a map and identifying those in coastal zones (and therefore at risk from coastal rise and associated impacts) and assuming that all healthcare facilities are exposed to the same extent to other climate shocks and stresses. In Kenya, the team utilized UNICEF's Kenya Subnational Children Climate Risk Index-Disaster Risk Model (CCRI-DRM) to identify counties at high to extremely high risk of one or more of the three weather events modeled in the report: droughts, heatwaves and floods (UNICEF 2023b). Using health facility data from Kenya's Ministry of Health, the team calculated the total number of public health facilities, categorized into five types, including health centres and hospitals (openAFRICA 2020).

TABLE 4: Estimated number of healthcare facilities at high/very high risk of weather and climate events

COUNTRY	CLIMATE/WEATHER EVENT	NUMBER OF FACILITIES
	Water scarcity/drought	119
	Heatwave	39
	Water scarcity/drought and heatwave	468
	Flood	33
	Flood and water scarcity/drought	48
	Flood and heatwaves	97
	Flood, heatwave and water scarcity/drought	106
	Total (flood, water scarcity/drought and heatwaves)	**910**
	Drought	12,451
	Drought and cyclone	1,086
	Flood	6,218
	Flood and cyclone	2,762
	Flood and drought	8,949
	Flood, drought and cyclone	4,982
	Total (flood, drought and cyclone)	**36,446**
	Heatwaves	**5,303**
	Flood and storm	15
	Drought and heatwave	15
	Flood, storm and sea level rise	10
	Total (flood, storm, drought, heatwave and sea level rise)	**15**

Source: Authors' own calculations, based on data and assumptions described in previous footnotes.

Some of the impacts of such weather and climate events on healthcare facility energy infrastructure can be approximately estimated based on the source of energy.

In Kenya, approximately 77 percent of all healthcare facilities have access to power from the grid (which is powered by clean energy), while 12 percent have on-site solar PV systems.[6] In total, 89 percent of healthcare facilities (public and private) have access to power, although this varies significantly across the country, from 54 percent of facilities in West Pokot County to 99 percent in Nairobi. However, the majority of these electrified facilities (estimated at approximately 60 percent) have irregular supply, with frequent power outages. There are approximately 157 unelectrified public healthcare facilities across the country (CEMA, no date). Grid-connected

[6] In Kenya, the 2023 Health Facility Census Report provides data on the proportion of 12,375 public, private and NGO-operated healthcare facilities across the country that have a reliable power supply, a grid-connected and solar primary source of energy, and a back-up source. There is no breakdown giving the proportion for public facilities specifically, and although this can be assumed to be much lower than the average, given the lack of alternative data, this study uses the Census Report average data.

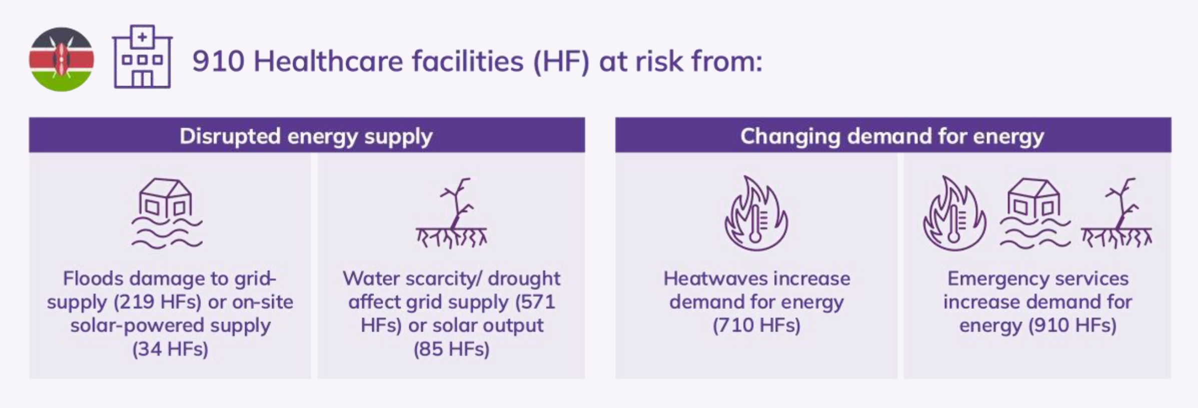
electricity is generated primarily from clean sources, with 47.5 percent from geothermal, 21 percent from hydropower/marine and 21 percent from other renewable sources (International Energy Agency (IEA) 2023).

Based on the foregoing, some of the potential impacts of climate change on Kenyan public health facilities' energy infrastructure are:

- The physical damage to grid transmissions and distribution lines, and resulting disruption of supply, for those grid-connected facilities at high risk of flooding (approximately 219).
- The physical damage to panels, wires and batteries, and resulting disruption of supply, for those solar-powered facilities at high risk of flooding (approximately 34).
- The reduced output generation of hydropower plants due to drought and water scarcity affecting supply for those grid-connected facilities in areas that are highly exposed to these climate shocks and stresses (approximately 571).
- The reduced output capacity from PV cells and/or reduced efficiency and performance of batteries due to increased temperature affecting supply for those solar-powered facilities at high risk of heatwaves (approximately 85).
- Increased demand for energy to power emergency services by all healthcare facilities at high risk of extreme weather events of droughts, floods and heatwaves (approximately 910).
- Increased demand for energy to power indoor cooling services by all healthcare facilities at high risk of heatwaves (approximately 710).

Heavy rainfall in March–April 2024 caused flooding and landslides across 80 percent of Kenya, increasing the demand on health facilities while also interrupting the supply of electricity (Hussein 2024; MSF 2024; UNICEF 2024). In Tana River County, the floods caused direct loss of life, the displacement of 43,000 people from their homes and a public health emergency, including a cholera outbreak. Public health facilities struggled to respond, with 10 percent of public health facilities (eight health facilities) being cut off and submerged by floods. There was also a shortage of electricity to power emergency services, including electricity outages from the grid due to damaged grid lines, and a shortage of fuel due to damaged transport supply routes.

FIGURE 4: Summary of some of the climate risks to public healthcare energy infrastructure in Kenya



Source: Authors' own, based on data presented above.

In India, approximately 91 percent of primary health centres have a grid-supplied source of power, although only 50 percent have a reliable supply.[7] This electricity relies on power generated primarily from coal (71 percent), followed by hydropower (9.6 percent) and solar (7.4 percent) sources (NITI Aayog 2024). Although there is no national data on the proportion of healthcare facilities that use an off-grid solar system as their primary source of electricity, there are several known programme-specific and state-specific efforts, such as the Government of Chhattisgarh's installing solar panels on 1,400 unelectrified facilities (The Economics Times 2022), and it can be estimated that 1 percent of all public healthcare facilities use on-site solar as their primary source of energy.[8] The electrification status of facilities varies across the country, with 93 percent of primary health centres in the state of Kerala receiving regular electricity and only 8 percent doing so in Manipur. There remains a large number of unelectrified public healthcare facilities, estimated at 17,045 across different levels of facilities.

Based on the foregoing, some of the potential impacts of climate change on Indian public health facilities' energy infrastructure are:

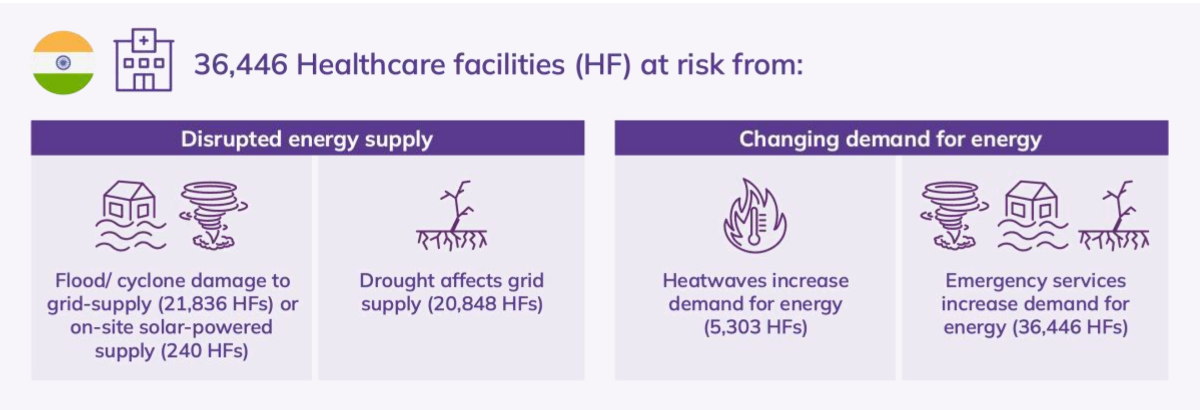
[7] In India, CEEW's (2019) report on the State of Electricity Access for Primary Health Centres in India uses data for 2012–13 for primary health centres only from the Government of India's District Level Household and Facility Survey on the proportion of all primary health centres with a grid-connected source of electricity and the level of reliability of this electricity. This suggests that 9 percent of all primary health centres are unelectrified (rural and urban), whereas data from the annual Rural Health Statistics mentions that there are still around 17,967 rural sub-centres (11.4 percent of total) and 934 rural primary health centres (3.7 percent) that function without an electricity connection (WRI 2023). For the purpose of this study, 9 percent of all types of public healthcare facilities are assumed to be unelectrified.

[8] There is no standard national survey on the proportion of healthcare facilities in India with installed solar systems and the proportion of energy consumed from different sources. Alliance for an Energy Efficient Economy's 2023 survey of energy consumption of 623 healthcare facilities across India reports that 87 percent of their total energy consumption was electricity sourced from the grid, then primary fuels (particularly liquefied petroleum gas) (9 percent of total consumption), on-site solar (2 percent) and on-site diesel generator (2 percent). The penetration of on-site solar PV was 11 percent for public facilities, while a deeper analysis of 18 facilities found that 11 used solar systems without battery storage for direct use in building operations. Using this study, together with expert consultations, this report estimates that only 1 percent of public healthcare facilities use an on-site solar system as their primary source of electricity, although others use one as a back-up system.

- The physical damage to generation plants, transmissions and distribution lines, and resulting distribution of supply, for those grid-connected facilities at high risk of flooding and/or cyclones (approximately 21,836 facilities). For example, in July 2023, flooding in Punjab, India, led to the shutting down of a 700-megawatt (MW) unit of the Rajpura thermal power plant, 20 substations and 41 power grids, causing widespread loss of power (PTI 2023).
- The physical damage to panels, wires and batteries, and resulting disruption of supply, for those solar-powered facilities at high risk of flooding and/or cyclones (approximately 240 facilities).
- The reduced output generation of water-cooled thermal power plants due to low river flows and higher steam temperatures affecting supply for those grid-connected facilities in areas at risk of drought conditions (approximately 20,848 facilities). For example, between 2013 and 2016, water shortages cost India's thermal power plants 30 terawatt hours in potential electricity generation (enough to power Sri Lanka for an entire year) (Luo 2017).
- Increased demand for energy to power emergency services for all healthcare facilities at high risk of extreme weather events of droughts, floods and cyclones (approximately 36,446 facilities).
- Increased demand for energy to power indoor cooling services for all healthcare facilities at high risk of heatwaves (approximately 5,303 facilities).

The severity of the 2018 floods and landslides in Kerala were unprecedented for the affected districts (Sharma 2023; Mint 2024; Sivan and V. 2024). The floods affected 5.4 million people and displaced 2 million people, with more than 400 people losing their lives. More than 4,000 electricity transformers were switched off by power companies to avoid mishaps, creating a power outage across the state. The direct damage to power supplies disrupted electricity supply to 2.5 million people, as well as many public health facilities. Over 330 such facilities were fully or partly damaged, of which the majority were single-storey primary health centres that lost their electricity back-up source in the floods.

FIGURE 5: Summary of some of the climate risks to public healthcare energy infrastructure in India



Source: Author's own, based on data presented above.

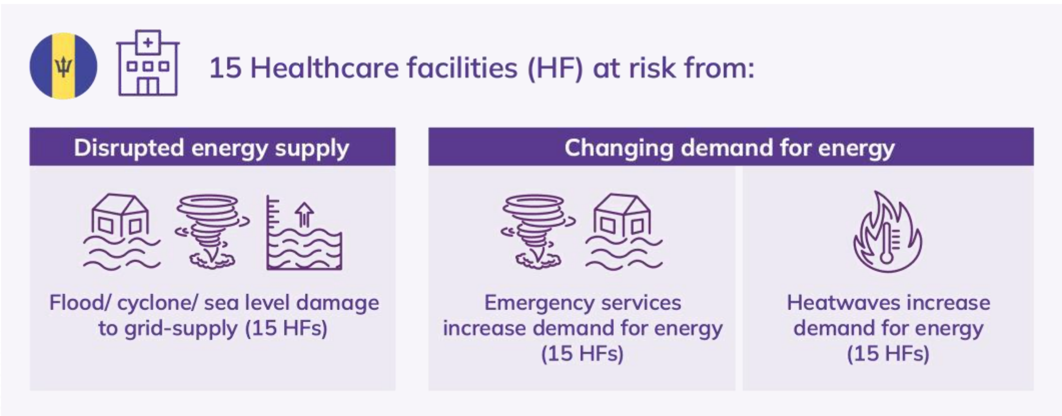
In Barbados, all of the 15 healthcare facilities in the country are connected to the grid, although they suffer from temporary power outages.[9] The source of grid-connected power supplied to the facilities is primarily fossil fuels: 85 percent of power generation comes from heavy fuel oil and only a very small proportion comes from renewables (SEforALL 2023).

Based on this background, some of the potential impacts of climate change on Barbados health facilities' energy infrastructure are:

- The physical damage to transmissions and distributions lines and disruption of fuel supply for generation, affecting supply for those grid-connected facilities at high risk of sea level rise, floods, drought and storms (approximately 15 facilities) (Buckholtz 2023).
- Increased demand for energy to power emergency services for all healthcare facilities at high risk of floods and storms (approximately 15 facilities).
- Increased demand for energy to power indoor cooling services by all healthcare facilities at high risk of heatwaves (approximately 15 facilities).

In 2021, the record-breaking number of lightning strikes during Hurricane Elsa's resulted in a five-day power outage across the island. Tropical storms are an annual occurrence, but experts reported that they are becoming more severe and starting earlier in the season. Hurricane Elsa was particularly severe, impacting Barbados with maximum sustained winds of 75 mph, alongside even more powerful gusts (CDEMA 2021). Such storms frequently cause damage to power lines from fallen trees, resulting in outages of grid-supplied electricity to hospitals. The national utility tries to restore electricity for all consumers within two weeks, and some hospitals are in a priority zone, which means their connection gets restored very quickly.

FIGURE 6: Summary of some of the climate risks to healthcare energy infrastructure in Barbados



Source: Authors' own, based on data presented above.

Across all three countries, disruption to the primary electricity supply for healthcare facilities is likely to be impacting the quality and scope of the healthcare services provided. Global studies

[9] Barbados is 100 percent electrified; while facilities have a back-up source of electricity in case of power outages, the primary source of power is from the grid.

have demonstrated the importance of energy access for health outcomes, including the operation of lifesaving equipment, refrigeration of vaccines and the availability of basic lighting for maternal services (Concessao et al. 2023).

Disruptions to electricity supply, coupled with increased energy demands for powering emergency and cooling services, also compel facilities to rely on fossil fuel-powered generators. Approximately 64 percent of all public healthcare facilities in India have a functioning back-up generator, while 41 percent of facilities in Kenya and 100 percent in Barbados have one.[10] Access to a back-up source of electricity is a common requirement for healthcare facilities (and is a key resilience measure, as described in the next section) but the use of diesel/ petrol generators has negative environmental and health outcomes.

[10] In India, the number of healthcare facilities with a fossil fuel-powered back-up supply of electricity is estimated based on CEEW's analysis on primary health centres only (CEEW 2019). In Kenya, the 2023 Health Facility Census Report reports that 41 percent of all public/private healthcare facilities operate a back-up power supply (without specifying the source of power). However, the 2018/19 Harmonized Health Facility Assessment reported that 42 percent of all public primary health centres were carrying out routine preventive maintenance for a generator in 2018/19. Therefore it is assumed that 42 percent of public healthcare facilities are using a diesel/ petrol generator as a back-up source. In Barbados, based on expert consultations, it is assumed that all public/private healthcare facilities have a functioning generator.

CHAPTER THREE

Increasing the climate resilience of healthcare energy infrastructure

3.1 Defining climate resilient healthcare facility energy infrastructure

A climate resilient healthcare facility is one that is able to anticipate, respond to, cope with, recover from and adapt to climate and weather events, so as to provide ongoing and sustained healthcare to their target populations, despite an unstable climate (WHO 2015)**.**

The figure below illustrates what it means for a healthcare facility to be climate resilient, indicating that resilience exists on a sliding scale. If a healthcare facility is exposed to an extreme weather event (a "shock"), such as a flood, drought or tropical storm, then the degree to which they recover to their pre-event state of performance (and the speed of this recovery) determines their level of resilience.

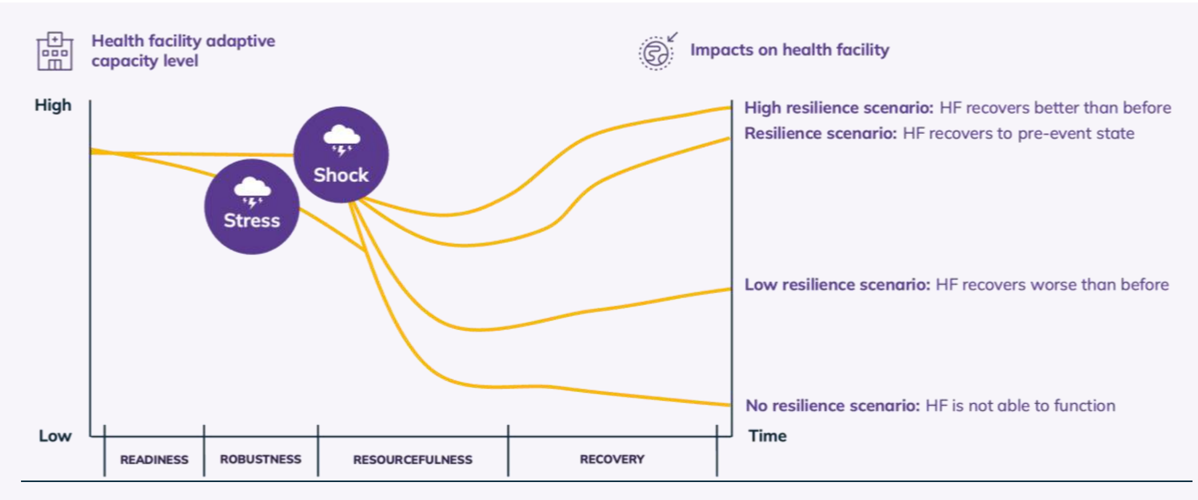
Similarly, if a facility that is exposed to slow-onset climate changes (a "stress") such as sea level rise, erratic rainfall patterns and increased temperatures, adapts and recovers fully and relatively quickly, then they can be deemed to be resilient. In the most extreme case, a healthcare facility that is not resilient may collapse entirely when exposed to climate shocks and stresses, ceasing operations and leaving communities without access to health services (WHO 2015).

In Nepal, the resilience of healthcare facilities in managing and recovering from the 2015 earthquake provides some insights that are relevant for climate shocks. The high-magnitude earthquake and aftershocks killed nearly 9,000 people and injured another 22,000. Almost 84 percent of health services in the affected districts were destroyed or damaged as they struggled with the surge in demand for their services. One hospital that was built to an earthquake-resistant standard largely avoided any damage to the building but was burdened by a huge influx in emergency care patients and resulting shortages in medical supplies, equipment and staff capacity. The hospital adapted to this situation, for example putting non-urgent cases on hold, and the individual resilience of hospital staff was a key factor in them continuing to work despite the difficult circumstances (Almeida 2022).

The adaptive capacity of a healthcare facility is the key determinant of whether a facility exposed to climate shocks and stresses is resilient and able to recover from the impacts. In the previous section, the definition of climate risk was described as having three contributing factors: the potential occurrence of *climate and weather events* (shocks and stresses); the *exposure* of healthcare facilities to such hazards as a result of their geographical location; and the *vulnerability* of facilities to the impacts of the hazard.

The vulnerability of a healthcare facility is the risk factor that can most easily be changed, by increasing the adaptive capacity of the facility. Adaptive capacity refers to the ability of the facility to adjust to potential damages and therefore minimize the impact of any climate shock or stress. This has four stages (highlighted in the timeline in the figure below). Firstly, *readiness* – to anticipate, prepare for and plan for any potential shock or stress. Secondly, *robustness* – to withstand long-term climate stresses. Thirdly, *resourcefulness* – to manage during a climate shock. Fourthly, *recovery* – to return to the original state pre-stress and pre-shock. The figure below illustrates how the resilience pathway of a healthcare facility, and whether it can recover from climate shocks and stress, depends on how it performs in these four stages.

FIGURE 7: Illustration of four potential resilience pathways (from high resilience to no resilience) of a healthcare facility when faced with climate shocks and stress



Source: Authors' own, adapted from IPCC 2012, 2014; WHO 2019; IEA 2022.

There are a range of infrastructure- and non-infrastructure factors that determine the adaptive capacity – and therefore resilience – of a healthcare facility. The table below sets out some dimensions that determine the level of resilience of a healthcare facility, as well as examples of "solutions" that can help to build resilience, drawn from different facility resilience frameworks and checklists (WHO 2015; Corvalan et al. 2020; WHO 2020a; Rentschler et al. 2021; WHO 2021a; United Nations Office for Project Services (UNOPS) 2024).

What is not included in the table of resilience solutions below, but which is a crucial foundational enabler of resilience, is a facility's ability to effectively manage routine healthcare demand for services during normal periods (Rentschler et al. 2021). This includes it having adequate financing, staff, equipment and infrastructure to deliver health services.

This study focuses on just one of the dimensions of healthcare facility resilience set out in the table below: a secure and sustainable supply of power. However, ideally, the resilience of a healthcare facility would be assessed and addressed in a holistic manner, considering all of these dimensions.

TABLE 5: Dimensions of resilience of healthcare facilities to climate change

DIMENSION	EXAMPLES OF RESILIENCE SOLUTIONS
Structural integrity and adaptability	Flood-resistant design; wind and storm resistance; heat-resistant design; heat-resilient materials; humidity-resilient materials; corrosion-resilient materials.
Secure and sustainable supply of energy (see section 3.2)	Resilience measures for grid-supplied electricity (e.g. protection of generation assets from physical damage); decentralized clean energy sources; energy efficient appliances, buildings and transportation; resilience measures for on-site energy systems; health facility energy planning and operations.
Secure and safe water and sanitation system	Robust water storage, filtration, and distribution systems; efficient waste management and sanitation systems.
Supply chain resilience	Diversified and reliable supply chains, emergency stockpiles, and contingency plans for logistics.
Operational continuity plans	Disaster preparedness plans; staff training in emergency protocols; alternative communication systems (e.g. satellite phones); strategies to manage surge in demand etc.
Community engagement and outreach	Engaging local communities and capturing local knowledge in preparedness strategies; coordination with disaster response and civil protection agencies.

Ensuring healthcare energy infrastructure is climate resilient involves safeguarding the facility itself and ensuring it has a secure and sustainable supply of energy in the face of climate risks. IEA defines a climate resilient energy system as one that can "*prepare for changes in climate, adapt to and withstand the slow-onset changes in climate patterns, continue to operate under the immediate shocks from extreme weather events, and restore the system's function after climate-driven disruptions*" (IEA 2022). IEA sets out four criteria for resilient energy systems, which can be applied to healthcare facilities:

- Readiness: healthcare facilities' energy systems are prepared for changes in climate change and the potential impact on their supply of energy.

- Robustness: healthcare facilities' energy systems withstand the gradual long-term changes in climate patterns and continues operation.
- Resourcefulness: the supply of energy to healthcare facilities continues during extreme weather events.
- Recovery: the supply of energy to healthcare facilities is restored after interruptions resulting from extreme weather events.

3.2 Resilience solutions for healthcare facility energy infrastructure

There is a long list of possible measures that can increase the resilience of healthcare facility energy infrastructure, but there is no one-size-fits-all prescription. This section describes resilience solutions discussed in the literature, but their actual relevance depends on the specific risks facing a facility's energy infrastructure (USAID 2011; WHO 2020a, 2021a; IEA 2022).

The resilience solutions can be grouped into five types:

- **Resilience measures for grid-supplied electricity:** These protect generation, transmission and distribution infrastructure from weather- and climate-related physical damage and use planning and technology to minimize any disruption that is caused by such events.
- **Decentralized clean energy sources:** These reduce the impact of any disruption to the primary source of energy by ensuring there is a back-up electricity supply, while avoiding contributions to climate change through the use of fossil fuels.
- **Resilience measures for on-site energy systems**: These protect on-site energy generation, particularly solar systems, from weather- and climate-related physical damage.
- **Energy efficient appliances, buildings and transportation:** These reduce the energy needs of healthcare facilities and therefore the pressure on their supply of energy, thereby offsetting the potential increase in demand and minimizing the impact of a reduced supply as a result of climate and weather events.
- **Health facility energy planning and operations**: This helps healthcare facilities to plan for, manage, and recover from any disruption to the supply of energy due to climate and weather events.

3.2.1. Resilience measures for grid-supplied electricity

Targeted measures across the generation, transmission and distribution of grid-supplied electricity can significantly enhance the resilience of the energy supply to healthcare facilities. These include the following:

Physical system improvements to safeguard grid-connected assets. For example, floodwalls, advanced ripraps, and improving dike construction can reduce the probability of damage to generation plants from flooding. For hydropower plants, increasing dam heights, sediment control facilities, and expanded spillway capacities can reduce the probability of damage by floods by 50 percent (Miyamoto International 2019; IEA 2021a). For thermal power plants, deploying dry or hybrid cooling systems reduces water dependency, which can help in managing the risk of growing water scarcity. For example, in South Africa utilities have adopted dry cooling systems, despite their reduced efficiency, due to the high risk of water scarcity (Eskom 2021).

Advanced wind power plant designs with stronger towers, reinforced foundations, and customized rotor sizes can withstand high wind speeds and protect against cyclone damage. Relocating coastal and low-lying generation and substation assets or constructing protective seawalls, dikes or natural flood barriers, such as wetlands, may be necessary to protect plants from flooding and sea level rise (IEA 2022).

Strengthened transmission and distribution networks to reduce physical damage during extreme weather events. Undergrounding electricity cables reduces vulnerability to cyclones and high winds, while replacing wooden or concrete poles with galvanized steel poles minimizes structural damage. Building robust, meshed networks with redundant lines helps maintain power supply even when primary lines are disrupted (IEA 2021b).

Advanced grid technologies to minimize the impact when the power grid is damaged. Smart grids can reroute power during outages or isolate damaged sections. For example, Florida's smart grid helped restore power quickly after Hurricane Irma in 2017, saving approximately USD 1.7 billion (IEA 2022, p. 202). Battery storage solutions also enhance the reliability of power systems by storing energy during periods of surplus and supplying it during outages. Voltage stabilizers can protect critical medical equipment from damage caused by electrical surges or fluctuations, ensuring operational continuity during power interruptions.

In the Philippines, the after-effects of Typhoon Haiyan in 2013 served as a critical motivation for enhancing the resilience of the centralized grid system. Recognizing the importance of maintaining electricity supply to healthcare facilities during natural disasters, the National Grid Corporation of the Philippines (NGCP) undertook significant infrastructure upgrades. These measures included constructing flood walls, reinforcing transmission towers with typhoon-resistant materials, and integrating advanced grid monitoring systems. To complement these efforts, decentralized solutions like solar power back-up systems were installed in key hospitals, ensuring uninterrupted energy for critical functions (NGCP 2018).

Similarly, Puerto Rico's USD 20 billion electrical grid modernization plan announced following Hurricane Maria in 2017 aimed for a more resilient energy system. The plan included hardening the grid by reinforcing substations, developing battery storage, and introducing advanced operational technologies for better grid management (Gupta 2021).

3.2.2 Decentralized clean energy sources

Healthcare facilities can reduce their dependence on the power grid by installing a decentralized source of energy supply for use in the case of disruption. It is common for healthcare facilities to have a fossil fuel-powered alternative source of energy – for example, diesel/petrol generators and kerosene lamps – but these have well-documented negative environmental and health outcomes[11] (SEforALL and OPM 2023). Decentralized clean energy sources include:

A standalone or micro/mini-grid renewable energy system can provide a back-up source of electricity if it is fitted with a battery. On-site solar PV systems are the most common such source. These are installed on the healthcare facility's rooftop or nearby grounds, can be grid-tied (with energy generated on-site feeding into the grid), off-grid (with energy generated being directly used by the facility) or hybrid (a grid-tied system but with a battery installed). In the event of a grid failure, a grid-tied solar system at a healthcare facility will cease to produce power and is therefore not an effective resilience solution (but does provide a range of energy cost and greenhouse gas (GHG) emissions savings). An off-grid system will continue to generate energy for the facility during sunlight hours, and with a battery, both the off-grid and hybrid systems can power critical equipment and services in a grid-down situation (Lagrange et al. 2020). In regions like Sub-Saharan Africa, off-grid systems are particularly prevalent due to limited advancements in feed-in tariffs, which makes grid-tied solar PV systems less attractive.

Solar PV ensured continuity of care in Sierra Leone during power grid failure. In April 2024, Sierra Leone experienced a week-long power grid failure when the government was unable to pay Karpowership, a major power generator. The power outage significantly affected essential services, including healthcare. Although climate change was not the direct cause of the power failure in this instance, it did demonstrate the resilience of two hospitals in regard to dealing with such outages. The Ola During Children's Hospital and Princess Christian Maternity Hospital in Freetown, which were equipped with a solar PV and storage solution by SEforALL, were able to sustain critical operations. These facilities operated for several hours each day, ensuring that lifesaving care continued uninterrupted.

Micro- and mini-grids provide an alternative decentralized source of energy, powering multiple buildings within a facility or connecting to other community users respectively (WHO 2023a). These systems generate electricity from clean energy sources, such as solar, wind, hydro and biomass, store it using battery systems, and distribute electricity via a mini-/micro-grid across buildings in a healthcare facility and/or to other consumers in the community (IRENA 2018). While

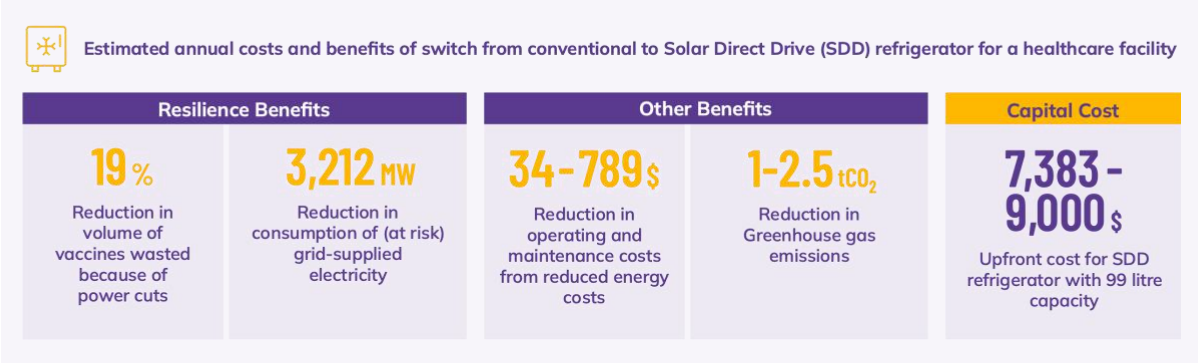
[11] While this study focuses on resilience solutions that are also clean and sustainable, the reality is that a large number of healthcare facilities will continue to rely on fossil fuel-powered generators in the short term. There are various measures that can reduce the impact on climate and weather events of these generators. This includes careful placement to avoid contact with flood water, and proper cooling and ventilation to manage high temperatures and to ensure an adequate supply of combustion air. The supply of fuel for these generators can also be disrupted by extreme weather events, and therefore facilities should have a plan for securing emergency fuel. Effective operation and maintenance of generators can preserve their lifespan and ensure they are operational during emergencies: for example, generator failure rates rise to approximately 15 percent after 24 hours of continuous use, and diesel fuel stored beyond 12 months begins to degrade, forming sediment and gum, which can damage generators (FEMA 2019).

they can be grid-tied or off-grid, if connected to batteries, these systems can help provide an uninterrupted source of power to healthcare facilities during extreme weather events (Liu et al. 2021).

In October 2019, wildfires spread across California in the United States, causing power outages from the centralized grid for 14 healthcare facilities run by Kaiser Permanente, forcing them to either close or restrict patients. These facilities continued urgent care by using expensive and polluting diesel back-up generators. The healthcare provider then decided to introduce green micro-grids powered by solar energy and large-scale battery systems that provide a regular additional source of clean power for the facility and community but also a back-up power supply for use during grid power outages. Another example comes from Ontario, where they are installing a 2 MW solar system with a 9.5 MWh battery, using an USD 8 million grant from the California Energy Commission (Gibbons et al. 2022).

Off-grid standalone solar appliances that are designed to operate on lower-voltage direct current can ensure essential equipment will continue to be powered despite any disruption in grid-supplied electricity. A range of healthcare facility items can be powered directly by solar panels, including lighting, water pumps, refrigerators and freezers, water heaters and food cookers, providing both resilience and mitigation benefits. Some appliances include a battery system to allow a continued supply of power even during non-daylight hours: for example, SDD refrigerators use solar energy to directly freeze water to keep vaccines cool during the night and on cloudy days (WHO and UNICEF 2017). The figure below provides the estimated costs and quantifiable benefits of a healthcare facility switching from using domestic refrigerators to SDD refrigerators for vaccine storage.

FIGURE 8: Estimated costs and benefits of switching from conventional to SDD refrigerators for vaccine storage



Source: Authors' own, using data from Kenya, India and Barbados. See annex for data sources.

The table below provides some further details on the benefits of different decentralized clean energy sources, and which types of healthcare facilities would most benefit from them.

TABLE 6: Summary of types of benefits of, and suitable facilities for, decentralized clean energy sources

ENERGY SOURCE	SUITABLE FACILTIES	RESILIENCE BENEFITS	MITIGATION BENEFITS	OTHER BENEFITS
Grid-tied solar system	Facilities with reliable grid access and at low risk of weather events disrupting power supply. *Assumes supportive regulatory framework, such as feed-in tariffs.*	No direct benefits.	Increases proportion of clean energy in national power mix, reducing national GHG emissions.	Reduces energy cost for healthcare facilities.
Hybrid solar system with battery storage	Grid-connected facilities with unreliable grid supply of power, including because of weather events. *Assumes supportive regulatory framework, such as feed-in tariffs.*	Provides uninterrupted power even during prolonged grid outages.	Increases proportion of clean energy in the national power mix and avoids the need for fossil fuel-powered back-up generator and resulting GHG emissions.	Reduces energy cost for healthcare facilities, including by avoiding costly fuel for back-up generators.
Off-grid solar system with battery storage	Unelectrified facilities and/or grid-connected facilities with unreliable grid supply of power, including because of weather events.	Provides uninterrupted power even during prolonged grid outages in many conditions.	Avoids the need for fossil fuel-powered back-up generator and resulting GHG emissions.	Avoids costly fuel for extended use of back-up generators.
Micro-/mini-grids	Large facilities with multiple buildings and/or community health centres near to houses/other consumers.	Provides uninterrupted power even during prolonged grid outages.	Avoids the need for fossil fuel-powered back-up generator and resulting GHG emissions.	Reduces energy cost for healthcare facilities, including by avoiding costly fuel for back-up generators.

ENERGY SOURCE	SUITABLE FACILTIES	RESILIENCE BENEFITS	MITIGATION BENEFITS	OTHER BENEFITS
Off-grid standalone solar appliances	Unelectrified facilities and/or grid-connected facilities with unreliable grid supply of power, including as a result of weather events.	Provides uninterrupted power for critical equipment even during prolonged grid outages. Reduces pressure on primary energy supply.	Avoids the need for fossil fuel-powered back-up generator and resulting GHG emissions.	Reduces energy cost for healthcare facilities, including by avoiding costly fuel for back-up generators.

3.2.3. Resilience measures for on-site clean energy systems

A decentralized source of clean energy situated on the site of a healthcare facility is a resilience solution (see above) but it needs to be protected from the physical risk of climate and weather events. A thorough site assessment of the system is required to identify any risks it faces from climate and weather events and to identify suitable resilience solutions. Some measures that can increase the resilience of an on-site energy source, particularly solar, are set out in the following paragraphs.

Physical system improvements to safeguard decentralized assets. For example, careful selection of roofs or ground space to minimize exposure to weather or climate events (Fried et al.). Solar panels can be securely mounted using a racking system and the use of wooden covers to shield arrays from flying debris, to reduce the impacts of high winds. Lightning and electrical surge arrestors can protect against electrical damage during storms. In flood-prone areas, solar panels and batteries should be placed above historical flood water levels (WHO et al. 2023).

Careful placement of solar panels and choice of material can reduce the impacts of extreme heat on the efficiency of the panels. This includes selecting panels that are suited to the local weather conditions, such as thin-film panels in regions with high diffuse radiation, ensuring optimal orientation to maximize solar capture, and avoiding shading. To compensate for efficiency losses due to high temperatures, the PV array can be slightly oversized, which should be feasible given the decreasing costs of solar panels. Additionally, spacing or mounting panels to allow airflow and incorporating cooling mechanisms like fans, heat sinks, or water circulation systems can further enhance performance (Ghosh 2023). Selecting solar panels with anodized aluminium frames can help protect against extreme heat and corrosion.

Put in place energy storage capacity to ensure a continuity of supply. As described in the previous solution, batteries are a critical part of a decentralized clean energy system, as they make it possible to avoid the use of fossil fuel-powered generators as a back-up source of power. Batteries themselves can also be charged by solar panels during periods of surplus electricity production and used to power critical equipment when demand exceeds generation (WHO et al. 2023). Lithium-ion batteries are increasingly favoured due to their longer lifespan, higher efficiency, and superior performance in high-temperature environments compared to lead–acid batteries. Their ability to endure two to three times more charge/discharge cycles and deeper discharge before capacity loss makes them a sustainable choice for healthcare facilities (SEforALL 2024b).

Ensure ongoing monitoring and regular maintenance of solar systems to identify and address any weather or climate risks. Routine and preventive maintenance of solar systems can help sustain optimal performance, especially in the face of climate and weather events. Panels must be cleaned periodically, especially in dusty environments, and batteries – especially lead–acid types – require regular terminal cleaning, electrolyte level checks, and timely topping up with distilled water. Scheduled inspections of key components like inverters, charge controllers, air conditioners and wiring connections, can help identify faults early and avoid disruptions to critical power supply. There are also job and livelihood creation benefits from developing a local private sector ecosystem to provide such maintenance and repair services for solar systems (Stewart and Trace 2021).

The SELCO Foundation's Energy for Health Initiative in India is at the forefront of learning and practice on building resilience into decentralized solar systems. One of the key lessons from its pilot programme in 2020–21, which set up 2,000 solar systems (from 1 to 30 kilowatt-hour (kWh) capacity, with battery storage) across four states was the importance of designing the systems for extreme weather. As the Initiative reports, it learned the lessons the hard way. For example, despite working with local partners, it did not account for extreme lightning conditions in parts of Meghalaya state. As a result, almost half of the approximately 35 clean energy systems deployed there stopped working after a single lightning strike that caused the inverters to burn out. The Initiative then had to install lightning protectors on the inverters. Now it carefully integrates local weather and climate conditions into the design process: for example, systems in cyclone risk areas of Odisha are designed to withstand high winds, and in flood-prone areas of lower Assam state batteries are elevated (Jaffer 2023).

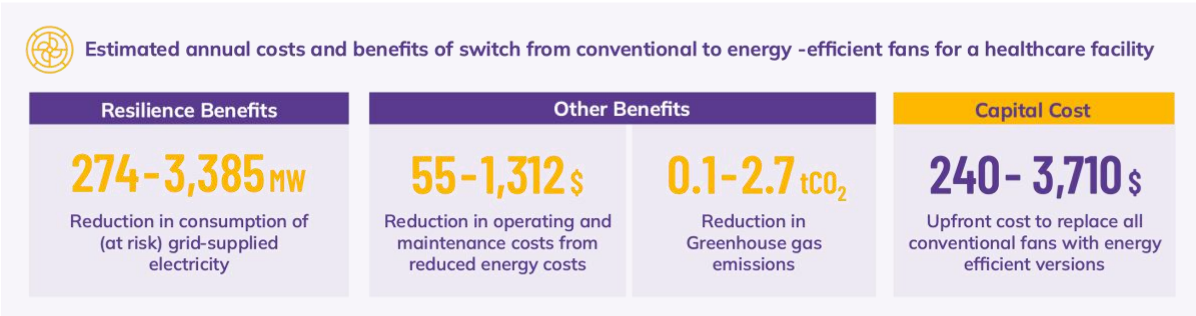
3.2.4 Energy efficient buildings, appliances and transportation

Healthcare facilities can reduce their consumption of energy by adopting energy efficient technologies and practices. This reduces pressure on the primary source of energy and therefore helps mitigate the increased demand for energy to power climate-related emergency services and indoor cooling/heating needs of facilities. Energy efficient measures do not obviously address the risk of a disruption to the power supply, and energy efficient appliances will not work in such instances. Energy efficiency also brings climate mitigation benefits, since electricity, heating and water consumption are the major sources of facilities' carbon footprint (Pichler et al. 2019). Some of the energy efficient measures that are most relevant for public healthcare facilities are set out in the following paragraphs.

Energy efficient appliances to reduce energy consumption: Highly efficient versions of appliances providing basic services, such as lights, fans, fridges, air conditioners and water heaters, are readily available in some countries in the Global South (Hendron et al. 2013; Zaza et al. 2022). For example, energy efficient LEDs consume less than a third of the energy consumed by fluorescents and seven times less than incandescent bulbs (National Centre for Disease Control (NCDC), Government of India (GoI) 2023a) and last four to five times longer than compact fluorescent lamps. Efficient heating, ventilation and air conditioning systems that include energy recovery devices can save energy and improve air quality (Delgado et al. 2021). For example, the most efficient 1.5 tonne split air conditioner consumes 1,172 watts, as compared to 1,702 for the least efficient version, representing 847 kWh of annual savings (assuming 1,600 hours of usage) (Singh and Phore 2020). The Government of India has published guidelines for public healthcare facilities on how the maximum load for their energy system can be reduced by installing a range of energy efficient appliances: for example, a public health centre's maximum load can be reduced from 7,870 to 4,620 watts (NCDC, GoI 2023b). There are also efficient versions of non-electric appliances, such as biomass cooking stoves, which can reduce fuel consumption (but they do not address the problem of indoor air pollution created by such stoves) (Bensch et al. 2024).

There is less availability of efficient versions of medical devices, such as X-ray machines, baby warmers and CT scanners. For example, a single autoclave consumes from 11 kWh/day when the unit sits idle to 222 kWh/ day during high usage periods (Priorclave 2025). Innovation that reduces the consumption of these devices could reduce energy consumption in facilities by an estimated 60–90 percent (Jaffer 2023).

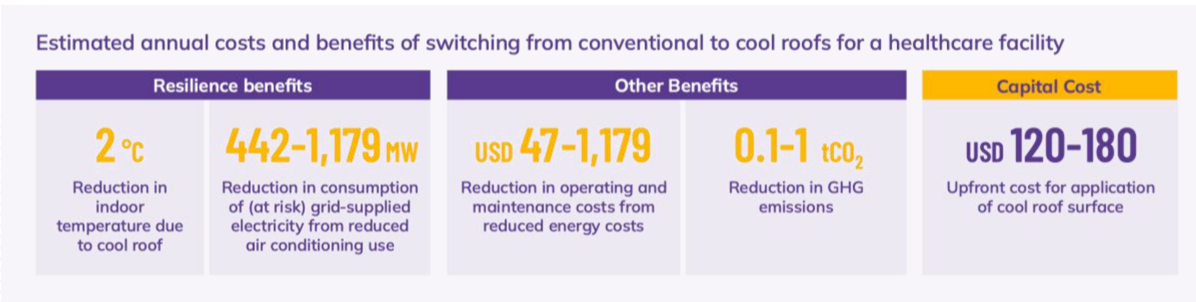
FIGURE 9: Estimated costs and benefits of switching from conventional to energy efficient fans



Source: Authors' own, using data from Kenya, India and Barbados. See annex for data sources.

Green building design to regulate indoor temperature and reduce the need for heating/cooling services: A green building can incorporate a range of design, construction and maintenance measures to reduce the environmental footprint of the healthcare facility, such as rainwater harvesting systems, the use of recycled construction materials as well as clean energy sources, and energy efficient appliances, as described in previous resilience solutions (Golbazi and Aktas 2020). Some passive cooling design features specifically reduce the need for energy-intensive heating and cooling services, such as incorporating natural ventilation into the design of the facility, which also provides better air quality and saves energy and costs as compared to air conditioners (Qian and Yang 2016). Adding insulation, replacing inefficient windows and using blinds also help to regulate temperature. Cool or white roofs, which are painted white using simple white lime or a special reflective coating, also reduce the solar radiation absorbed by buildings and reduce indoor temperature by 2–5° degrees Celsius (BBC News 2019).

FIGURE 10: Estimated costs and benefits of retrofitting roofs with cool roof surface



Source: Authors' own, based on data from Kenya, India and Barbados. See annex for data sources.

Electric vehicles to reduce energy consumption linked to transporting patients. While the primary benefit of electric ambulances is to reduce GHG emissions and air pollution from petrol/diesel conventional vehicles, they also consume less energy, making them an energy efficient (and cost saving) option for facilities. Although their in-built batteries can allow them to manage short disruptions to the power supply, they should ideally be powered by an on-site solar system to make them resilient to extreme weather events (Clean Mobility Shift 2024).

Monitoring the energy consumption of healthcare facilities to identify and encourage energy saving technologies and behaviours. Better information on how much energy facilities are consuming, and for what, can help facility managers to manage the demand and supply of energy. Energy audits identify potential inefficiencies and cost savings, and energy monitoring systems help facilities to monitor consumption patterns (Prada et al. 2020). A remote energy monitoring system uses on-site sensors and other technology to provide real-time performance data on energy generation, consumption and storage through a smartphone or laptop. This continuous data flow can help prioritize resources and guide timely maintenance interventions, although it relies on facilities being able to transmit data through telecommunications (USAID 2022). For larger facilities, motion sensors may be possible to optimize lighting and air conditioner usage based on occupancy (Zaza, Sepetis and Bagos, 2022). Encouraging and enforcing energy efficient human behaviours, such as switching off lights when leaving a room and regulating the temperature settings of air conditioners, can also make a significant difference to energy consumption.

Green hospital design in Vistex Hospital, Bihar, India. The rural healthcare facility Vistex Hospital is an example of a climate-smart healthcare facility that is powered by renewable energy. Frequent power outages in the area posed significant obstacles to reliable healthcare delivery. The hospital therefore installed on-site solar energy generation, energy efficient equipment, and climate-smart architectural designs. These measures have resulted in a 58 percent reduction in energy consumption and operational costs, saving the hospital approximately USD 10,000 annually. The top-floor walls of the facility were constructed using panels made from agricultural waste, "rice straw", to increase the insultation of the building (GGHH 2022).

3.2.5 Health facility energy planning

Regular screening of risks to healthcare facility energy infrastructure and taking proactive measures to minimize risks and prepare for any disruption to the power supply can reduce the impact of a weather or climate event. Some of the planning measures that facilities can adopt are set out in the following paragraphs.

Risk screening of healthcare facility energy infrastructure to identify and address potential risks from climate and weather events. At a minimum, this involves checking health facility buildings and appliances are meeting national standards for disaster protection. This should include checking the readiness of back-up systems and ensuring their components, such as batteries and interconnecting cables, are routinely maintained to prevent failure during critical times. In addition, it should include regular checks of energy infrastructure to identify any potential risks from extreme weather events: for example, whether a battery is stored above flood water and whether a solar system can withstand strong winds. Placing thermometers in refrigerators and freezers will allow the safety of vaccines, food and medical supplies to be checked during outages.

Accurate assessment of the energy needs of the facility during normal and emergency periods. Regular monitoring not only ensures the functionality of energy systems but also helps identify and address potential issues before they escalate, thereby securing uninterrupted healthcare delivery. This includes an accurate assessment of the current and projected future energy needs of the facility, during normal times and emergency situations. Critical loads, such as baby warmers, oxygen concentrators, and refrigerators, must be prioritized for reliability. Non-critical loads, such as fans, mobile charging points, and printers, should not disrupt the functionality of critical systems. Tools to help facilities assess their energy needs include the Global Electrification Platform and Energy Access Explorer, which combine facility-level information with satellite imagery, demographic data, and power infrastructure details to generate demand estimates (World Bank 2024a; WRI 2024). The hospital electrical wiring should be designed to connect critical loads to dedicated circuits connected to an emergency power supply. Energy management control systems can be applied at varying levels to optimize load distribution through rewiring or zoning for critical loads, minimize excessive demand peaks, and enhance operational efficiency by shutting down non-critical loads to optimize back-up power usage (ICF International 2009).

Emergency protocols to quickly respond to sudden surges in energy needs and/or disruption to energy supply during extreme weather events. There should be clear guidelines for the facility that are accessible and well understood by all staff to ensure safety and the delivery of critical health services. Key safety measures include ensuring a qualified electrician has inspected and confirmed the integrity of the electrical system before restoring power and using electrical equipment that has been exposed to floods or other damage; exercising extreme caution when working near overhead power lines or in areas obscured by thick smoke; and not entering flooded areas or handling electrical equipment on wet ground while the power remains on. Regular training and drills on emergency energy protocols will ensure that all personnel are prepared to respond effectively during crises, safeguarding both patient care and the energy systems that sustain it.

The facility-level emergency plan should ideally be part of a wider government disaster management preparedness plan. This should guide facilities on how to manage a disruption in energy supply and/or surge in demand, and the role of power utilities in prioritizing the restoration of grid-connected power to health facilities.

The table below maps the solutions set out above in terms of the resilience benefits they provide.

TABLE 7: Mapping of resilience measures to type of resilience benefits they can provide

MEASURE	READI-NESS	ROBUST-NESS	RESOURCEFUL-NESS	RECOVERY
Resilience measures for grid-supplied electricity				
Physical system improvements to safeguard grid-connected assets.	✓	✓		
Strengthening transmission and distribution networks to reduce physical damage.	✓	✓		

Advanced technologies to minimize the impact when the power grid is damaged.			✓	✓
Decentralized clean energy sources				
On-site solar system, mini-/micro-grid and/or off-grid solar appliances as back-up source.			✓	
Resilience measures for on-site energy systems				
Physical system improvements to safeguard decentralized assets.	✓	✓		
Ongoing monitoring and maintenance of solar system.	✓	✓		
Energy storage capacity to ensure a continuity of supply.			✓	
Energy efficient appliances and green buildings				
Energy efficient appliances, buildings and transportation.		✓		
Monitoring energy consumption.		✓		
Health facility energy planning and operations				
Risk screening of energy infrastructure.	✓			
Assessment of energy needs of facility.		✓		
Emergency protocols to respond to impacts on energy.				✓

CHAPTER FOUR

Climate resilient pathways for healthcare facility energy infrastructure

4.1 Current level of resilience of healthcare facility energy infrastructure

The current level of adoption of resilience solutions for healthcare facility energy infrastructure appears to be limited, although there is very little global evidence on uptake of such resilience measures. There is a scarcity of climate vulnerability assessments published at the health facility level, and none are specifically focused on energy infrastructure (Schwerdtle et al. 2024). Even for the most researched resilience solutions, such as on-site solar systems, there is no comprehensive survey of uptake by healthcare facilities. To fill this gap, this section estimates the level of uptake in the three focus countries based primarily on expert consultations.

In Kenya, India and Barbados, no resilience solution appears to be in place for the majority of public healthcare facilities that face climate risks, and the vast majority of these solutions have been implemented in only an ad-hoc and limited way. The table below gives a snapshot of the estimated coverage for the five types of resilience measures, although the description that follows of the situation for each country shows that uptake varies considerably for different specific solutions and for different levels of facility.

TABLE 6: Estimated coverage of resilience solutions in Kenya, India and Barbados

RESILIENCE SOLUTION TYPE	HIGH COVERAGE	MEDIUM COVERAGE	LOW COVERAGE	VERY LOW COVERAGE
Resilience measures for grid-supplied electricity				
Decentralized clean energy sources				
Resilience measures for on-site energy systems				
Energy efficient buildings, appliances and transportation				
Health facility energy planning and operations				

 **Trends in the uptake of relevant resilience solutions for public healthcare facilities in Kenya:**

Resilience measures for grid-supplied electricity: There are efforts to manage the impacts of floods and droughts on hydropower plants: for example, the rehabilitation using trees and plants of the Mathioya river to reduce siltation in hydropower plants (Waithera 2023). There is also a programme underway to integrate smart grid technology and 400 MW of battery storage to increase the resilience of grid-supplied electricity (World Bank 2023). However, these and other initiatives are yet to be fully rolled out.

Decentralized clean energy sources. An estimated 12 percent of public and private healthcare facilities are powered by on-site solar systems, although experts indicate that the proportion for public facilities (and particularly Level 4 facilities and under) is likely far smaller and concentrated in certain counties (e.g. Turkana and Marsabit) (CEMA, no date). Makueni County Referral Hospital is a public facility that has installed 200 kWp of solar power to meet 30–33 percent of its electricity needs to save costs (USD 55,000 annually) and to bring stability given the frequent grid outages (Ireri et al. 2024). There are very few PV-based mini-grids powering healthcare facilities. Experts estimate that 40–50 percent of public healthcare facilities use diesel-powered generator as a back-up source of power, and critical equipment such as incubators and X-ray machines have their own substantial battery systems.

Resilience measures for on-site energy systems: While larger hospitals with solar PV systems are likely to design and maintain their systems to minimize the risk of flooding and extreme heat, this is less likely to be the case in smaller facilities. The proportion of on-site energy systems with battery storage capacity is not known, but of those with batteries, approximately half in bigger facilities are likely to have a cooling device, while very few in smaller facilities are likely to have one. Only a small proportion of the solar PV systems are fitted with a lightning conductor. Most facilities carry out routine cleaning of the solar panels.

Energy efficient buildings, appliances and transportation: Energy efficient practices and technologies are not yet mainstream in public healthcare facilities, especially at the primary and secondary care levels. The most common energy efficient appliance is LED bulbs (used by an estimated 40 percent of all facilities), but in general energy consumption is not being monitored or managed. Ambulances are petrol- or diesel-powered and there is no known electric ambulance in the country. In general, healthcare facilities are built using the same set of materials, whether in hot, dry, humid or tropical climates, although experts pointed to some examples of using passive environmental design in new facilities, with openable windows, adequate natural lighting, and cross ventilation to reduce the need for electricity.

Health facility energy planning and operations: There is no standard guidance or set of standard operating procedures to guide healthcare facilities on preparing for and managing the impacts of climate and weather events on their energy infrastructure. There are only examples of individual facilities that have taken the initiative to plan and prepare: for example, balancing energy loads between critical care areas (that require a back-up source of power) and those that do not. There are some counties, like Wajir, where certain facilities get hit by floods every year and the government and development partners finance the reconstruction every year.

Trends in the uptake of relevant resilience solutions for public healthcare facilities in India:

Resilience measures for grid-supplied electricity: There are significant investments underway to upgrade India's grid to provide reliable electricity to all households and to integrate a large amount of variable renewable energy power. This includes regular changes (e.g. bringing energy storage into the ancillary services market), technological advances (e.g. rolling out smart meters) and infrastructure strengthening (e.g. underground cabling). These efforts to build flexibility and reliability into the grid are also bringing resilience, but there are still a large number of additional solutions that are needed to address climate risks: for example, grid hardening of distribution lines, which continue to face poor construction standards (RMI India and Stranger 2021).

Decentralized clean energy sources: An estimated 11 percent of public healthcare facilities have an on-site solar system, with a very small number using this as the primary source of electricity. From a sample of 341 hospitals across the country, only 2 percent of energy consumed was from on-site solar systems, and over half of the systems were grid-tied without battery storage (NCDC, GoI 2023c). Experts report that installation of solar energy is on the rise, with India having the highest number of facilities being electrified (25,663) under initiatives led and/or funded by development partners (SEforALL 2024a). However, the vast majority of the estimated 64 percent of public healthcare facilities with a functional back-up source of electricity are still using diesel-powered generators (Mani et al. 2019; NCDC, GoI 2023c). The penetration of off-grid solar appliances remains limited (e.g. approximately 1 percent of public healthcare facilities are using solar water heaters), although SDD refrigerators have received a push from the government, the United Nations Children's Fund (UNICEF) and others due to the cooling requirements for Covid-19 vaccines. However, of the 40 percent of primary health centres with cold chain equipment, very few (~1 percent) are using SDD technology (Ramji et al. 2017; NCDC, GoI 2023c).

Resilience measures for on-site energy systems: It is estimated that in the majority of public healthcare facilities with solar panels, these systems – particularly in larger facilities and those installed by the government – are grid-tied and therefore do not operate as a back-up source in case of grid failure. On-site solar systems at off-grid facilities and/or those installed by development partners typically include a battery system. Larger, district-level public healthcare facilities generally have batteries and invertors to power critical equipment for temporary outages (estimated ~2 percent of the total). Studies and experts report gaps in the maintenance of solar systems, with broken components visible, which reduces the amount of power generated (NCDC, GoI 2023c).

Energy efficient buildings, appliances and transportation: There is a large diversity in the energy efficiency performance of public healthcare facilities, even between those of the same level and type. A study of the energy consumption patterns of 341 hospitals across the country showed a mixed picture (NCDC, GoI 2023c). The use of LED lighting is relatively widespread in public healthcare facilities, with 30 percent having a high penetration, 53 percent a medium penetration and 17 percent a low penetration. The use of indoor technology is limited to larger public healthcare facilities (approximately 0 percent of sub-centres, 36 percent of primary health centres and 95 percent of district hospitals have some form of HVAC). For those public healthcare facilities using air conditioners, approximately half are using energy efficient versions (with star rating above 3).

Experts reported that while penetration is still very limited, energy efficient specialist medical equipment, such as diagnostic tools and LED-based medical imaging equipment, are available in some larger facilities. New facilities are being constructed with green building features, including cool roofs and natural ventilation for those in hot climates. The approximately 30,000 ambulances operating in India currently run on petrol, diesel or compressed natural gas, but through a new government scheme, a relatively small number will soon be electric vehicles (Clean Mobility Shift 2024).

Health facility energy planning and operations: District disaster management plans and protocols for healthcare facilities are relatively well defined and include standard operating procedures related to the need for back-up sources of power that are protected from flooding or other weather events. However, experts reported that the implementation and enforcement of the rules and guidance is not uniform across the country. For example, even one of India's largest and most famous hospitals in New Delhi, the All-India Institute of Medical Sciences, had to suspend operations on 29 July 2024 when flood water entered the basement where most of the electrical installations supplying power to the operating theatres were stored (Hindustan Times 2024).

Clean energy and energy efficient measures in a large government hospital have saved energy and costs. King George's Medical University (KGMU), a 4,000-bed tertiary care public hospital in Lucknow, India, has invested in a 400 kW solar power plant that saves around 32 Lakhs rupees per year in the hospital's electricity bill. At the same time, energy efficiency measures have reduced consumption. This includes an Automatic Power Factor Control Panel, an electric device installed with the solar system that reduces consumption by 35–40 percent, replacing sodium lights with LED lights, and installing 30 solar parabolas to cook food for 3,000 patients. A team of electrical engineers has been deployed to maintain and coordinate the efficient functioning of solar power plants and solar parabolas (KGMU 2019).

Trends in the uptake of relevant resilience solutions for public healthcare facilities in Barbados:

Resilience measures for grid-supplied electricity: It is highly likely that an extreme weather event, particularly a tropical storm, would disrupt the supply of electricity to facilities from the grid. Most of the distribution network is overland, due to the country's rocky terrain, making it difficult to lay cables underground. However, a few of the major hospitals in the country are located in the priority zone, which has an underground distribution network and a back-up system of substations. Healthcare facilities in this priority zone are also given priority by the national power company for the restoration of power. The national dependence on imported fuel for electricity remains a key risk, although there is an ambitious plan to become fully energy independent by 2030, powered by 100 percent renewable energy, and to add energy storage capacity to the grid (MoEB, GoB 2024; MoE&WR, GoB 2024).

Decentralized clean energy sources: Most of the country's 15 public and private healthcare facilities rely on grid-connected electricity, with only a few having grid-tied solar panels, but without battery storage capacity. All therefore rely on diesel-powered generators. There is no evidence of off-grid solar appliances in use In any healthcare facility in Barbados.

Resilience measures for on-site energy systems: Given the very few health facilities in Barbados with on-site solar systems, there is little evidence about the climate risks facing these systems. The experience of the Queen Elizabeth Hospital (see below) indicates that understanding on how to maintain solar panels is still at the early stages.

Energy efficient buildings, appliances and transportation: The government has commissioned energy audits of healthcare facilities, which has prompted the adoption of energy efficient appliances and practices by some facilities. For example, it has been reported that the Queen Elizabeth Hospital is changing 97 percent of its air conditioning units to a more efficient unit, and all lighting will gradually be replaced with LED bulbs. It has also installed some variable frequency drives on some motors for automatic turn-off, switched to natural gas for water heaters, and introduced a "turn off the light" behavioural campaign. All ambulances in the country are petrol or diesel, with no electric vehicle ambulance in operation.

Health facility energy planning and operations: Barbados' Comprehensive Disaster Management Plan and disaster emergency management protocols set out the roles and responsibilities of agencies in regard to ensuring the delivery of critical public health services. However, given the small size of the country, experts suggest that facilities directly liaise with the national power company to inform them of disruptions to supply and the need for restored power.

Queen Elizabeth Hospital in Barbados benefits from a priority supply of grid-connected electricity. As the country's primary acute medical facility and teaching hospital, it is part of the national capital's priority zone for electricity supplied by the power company. This means that it is served by underground distribution cables and any lost connection is restored on a priority basis. Despite this, the hospital still faces blackouts from the increasingly intense hurricanes, reverting to using three 1.4 megavolt-amperes generators in such cases. Initially, the hospital only powered critical care with this back-up source, but as power disruptions became more frequent it invested in a storage tank that can store enough diesel to power the hospital for two weeks.

Grid-tied solar panels were installed by the government (with no batteries) but have not been used due to the lack of a dedicated transformer and the need to completely turn off the hospital's power to connect the panels to the existing electrical control system. The hospital was also concerned about potential leaks from drilling holes to secure panels and would prefer panels to be installed on the car park, although this structure might not be strong enough.

4.2. Barriers to adoption of resilience solutions by public healthcare facilities

Each country faces a specific set of barriers to the widespread application of each of the resilience solutions. However, some of the most significant challenges, and those most frequently cited by experts consulted, include the following:

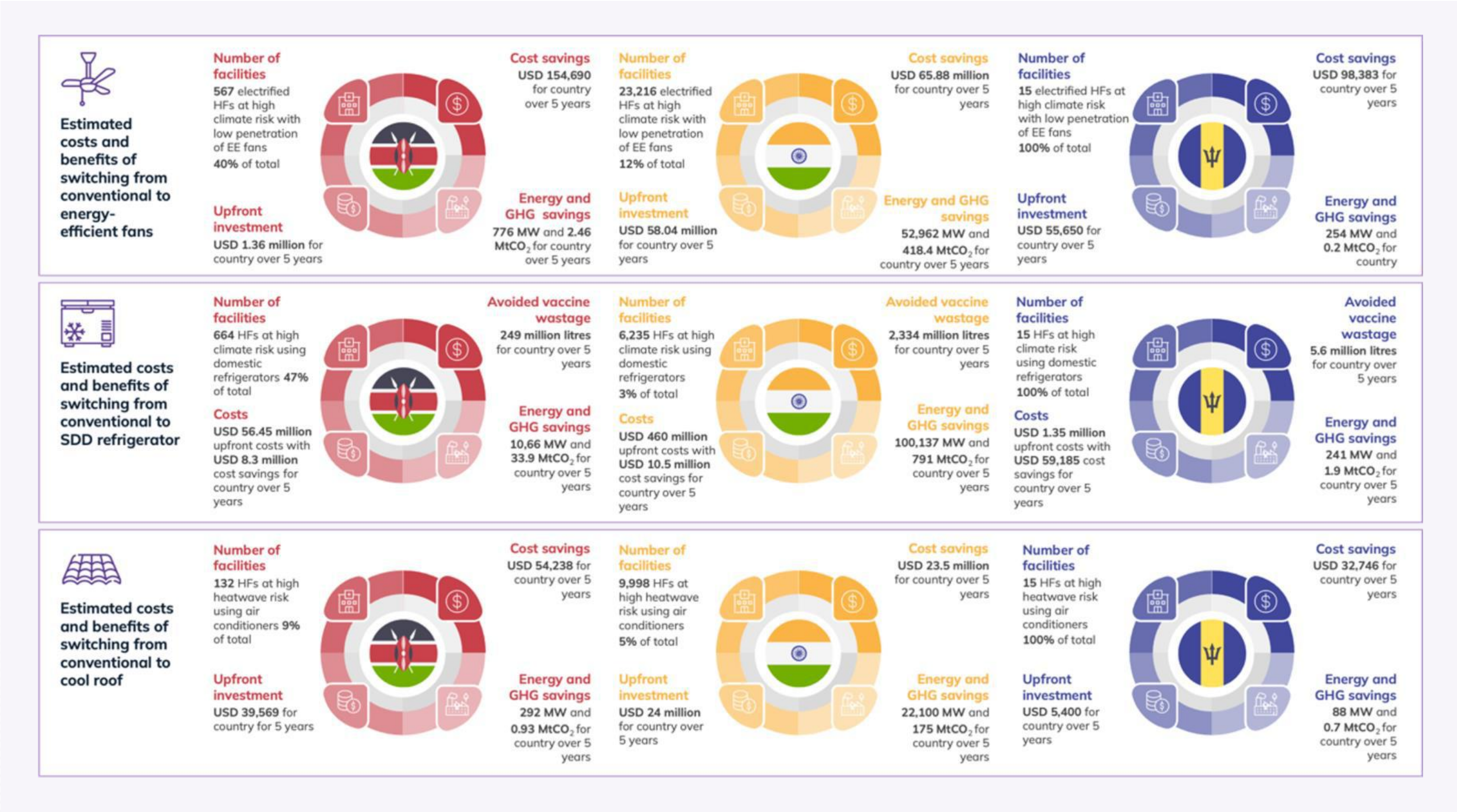
Access to finance for upfront capital and operating and maintenance costs. For some resilience solutions, particularly those that provide energy cost savings, there is well-documented evidence on the return on investment. For example, replacing a petrol/diesel back-up generator with a 2–5 kWp solar system can provide financial returns of 5–11 percent over the 25-year lifespan of the system (SEforALL and OPM 2023; UNICEF 2023). However, the scale of the financing required across an entire country is high. In India, it would require an estimated USD 1.4–2.6 billion to install solar systems in 152,101 energy-deficient healthcare facilities (SEforALL and OPM 2023; UNICEF 2023). In Turkana County in Kenya, UNICEF has calculated that USD 19.3 million is required to install 10.3 MWp of solar power with 25.9 MWp of battery capacity and invertors in 872 public healthcare and education facilities. The figure below provides some additional estimated costs and benefits for three sample resilience solutions for Kenya, India and Barbados (see TABLE 11 in the annex for the full breakdown of costs and benefits).

For other resilience solutions that do not have a direct or significant impact on energy costs (e.g. physical enhancements to grid and on-site electricity infrastructure to protect from extreme weather events) the return on investment is harder to demonstrate. For example, the Kenya Energy Transition and Investment Plan requires around USD 600 billion in capital for investments required in power and transport sectors (MoE&P, GoK 2024). For some of the resilience solutions, such as battery storage, the operating and maintenance costs are an even bigger constraint than the initial capital costs.

Public healthcare facilities have limited access to finance for proactively installing facility-level resilience solutions and typically rely on top-down government or development partner-led programmes. In India, there are government subsidies available for installing solar panels, but a long chain of actors, from the primary health centre to the state government, need to be involved to make this happen. Across the Global South, public healthcare facilities have very limited flexible annual budgets to spend on their infrastructure, and replacing batteries or broken solar panels is rarely budgeted for (Concessao et al. 2023). Fossil fuel subsidies and other policies also reduce the financial incentive for governments and healthcare facilities in many countries to invest in clean energy (IMF 2023).

The costs and benefits of the different resilience solutions, and their return on investment, needs to be further developed to make a strong economic and finance case for them. This should include the fact that in many countries there are a significant number of unelectrified healthcare facilities, and facilities that still need to be built, and therefore potential savings can be made by leap frogging to the most advanced, sustainable and resilient technologies, designs and practices.

FIGURE 11: Investment case for three sample resilience solutions in Kenya, India and Barbados



Source: Authors' own. See annex for a table with the data and data sources presented.

Limited facility-level management capacity: Given that each facility faces a unique set of climate risks and has its own specific set of energy needs, ideally, each facility would undertake a risk assessment for its energy infrastructure and identify the specific resilience solutions it requires. However, beyond a small number of large public healthcare facilities in each country, few have the human resource capacity to do this. Beyond a general awareness of the potential of solar energy to reduce energy costs, there is limited understanding of the benefits of other resilience solutions, and very little technical knowledge on how to install or implement them.

The impacts of climate and weather events are often considered to be something a facility has to manage and recover from (often every year), rather than something that can be reduced. There is in general limited awareness of risk prevention measures, and proactive measures that can reduce the likelihood that energy supply will be disrupted.

A lack of focus on climate risk and resilience in healthcare facility infrastructure programmes. The governments and implementing partners that are currently involved in rolling out large-scale electrification efforts at healthcare facilities in the Global South report having learned during the implementation process of the importance of considering site-specific weather conditions and long-term climate risks. However, this learning has not yet been embedded in the design of ongoing and new programmes. There is limited guidance and requirements regarding how to incorporate current and projected future climate and weather events into the technical specifications of systems.

Adequacy of, and/or enforcement gaps for, infrastructure standards. The extent to which resilience solutions are being promoted or required under healthcare facility building laws and guidance differs across the Global South. In Kenya, a new national building code should increase green building principles (e.g. it mandates solar water heaters) in the construction of new facilities going forward, while India has an Energy Conservation Building Code, disaster management building standards and Guidelines for Green and Climate Resilient Healthcare Facilities. In India, experts consider that the standards are sufficient, but implementation is limited, and enforcement is lacking, partly because different agencies are responsible for different standards.

Technical limits to retrofitting facilities. There are practical challenges to installing the resilience solutions in some existing facilities. For example, in Barbados it was reported that facilities lack sufficient space for a PV array while in older facilities in India it is a challenge for staff to access the roofs to clean and maintain the panels. Installing a solar system can require facilities to completely turn off their electric system, which is not feasible for those with 24/7 critical care services. It is also difficult to retrofit buildings with natural ventilation and other green building design features.

4.3 Opportunities for building the resilience of healthcare energy infrastructure

The stakeholders who are able to implement, finance and/or enable the adoption of resilience solutions vary according to the specific solution. As the table below shows, most solutions, apart from those related to building the resilience of grid-supplied electricity, can be directly adopted by public healthcare facilities and/or private sector companies on their behalf. However, the source of financing will come from the national government and/or development partners, including development finance institutions, philanthropic organizations etc. Across all solutions, national and sub-national government agencies for energy, health and/or disaster management play a crucial enabling role, such as by setting supportive guidelines and regulations and building the awareness and capacity of healthcare facilities.

TABLE 7: Stakeholder mapping for the five types of resilience solutions

RESILIENCE SOLUTION TYPE	IMPLEMENTING ACTOR(S)	FINANCING ACTOR(S)	ENABLING ACTOR(S)	IMPLEMENTING ACTOR(S)
Resilience measures for grid-supplied electricity	Public and private power sector companies	Power companies, ministry of energy, development partner	Ministry of energy	Public and private power sector companies
Decentralized clean energy sources	Public healthcare facility, energy service company	Ministry of energy, ministry of health, development partner, energy service company	Ministry of energy, ministry of health	Public healthcare facility, energy service company
Resilience measures for on-site energy systems	Public healthcare facility, energy service company	Ministry of energy, ministry of health, development partner, energy service company	Ministry of energy, ministry of health	Public healthcare facility, energy service company
Energy efficient buildings, appliances and transportation	Public healthcare facility, construction company	Ministry of health, development partner	Ministry of energy, ministry of health, ministry of public works	Public healthcare facility, construction company
Health facility energy planning and operations	Public healthcare facility, sub-national governments	Ministry of energy, ministry of health, development partner	Disaster management agency	Public healthcare facility, sub-national governments

A supportive enabling environment for ensuring the climate resilience of healthcare facility energy infrastructure requires coherence and focus across energy, health and disaster management policies and regulations. The extent to which the responsible national and sub-national agencies have brought policy attention to this issue differs across Kenya, India and Barbados.

In Kenya, the climate resilience of healthcare facility infrastructure has not been a policy priority to date, although the new Climate Change and Health Strategy (2024–29) might change this (Ouma 2024). Ongoing initiatives by the Ministry of Health include a USD 215 million Building Resilient and Responsive Health Systems project, although this does not include financing for healthcare facility energy infrastructure (World Bank 2023a). Healthcare facilities are under the jurisdiction of county governments, and given the lack of an umbrella policy framework some counties have shown more proactive and advanced adoption of resilience solutions than others. For example, Marsabit County has made significant investments in the energy system for the Level

4 Marsabit County Referral Hospital, comprising a hybrid system of solar (and alternatives like wind energy) and a separate grid connection.

Kenya's energy policy framework has in general focused on grid expansion to meet the national target for universal energy access, although the Kenya Rural Electrification and Renewable Energy Corporation is implementing a project to achieve electrification of all public facilities, including in the health sector, either by the grid or by installing solar systems. The national Energy Efficiency and Conservation Strategy and Implementation Plan 2022 calls for new energy building codes, retrofitting public hospitals with LED bulbs, and a national cooling action plan (MoE, GoK 2022).

There is a lack of clarity within national policies and institutions on the roles and responsibilities of national and county-level agencies in national disaster management in the health sector (Maarifa Centre 2022).

TABLE 8: Key stakeholders in Kenya for resilient healthcare energy infrastructure

NATIONAL GOVERNMENT	OTHER GOVERNMENTS	DEVELOPMENT PARTNERS	COMPANIES	NON-PROFITS
Rural Electrification and Renewable Energy Corporation; Energy and Petroleum Regulatory Authority; Ministry of Energy; National Disaster Management Unit; National Drought Management Authority; National Disaster Operations Centre; State Department for Public Works	County governments	World Bank (Kenya off-grid Solar Project); United States Agency for International Development (USAID) (Power Africa programme); UNICEF (solar refrigerators); UNOPS	Solibrium, Voltmatic Energy Solutions, CP Solar	Mercy Corps (Energy4Impact), Red Cross, World Resources Institute (WRI), Kenya Green Building Society

In India, there are multiple policies, plans and guidelines promoting one or more resilience solution for healthcare facility energy infrastructure, but these are fragmented, spread across multiple national and sub-national agencies, and not complete (Chatterjee et al. 2024)**.** Public healthcare facilities need to adhere to the Indian Public Health Standards, which in 2022 were revised to include guidelines that promote many resilience solutions, including on-site solar systems with battery back-up, energy efficient appliances and cool roofs (NHM 2024). As part of the National Programme on Climate Change and Human Health, the NCDC is promoting green and climate resilient health facilities through tools such as guidelines, checklists, standard operating procedures and assessment frameworks. The guidelines feature many of the resilience solutions a facility can adopt itself, although with some gaps, such as on the importance of energy storage and how to protect batteries from weather events (NCDC, GoI 2023a). Under this programme, districts are formulating district action plans for climate change and human health, which should include a focus on facility infrastructure.

There is a separate set of guidelines and policies focused on disaster management for healthcare facilities – for example, guidelines and training on safe hospitals – but these do not address energy infrastructure risks (NDMA 2016; GHS 2022). State governments have prepared disaster management plans, with some (e.g. Kerala and Assam) having emergency preparedness plans for hospitals, and all districts should have district disaster management plans in place (Chatterjee et al. 2024). However, in a study of 36 districts in Maharashtra, 19 of the district disaster management plans did not list norms for structural compliance of their healthcare facilities (Chatterjee et al. 2024).

The Government of India has been very focused on achieving universal energy access of households through expansion of the grid, although the supply of decentralized sources of energy is now receiving more policy attention. Most progress in installing solar energy in public health facilities has come from partnerships and funding between state governments (e.g. Chhattisgarh, Meghalaya and Nagaland) and not-for-profit organizations and development partners (e.g. SELCO, World Bank, international foundations). The Ministry of New and Renewable Energy (MNRE) has a target and programme for decentralized solar, but this focuses on household and community lighting, agriculture pumps and powering government offices (MNRE, GoI 2024). India also has advanced policy measures on energy efficiency, including mandatory and voluntary appliance labelling schemes, energy conservation building codes (which apply to healthcare facilities) and bulk procurement of LED bulbs (MoP, GoI 2024). However, the actual uptake and enforcement of these energy efficient guidelines and norms by public healthcare facilities is relatively limited (NCDC, GoI 2023c).

TABLE 9: Key stakeholders in India for resilient healthcare energy infrastructure

NATIONAL GOVERNMENT	OTHER GOVERNMENT	DEVELOPMENT PARTNERS	COMPANIES	NON-PROFITS
NCDC (Ministry of Health and Family Welfare), National Institute of Disaster Management, MNRE, Bureau of Energy Efficiency	State governments, District Disaster Management Committees	UNICEF, World Bank (Nagaland Health Project), CDRI, SEforALL, IKEA	SMC, Elpro, Development Environergy, Smart Joules, First ESCO India	WRI, Alliance for an Energy Efficient Economy, SELCO Foundation

In Barbados, more attention should be paid to the resilience of healthcare facilities in general, and their energy supply specifically. The Barbados National Electricity Plan has a target of ensuring a more resilient supply of grid-connected electricity, with 100 percent renewable energy by 2030, with the Implementation Plan setting out required actions to deploy solar energy and promote energy efficiency, although it contains nothing specifically on public infrastructure (Harewood 2024). A new Electricity Supply Bill to regulate the sector is currently being developed (Moore 2024). There are limited policy measures promoting energy efficiency, although there are specific standards for efficient lighting and the import of inefficient bulbs is prohibited (CCREEE 2022). There are reported to be National Standards for Energy Efficiency in Buildings, although these are not available online (Burca 2023).

The government has mainstreamed resilient and low-carbon principles within its overarching National Strategic Plan (2005–25) and the 2021 Updated Physical Development Plan for Barbados. The 2012 National Climate Change Policy Framework sets the government's broad approach to tackling climate change, while the 2021 Nationally Determined Contribution sets specific targets, including tackling the human health impacts of climate change.

The national Comprehensive Disaster Management Policy, which is currently being updated, expects a health sector disaster plan to be prepared, but this has not been published (MoHA&I 2022). The government's Roofs to Reefs programme is reported to be a national effort to protect homes and critical infrastructure from climate and weather events, although no detailed information on the scheme is available (UNEP 2024).

TABLE 10: Key stakeholders in Barbados for resilient healthcare energy infrastructure

NATIONAL GOVERNMENT	OTHER GOVERNMENT	DEVELOPMENT PARTNERS	COMPANIES	NON-PROFITS
Ministry of Health and Wellness; Ministry of Energy and Business Development; Barbados Light and Power Company Ltd; Ministry of Transport, Works and Water Resources.	Constituency Councils	Inter-American Development Bank	ECRL, Williams Solar, Prosolar 246	Barbados Renewable Energy Association

There are global efforts to electrify and/or build the resilience of healthcare facilities to the impacts of climate change that can be tapped into at the national level. The WHO has been championing climate resilient health systems for over a decade, while bringing clean energy to healthcare facilities is a key part of the Sustainable Development Goal for energy (SDG 7) and was a key factor in SEforALL's inception in 2011. Global funders are increasingly matching this commitment with funding: for example, 41 funders and international partners have signed up to a set of Guiding Principles for Financing Climate and Health Solutions and in late 2023, Green Climate Fund (GCF), the United Nations Development Programme (UNDP) and WHO announced plans for a new USD 122 million Climate and Health Co-Investment Facility. Specifically In regard to electrifying healthcare facilities, the SEforAll Global Heatmap shows 387 initiatives that are underway/completed, involving 78 stakeholders in 90 countries.

In terms of sources of financing, public healthcare facilities will in most cases need to utilize financing to adopt the resilience solutions, with only a few dedicated pots of funding available. Public health facilities are financed by central and sub-national government grants, revenue generated by the facilities from out-of-pocket spending of patients and philanthropic/ private sectors, with the proportion from different sources depending on the country. Although expenditure on public healthcare across the Global South is insufficient, in some countries, such as India, there is still underutilization of funds that, if this was enabled by the government, could be utilized for some of the resilience solutions (WHO 2021b; Concessao et al. 2023; Kadarpeta et al. 2024). However, facilities need to be empowered and supported to unlock existing public healthcare budgets for financing resilience solutions. For example, in Chhattisgarh, India, the government made it clear that health department budget allocations could be spent on the maintenance of solar systems, including replacing batteries, which has reduced the number of stranded assets.

The upfront capital costs for larger investments, such as on-site solar systems and SDD refrigerators, are typically financed by grants or subsidies from government and/or development partners. For example, the Government of India has announced a 30 percent subsidy for electric ambulances (PIB 2024). Development partners have been financing investments particularly in solar energy for facilities: for example, the IKEA and SELCO Foundations are providing grants and technical support to 25,000 healthcare facilities in 12 states in India to install clean energy and upgrade to energy efficient medical equipment by 2026 (IKEA Foundation 2023). Climate finance can also be utilized: for example, the GCF is supporting the Ministry of Health in Malawi to develop and apply national standards for climate resilient facilities (SEforALL and OPM 2023; GCF 2024).

Given the challenge of financing infrastructure upgrades in public healthcare facilities, public–private models are being explored for certain resilience solutions. For example, energy service-based models, where the private sector provides an electricity service, such as supplying clean energy, help to manage some operation and maintenance costs. In India, the Bureau of Energy Efficiency uses bulk procurement of energy efficient appliances, e.g. LED bulbs, super-efficient air conditioners, to bring down the cost of the technology in the market (Singh and Gurumurthy 2019).

CHAPTER FIVE

Conclusion

This study is the first effort to understand the climate risks facing the energy infrastructure of public healthcare facilities in the Global South, and the possible measures that can help build their climate resilience. The available evidence presents a clear impact pathway between current and projected climate and weather events and disruption to the energy supply and demand of healthcare facilities. There is a known set of potential resilience solutions that can help facilities prepare for, adapt to, respond to, and recover from such climate impacts.

Many resilience solutions are already being promoted by governments and development partners due to the other benefits they provide, such as improved energy access and cost savings. However, actual uptake remains limited and fragmented, and if climate change risks are not integrated into the design and implementation of all healthcare facility infrastructure projects, there is a high chance that resilience measures will be missed. For example, the resilience benefits of a standalone solar system for a healthcare facility will be missed unless it is fitted with a battery (so it provides power during grid outages) and it itself is protected from extreme weather (e.g. the battery elevated to avoid flood water, and a lightning conductor to protect the invertor).

For partners who are engaged in ongoing work in powering healthcare in the Global South, there are three areas of potential action to strengthen the resilience of public healthcare facility energy infrastructure:

Firstly, bring together the three communities of practice – health, clean energy, and climate resilience – to develop a shared understanding and approach to the issue. There are collaborative efforts underway between stakeholders on clean energy for healthcare, climate resilient healthcare and climate resilient energy systems), but there are no strong collaborative efforts across the three issue areas that seek to look at the climate resilience of healthcare facility energy infrastructure. A starting point could be to build awareness of and to use the WHO's

Guidance on Climate Resilient Healthcare Facility (WHO 2020b).

One immediate and straightforward action point is to broaden the data being collected by each set of stakeholders to develop an evidence base on climate resilient healthcare facility energy infrastructure. For example, Organizations that collect data on electricity access and energy consumption from facilities could add some survey questions related to the type and frequency of climate and weather events facing facilities, the impact on the facility's energy infrastructure, and whether the facility is implementing any of the resilience solutions. Similarly, organizations that have checklists for assessing the climate risks facing healthcare facilities, which includes energy infrastructure, could include a more specific set of questions related to energy sources and needs.

Secondly, pursue co-benefits and identify potential trade-offs for resilience from powering healthcare initiatives. One immediate priority is to ensure that the programmes underway to install solar energy systems in public healthcare facilities incorporate risk reduction measures in the design, placement and management of the system. However, a broader perspective could also be applied to the issue of powering healthcare. This study has highlighted the resilience benefits that can come from electrifying healthcare facilities with a clean and reliable source of power, but that a wider set of technologies and practices are also relevant: for example, energy efficient measures to reduce pressure on the supply of electricity, emergency protocols so facilities are better prepared to manage blackouts, and monitoring energy consumption in order to prioritize supply during emergency situations.

The resilience of grid-supplied power to climate and weather events should also not be ignored, particularly as grid expansion remains the primary route to electrification for facilities in the Global South. The stakeholders that need to be involved in grid-related resilience solutions, such as physical system enhancement (e.g. flood defences for generation assets) and smart grids, are different from those typically involved in powering healthcare discussions and projects. However, looking at the resilience of energy infrastructure more holistically will require some joining of the dots between different stakeholders and initiatives.

Thirdly, proactively promote a set of resilience solutions that most healthcare facilities will benefit from. The starting point to building the resilience of a healthcare facility's energy infrastructure to climate change is to carry out a proper assessment of the actual risks, meaning its level of exposure to different climate and weather events and its level of vulnerability. As such, the outputs of most development partner-funded projects to build resilient healthcare facilities have been assessment frameworks, resilience checklists and other such tools. However, given the capacity and resource constraints, it is unrealistic to imagine that these tools can be used to carry out a risk assessment for every single facility in the Global South. Therefore, some amount of top-down prescription of resilience solutions in areas at high risk of particular climate and weather events should be considered. This follows the approach typically used for energy efficient appliances and decentralized clean energy sources. This approach will make it more likely that resilience solutions are promoted at the scale needed.

Identifying a distinct set of resilience solutions that will benefit a large number of healthcare facilities in each country will also help to mobilize partners and funding. For example, three such solutions could be energy efficient fans, SDD refrigerators for vaccine storage, and cool roofs. If all the healthcare facilities that required such solutions in Kenya, India and Barbados adopted them, the total investment required in each country would be USD 5.8 million, 54 million and 0.2 million, respectively. There is an opportunity to leverage and combine ongoing and planned health, clean energy, and climate resilience programmes to cover this investment.

ANNEX: Data and assumptions

This annex provides a breakdown of the data used to estimate the costs and benefits of the sample of resilience solutions. The first table provides the complete set of estimated results for each country. The second table describes the data sources and assumptions used.

TABLE 11: Breakdown of costs and benefits of three sample resilience solutions

Energy efficient fans scenario: Healthcare facilities at risk from climate and weather events replace the use of conventional ceiling fans with the use of energy efficient versions.			
Per facility capital expenditure (CAPEX) (USD/per facility)	240	250	3,710
Per facility annual energy savings (MW/per facility)	274	456	3,385
Per facility annual operating expenditure (OPEX) savings (USD/per facility)	55	57	1,312
Total number facilities	567	23,216	15
Total CAPEX over five years (USD/all facilities)	-136,063	-5,804,026	-55,650
Total energy savings over five years (MW/all facilities)	776	52,962	254
Total OPEX savings over five years (USD/all facilities)	154,690	6,587,569	98,383
Total CO2 emissions savings over five years (tonnes CO2/all facilities)	246,298	41,839,769	20,074
SDD refrigerator scenario: Healthcare facilities at risk from climate and weather events replace the use of domestic refrigerators with the use of SDD refrigerators for vaccine storage.			
Per facility CAPEX (USD/ per facility)	8,500	7,383	9,000
Per facility annual avoided vaccine wastage (litres/per facility)	7,486	7,486	7,486
Per facility annual energy savings (MW/per facility)	3,212	3,212	3,212
Per facility annual OPEX savings (USD/per facility)	250	34	789
Total number facilities	664	6,235	15
Total CAPEX over five years (USD/all facilities)	-5,645,003	-46,034,346	-135,000
Total avoided vaccine wastage over five years (litres/all facilities)	24,859,199	233,394,697	561,479
Total energy savings over five years (MW/all facilities)	10,666	100,137	241
Total OPEX savings over five years	828,607	1,053,434	59,185
Total CO2 emissions savings over five years (tonnes CO2/all facilities)	3,385,304	79,108,244	190,456
Cool roof scenario: Healthcare facilities at risk from extreme heat apply cool roof technology.			
Per facility CAPEX (USD/per facility)	150	120	180
Per facility annual energy savings (MW/per facility)	442	442	1,179
Per facility annual OPEX savings (USD/per facility)	82	47	437
Total number facilities	132	9,998	15

Total CAPEX over five years (USD/all facilities)	-39,569	-2,399,517	-5,400
Total energy savings over five years (MW/all facilities)	292	22,100	88
Total OPEX savings over five years	54,238	2,352,007	32,746
Total CO2 emissions savings over five years (tonnes CO2/all facilities)	92,537	17,458,647	69,902

TABLE 12: Data and assumptions

Number of health facilities with a regular supply of electricity at risk from various climate and weather events	**810**	**33,166**	**15**
	Calculated using the 2023 Health Facility Census Report, and Kenya's Sub-National Children Climate Risk Index-Disaster, and assuming electricity access rate of 89 percent.	Calculated using the District-wise Healthcare Infrastructure database 2017, and Council on Energy, Environment and Water's district-level Climate Vulnerability Index, and assuming electricity access rate of 91 percent.	Calculated by plotting each health facility on a map and estimating distance from coast.
	Data source: Mani et al. 2019; MoHFW 2024; CEMA		
Number of electrified health facilities at risk from various climate and weather events using conventional fans	**567**	**23,216**	**15**
	Estimated based on number of electrified health facilities at risk (see above) with assumed low penetration of efficient fans (70 percent).		Assumes for all health facilities that some proportion of fans are inefficient.
	Data source: NCDC, GoI, 2023b		
Number of electrified health facilities at risk from various climate and weather events using non-solar vaccine refrigerators	**664**	**6,235**	**15**
	Estimated based on number of electrified health facilities at risk (see above) and the average proportion of non-solar cold chain capacity (82 percent).	Estimated based on number of electrified health facilities at risk (see above) and study indicating that 40 percent of health facilities have cold chain capacity, of which 47 percent is domestic refrigerator.	Assumes for all health facilities that some proportion of refrigerators are non-solar.
	Data source: SEforALL, 2022; NCDC, GoI, 2023b		
Number of electrified health facilities at risk from extreme heat currently using air conditioning	**132**	**9,998**	**15**
	Estimated based on number of electrified health facilities at risk from extreme heat (see above), with assumption that 20 percent of these	Estimated based on number of electrified health facilities at risk from extreme heat (see above), with assumption that 40 percent of these	Assumes all health facilities are using air conditioning.

	will be using air conditioning.	will be using air conditioning.	
	Data source: Based on expert opinion and study of sample of health facilities in India (NCDC, GoI 2023c).		
Price of grid-supplied electricity to health facility (USD/kWh)	**0.203**	**0.12**	**0.378**
	Data source: www.globalpetrolprices.com, using an estimate for the commercial tariff.		
Emissions factor for grid-supplied electricity (Kg of CO_2 per MW)	**0.3174**	**0.79**	**0.7906**
	Data source: UNFCCC 2020.		
Operation and maintenance costs for facility infrastructure/ appliances (percent CAPEX/ year)	**5 percent**	**5 percent**	**5 percent**
	Data source: Assumes that in all baseline and resilience scenarios the operation and maintenance costs are 5 percent of the capital costs.		
Capital cost of conventional ceiling fan with 10-year lifespan (USD/ unit)	**20**	**18**	**20**
	Data source: Uses costs data from "no star" rated fans in India and assumes additional cost for Kenya and Barbados given market size (Mathew et al., 2019).		
Capital cost of energy efficient ceiling fan with 10-year lifespan (USD/ unit)	**80**	**50**	**100**
	Data source: Uses costs data for five-star rated fans in India and assumes additional cost for Kenya and Barbados given market size and likely need to import the technology (Mathew et al., 2019).		
Total annual volume of electricity consumed by conventional ceiling fans (Kw/facility/year)	**821**	**1,369**	**10,156**
	Assumes three fans per facility, for 10 hours per day (365 days a year), with kWh of 0.8.	Assumes five fans per facility, for 10 hours per day (365 days a year), with kWh of 0.8.	Assumes average of 37 fans per facility, for 10 hours per day (365 days a year), with kWh of 0.8.
	Data source: Mathew et al. 2019		
Total annual volume of electricity consumed by efficient ceiling fans (Kw/facility/year)	**821**	**913**	**6,771**
	Assumes three fans per facility, for 10 hours per day (365 days a year), with kWh of 0.05.	Assumes five fans per facility, for 10 hours per day (365 days a year), with kWh of 0.05.	Assumes average of 37 fans per facility, for 10 hours per day (365 days a year), with kWh of 0.05.
	Data source: Mathew et al. 2019		
Capital cost of non-solar refrigerator with 99 litre capacity and 10-year lifespan (USD/ unit)	**450**	**350**	**500**
	Data source: Uses market rates from India for domestic refrigerators and assumes additional cost for Kenya and Barbados given market size and likely need to import the technology.		
Capital cost of SDD refrigerator with 99 litre capacity and 10-year lifespan (USD/unit)	**8,500**	**7,383**	**9,000**
	Data source: Uses market rates from India for domestic refrigerators and assumes additional cost for Kenya and Barbados given market size and likely need to import the technology (Kumar et al. 2023).		

Total annual volume of electricity consumed by non-solar refrigerator (Kw/facility/year)	**3,212**	**3,212**	**3,212**
	Assumes one refrigerator per facility, for 22 hours per day (365 days a year), with KwH of 0.4.		
	Data source: Uses estimates of wattage of domestic refrigerators on the market.		
Total annual volume of vaccines wasted in non-solar refrigerators due to temperature fluctuations from power outages (litres/facility/year)	**7,486**	**7,486**	**7,486**
	Assumes 19 percent of the 398 litres of vaccines refrigerated annually are wasted due to temperature fluctuations.		
	Data source: Uses calculation of approximate volume of vaccines that can be stored annually in a 99-litre capacity refrigerator, and a National Vaccine Wastage Assessment in India showing that 27 percent of vaccines are wasted on average each year, of which 71 percent is due to exposure to heat.		
Capital cost of retrofitting health facility with cool roof surface, with lifespan on four years (USD/facility)	**150**	**120**	**180**
	Data source: Assumes an average roof size of 200 m^2 and cost per m2 to apply cool roof surface of USD 0.02 in India, with higher costs in Kenya and Barbados (BBC News 2019).		
Total annual volume of electricity consumed for air condition in health facility with conventional roofs (Kw/facility/year)	**2,210**	**2,210**	**5,894**
	Assumes three air conditioners per facility, for six hours per day (200 days a year), with kWh of 0.61.	Assumes three air conditioners per facility, for six hours per day (200 days a year), with kWh of 0.61.	Assumes eight air conditioners per facility, for six hours per day (200 days a year), with kWh of 0.61.
	Data source: Based on expert consultations on the use of air conditioners by public healthcare facilities.		
Total annual volume of electricity consumed for air condition in health facility with cool roof (Kw/facility/year)	**1,768**	**1,768**	**4,716**
	Assumes 80 percent of electricity Is consumed under baseline scenario.		
	Data source: Uses estimates of electricity savings from cool roofs (NRDC 2020).		

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ABOUT SEforALL

Sustainable Energy for All (SEforALL) is an independent international organization that works in partnership with the United Nations and leaders in government, the private sector, financial institutions, civil society and philanthropies to drive faster action on Sustainable Development Goal 7 (SDG7) – access to affordable, reliable, sustainable and modern energy for all by 2030 – in line with the Paris Agreement on climate change.

SEforALL works to ensure a clean energy transition that leaves no one behind and brings new opportunities for everyone to fulfil their potential. Learn more about our work at www.SEforALL.org