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Electrification with renewables: Enhancing healthcare delivery in

Mozambique

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ABBREVIATIONS

AMC	annual maintenance contract
CAPEX	capital expenditure
DOD	depth of discharge
DRE	decentralised renewable energy
FUNAE	Fundo de Energia (Mozambique Energy Fund)
HIV/AIDS	human immunodeficiency virus/acquired immunodeficiency syndrome
IRENA	International Renewable Energy Agency
kVA	kilovolt ampere
kWh	kilowatt hour
kWp	kilowatt peak
km	kilometre
LED	light-emitting diode
$LiPO_4$	lithium phosphate
$LiFePO_4$	lithium iron phosphate
m^2	square metre
MCH	maternal and child health
NGO	non-governmental organisation
O&M	operation and maintenance
OPD	outpatient department
PESS	Plano Estratégico do Sector Saúde (Health Sector Strategic Plan)
PPP	public-private partnership
PV	photovoltaic
RHC	rural health centre
SDG	Sustainable Development Goal
SELCO	SELCO Foundation (Social Enterprise for Lighting and Cooking)
UHC	urban health centre
WASH	water, sanitation and hygiene
Wh	watt hour

EXECUTIVE SUMMARY

Reliable, affordable modern energy is crucial for delivering quality healthcare – whether it is to power life-saving critical medical equipment in maternity wards, or to meet basic daily needs, such as for lighting. Securing electricity access is a significant challenge in regions highly susceptible to the adverse impacts of climate change, including frequent extreme weather events. Climatic disruptions can interrupt services, damage infrastructure, strain emergency response services and disrupt health supply chains.

Decentralised renewable energy (DRE) solutions can play a pivotal role in democratising essential services like healthcare. DRE can catalyse a transformation of healthcare delivery by helping to ensure that the design of energy systems considers the needs of the populations accessing healthcare, especially primary healthcare. In particular, DRE solutions can be used to improve:

- Maternity and child care
- Immunisation rates
- Diagnostic and laboratory services
- Preventive and therapeutic care
- Health administration
- Daily working environments of healthcare providers

Mozambique faces significant health challenges, including high rates of maternal and neonatal mortality, communicable diseases and malnutrition. Frequent extreme weather events, such as cyclones, floods and droughts, compound these issues as well as the risk of diseases like cholera, malaria and diarrheal infections, putting additional strain on an already overburdened health system. Figure S1 summarises several of the key challenges.

Figure S1 **Key challenges facing Mozambique's healthcare system**

High disease burden

Over 10% of adults were affected by the human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS) in 2021; also, the rates of tuberculosis, diarrhoea and malnutrition are high, compounded by disasters and displacements, as is the frequency of infectious disease outbreaks (polio, cholera, measles).

High prevalence of neglected tropical diseases

The focus is on specialised healthcare to manage neglected tropical diseases, which cause developmental delays in children and disabilities, and are linked to anaemia, malnutrition and other health conditions.

High prevalence of neglected tropical diseases

Disease patterns in Mozambique are heavily influenced by climate; malaria and cholera peak during rainy seasons and diarrheal diseases and meningitis during dry periods.

Healthcare facilities exposed to climate risks

About 10% of healthcare facilities are exposed to cyclones; 2% are at risk from floods. Cyclones in 2019 alone destroyed over 123 healthcare facilities, severely affecting essential services.

Severe staff shortages

There are three doctors per 100 000 persons – among the lowest doctor-patient ratios in the world. To enhance services, it is important to ensure care providers' comfort and safety.

Access challenges

Sixty-two percent of the population lives in rural areas; many travel over 12 kilometres (km) to reach a healthcare facility. The distance to a healthcare facility varies considerably across regions – 1.6 km in Maputo City versus over 14 km in Niassa and Cabo Delgado provinces.

Mozambique's healthcare infrastructure, which consists of 1769 facilities (Table S.1), is often under-resourced and ill-equipped to handle demand, especially during extreme weather events. The Ministry of Health's strategic plans emphasis the need to decentralise services, improve maternal and child health, and expand vaccination programmes, but these goals are hindered by a lack of energy access and climatic events that frequently damage infrastructure and disrupt service delivery.

Table S1 **Type and number of healthcare facilities, by level**

Level	Types and number of facilities at each level			Total
I	**Rural health centre**	**Urban health centre**	**Health post**	**1 702**
	1 375	191	136	
II	**Rural hospital**	**District hospital**	**General hospital**	**53**
	18	28	7	
III	**Provincial hospital**			**7**
	7			
IV	**Central hospital**	**Specialised hospital**	**Military hospital**	**7**
	4	2	1	
Grand total				**1 769**

DRE solutions offer an opportunity to pragmatically and cost-effectively address the many challenges outlined above. As a reliable power supply for healthcare facilities, DRE enables the continuous operation of essential medical equipment, lighting and refrigeration for vaccines.

For example, solar-powered refrigeration can help ensure a stable vaccine cold chain, minimising spoilage and helping to improve immunisation rates. Solar power can support healthcare workers in providing quality care even during power outages and thus enable basic diagnostics, laboratory services and maternity care. By integrating DRE solutions, Mozambique can leapfrog traditional energy sources, ensuring sustainable and resilient healthcare services that serve the needs of all communities, especially in remote and vulnerable areas.

The present assessment addresses key aspects of Mozambique's health-energy landscape, including technical designs, cost estimates and recommendations for long-term operations and sustainability. The assessment was performed to:

- gain a thorough understanding of the health-energy ecosystem;
- gather key information on the energy needs of public healthcare infrastructure across different levels in varying contexts;
- inform the design of modular DRE systems, especially solar photovoltaic (PV) for meeting differentiated load requirements and the needs of primary healthcare facilities;
- estimate the funding required to implement robust DRE-enabled health system models;
- identify gaps and opportunities regarding capacity building for healthcare staff in the operation and maintenance (O&M) of systems; and
- recommend pathways for sustainability, a key consideration for a health-energy programme.

In Mozambique, 90% (1 702) of healthcare facilities offer primary care (Level I of the four-tiered health delivery system). The study focused the energy needs of primary healthcare and the design of robust DRE solutions to meet them. Of the existing Level I facilities, 88.8% (1 511) are rural health centres (RHCs) and health posts (to be upgraded as RHCs), and 11.2% (191) are urban health centres (UHCs), which deliver the first line of care to the population.

The assessment focuses on a sample of 40 primary care facilities, which represent different care levels, energy footprints, and variations in location, demographic profile, energy source and degree of energy access. The 40 facilities are located in 25 districts spread across 6 of the 11 provinces, specifically, Manica, Nampula, Niassa, Sofala, Tete and Zambezia.

Based on comprehensive secondary analysis, consultations and primary data collected for the assessment, several key observations are summarised in Table S2.

Table S2 **Key observations from assessment of 40 healthcare facilities**

Unreliable power supply	• Power supply interruptions last 4 hours on average; some facilities experience outages of up to 18 hours. • 25% of RHC Type II facilities provide services during power outages, including by using torchlights to deliver babies at night. • 25% of facilities with backup sources primarily rely on diesel generators.
Absence of grid infrastructure	• 40% of facilities are not grid connected and rely completely on solar photovoltaic energy to power health services. • 86% of off-grid facilities were RHCs, located in rural areas and providing health services to two-thirds of Mozambique's population.
Grid fluctuation and instability	• 25% of facilities noted that voltage fluctuations damaged equipment such as water pumps, photocopiers and computers, impeding the delivery of safe sanitation and basic administrative and diagnostic services.
Impact of climate disasters	• 57.5% of respondents stressed that cyclones, strong winds and floods commonly affect service delivery.
Weak civil infrastructure	• Buildings are in a fragile state due to climate disasters like cyclones and poor maintenance. • 25% and 14% of RHC-I and RHC-II staff, respectively, reported working in damaged buildings. • 38% and 33% of RHC-I and RHC-II staff, respectively, reported weak roofs.
Poor water and sanitation services	• Only 60% of primary health facilities have functional water supply. • 97% of facilities have no water heating.
Existing DRE systems fail to meet the energy needs	• 47% of respondents reported that existing DRE systems did not meet basic lighting needs. • 77% of RHC-II's existing DRE systems have frequent operational issues, affecting critical vaccination, maternity and outpatient services.
Lack of working capital for O&M	• Some DRE systems were not operational due to lack of maintenance and the absence of functional batteries. • Maintenance funds and the number of appropriately skilled technicians are insufficient.

Notes: DRE = decentralised renewable energy; O&M = operation and maintenance; RHC = rural health centre.

To address the challenges noted during primary data collection and secondary consultations, the assessment includes:

- Detailed technical designs[1] to meet the energy needs of the various categories of primary healthcare facilities based on their load profiles and medical services, and help resolve the issues of unreliable power supply and grid fluctuations.
- An estimation of the funding requirements for implementing a healthcare electrification programme focused on DRE solutions in primary care facilities. This includes estimates for working capital to ensure long-term sustainability by incorporating funding needs for at least ten years of system O&M.

The system designs are indicative and offer a blueprint for comprehensively meeting the electricity needs of primary healthcare facilities using solar PV (Table S3).

Table S3 **Technical designs (indicative) for various types of primary healthcare facilities**

Healthcare facility type	Design approach	System type	Total load (W)	Total units (Wh)	Solar panel (kWp)	$LiPo_4$ battery (Ah) @ 12.8 V (min capacity)	Battery capacity (kWh)	Solar inverter (kVA)
RHC – Type 2	**Option 1 – all load**	Primary system	2 358	8 334	3.2	1 000	12.8	5
		Backup system		5 373	2.5	650	8.32	4
	Option 2 – critical load	Primary system	898	5 024	2	600	7.68	3
		Backup system		2 743	1	350	4.48	2
RHC – Type 1	**Option 1 – all load**	Primary system	7 680	27 600	11	3 500	44.8	15
		Backup system		16 325	7	2 000	25.6	10
	Option 2 – critical load	Primary system	4 322	22 239	9	2 800	35.84	12.5
		Backup system		14 367	6	1 800	23.04	10
UHC – Type C	**Option 1 – all load**	Primary system	2 314	8 072	4	1 000	12.8	6
		Backup system		5 241	2.5	650	8.32	4
	Option 2 – critical load	Primary system	894	5 004	2	600	7.68	3
		Backup system		2 731	1	350	4.48	2
UHC – Type B	**Option 1 – all load**	Primary system	5 480	19 940	8	2 500	32	12
		Backup system		11 145	5	1 400	17.92	7.5
	Option 2 – critical load	Primary system	4 131	12 633	5	1 600	20.48	7.5
		Backup system		6 617	3	850	10.88	5
UHC – Type A	**Option 1 – all load**	Primary system	10 149	35 435	14	4 300	55.04	20
		Backup system		22 002	9	2 700	34.56	15
	Option 2 – critical load	Primary system	5 071	27 341	11	3 350	42.88	15
		Backup system		19 014	8	2 300	29.44	12

Note: Ah = ampere hour; kVA = kilovolt ampere; kWh = kilowatt hour; kWp = kilowatt peak; $LiPo_4$ = lithium phosphate; RHC = rural health centre; UHC = urban health centre; V = volt; W = watt; Wh = watt hour.

[1] *Because of its modular nature and ready availability, solar PV has been selected as the DRE technology to meet the energy needs of facilities. Although other DRE technologies, such as micro-hydro, may exist in some locations, they are not considered in the design and cost calculations in this assessment.*

The findings from this assessment indicate a funding need of **USD 16.5 million** to power the country's entire primary healthcare infrastructure (1 649 facilities) with reliable decentralised solar energy for all regular services (Table S4). Powering all critical loads of the primary healthcare facilities with decentralised solar as a backup power source would cost an estimated **USD 7.7 million.** This is beside the funding needed for electrifying staff quarters using decentralized solar photovoltaic solutions, estimated at USD 4,023 per staff quarter, totalling approximately USD 6.6 million a quarter per facility to USD 17.4 million for three quarters per facility (see Table 4.17).

Table S4 **Estimates costs of DRE (solar PV) solutions to power different types of primary healthcare, based on load (USD)**

	RHC-I	RHC-II	UHC-A	UHC-B	UHC-C	Total
No. of facilities*	176	1 293	55	65	60	**1 649**
Powering all loads with DRE as the primary source	4 407 796	8 646 405	1 801 940	1 274 329	411 915	**16 542 385**
Powering critical loads with DRE as the primary source	3 016 321	5 450 431	1 340 549	816 489	263 943	**10 887 734**
Powering all loads with DRE as a backup source	2 786 065	6 529 541	1 157 008	758 364	316 201	**11 548 178**
Powering critical loads with DRE as a backup source	2 579 129	3 709 620	790 096	410 011	179 642	**7 668 498**

* Costs are for the total number of facilities in each category.

Note: DRE = decentralised renewable energy; PV = photovoltaic; RHC = rural health centre; UHC = urban health centre.

The assessment also offers a study of four financing and business models for the installation and O&M of DRE systems in Mozambique's healthcare facilities:

- Capital expenditure subsidy with O&M primarily through local private sector operators.
- Capital expenditure subsidy with O&M primarily through public sector energy agencies.
- Capital expenditure subsidy and O&M primarily through healthcare facility staff, local community groups or non-governmental organisations.
- Energy as a service.

The integration of DRE systems into Mozambique's healthcare sector is a vital move towards making health services more reliable and sustainable nationwide. This assessment offers comprehensive recommendations to ensure the successful deployment of DRE systems, with a focus on key steps, organised by topic:

1. **Strengthen government co-ordination and forge partnerships**
    a. **Establish an inter-ministerial task force.** Create a task force with representatives from key ministries and organisations to align strategies and co-ordinate the deployment and maintenance of DRE systems.
    b. **Facilitate joint studies and data sharing.** Conduct joint studies on energy needs and DRE integration and create a centralised database for shared information.
    c. **Secure high-level political buy-in.** Engage high-ranking officials to commit to the DRE initiative and ensure it remains a national priority.
    d. **Develop public sector budget provisions.** Collaborate on annual budgets for DRE projects, supplemented by international donor funds.
    e. **Form an integrated technical team.** Assemble a multi-disciplinary team to conduct feasibility studies, design energy systems and oversee the implementation of DRE projects.
2. **Conduct site-specific assessments**
    a. **Initiate facility-level energy assessments.** Conduct energy audits at each healthcare facility to determine current consumption, equipment needs and service requirements for accurate DRE system sizing.
    b. **Develop a standardised assessment protocol.** Create a consistent protocol for assessments, including guidelines for evaluating energy demand, infrastructure and future growth.
    c. **Incorporate local context and needs.** Consider geographic, climatic and socio-economic factors in assessments and engage local staff to gain insights into operational and energy challenges.
    d. **Use assessment data to inform system design.** Utilise assessment data to design and specify DRE systems tailored to each facility's needs.
3. **Develop a comprehensive financing strategy**
    a. **Identify funding sources.** Explore government budgets, international grants, concessional loans and philanthropic contributions. Engage with agencies like the World Bank, the African Development Fund, the Global Fund, GAVI (The Vaccine Alliance), the United Nations Children's Fund and the United States Agency for International Development.
    b. **Establish a dedicated fund for DRE for healthcare.** Create a fund within the Ministry of Economy and Finance or the Ministry of Health; pool and manage resources transparently.
    c. **Leverage public-private partnerships (PPPs).** Develop PPP models to incentivise private sector investment in DRE systems through tax incentives and risk-sharing mechanisms.
    d. **Implement a blended financing approach.** Combine grants, concessional loans and private investments to reduce capital costs and attract investors.
    e. **Develop a long-term sustainability plan.** Include provisions for ongoing operations, maintenance, battery replacement and system upgrades.

4. **Formulate a robust procurement plan**

   a. **Assess local market capabilities.** Evaluate local suppliers and installers for quality standards and import equipment if needed.

   b. **Establish strict quality standards.** Implement stringent quality control for procurement, ensuring all equipment meets international standards and is climate tested.

   c. **Create a transparent procurement process.** Ensure a transparent, competitive procurement process aligned with national and World Health Organanization guidelines.

   d. **Develop long-term supplier relationships.** Build long-term relationships with reliable suppliers for ongoing support and maintenance.

5. **Implement comprehensive capacity-building programmes**

   a. **Develop training modules.** Create comprehensive modules on renewable energy, system operation, maintenance, procurement and the healthcare–energy nexus for healthcare staff, technicians and officials.

   b. **Enhance maintenance training.** Collaborate with the National Directorate for the Training of Health Professionals (NDTHP) and the National Directorate of Energy (DNE) to provide specialised training on repairs and energy system management for maintenance personnel.

   c. **Implement on-the-job training.** Offer hands-on workshops, refresher courses and mentorship programmes for healthcare staff and local technicians.

   d. **Develop certification programmes.** Introduce certification programmes for technicians and service providers to ensure DRE systems are maintained to high standards.

   e. **Promote awareness.** Launch campaigns to educate healthcare staff and communities on the benefits and maintenance of DRE systems, fostering ownership and responsibility.

6. **Establish a robust O&M framework**

   a. **Integrate DRE maintenance.** Embed DRE system maintenance within the Ministry of Health's existing framework to leverage resources and expertise.

   b. **Develop remote monitoring.** Implement a real-time monitoring system linked to a central control room to promptly identify when maintenance is needed.

   c. **Create an asset management process.** Include DRE systems in asset registers for better tracking, budget allocation and accountability.

   d. **Establish O&M funding.** Allocate dedicated funds for O&M activities, including system checks and emergency repairs, possibly through an escrow account.

   e. **Engage long-term service providers.** Enter into long-term contracts with service providers, including maintenance schedules and performance guarantees.

   f. **Monitor and evaluate.** Implement a framework for regular audits, performance assessments and feedback to ensure continuous improvement.

Implementing these recommendations will help Mozambique position itself to effectively leverage renewable energy, especially solar PV, to enhance its healthcare system.

SUSTAINABLE ENERGY FOR HEALTHCARE

Robust primary healthcare systems are crucial for reaching Sustainable Development Goal (SDG) 3, "Ensure healthy lives and promote well-being for all at all ages", and related targets, including reducing mortality from a variety of diseases and achieving universal health coverage. Whether it is a young woman in a migrant settlement seeking safe delivery services, a newborn in a mountainous region needing vaccination or an elder in a small village trying to access specialised healthcare, robust primary health services are a necessity for achieving global health outcomes. However, primary healthcare systems in many countries, particularly in the developing world, often lack the resources and facilities needed to deliver adequate, accessible and high-quality healthcare.

Reliable healthcare infrastructure, including medical equipment and information technologies (SE4All, 2022), requires access to reliable and sustainable energy (SDG 7). SDG 7, as an enabling, catalytic force, plays an important role in supporting the achievement of SDG 3.

1.1 THE ENERGY–HEALTH NEXUS

A growing body of literature has established the positive impacts of electrification on health indicators and outcomes (WHO, *et al.*, 2023). Studies also indicate a disproportionate effect of a lack of electrification on vulnerable populations such as women and children (Khogali, 2023).

The following are some key healthcare services whose delivery is enhanced by reliable electricity:

- **Basic administrative services:** Power is needed for lighting, fans, computers, printing services and mobile charging for staff and patients.
- **Maternity and childcare:** Energy is needed, among other things, for diagnostic equipment for identifying high-risk pregnancies and devices used during and after delivery, such as radiant baby warmers, operation spotlights and phototherapy units.

- **Immunisation:** Energy is needed to maintain cold chains using deep freezers and ice-lined refrigerators for storing medicines, drugs and vaccines.
- **Basic diagnostics, laboratory and medical care:** Energy for microscopes and centrifuges, instrument sterilisers, lighting above operating tables and non-communicable disease kits.
- **COVID-19 preventive and therapeutic care:** Energy is needed for space heating and cooling, at a basic level for testing and quarantine facilities, and for cold chains for vaccine storage and delivery.
- **Staff members' ability to provide care:** It is important that healthcare workers have adequate lighting and access to water, are able to sterilise equipment and can maintain safety during medical procedures. Reliable electricity in staff living quarters also boosts staff motivation and retention.

1.2 HEALTHCARE AMID CLIMATE CHANGE

Climate change poses a fundamental threat to human health and is expected to cause an additional 250 000 deaths related to under-nutrition, malaria, diarrhoea and heat stress between 2030 and 2050 (WHO, 2023). At-risk areas with weak infrastructure, mostly in developing countries, will be disproportionately affected and the capacity to achieve universal health coverage will be diminished.

Climate change affects individual and community health and healthcare in various ways.

Extreme weather events. The increased frequency and severity of extreme weather events like hurricanes, floods, heatwaves and droughts can lead to injuries, fatalities and mental health issues. They can also disrupt and damage healthcare infrastructure, services and supply chains, making it difficult to provide medical care and essential goods.

Heat-related illnesses. Rising temperatures increase the risk of heat-related illnesses such as heat exhaustion and heatstroke. Vulnerable populations, including the elderly, children and those with pre-existing conditions, are particularly at risk.

Vector and water-borne diseases. Changes in temperature, precipitation and humidity can alter the distribution and activity of vectors like mosquitoes and ticks. Such changes could result in an increase in the spread of diseases such as malaria, dengue fever, Lyme disease and the Zika virus, and waterborne diseases such as cholera, especially in areas with inadequate sanitation and water infrastructure.

Displacement and migration. Climate change can force people to migrate due to rising sea levels, desertification and other environmental changes. Displacement could lead to overcrowding, poor sanitation and limited access to healthcare, compounding health risks.

The magnitude of risks to health and healthcare delivery associated with climate change point to the dire need to adopt robust, sustainable and transformative solutions that can pave the way for a climate-resilient, and socially, economically and environmentally sustainable healthcare system that is able to meet the needs of diverse locales and last-mile communities.

The role of decentralised energy in achieving resilient healthcare delivery systems

Amid the growing challenges of climate change, healthcare facilities are essential for delivering key services. However, while many struggle to access these facilities, the health sector itself consumes significant energy. By repositioning the healthcare system to integrate decentralised renewable energy (DRE), it is possible to create more sustainable, resilient and cost-effective health infrastructure with reduced environmental impact. Nearly 1 billion people living in low- or lower-middle-income countries are served by healthcare facilities that do not have reliable or any electricity access (IEA, 2017). The majority of these healthcare facilities are in remote areas and provide services ranging from basic care to specialised services. Facilities in areas with limited resources, that are vulnerable to climate risks, or are remote tend to break down or malfunction due to inadequate repair of infrastructure and equipment. These facilities mostly rely on diesel generators, which have environmental and economic impacts.

DRE has proven to be a reliable, affordable and clean alternative that, through customised solutions, can fit the needs of the regions and communities it is intended to serve. As supply chains mature and DRE technology components become increasingly available, DRE has become a cost-effective solution for providing electricity at scale for healthcare.

DRE can also help provide timely electricity access for healthcare facilities, to be upgraded modularly as and when needed. This can aid in achieving universal healthcare more effectively by helping economically, socially and geographically vulnerable communities access basic and critical services. It would also strengthen the ability of last-mile communities to have more control over their energy generation, supply and consumption.

Introducing the present assessment

The International Renewable Energy Agency (IRENA), with support from SELCO Foundation and Greenlight Africa, is assisting Mozambique's Ministry of Mineral Resources and Energy and the Ministry of Health in assessing opportunities to integrate DRE to improve the country's healthcare. It was recognised as urgent to develop a comprehensive, country-level energy strategy focused on deploying DRE systems to, in particular, strengthen last-mile health facilities.

This assessment is a part of the Empowering Lives and Livelihoods: Renewables for Climate Action initiative launched by the United Arab Emirates and IRENA at the 2023 United Nations Climate Change Conference (COP28). The initiative aims to make health and agriculture sectors more resilient by promoting the use of renewable energy solutions. As part of this assessment, a roadmap has been developed. The roadmap outlines DRE system designs and the cost requirements for resilient solutions across Mozambique's primary healthcare facilities. The present report provides a framework and recommendations for the Ministry of Health, the Ministry of Mineral Resources and Energy, and other stakeholders to strengthen the enabling ecosystem for a sustainable energy–health nexus.

The details of the assessment, including methodology and assessment findings, are presented in chapter 4.

02 MOZAMBIQUE'S HEALTHCARE LANDSCAPE

INDICATORS, INSTITUTIONS, INFRASTRUCTURE AND CHALLENGES

Mozambique is located in southeast Africa and bordered by the Indian Ocean to the east. It shares land borders with Tanzania to the north, Malawi and Zambia to the northwest, Zimbabwe to the west, and Eswatini and South Africa to the southwest. As of 2021, Mozambique was estimated to have a population of approximately 33 million, with a relatively young demographic profile (the median age is about 17 years), with approximately two-thirds living in rural areas.

Mozambique is rich in natural resources, including arable land, plentiful water sources, energy potential, minerals and recently discovered off-shore natural gas deposits. The country's infrastructure includes three deep seaports, and it offers a substantial potential workforce. Mozambique's geographical position is particularly advantageous, as it serves as a vital access point to global markets for four of its six landlocked neighbours. Further, its strong connections with South Africa, the region's economic powerhouse, highlights Mozambique's crucial role in the stability and economic growth of Southern Africa. Mozambique's development across economic, political and social spheres is thus integral to the broader progress of the region (WHO 2024).

2.1 HEALTHCARE SYSTEM: KEY STATISTICS

Mozambique has 1 769 healthcare facilities serving a population of 33.9 million (UNFPA, 2023). Seventy percent of these facilities are in rural areas, where a similar proportion of the population lives.

The country's health policies and strategies are guided by an overarching policy framework for poverty alleviation called the Government Five-Year Development Plan (Programa Quinquenal do Governo). Under this larger vision, the Ministry of Health has been designing five-year health strategies called the Health Sector Strategic Plans (PESS); the most recent of these is for 2014-2019 (Mwai, 2023). The plans seek to identify key challenges in healthcare delivery in the country and set priorities, programmes and indicators to achieve health outcomes aligned to national and global targets. PESS 2014-2019 was designed as the country navigated a complex humanitarian situation, including natural disasters like cyclones Idai, Kenneth and Freddy, and conflicts in the northern district of Cabo Delgado.

A low- to moderate-elevation plateau, which slopes towards the Indian Ocean, covers roughly 44% of the country as a coastal belt. Mozambique faced 75 natural disasters in the last 35 years, including droughts, cyclones and epidemics.

Source: World Bank, n.d.

PESS 2014-2019 categorised Mozambique's health priorities under two main pillars. Pillar 1 focuses on improving the quality of health services and expanding access to them, while Pillar 2 hinges on engaging in a series of sectoral reforms that decentralise health services to increase their efficacy and efficiency at all levels. Key areas of focus may be summarised as follows.

Improving maternal and child health (MCH) and reducing the disease burden. Pillar 1 of PESS 2014-2019 prioritised the prompt achievement of commitments towards reducing maternal and neonatal mortality, and malnutrition, demonstrating a concerted effort towards improving MCH service delivery.

Enhanced vaccination and outbreak prevention. Recognising the impact climate change has on the disease burden and incidence of outbreaks in Mozambique, the government has been actively setting targets and deploying programmes to speed up vaccination for several vector-borne diseases, such as malaria, cholera, diarrhoea, measles and meningitis, and viruses such as human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS) and polio. It has launched the Intensification of Routine Immunisation (PIRI) campaigns, which consist of time-limited, specifically targeted activities to reach 750 000 "zero dose" children in 2024 (Mwai, 2023). Beyond this initiative, there are plans to boost the long-term resilience of healthcare by investing in the cold chain, modern logistics systems and expanded vaccination infrastructure, as well as by strengthening community health subsystems to improve immunisation services in remote communities.

Decentralising key health services. Pillar 2 of the national strategy emphasises decentralisation to promote health equity and strengthen basic services at the community level. Since 2002, the Government of Mozambique has implemented reforms to decentralise healthcare services. The PESS policies have consistently supported this shift; they have prioritised infrastructure improvement, including of buildings, electricity, water and communication. The strategy also prioritises empowering community health workers through adequate staffing, logistics, medical technology and health information systems at the community level.

Service expansion. Definitive steps have been taken to improve last-mile delivery mechanisms. Healthcare services and the number of workers at the community level are being increased under the Mozambique Primary Healthcare Strengthening Programme funded by the World Bank with a USD 105 million grant. The programme prioritises the expansion of basic and comprehensive emergency obstetric and newborn care, the expansion of community and outreach-based services, increase in consultations and the expansion of full immunisation for children (World Bank, 2017). The number of trained and active community health workers increased from 1 000 in 2018 to 8 300 in 2022. In those same years, community access to health services reportedly expanded four-fold, from nearly 240 000 households to an estimated 2 million (World Bank, 2023).

Challenges to healthcare delivery

Policies and programmes in Mozambique demonstrate the Ministry of Health's sustained effort towards strengthening basic services and enabling healthcare workers. However, key health indicators in the country are not improving at the expected rate (Table 2.1).

Table 2.1 **Key health indicators against national and global targets**

Health indicator	National level (year)	Global level (year)	PESS 2014-2019 target
Maternal mortality/1 000 live births	2.27 (2020)	2.23 (2020)	1.9 (2019)
Neonatal mortality/1 000 live births	27.5 (2021)	17.1 (2021)	23 (2019)
Infant mortality/1 000 live births	51 (2021)	26.8 (2021)	45 (2019)
Percentage of fully vaccinated children (%)	80 (2017)	86	94 (2019)
Malaria incidence/1 000 inhabitants	288 (2018)	57.2 (2019)	120 (2019)

Source: (MISAU, 2014; UNICEF, 2020; WHO, 2024b).

Despite government efforts to tackle their prevalence, in 2019 HIV/AIDS was the leading cause of death nationwide, and malaria, the leading cause among children under age five (WHO, 2024a). As of 2021, over 10% of the country's adult population was reportedly affected by HIV/AIDS – of which 200 000 were women and children. Other prevalent health issues in Mozambique include tuberculosis, diarrhoea, child malnutrition and lung infections, with neonatal problems, strokes, lung infections, heart disease and diarrhoea among the top causes for hospital admissions. Outbreaks like polio, cholera and measles highlight immunisation and surveillance gaps, worsened by disasters and displacements in the northern and central regions (Amimo *et al.*, 2021).

The health system's ability to tackle these significant challenges remains constrained for various reasons.

Service quality. As noted in PESS 2014-2019, Mozambique's healthcare infrastructure suffers from inadequacies in technology, human resources, and the supply chain for essential medicines and equipment. Supplies are understocked and facilities poorly equipped. For example, Mozambique scored 75% in a study assessing the readiness of primary healthcare to provide nutrition and diarrhoea-related services for children (Sambo *et al.*, 2022). Unreliable or altogether lacking electricity further exacerbates these issues. Only 52.5% of Mozambique's healthcare facilities meet their basic lighting needs, highlighting a need for decentralised and reliable energy solutions.

Access to infrastructure and services. Accessibility is a significant challenge; 62% of the population lives in rural areas and travels an average distance of 12 kilometres (km) to reach a healthcare facility. This travel distance varies considerably across locales – 1.6 km in Maputo City versus over 14 km in Niassa and Cabo Delgado Provinces. About 60% of the population travels on foot, often walking over an hour to access healthcare. A more decentralised healthcare delivery system is needed to bring services closer to the people.

Ratio of healthcare facilities to habitants

1:17 429

Average distance to a rural healthcare facility

12 km

Source: (MISAU, 2023).

Inadequately resourced facility staff. While efforts have been made to increase the volume of trained healthcare staff, Mozambique has only three doctors per 100 000 persons – among the lowest ratios in the world (USAID, 2021). PESS 2014-2019 highlights inadequate, unevenly distributed and underperforming staff. Sustainable energy and efficient technology would optimise staff efforts, improve service delivery and enhance the well-being of healthcare workers.

Climatic variabilities and their impact on the disease burden. Mozambique's climate significantly influences its disease patterns. Malaria and cholera are prevalent during rainy seasons, while diarrheal diseases and meningitis are more common in dry periods. The country is also prone to natural disasters like floods, droughts and cyclones, which strain health services and damage infrastructure.

Climate change and infrastructure concerns. According to the Disaster Risk Profile put forward by the Global Facility for Disaster Reduction and Recovery (GFDDR) and the World Bank, about 10% of Mozambique's education and healthcare facilities are vulnerable to cyclones and 2% are at risk from floods. According to UN-Habitat data, 95 health units, including the main hospital in Beira, were damaged or destroyed during the two cyclones that hit Mozambique in 2019. These cyclones, along with additional floods, led to the destruction of over 123 healthcare facilities, severely affecting essential health services for the population. Droughts also pose a significant threat by limiting the supply of water, which is critical for both healthcare staff and patients. Robust environmental initiatives are needed if Mozambique is to mitigate the effects of these disasters on healthcare facilities.

The following sections explore the physical infrastructure of Mozambique's health sector and dive deeper into the impact of the climate on infrastructure and, consequently, the ability to provide services.

2.2 HEALTHCARE INFRASTRUCTURE

Mozambique's public healthcare system includes 1 769 healthcare facilities, spread across the 11 provinces (Table 2.2). Most are in rural areas.

The National Health Service (NHS) has organised the healthcare system into four levels of service provision – primary, secondary, tertiary and quaternary:

The primary level (I) is the first point of contact for patients, and it is where most preventive and curative health services are provided. This level consists of rural health centres (RHCs), urban health centres (UHCs) and health posts. Almost 96% of all facilities, serving over 90% of the population, are at this level.

The secondary level (II) provides more specialised care, including diagnostic and treatment services. It generally serves more than one district. This level consists of district hospitals, general hospitals and rural hospitals.

The tertiary level (III) is focused on specialised medical care and consists of eight provincial hospitals.

The quaternary level (IV) focuses on the most complex and specialised medical care through central, specialised and military hospitals.

Table 2.2 **Number of healthcare facilities disaggregated by level and sub-level**

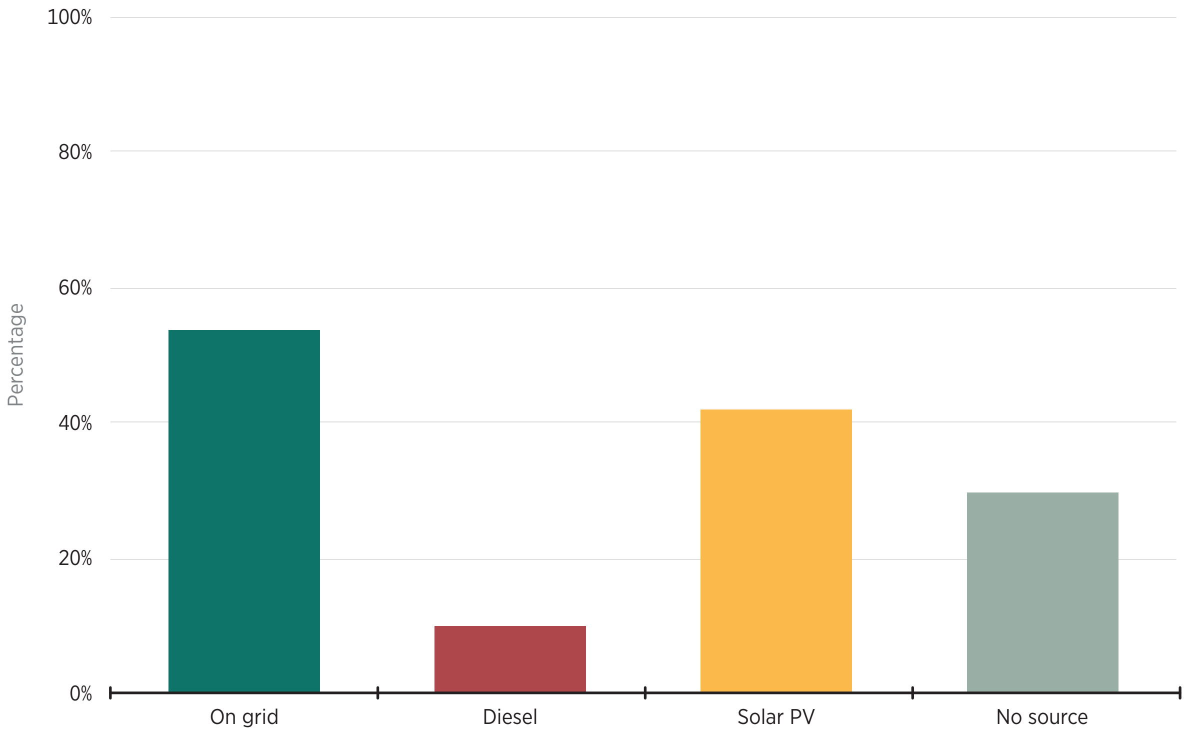
Level	Types and number of facilities at each level			Total
I	Rural health centre	Urban health centre	Health post	1 702
	1 375	191	136	
II	Rural hospital	District hospital	General hospital	53
	18	28	7	
III	Provincial hospital			7
	7			
IV	Central hospital	Specialised hospital	Military hospital	7
	4	2	1	
Grand total				1 769

At the primary level, services have been further disaggregated by need. RHCs are categorised as types 1, 2 and 3, serving different population densities and providing different services. UHCs are categorised into types A, B and C for similar reasons.

Infrastructure energy sources

As can be seen in Figure 2.1, different sources, including renewable energy in the form of solar photovoltaic (PV) systems, power Mozambique's healthcare facilities (MISAU, 2023). Facilities continue to struggle to gain adequate electricity access, even though more than 40% (727 facilities) are connected to off-grid energy systems. Too often, the operation and maintenance (O&M) of these systems are disregarded.

Figure 2.1 **Sources of electricity at Mozambique's healthcare facilities**



Notes: N = 1 671 facilities surveyed in Provincial Health Directorate Report, 2023. Facilities may have more than one source of electricity. PV = photovoltaic.

Nationally, only 55% of medical technicians servicing equipment at healthcare facilities were reportedly trained, as per indicators reported in the Service Availability and Readiness Assessment, 2018 (Sambo *et al.*, 2022).

Box 2.1 **Mozambique's energy landscape at a glance**

Mozambique is rich in energy resources (renewable and non-renewable), which it utilises to not only meet its domestic energy needs but also export to countries in South Africa and to other international markets. Despite the huge potential for generation capacity in the country, only 40% of Mozambique's population (36% on-grid and 4% off-grid) have access to electricity and more than 90% of the fossil fuels used and sold in the country are imported (African Development Bank, 2021). The low level of electrification is due to an underdeveloped power distribution network and results in high fuel imports since local fuel production is not present.

Buildings and roofing

In Mozambique, construction practices typically involve the extensive use of conventional materials like metal sheets on sloping roofs. While sloping roofs are effective in heavy rainfall regions, metal sheets can trap heat, reducing indoor thermal comfort. Also, uncoated or unfinished metal sheets are prone to rust and degradation, which compromise roofing and potentially cause damage to the facility. In cyclone-prone areas, it is crucial to reinforce roofing adequately to minimise damage.

Building resilient structures is essential to adapt to the destructive effects of climate change (*e.g.* heat stress) on patients and staff, and for optimising costs related to mitigation, recurrent repairs and retrofitting.

WASH infrastructure

Safe water supply, sanitation and hygiene (WASH) in healthcare facilities saves lives (WHO and UNICEF, 2019). Safe water in sufficient quantities is needed at healthcare facilities for various services – from basic services like drinking, cooking, hand washing and bathing, to generalised services such as reduced exposure to infections for patients and staff, and specialised services such as the water and sanitation needs of mothers in delivery and for the newborn.

Healthcare facilities often need powered water pumps to obtain the water necessary to provide services, and water heaters to provide comfort to patients. Water purifiers are also essential in areas with poor water quality.

Distributed and modular renewable energy solutions enable healthcare facilities to improve the provision of other infrastructure, for example, WASH services. Decentralised solar energy, for example, can be used as a source of reliable power for pumping water and for purification facilities, as well as to power waste management equipment such as incinerators, along with other equipment to ensure adequate WASH conditions at healthcare facilities.

BUILDING A DECENTRALISED RENEWABLE ENERGY ECOSYSTEM IN MOZAMBIQUE

To maximise the value of health facilities and reduce the distance to care, strengthening infrastructure and improving service delivery at the primary healthcare level is crucial. Healthcare services can be made significantly better and more affordable for last-mile communities if they have access to energy and to efficient medical equipment.

3.1 IMPLEMENTATION APPROACH

This chapter outlines a comprehensive approach to planning and implementing DRE in Mozambique's healthcare system; the approach is based on the work of IRENA with support from SELCO Foundation and other partners. The methodology is divided into five main stages, which may overlap. Table 3.1 details the purpose and expected outcomes of each stage. This scalable framework allows stakeholders to apply these principles to improve rural healthcare infrastructure. The goal is to offer a flexible, structured approach to strengthen healthcare systems with better energy solutions.

Table 3.1 **Approach and methodology to assess energy needs and implement renewable energy solutions across Mozambique health sector.**

#	Stage	Details and rationale
1	**Energy-health assessment**	**Outcome: A clear understanding of facilities' energy needs based on the specific health situation, disease burden and human resource capacity.** ▪ Assess local health needs and concerns, identifying, among others, gaps in the current healthcare service provision, climate-related risks and human resource capacity. ▪ Employ a participatory and consultative approach that involves stakeholders from the health and energy sectors. An understanding of a region's healthcare needs and disease burden can help design effective solutions and energy systems. Including stakeholders from both the health and energy sectors fosters a strong sense of ownership during the planning phase and ensures appropriate utilisation and maintenance after implementation.

2	**System design and costing**	**Outcome: DRE system design templates are created based on the assessment conducted, and cost quotations are obtained from local clean energy enterprises.** ▪ Design the decentralised solar system, addressing the energy gaps and future health needs/services identified through the health-energy assessment. ▪ Using these designs, estimate the indicative costs of deploying the energy system using efficient equipment. These costs should cover materials, transportation, installation, operation and maintenance. Developing the system design also provides evidence for efficiency initiatives by comparing energy systems with and without efficient medical and electrical equipment. It ensures that the system design considers, among other factors, sunlight hours, rainy days and the remoteness of the facility. Cost estimates for solar-based solutions should be obtained from at least three local clean energy enterprises.
3	**Procurement and installation**	**Outcome: Energy systems are installed following procurement guidelines that promote quality, timely after-sales service and support local entrepreneurship.** ▪ Develop procurement guidelines based on the design, incorporating efficient equipment; high-quality energy system components; and considerations for installation, maintenance and servicing.
4	**Ownership and maintenance**	**Outcome: Develop clear and tailored financial and ownership models to ensure proper maintenance and utilisation of the energy system.** ▪ Based on initial assessments and healthcare facilities' ownership structures and budgets, create an ownership model that ensures accountability for maintaining the energy system. ▪ Establish annual maintenance and servicing contracts between healthcare facilities and local enterprises, and allocate financial resources for annual maintenance and battery replacements. Institutionalising maintenance practices and fund allocation can better ensure the sustainability and effective use of the DRE system.
5	**Capacity building and training**	**Outcome: Staff are well prepared to use medical appliances for service delivery and to maintain and manage the energy system.** ▪ Train health staff and build their capacity to use medical appliances; such training and capacity building can be integrated into regular departmental skill enhancement programmes for healthcare workers. ▪ Train staff on the efficient use of energy systems, including basic troubleshooting and maintenance. ▪ Train and support local technicians for more complex maintenance and replacement tasks. This approach also enhances ownership of energy systems and plays a crucial role in improving service delivery, as healthcare workers gain greater confidence in using the equipment. Better use of energy systems through training ensures improved system performance and longer asset life.

3.2 KEY STAKEHOLDERS

Health-energy programmes are designed to support healthcare facilities in improving the delivery of services for all. Mozambique's Ministry of Health is the primary government body responsible for formulating and implementing healthcare policies within the national health system. It is important to understand how the institution is structured and what mechanisms it employs to improve primary healthcare in the country. The institutional framework of Mozambique's health sector consists of the National Health System, which further consists of the public sector, known as the National Health Service, the for-profit private sector (clinics, hospitals and private health units) and not-for-profit private sector organisations (non-governmental organisations), which work together to improve the population's health status (MISAU, 2024).

The Ministry of Health oversees several other agencies and programmes, including those listed in Table 3.2.

Table 3.2 **Services and agencies under the Ministry of Health**

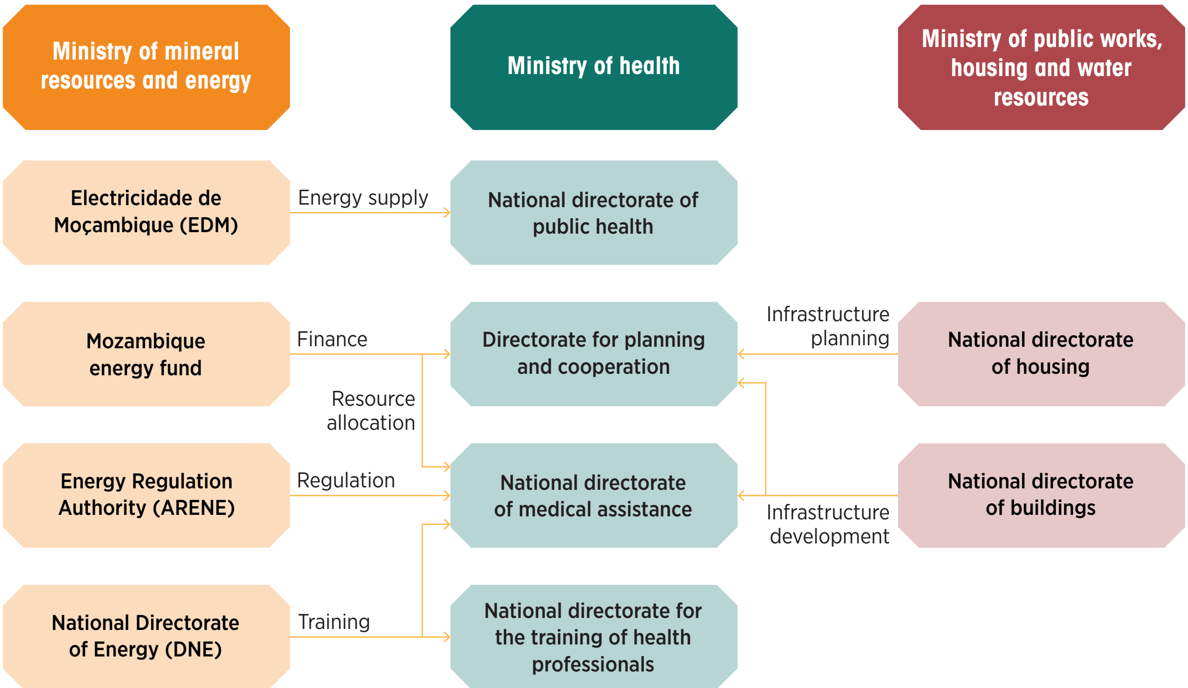
The National Institute of Health, an entity under the Ministry of Health responsible for managing, regulating and supervising activities related to the generation of scientific evidence in health to ensure better health and well-being.
11 provincial health directorates, responsible for implementing health programmes and managing healthcare facilities at the provincial level.
154 district health services, responsible for the implementation of health programmes and the management of healthcare facilities at the district level.
National Health Services, which oversee the management of central hospitals and specialised centres, and the training of health professionals.
The National Health Insurance Institute, responsible for the administration of the national health insurance programme.
The National Directorate of Medical Assistance, which provides support in improving regulatory systems and the appropriate use of medicines.
The National Directorate of Health Promotion and Disease Control, which implements disease prevention and health promotion programmes.
The National Directorate of Human Resources for Health, responsible for the training and management of health professionals.

Co-ordinating efforts to electrify healthcare facilities

The Ministry of Health works with other key government departments to plan and deliver energy and energy programmes to healthcare facilities in the country. The Ministry of Mineral Resources and Energy is the nodal department for energy supply to households and public infrastructure in Mozambique, and the Ministry of Public Works, Housing and Water Resources is responsible for infrastructure planning and delivery, including for the country's health infrastructure.

Figure 3.1 shows the key departments that are important to health-energy programmes and outlines the existing interministerial structures, flows and convergences that provide opportunities for future programmes.

Figure 3.1 **Organisational structure and overlap of key ministries for energy-health programmes**



Overlap with the Ministry of Mineral Resources and Energy

The National Directorate of Public Health at the Ministry of Health partners with Electricidade de Moçambique, a state-owned energy company dealing with electricity generation, transmission, distribution and sales, to ensure reliable electricity access for public healthcare facilities, which is vital for their operation. Simultaneously, the National Directorate of Medical Assistance works alongside the Regulatory Authority for Energy to co-ordinate energy standards and regulations affecting medical equipment and facilities, ensuring compliance with necessary energy requirements.

The National Directorate for the Training of Health Professionals collaborates with the National Directorate of Energy on training programmes that emphasise energy efficiency and the management of healthcare facilities (Ministry of Mineral Resources and Energy, 2024).

Role of the Ministry of Public Works, Housing and Water Resources in health-energy programmes

The Directorate for Planning and Co-operation plays a central role in co-ordinating planning and development for healthcare infrastructure. It aligns projects with the needs of health services. Additionally, the National Directorate of Medical Assistance partners with the National Directorate of Buildings to oversee the construction and maintenance of healthcare facilities, ensuring they adhere to health standards and are suitably equipped for medical assistance (MISAU, 2024). Further, the National Directorate of Housing works with the Directorate for Planning and Co-operation to integrate healthcare infrastructure planning with housing projects, supporting the overall delivery of health services (MPWHWR, 2024).

Mozambican Energy Fund (FUNAE)

FUNAE is the public institution responsible for rural off-grid electrification. It had electrified 580 schools, 74 administrative posts and 561 health centres in 260 villages as of March 2019. FUNAE prioritised solar electrification of schools and health centres in off-grid areas.

In December 2021, FUNAE and the João Ferreira dos Santos Group initiated the "Ilumina Saúde" project in Cuamba, Niassa, to benefit over 2 000 families with a budget of MZN 116 million The project is part of Mozambique's 2020-2024 goal to electrify all administrative posts, in alignment with the National Health Programme and UN directives for rural health electrification to improve disease response, including COVID-19 campaigns.

The "Ilumina Saúde" project starts with the electrification of the Muthaco Health Centre, in the Administrative Post of Lúrio, District of Cuamba, Niassa province, and foresees the electrification of the headquarters of the Administrative Posts of Gomba and Matondovela, District of Mecula, through the construction of solar photovoltaic stations with 40-60 kilowatts peak (KWp) of installed capacity over the two-year term of the memorandum of understanding between FUNAE and the JFS Group.

3.3 POTENTIAL IMPACTS OF DRE ON HEALTH OUTCOMES

If planned to account for all ecosystem components, integrating renewable energy for improved healthcare has multiplying impacts at the level of the patient, facility and system.

Patient-level impacts

- **Timely and reliable access to healthcare facilities.** DRE solutions improve healthcare; they enable 24/7 access to quality care for communities and reduce mortality rates.
- **Improved utilisation of healthcare services.** Efficient and resilient structures result in a higher percentage of the population utilising healthcare services.
- **Improved maternal and childcare services.** Strengthened healthcare facilities result in greater vaccination coverage, early detection of high-risk pregnancies and overall improved well-being. Inadequate services, such as a lack of fans during summer, discourage mothers from staying in facilities after delivery. Better climate control, greater bed capacity, improved toilet facilities and better amenities for mothers and attendants during recovery are crucial for encouraging institutional deliveries and ensuring access to essential maternal and child services.
- **Reduced "out of pocket" expenditure.** Greater access to healthcare closer to home reduces financial strain by minimising travel expenditures.
- **Greater patient safety and well-being.** Reliable electricity in healthcare facilities improves patient safety and well-being through consistent lighting, ventilation and phone charging. DRE guarantees uninterrupted essential services, creating a safer and more supportive recovery environment.

Facility-level impacts

- **Staff well-being and productivity.** Reliable electricity improves the work environment at healthcare facilities through greater comfort, safety and access to essential equipment. In turn, service delivery becomes more efficient and staff productivity increases. Improved facilities boost job satisfaction and confidence, especially in remote areas, in turn increasing staff retention.
- **Financial savings for healthcare facilities due to clean energy.** The adoption of DRE solutions can reduce energy expenses by eliminating the need for grid electricity and diesel. Also, reduced electricity disruption minimises fluctuation of and damage to equipment.
- **Reduction in health appliance damages.** Reliable electricity improves service quality, reducing waste and extending operational hours.
- **Reduced waste of medicine and vaccines.** DRE-powered refrigeration minimises spoilage by maintaining a consistent, appropriate temperature. This ensures vaccines and medications remain efficacious and reduces waste.

System-level impacts

- **Cost-effective electrification.** Off-grid systems avoid the high costs associated with grid extension. Solar energy has been the cheapest source of energy in recent years.
- **Improvements in societal/community health outcomes.** Energy solutions and efficient environments and structures can reduce risks in the delivery of maternal and childcare services at healthcare facilities, and improve national health outcomes, thus helping achieve sustainable development targets. About 41% of Mozambique's healthcare facilities with solar installations reported overall improvement in services, having made a significant transition from no electricity access to being fully powered.
- **Increased savings and reduction in the public cost burden.** Implementing energy-efficient measures at hospitals can help these institutions save 10-20% on energy consumption, in turn generating substantial economic benefits with short payback periods for upgraded equipment.
- **Independence from carbon-based fuels.** Adopting decentralised, sustainable energy systems can lessen the environmental impact by reducing emissions from conventional, carbon-intensive energy sources like diesel.
- **Job creation/local entrepreneurship.** Solar energy solutions can create job opportunities and promote local entrepreneurs by involving local enterprises in system design, implementation and maintenance. Similarly, local architects, engineers and contractors can be involved in the design and construction of climate-adaptive and resilient structures for healthcare facilities.

04 ROADMAP FOR HEALTHCARE POWERED BY DECENTRALISED RENEWABLE ENERGY

A crucial step in designing robust and sustainable DRE interventions is ensuring that the technology responds to felt needs. Optimising an energy system design to account for all site-specific conditions requires understanding facility-level problem statements related to energy, infrastructure, service delivery and staff comfort.

IRENA, with support from the SELCO Foundation and Greenlight Africa, undertook an assessment of public healthcare facilities in Mozambique as part of designing a roadmap and recommendations for a reliable energy delivery system in the country. The assessment covered a sample of 40 public healthcare facilities in the country and sought to:

1. Help build a comprehensive understanding of the health-energy ecosystem in Mozambique, including, among other key indicators, the energy consumption of public health infrastructure, and its effect on patient care and service delivery.

2. Gather key information on the energy needs at different levels of public health infrastructure across varying contexts in Mozambique to further plan an evidence-based health-energy programme suited to the country's needs.

3. Design modular DRE systems that meet differentiated load requirements and the needs of all primary healthcare facilities.

4. Estimate the investment required to implement robust DRE-enabled health system models in Mozambique.

5. Identify gaps and opportunities for the skill development of healthcare staff so they can operate and maintain DRE systems at healthcare facilities.

6. Recommend pathways for sustainability, a key consideration of any health-energy programme in Mozambique.

Because 96% (1 702) of Mozambique's healthcare facilities are at the primary level (Level I of the four-tiered health delivery system), the study focused on understanding the needs at the primary delivery level and designing corresponding robust DRE solutions. Of the existing Level I facilities, 88.8% (1 511) are rural health centres and health posts (to be upgraded as rural health centres), and 11.2% (191) are urban health centres. All types of facilities and variations among them were considered for the purpose of providing the designs.

The assessment included the key steps outlined in Table 4.1.

Table 4.1 **Key steps of assessment process**

Step 1	• In-depth understanding of the health-energy landscape through primary consultations and secondary findings
Step 2	• Selection of a sample for collecting primary data
Step 3	• Training of local health-energy personnel in collecting data
Step 4	• On-ground assessment of all types of primary healthcare facilities
Step 5	• Decentralised renewable energy (DRE) solution designs and cost estimates
Step 6	• Developing DRE-based recommendations for the health-energy ecosystem

4.1 HEALTH-ENERGY ASSESSMENT METHODOLOGY

A mixed-methods approach

The assessment sought to build a foundational understanding of the overall health-energy nexus in Mozambique and included an in-depth secondary literature review of documents and information from the health and energy departments, as well as other valid information sources.

Primary data were collected for further validation, and key stakeholders were consulted on key aspects of programme finance and ownership based on existing structures and past programme learning, system design, technical capacity, training modalities, O&M processes and key policy levers for health-energy programmes. The stakeholder consultations were conducted to build an in-depth understanding of the health-energy landscape in Mozambique.

The assessment also included energy audits via physical observations of facilities and interviews with healthcare staff. The audits, conducted with an aim to understand the site-level energy needs of Mozambique's public healthcare infrastructure, were a means to obtain qualitative insights from healthcare providers' experiences under varying contexts.

Study sample

To ensure the assessment represented Mozambique's primary healthcare infrastructure, 40 sample facilities across different types were assessed.

Table 4.2 **Number and type of primary healthcare facilities assessed**

Primary healthcare facility type	No. sampled
RHC Type I	10
RHC Type II	26
UHC Type A	1
UHC Type B	3
Total	**40**

Notes: RHC = rural health centre; UHC = urban health centre.

The sample covered 6 of the 11 provinces, namely, Manica, Nampula, Niassa, Sofala, Tete and Zambezia. These represent 25 districts across the country. The choice of provinces captures variances in healthcare facilities' needs and subsequent design requirements shaped by the region's geographic, climatic and demographic characteristics. A list of the sampled facilities and their details are provided in Annex 1. The following selection criteria were used:

- Primary healthcare facilities representing all levels
- Geographic variances and spread of facilities
- Status of electrification and sources of energy
- Facility footfall or the number of patients visiting the facility

Types and numbers of respondents, and the tools used to collect data for the assessment are outlined in Table 4.3.

Table 4.3 **Overview of respondents and consultation tools**

Respondent type	Respondent (no.)	Reason for selection	Tools used
Facility-level staff: nurses, doctors, electricians, facility administrators, pharmacists	40	To understand the facility-level energy needs and how energy impacts the health staff's experiences in delivering services.	✓ Facility observation checklist ✓ Key informant interview guide
Local DRE component suppliers	4	To obtain realistic cost estimates of DRE components to ensure their appropriate representation.	✓ Secondary literature review
Ministry of Health, Ministry of Energy, Ministry of Infrastructure and bilateral organisations in the country		To obtain key documents offering insights into the status of health and energy in the country, as well as information on any ongoing programme.	✓ In-depth desk review
Healthcare facility	40	To assess the energy needs of different types of healthcare facilities through energy audits.	✓ Observation checklist

Note: DRE = decentralised renewable energy.

The key findings from in-depth secondary analysis, consultations and facility observations are summarised as follows.

Key findings from the health-energy assessment

Unreliable power supply. Respondents reported prolonged electricity supply interruptions at facilities – 4 hours on average, with some facilities experiencing interruptions lasting up to 18 hours at a time. The need for reliable energy systems was further highlighted by the finding that respondents from over 25% of the 26 RHC Type II facilities surveyed reportedly provide services during power outages, including having to deliver babies by torchlight at night. Thirty of the 40 sampled sites were found to be without any backup energy source. Facilities that had backup sources primarily relied on diesel generators – which are a financial strain on healthcare facilities and have adverse impacts on the environment.

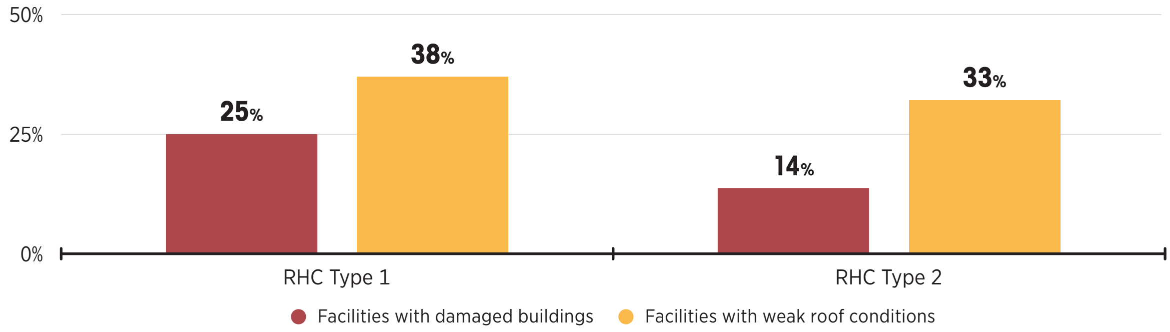
Absence of grid infrastructure. About 46% of the healthcare facilities are not grid connected and completely rely on diesel or solar PV for electricity. Eighty-six percent of the off-grid facilities were RHCs, located in rural areas and providing health services for two-thirds of Mozambique's population.

An unreliable existing grid infrastructure. The inadequate grid supply hampers service delivery. Twenty-five percent of the respondents noted that voltage fluctuations caused facility equipment like water pumps, photocopiers and computers to break down or sustain damage, in turn impeding the delivery of safe sanitation and basic administrative and diagnostic services. Healthcare staff reported the adverse effects of electricity disruptions on in-patient services, emergency care, laboratory services and post-natal care services.

Impact of climate on service delivery. Approximately 57.5% of respondents stressed that cyclones, strong winds and floods commonly affect service delivery.

Structural quality of facilities. Respondents reported some physical infrastructure as being in poor condition (Figure 4.1). Disaster-induced damages also have a financial component, which needs to be considered to ensure proper and reliable functioning over the long term.

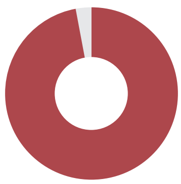
Figure 4.1 **Percentage of healthcare staff reporting damaged buildings and roofs**



Source: Primary interviews.
Notes: RHC Type I, 10; RHC Type II, 26. RHC = rural health centre.

WASH conditions at healthcare facilities. Only 60% of primary healthcare facilities have a functional water supply (WHO, 2013).

Percentage of sampled facilities with no water supply[2]
(N = 40, all sampled facilities)
42%



Percentage of sampled facilities with no water heating facility
(N = 40, all sampled facilities)
97%

Respondents in the primary interviews reported a lack of basic WASH facilities at both rural and urban primary healthcare centres. Nearly half of the RHC Type II facilities, which serve the bulk of Mozambique's rural and remote population, lack a source of water supply. This severely affects these facilities' ability to provide delivery and post-natal care services, since delivery equipment requires sterilisation, and mothers require hot water to bathe after giving birth.

Current DRE systems do not meet basic needs. In the 40 primary healthcare facilities surveyed, 47% of facility staff reported that the existing renewable energy system did not meet the facilities' basic lighting needs. Additionally, 87% of respondents indicated that they experienced some issues with the system. Of the concerns reported by respondents, 77% were at RHC Type II facilities, which are crucial for providing vaccination, maternity and outpatient services to rural communities. This is reportedly due to a lack of funds for maintenance and an insufficient number of appropriately skilled technicians to make the necessary repairs. This highlights a need for comprehensive health-energy assessments to identify specific end-user needs before deploying energy systems. Cases of theft of solar panels were also reported as reasons for dissatisfaction.

[2] *Primary data collected for 40 primary healthcare facilities as part of the health-energy assessment.*

Battery quality. It was observed that batteries across sites were non-functional. This significantly contributes to the short lifespan of PV systems in Mozambique. A clean energy enterprise owner pointed out that "the public sector lacks the financial resources to replace these battery banks, which last fewer years, and lacks the capacity to recycle them properly, creating severe environmental hazards".

4.2 SOLAR ENERGY SYSTEM DESIGNS FOR PRIMARY HEALTHCARE

Informed by the energy requirements and energy use at each type of facility surveyed, the assessment recommends a set of modular solar PV solutions based on certain design parameters and assumptions. Multiple options for system designs were considered, based on several factors that have a bearing on the energy system (*e.g.* availability and quality of grid infrastructure, and critical loads that require powering at facilities). The design options for each level of primary healthcare facility (RHC Type I, RHC Type II, UHC Type A, UHC Type B, UHC Type C), along with the design parameters and assumptions, are presented below.

Table 4.4 **Energy system design considerations**

Specifics of healthcare facility	Load specification	System design consideration
▪ Healthcare facility level ▪ Number of rooms ▪ Services delivered ▪ Future growth needs ▪ Safety and well-being needs	▪ Standard design with typical operational hours ▪ Critical and non-critical loads ▪ Climatic disaster	▪ Peak sunshine hours ▪ Days of autonomy ▪ Depth of discharge ▪ Energy efficiency of equipment

Solar energy system design parameters

The overarching factors considered in the design process are summarised in Table 4.4.

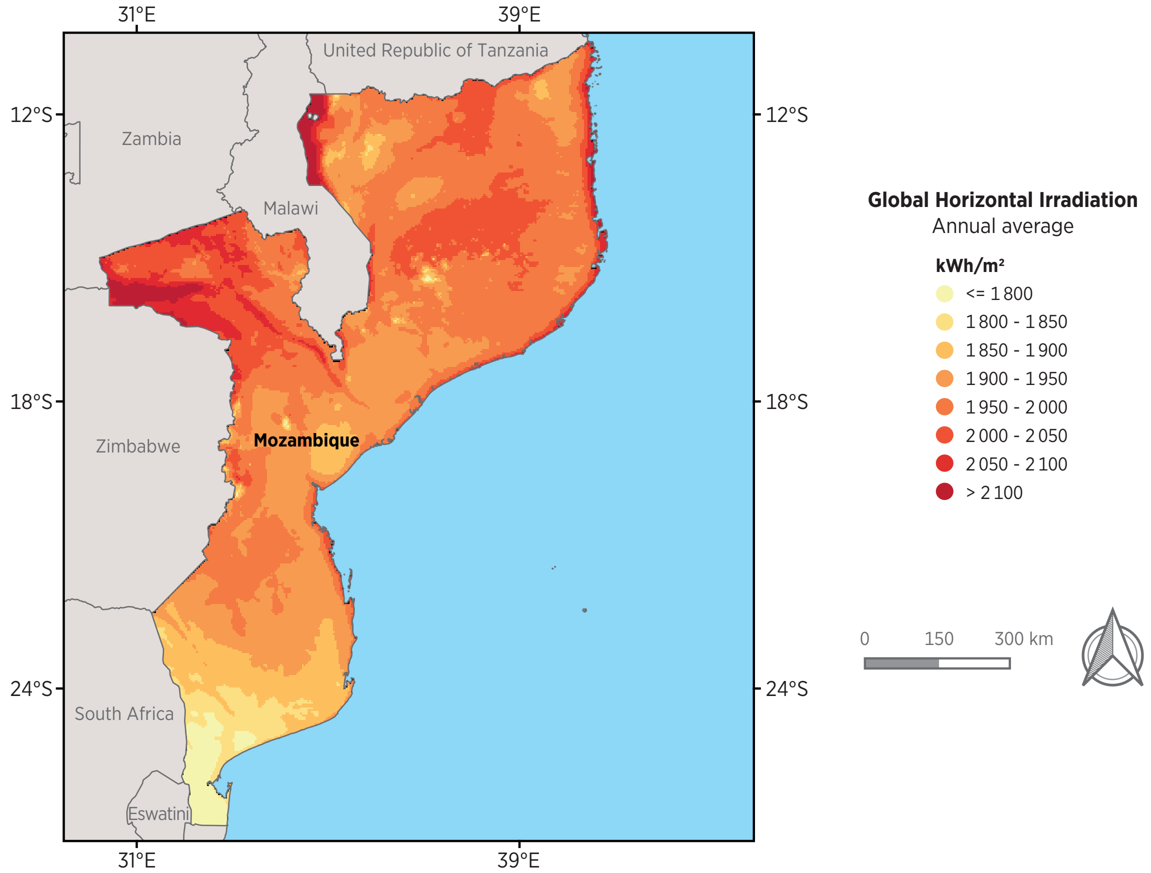
Solar energy system design assumptions

Several key assumptions underlie the design parameters for each solar energy system's main components: solar panels, batteries and inverters. These assumptions serve as a foundation for analysing the integration of DRE into the healthcare system. While this analysis provides a general framework, it is important to note that customised designs are recommended for specific geographical areas within the country, considering local conditions and more detailed requirements.

Solar irradiation

Solar irradiation represents the amount of solar energy received at a given location. This is important since it affects how much solar energy the panels are able to absorb. Mozambique receives annual average direct normal irradiance (DNI) of around 4.05-5.51 kilowatt hours per square metre per day (kWh/m^2/day), and the average global horizontal irradiance (GHI) of around 4.77-5.87 kWh/m^2/day (IRENA Global Atlas, 2024). GHI is the appropriate parameter for calculating electricity yield and evaluating the performance of flat-plate PV technologies. For the purposes of the assessment, sunshine hours are assumed to be 4.5 hours (as per DNI) based on Mozambique's geographical location and climatic conditions in the tropical region, as shown in Figure 4.2.

Figure 4.2 **Mozambique average annual global horizontal irradiation**



Sources: (IRENA, 2024; ESMAP 2019).

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

Days of autonomy

Autonomy is the length of time a battery bank can support a specific load without charging. It is a value used to measure battery reserve capacity and system reliability. Autonomy enables a system to perform as required even under cloudy conditions for the specified duration and enhances battery life (depth of discharge [DOD] versus cycle life). For **RHC types I and II, two-day autonomy has been considered, enabling them to remain resilient to power outages during cloudy days.**

Considerations for solar PV panels

The required solar PV panel wattage is calculated using the electricity needed to operate the connected load; the available sunshine hours; and other parameters including battery charging efficiency, load efficiency and dust factor (Table 4.5). The calculation for PV panels is as follows:

Panel wattage required = (total electricity required [Wh]) / (sunshine hours x battery charging efficiency x load efficiency x dust factor) (Assumption in Table 8)

Considerations for batteries

The battery or the energy that must be stored is determined by the total energy required to operate the connected load, its efficiency, the days of autonomy considered and the battery DOD. Lithium phosphate ($LiPO_4$) batteries are considered for the design. In contrast, lithium iron phosphate ($LiFePO_4$) batteries offer clear technical advantages over lead-acid batteries, including high charge/discharge capabilities, a DOD of 3 000 cycles, 90% usable capacity and a lifespan of up to ten years when managed properly. Additionally, $LiPO_4$ batteries have an energy density of approximately 130-140 watt hours per kilogramme (Wh/kg) – four times the typical lead-acid battery density of 30-40 Wh/kg. The high energy density means portable power stations using $LiFePO_4$ batteries weigh less, which significantly reduces logistical costs (EcoFlow, 2023). The calculation for batteries is as follows:

Battery capacity required = (days of autonomy x total load [Wh]) / (load efficiency x system voltage x DOD x discharging efficiency)

Solar inverters

Solar inverters are chosen based on the power consumption and the type of the connected load, the capacity of the solar PV system and the voltage of the battery bank.

Table 4.5 **Assumptions for solar energy system design**

Battery type	$LiPO_4$
Load efficiency	80%
Charging efficiency	90%
Dust factor	90%
Discharging efficiency	90%
DOD	90%
Temperature co-efficient	90%
Autonomy	2 days
Sunshine hours (h)	4.5

Notes: DOD = depth of discharge; h = hours; $LiPO_4$ = lithium phosphate.

Existing loads at primary healthcare facilities in Mozambique

An understanding of the differentiated energy needs at Level I is essential to be able to design to meet those needs. Such a design will depend on the level and type of infrastructure providing specific services. In Mozambique, Type I RHCs serve a larger population and offer a wider range of services, including specialised rooms for maternal care and lab services, whereas Type II RHCs cater to a smaller population and provide basic health services and essential facilities (Table 4.6).

Table 4.6 **Key services of Mozambique's two types of rural health centres**

Type I rural health centre	Type II rural health centre
Population served: 16 000-35 000	**Population served:** 7 500-20 000
Location: District headquarters	**Location:** Less densely populated areas
Key services:	**Key services:**
▪ External service zone with MCH/immunisation exit ▪ General medicine, adult and child screening ▪ Small laboratory, treatment room, pharmacy ▪ Maternity unit: Admission, observation, dilation and delivery rooms, postpartum ward (10-18 beds) ▪ In-patient block, nursing station, sterilisation area ▪ Changing rooms, sanitary facilities, kitchen, laundry, warehouse, mortuary ▪ Water and electricity supply, waste treatment, secure fencing	▪ MCH/immunisation, general medicine consultation ▪ Treatment room, small medicine storage, waiting area ▪ Maternity: Delivery room, postpartum ward (three beds) ▪ Peripheral: Staff and public restrooms, water and energy supply, fence, waste disposal area

Source: (MISAU, 2021).
Note: MCH = maternal and child health.

Type A UHCs serve large urban populations (40 000-100 000) with comprehensive services including specialised consultation rooms, a full range of medical facilities and extensive support infrastructure. Type B UHCs cater to moderately populated urban areas (18 000-48 000) with a wide range of medical services and essential management and peripheral facilities. Type C UHCs serve smaller urban populations (10 000-25 000) and provide basic medical care, have treatment rooms, and the necessary infrastructure for patients' and staff's needs (Table 4.7).

Table 4.7 **Key services of Mozambique's three types of urban health centres**

<table>
<tr><th>Type A urban health centre</th><th>Type B urban health centre</th><th>Type C urban health centre</th></tr>
<tr><td>Population served:
40 000-100 000</td><td>Population served:
18 000-48 000</td><td>Population served:
10 000-25 000</td></tr>
<tr><td>Location:
Urban areas</td><td>Location:
Densely populated urban zones</td><td>Location:
Towns or sparsely populated city areas</td></tr>
<tr><td>Key services:</td><td>Key services:</td><td>Key services:</td></tr>
<tr><td>▪ Pre/post-natal services and family planning</td><td rowspan="3">▪ External service area: MCH/immunisation, general medicine consultation, screening spaces, dentistry room, laboratory, treatment room, medicine storage
▪ Patient waiting room for referrals (2 beds)
▪ Management spaces, peripherals: Sanitary facilities, warehouse, water and electricity supply, fencing, waste disposal area</td><td rowspan="3">▪ MCH/immunisation, general medicine consultation, treatment room
· Small medicine storage, patient waiting room for referrals (1-2 beds)
▪ Peripherals: Sanitary facilities, water and energy supply, fence, waste disposal area</td></tr>
<tr><td>General medicine consultation</td></tr>
<tr><td rowspan="5">▪ Waiting room along with a clinical archive
▪ Dentistry-stomatology offices with ≥3 chairs
▪ Sterilisation area
▪ Laboratory
▪ X-ray room with darkroom
▪ Tuberculosis and leprosy care
▪ Pharmacy, medicine warehouse
▪ Patient waiting room for referrals (2-3 beds)
▪ Sanitary facilities for public and staff (incl. changing rooms)
▪ Small warehouse
▪ Water and electricity supply systems, fencing, possibly covered passages between buildings, waste treatment areas (landfills/incinerator/pit)</td></tr>
<tr><td colspan="2">Maternity unit (attached to Type B/C urban centres)</td></tr>
<tr><td colspan="2">Population served: 20 000-60 000</td></tr>
<tr><td colspan="2">Key services:</td></tr>
<tr><td colspan="2">▪ Admission and observation room, dilation room (2 beds), delivery room (2 labouring women capacity)
▪ Postpartum ward (8-12 beds), nursing station, waiting area</td></tr>
</table>

Source: (MISAU, 2021).
Note: MCH = maternal and child health.

Solar system design options

To best represent the facility types and requirements in the country, DRE system design templates have been developed for the types of healthcare facilities and loads outlined in Table 4.8.

Table 4.8 **Design considerations for solar systems by RHC type**

Type of facility	Solar as the primary energy source
Rural health centre Type I	✓ All loads ✓ Critical loads
Rural health centre Type II	✓ All loads ✓ Critical loads

DRE solution specifications depend on the services provided. DRE solutions can be utilised as the primary energy source or as a backup energy source. If the primary objective of providing reliable and cost-effective energy infrastructure is to ensure reliable health services, then a backup system should be chosen only when funds are constrained and when healthcare facilities have a good-quality grid connection (*i.e.* consistent power across seasons, and low voltage fluctuation, making it possible to use multiple pieces of medical equipment at once). To summarise:

- Primary systems are DRE-based systems that cover loads for the operational hours of a healthcare facility, that is, solar energy is the primary energy source for the healthcare facility. It is to be noted that a facility may be grid connected and can rely on the grid during system downtime.
- Backup systems are designed considering the grid as the primary energy source, and solar energy serves as a backup for a set time duration (*i.e.* three hours of grid power outage).

Healthcare facility loads may differ based on the facility type and the services it provides. For the primary system solution, two design options have been considered in rural areas (as detailed in Box 4.1) and two options in urban areas (Box 4.2).

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Box 4.1 **Examples of primary energy system design options in rural facilities**

<table>
<tr><td rowspan="7">Option A</td><td>This option considers multiple services being offered, as per the facility mandate. The services have been categorised as life-saving critical services, and other services that improve healthcare delivery. Critical equipment with higher energy requirements, such as labour room equipment, laboratory rooms, vaccine fridges and other equipment, have been considered.</td></tr>
<tr><td>All loads for Type I health centres:</td></tr>
<tr><td>Rooms: External service zone – entrance + immunisation room + outpatient department (OPD) + laboratory + treatment room + pharmacy/medical storage + waiting area

Maternity unit: Admission room + observation and nursing station + dilation and delivery room + post-delivery ward

In-patient block: Male ward + female ward + nursing station + treatment room + sterilisation area

Others: Changing rooms + small kitchen + toilets + small warehouse</td></tr>
<tr><td>Loads: 18 light-emitting diode (LED) tube lights + 6 LED bulbs + 3 ceiling/wall/pedestal fans + 1 baby warmer + 1 suction machine +1 blood count device + 1 biochemistry unit + 1 GeneXpert device + 1 phototherapy unit + 1 centrifuge + 1 microscope + 1 fridge + 1 desktop + 1 printer + 4 mobile charging points</td></tr>
<tr><td>All loads for Type II health centres:</td></tr>
<tr><td>Rooms: Entrance + waiting area + OPD + medicine storeroom/pharmacy + treatment room + immunisation room + male ward + female ward + toilet + maternity room</td></tr>
<tr><td>Loads: 3 ceiling/wall/pedestal fans + 8 LED bulbs + 5 LED tube lights + 1 baby warmer + 1 suction machine + 1 fridge + 1 printer + 1 desktop + 1 fridge + 4 mobile charging points</td></tr>
<tr><td rowspan="7">Option B</td><td>This option includes basic loads, administrative equipment like desktops and printers, and common equipment required to serve the population at large, for example, fridges. This intermediate design option is applicable only for Type II RHCs without maternity equipment and Type I RHCs without a laboratory.</td></tr>
<tr><td>Critical load for Type I health centres:</td></tr>
<tr><td>Rooms: External service zone: Entrance + immunisation room + OPD + treatment room + pharmacy/medical storage + waiting area

Maternity unit: Admission room + observation and nursing station + dilation and delivery room + post-delivery ward

In-patient block: Male ward + female ward + nursing station + treatment room + sterilisation area

Others: Changing rooms + small kitchen + toilets + small warehouse</td></tr>
<tr><td>Loads: 1 baby warmer + 3 ceiling/wall/pedestal fans + 6 LED bulbs + 17 LED tube lights + 4 mobile charging points + 1 phototherapy unit + 1 suction machine + 1 desktop + 1 printer + 1 fridge</td></tr>
<tr><td>Critical load for Type II health centres:</td></tr>
<tr><td>Rooms: Entrance + waiting area + OPD + medicine storeroom + treatment room + immunisation room + male ward + female ward + toilet + maternity room (with basic load)</td></tr>
<tr><td>Loads: 3 ceiling/wall/pedestal fans + 8 LED bulbs + 5 LED tube lights + 4 mobile charging points + 1 desktop + 1 printer + 1 fridge</td></tr>
</table>

Box 4.2 **Examples of primary energy system design options in urban facilities**

Option A	This option considers multiple services being offered, as per the facility mandate. The services have been categorised as life-saving critical services, and other services that improve healthcare delivery.
	All loads for Type A UHCs
	Rooms: Entrance + waiting area + pre-natal room + post-natal room + OPD + Children's OPD + maternal and child health (MCH)/nurse room + MD consultation + immunisation room + treatment room + pharmacy + admission room + waiting room + medical care/nursing room + maternity + post-delivery ward + male ward + female ward + nursing station + treatment room + ultrasound room + laboratory + dental room + X-ray room + dark room **Other rooms:** Changing rooms + small kitchen + toilets + small warehouse + outside entrance **Loads:** 1 analytical balance + 1 automatic analyser + 2 baby warmers + 1 biochemistry unit + 1 blood count device + 1 CD4 analyser + 34 ceiling/wall/pedestal fans + 1 centrifuge + 1 dental chair with compressor + 1 desktop + 1 echograph/ultrasound + 1 fridge + 2 focus lights + 1 GeneXpert device + 1 haematology analyser + 13 LED bulbs + 42 LED tube lights + 1 microscope + 2 mobile charging points + 1 printer + 1 oxygen concentrator + 1 phototherapy unit + 1 portable X-ray machine + 1 sample shaker + 1 suction machine + 1 RX device + 1 X-ray viewer
	All loads for Type B UHCs
	Rooms: Entrance + waiting area + OPD + immunisation room + treatment room + pharmacy + admission room + medical care/nursing room + maternity + post-delivery ward + laboratory + dental room **Other rooms:** Changing rooms + small kitchen + toilets + small warehouse + outdoor entrance **Loads:** 1 analytical balance + 1 automatic analyser + 1 baby warmer + 13 ceiling/wall/pedestal fans + 1 centrifuge + 1 dental chair with compressor + 1 desktop + 1 fridge + 2 focus lights + 1 haematology analyser + 12 LED bulbs + 19 LED tube lights + 1 microscope + 2 mobile charging points + 1 printer + 1 oxygen concentrator + 1 phototherapy unit + 1 sample shaker + 1 suction machine
	All loads for Type C UHCs
	Rooms: Entrance + waiting area + OPD + medicine storeroom + treatment room + immunisation room + male ward + female ward+ toilet + maternity room **Loads:** 1 baby warmer + 3 ceiling/wall/pedestal fans + 1 desktop + 1 fridge + 8 LED bulbs + 5 LED tube lights + 2 mobile charging points + 1 printer + 1 oxygen concentrator + 1 suction machine

Option B	This option includes basic loads, administrative equipment like desktops and printers, and common equipment required to service the population at large. It focuses on critical services, and equipment with higher energy requirements, such as labour room equipment, laboratory rooms and vaccine fridges.
	Critical loads for Type A UHCs
	Rooms: Entrance + waiting area + pre-natal room + post-natal room + OPD + children's OPD + MCH/nurse room + MD consultation + immunisation room + treatment room + pharmacy + admission room + waiting room + medical care/nursing room + maternity + post-delivery ward + male ward + female ward + nursing station + treatment room + ultrasound room + laboratory + dental room + X-ray room + dark room **Other rooms:** Changing rooms +small kitchen + toilets + small warehouse + outside entrance **Loads:** 2 baby warmers + 33 ceiling/wall/pedestal fans + 1 desktop + 1 fridge + 2 focus lights + 11 LED bulbs + 36 LED tube lights + 2 mobile charging points + 1 printer + 1 oxygen concentrator + 1 phototherapy unit + 1 suction machine
	Critical loads for Type B UHCs
	Rooms: Entrance + waiting area + OPD + immunisation room + treatment room + pharmacy + laboratory **Other rooms:** Changing rooms + small kitchen + toilets + small warehouse + outdoor entrance **Loads:** 1 analytical balance + 1 automatic analyser + 7 ceiling/wall/pedestal fans + 1 centrifuge + 1 desktop + 1 fridge + 2 focus lights + 1 haematology analyser + 11 LED bulbs + 12 LED tube lights + 1 microscope + 2 mobile charging points + 1 printer + 1 oxygen concentrator + 1 sample shaker
	Critical loads for Type C UHCs
	Rooms: Entrance+ waiting area + OPD + medicine storeroom + treatment room + immunisation room + male ward + female ward+ toilet + maternity room **Loads:** 2 ceiling/wall/pedestal fans + 1 desktop + 1 fridge + 8 LED bulbs + 4 LED tube lights + 2 mobile charging points + 1 printer

Solar system design templates: **Rural health centres**

Based on the findings of the health-energy assessment and assumptions presented, Table 4.9 outlines the design templates recommended for RHCs using DRE as their primary energy source. **Design specifications account for the difference in services offered by Type I and Type II RHCs.**

Table 4.9 **Load considerations and DRE system design for rural health centres**

Healthcare facility type	Design approach	System type	Total load (W)	Total units (Wh/day)	Solar panel (kWp)	$LiPo_4$ solar battery (Ah) @ 12.8 V (min capacity)	Battery capacity (kWh)	Solar inverter (kVA)
Type I RHC	Option 1 – all load	Primary system	7 680	27 600	11	3 500	44.8	15
		Backup system		16 325	7	2 000	25.6	10
	Option 2 – critical load	Primary system	4 322	22 239	9	2 800	35.84	12.5
		Backup system		14 367	6	1 800	23.04	10
Type II RHC	Option 1 – all load	Primary system	2 358	8 334	3.2	1 000	12.8	5
		Backup system		5 373	2.5	650	8.32	4
	Option 2 – critical load	Primary system	898	5 024	2	600	7.68	3
		Backup system		2 743	1	350	4.48	2

Notes: Ah = ampere hour; DRE = decentralised renewable energy; kVA = kilovolt ampere; kWh = kilowatt hour; kWp = kilowatt peak; $LiPo_4$ = lithium phosphate; RHC = rural health centre; V = volt; W = watt; Wh = watt hour.

Type I RHC

Powering all loads. According to the designs outlined in Table 4.9, individual Type I RHCs would need 11 kWp of solar panel capacity, 44.8 kWh of battery capacity and a 15 kilovolt ampere (kVA) inverter if they consider using DRE as their primary energy source during operational hours. This would include supporting maternity, laboratory and dental services.

Powering critical loads. If the priority is to power only the critical loads of a healthcare facility, specifically maternity and emergency services, then individual facilities would need 9 kWp of solar panel capacity, 35.84 kWh of battery capacity and a 12.5 kVA inverter.

DRE as a backup energy source. Individual facilities would need 7 kWp of solar panel capacity, 25.6 kWh of battery capacity and a 10 kVA inverter if they consider DRE as a backup solution to support **all loads**.

To support critical loads, individual facilities would need 6 kWp of panel capacity, 23.04 kWh of battery capacity and a 10 kVA inverter.

Type II RHCs

Powering all loads. As per the designs outlined in Table 4.9, a Type II RHC with a regular load would need 3.2 kWp of panel capacity, 12.8 kWh of battery capacity and a 5 kVA inverter to power all equipment for the full operational hours.

Powering critical loads. Option 2, which seeks to power critical loads for Type II RHCs, including meeting administrative and immunisation needs, would need 2 kWp of panel capacity, 7.68 kWh of battery capacity and a 3 kVA inverter.

DRE as a backup energy source. Individual facilities would need 2.5 kWp of panel capacity, 8.32 kWh of battery capacity and a 4 kVA inverter if they have to support **all loads** using DRE as a backup source.

Meanwhile, **to support critical loads**, individual facilities would need 1 kWp of panel capacity, 4.48 kWh of battery capacity and a 2 kVA inverter.

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Solar system design templates: **Urban health centres**

Based on the findings of the health-energy assessment and assumptions presented, Table 4.10 outlines the design templates recommended for UHCs using DRE as their primary energy source. **Design specifications account for the difference in services offered by Type A, B and C UHCs.**

Table 4.10 **Load considerations and DRE system design for urban health centres**

Healthcare facility type	Design approach	System type	Total load (W)	Total units (Wh)	Solar panel (kWp)	Solar battery (Ah) @ 12.8 V (min capacity)	Battery capacity* (kWh)	Solar inverter (kVA)
Type A UHC	**Option 1 – all load**	Primary system	10 149	35 435	14	4 300	55.04	20
		Backup system		22 002	9	2 700	34.56	15
	Option 2 – critical load	Primary system	5 071	27 341	11	3 350	42.88	15
		Backup system		19 014	8	2 300	29.44	12
Type B UHC	**Option 1 – all load**	Primary system	5 480	19 940	8	2 500	32	12
		Backup system		11 145	5	1 400	17.92	7.5
	Option 2 – critical load	Primary system	4 131	12 633	5	1 600	20.48	7.5
		Backup system		6 617	3	850	10.88	5
Type C UHC	**Option 1 – all load**	Primary system	2 314	8 072	4	1 000	12.8	6
		Backup system		5 241	2.5	650	8.32	4
	Option 2 – critical load	Primary system	894	5 004	2	600	7.68	3
		Backup system		2 731	1	350	4.48	2

* The battery is assumed to support approximately 50-60% of total energy consumption.

Notes: Ah = ampere hour; DRE = decentralised renewable energy; kVA = kilovolt ampere; kWh = kilowatt hour; kWp = kilowatt peak; UHC = urban health centre; V = volt; W = watt; Wh = watt hour.

Powering critical loads. Individual Type B UHCs would need 5 kWp of panel capacity, 20.48 kWh of battery capacity and a 7.5 kVA inverter if they consider powering their critical loads with DRE.

DRE as a backup energy source. Individual Type C UHCs would need 5 kWp of panel capacity, 17.92 kWh of battery capacity and a 7.5 kVA inverter if they prefer DRE as a backup solution to support **all loads**.

Meanwhile, **to support critical loads**, individual Type B UHCs would need 3 kWp of panel capacity, 10.88 kWh of battery capacity and a 5 kVA inverter.

Type C UHCs

Powering all loads. Individual Type C UHCs with DRE would need 4 kWp of panel capacity, 12.8 kWh of battery capacity and a 6 kVA inverter if they consider using DRE to power all loads for all equipment across the full operational hours.

Powering critical loads. Individual Type C UHCs would need 2 kWp of panel capacity, 7.68 kWh of battery capacity and a 3 kVA inverter if they consider using DRE to support critical loads.

DRE as a backup energy source. Individual Type C UHCs would need 2.5 kWp of panel capacity, 8.32 kWh of battery capacity and a 4 kVA inverter if they prefer DRE as a backup solution to support **all loads**.

Meanwhile, **to support critical loads**, individual Type C UHCs would need 1 kWp of panel capacity, 4.48 kWh of battery capacity and a 2 kVA inverter.

Solar system design templates: **Staff quarters**

Staff quarters in Mozambican healthcare facilities are currently not powered by solar energy systems. Using solar as the primary energy source to power all loads could enhance the comfort of staff members, and thus improve services by allowing them to work more efficiently.

Table 4.11 **Design considerations for solar energy in staff quarters**

Solar as the primary energy source	
Staff quarters	✓ All loads (including luminaries and regular loads) ✓ Basic loads (including luminaries and mobile charging points)

Box 4.3 outlines DRE system design options that can be adopted in existing and emerging healthcare facilities based on the number of staff quarters. The design considerations for staff quarters are based on data available from other African countries. Usually, healthcare facilities have 3-5 staff quarters. The most common design for staff quarters includes three bedrooms, a kitchen, a toilet and a shower, a laundry area, a living room and a passage area. Considering regular loads and staff needs, two design options have been developed for staff quarters.

Box 4.3 **Example system design options for staff quarters**

Option A	This option covers all loads required for staff members to feel comfortable at any time.
	All loads for one staff quarter
	Rooms: Living room and dining + kitchen + laundry + main bedroom + 2 bedrooms + passage + shower + WC + outdoor lighting **Load types:** 5 ceiling/wall/pedestal fans + 1 fridge + 10 LED bulbs + 4 mobile charging points + 1 TV + 1 outdoor light
Option B	This option covers luminaries and the ventilation system that makes for a comfortable stay for staff members.
	All loads for one staff quarter
	Basic loads for one staff quarter: This is a direct current (DC) system with a three-day autonomy. **Rooms:** Kitchen + main bedroom + shower + WC **Loads:** : 1 ceiling/wall/pedestal fan + 4 LED bulbs + 1 mobile charging point

Table 4.12 **Parameters for solar energy systems for staff quarters**

Facility	Design approach	Total connected load (kW)	Total energy (kWh/day)	Solar panel capacity (kWp)	Battery bank sizing (kWh)	Solar MPPT inverter sizing (kVA)
Staff quarters – all loads	One staff quarters	0.6	2.5	0.8	7.2	1
	Three staff quarters	1.8	7.6	2.5	24	3
	Five staff quarters	3.1	12.7	4	36	5
Staff quarters – basic load	One staff quarter	0.1	0.3	0.1	1.8	20 A, 12 V (CR)
	Three staff quarters	0.3	1.0	0.3	4.8	25 A, 24 V
	Five staff quarters	0.5	1.7	0.6	8.64	20 A, 48 V

Notes: CR = charge regulator; kVA = kilovolt ampere; kW = kilowatt; kWh = kilowatt hour; kWp = kilowatt peak; MPPT = maximum power point tracking; V = volt.

Powering all loads. As per the designs in Table 4.12, each health staff quarter would need 0.8 kWp of panel capacity, 7.2 kWh of battery capacity and a 1 kVa inverter to power regular loads using DRE as the primary system.

But if three staff quarters are in one place, then 2.5 kWp of panel capacity, 24 kWh of battery capacity and a 3 kVA inverter would be needed to power regular loads for all three.

Similarly, if five staff quarters are in one place, then 4 kWp of panel capacity, 36 kWh of battery capacity and a 5 kVA inverter would be needed to power regular loads for all five.

It is important to note that system reliability will be higher if each staff quarter has its own system.

Powering basic loads. Powering the basic loads for the essential rooms of one health staff quarter using DRE as the primary system would require 0.1 kWp of panel capacity, 1.8 kWh of battery capacity and a 20 A, 12 V charge regulator.

But if three staff quarters are in one place, then 0.3 kWp of panel capacity, 4.8 kWh of battery capacity and a 25 A, 24 V charge regulator would be needed to power the basic loads for all three.

Similarly, 0.6 kWp of panel capacity, 8.64 kWh of battery capacity and a 20 A, 48 V charge regulator would be needed to power the regular loads for all five.

This is the groundwork for designing and implementing DRE systems across various types of healthcare facilities in Mozambique. Detailed assessment findings, along with pragmatic assumptions, have highlighted that fulfilling the diverse energy demands inherent to the operation of both urban and rural healthcare facilities requires meticulously designed system templates that not only cater to the specific operational nuances of each type facility but also anticipate future growth, in turn ensuring scalability and sustainability. The inclusion of cost analysis, grounded in local market realities, further enhances the practical applicability of these recommendations. As Mozambique continues to advance towards greater energy resilience in healthcare, these insights and frameworks serve as a pivotal reference point that support the nation's commitment to harnessing renewable energy to bolster healthcare infrastructure and service delivery.

4.3 COSTING DRE-ENABLED SYSTEMS FOR PRIMARY HEALTHCARE IN MOZAMBIQUE

The cost of a DRE system includes the supply of panels, batteries, inverters and cabling; installation and transportation. The costs of panels' solar components, batteries and inverters are estimated based on online platforms maintained by three South African clean energy enterprises supplying solar systems to Mozambique (Annex 3). The costs for installation and transportation have been calculated based on an understanding of costs in the region.

The average costs for various components are provided in US dollars.[3] Certain assumptions were made based on the requirements for installing DRE systems at various types of healthcare facilities.

System costs

System costs include costs for solar panels, batteries and inverters. Additional costs for charge regulators, wiring and module-mounting structures are considered at 25%. This component also includes the cost of installation, commissioning and the labour for installation, which is estimated to be USD 250 for systems under 4 kWp, USD 500 for systems between 4 and 8 kWp, and USD 750 for systems over 8 kWp in the region. All costs are based on the components available in the region, and for $LiPo_4$ batteries. The minimum available inverter size was 3 kVA, priced at USD 610. For systems under 1 kWp, the inverter cost is estimated to be USD 300.

Annual maintenance contract costs

The annual maintenance contract (AMC) costs account for twice-a-year technician visits and repair/replacement of parts as and when required for a duration of five years. This cost covers any change of parts in warranty, which can be utilised to track the efficient usage of the installed systems. AMC costs constitute 10% of total system costs.

Transportation costs

Since most components have to be imported from neighbouring countries and transported from the capital to remote regions, transportation costs constitute a significant share of overall costs. While the cost of importing is included in the system costs, the cost of internal transport accounts for 4% of total costs.

[3] For the costs of the main components, which are mostly imported from South Africa, the exchange rate considered was ZAR 1 = USD 0.054 as of 8 August 2024.

Table 4.13 offers a summary of cost estimates by proportion of the total cost.

Table 4.13 **Cost components of DRE solutions, by share of total (%)**

Cost component	Description	Proportion of total cost
Solar energy system components	Cost of panels, batteries, inverters *Also includes the cost of importing components from supplier countries*	66%
Installation	Cost of installing systems	4%
Additional components	Cost of charge regulators, wiring, module-mounting structures	16%
Operation and maintenance *(costs considered for annual maintenance contracts for five years, excluding human-caused and natural-disaster-related issues)*	Cost of planned maintenance visits and of replacement of parts in warranty	10%
Transportation	Cost of transporting the system from the godown to the healthcare facility	4%
Total		**100%**

Solar energy system costs for rural health centres

Installing solar PV energy systems at **Type II RHCs** costs **USD 2 636-USD 6 101** depending on the loads the systems support. For **Type I RHCs,** installation costs **USD 12 808-USD 21 895.** Additionally, transportation and AMC together can cost **USD 358-USD 878 for Type II RHCs** and **USD 1 321-USD 3 169 for Type I RHCs** depending on the size of the system and geographical location. Therefore, overall, system installation and maintenance can cost **USD 2 994-USD 6 979** for a Type II RHC and **USD 14 654-USD 25 044** for a Type I RHC (Table 4.14).

Table 4.14 **Cost of DRE solutions for rural health centres in Mozambique (USD)**

Healthcare facility type	Design approach	System cost with installation*		Transportation + AMC*		Total cost	
		Primary	Backup	Primary	Backup	Primary	Backup
Type I RHC	**Option 1 – all load**	21 875	13 835	3 169	2 000	25 044	15 835
	Option 2 – critical load	15 001	12 808	2 138	1 846	17 139	14 654
Type II RHC	**Option 1 – all load**	6 101	4 615	878	655	6 979	5 270
	Option 2 – critical load	3 858	2 636	541	358	4 399	2 994

* The costs of installation, transportation and AMC are estimates. They would vary based on geography and supplier. These costs do not include costs to cover human-caused or natural-disaster-related issues.

Notes: AMC = annual maintenance contract; DRE = decentralised renewable energy; RHC = rural health centre.

System maintenance costs for five years have been included. Beyond this period, working capital will be required to replace the battery, as well as to account for inverter replacement, where required.

Solar energy system costs for urban health centres

Installing solar energy systems based on solar PV technology at **Type A UHCs** costs **USD 28 587-USD 12 557** depending on the loads the systems support. For **Type B UHCs**, installation costs **USD 5 518-USD 17 113** and for **Type C UHCs**, it costs **USD 2 636-USD 6 035**. Additionally, transportation and AMC together can cost **USD 358-USD 830 for Type C UHCs**, **USD 790 and USD 2 498 for Type B UHCs** and **USD 1 809 and USD 4 176, respectively, for Type A UHCs** depending on the size of the system, the geographical location and the supplier. Therefore, overall, system installation and maintenance can cost, respectively, USD 14 366 and USD 32 763 for a Type A UHC, USD 6 308-USD 19 611 for a Type B UHC, and USD 2 994 and USD 6 865 for a Type C UHC (Table 4.15).

Table 4.15 **Costs of DRE solutions for urban health centres in Mozambique (USD)**

Healthcare facility type	Design approach	System cost with installation*		Transportation + AMC*		Total cost	
		Primary	Backup	Primary	Backup	Primary	Backup
Type C UHC	Option 1 – all load	6 035	4 615	830	655	6 865	5 270
	Option 2 – critical load	3 858	2 636	541	358	4 399	2 994
Type B UHC	Option 1 – all load	17 113	10 211	2 498	1 457	19 611	11 668
	Option 2 – critical load	10 988	5 518	1 573	790	12 561	6 308
Type A UHC	Option 1 – all load	28 587	18 390	4 176	2 646	32 763	21 036
	Option 2 – critical load	21 292	12 557	3 081	1 809	24 373	14 366

* The costs of installation, transportation and AMC are estimates. They would vary based on geography and supplier. These costs do not include costs to cover human-caused or natural-disaster-related issues.

Notes: AMC = annual maintenance contract; DRE = decentralised renewable energy; UHC = urban health centre.

Table 4.16 **Total cost of powering health centres of all types (USD)**

Healthcare facility type	Design approach	Number of facilities	Cost of DRE as the primary energy source for all facilities	Cost of DRE as a backup energy source for all facilities
Type C UHC	Option 1 – all load	60	411 915	316 201
	Option 2 – critical load		263 943	179 643
Type B UHC	Option 1 – all load	65	1 274 329	758 364
	Option 2 – critical load		816 489	410 011
Type A UHC	Option 1 – all load	55	1 801 940	1 157 008
	Option 2 – critical load		1 340 549	790 096
Type I RHC	Option 1 – all load	176	4 407 796	2 787 065
	Option 2 – critical load		3 016 321	2 579 129
Type II RHC	Option 1 – all load	1 293	8 646 405	6 529 541
	Option 2 – critical load		5 450 431	3 709 620

Notes: DRE = decentralised renewable energy; RHC = rural health centre.

Based on the cost estimates, it would take USD 3 488 184 (for all UHCs) and USD 13 054 201 (for all RHCs) to power regular loads using DRE. Using DRE as a backup energy source for all facilities would cost between USD 1 379 749 (for all UHCs) and USD 6 288 749 (for all RHCs) (see Table 4.16).

Solar energy system costs for staff quarters

Powering staff quarters with solar PV costs USD 1 585-USD 16 225 depending on the loads supported and the number of staff quarters. With one staff quarter per healthcare facility as the minimum, it would cost USD 6 633 927 to power all of Mozambique's healthcare facilities using DRE (Table 4.17).

Table 4.17 **Cost of DRE solutions for staff quarters in Mozambique (USD)**

Facility design approach		Cost per facility	Cost for all facilities
Staff quarters – all load	**One staff quarter**	4 023	6 633 927
	Three staff quarters	10 558	17 410 142
	Five staff quarters	16 225	26 755 025
Staff quarters – basic load	**One staff quarter**	1 585	2 613 665
	Three staff quarters	2 675	4 411 075
	Five staff quarters	4 127	6 805 423

Note: DRE = decentralised renewable energy.

The cost estimates above are indicative for each category of facility. The actual funding requirements will depend on precise load requirements and the customised system designs.

4.4 OPERATION AND MAINTENANCE

O&M is key to the sustainability of DRE systems. Technologies require maintenance to be utilised in the most optimal manner.

Solar panels require periodic checks to ensure optimal performance and security. The extent and frequency of monitoring and maintenance services depends on the system configuration, installation type and location of the DRE system. Periodic inspections are a key pre-requisite to ensure smooth system functioning.

Preventive maintenance is a proactive approach to maintaining solar systems and preventing potential failures. It includes regular cleaning of solar panels to remove dust, dirt and debris, which can diminish energy production. Electrical system inspections involve checking for loose connections, damaged cables and proper grounding. Inspections of mechanical components cover mounting structures, tracking systems (if applicable) and other moving parts. Vegetation control is also crucial to ensure access to solar panels and to prevent shading.

Corrective maintenance involves repairing or replacing components that have failed or are nearing the end of their useful life. This may include inverter replacement, cable replacement or repairs to mounting structures. Corrective maintenance must follow appropriate repair procedures and safety protocols to ensure system integrity and personnel safety.

Maintenance must be scheduled and planned to co-ordinate and execute the corresponding activities efficiently. A well-designed maintenance plan considers factors such as weather conditions, system downtime and availability of spare parts and personnel.

Annual maintenance contracts

An AMC for scheduled maintenance is provided by solar installation providers/vendors/enterprises to end users (here healthcare facilities). Scheduled maintenance ensures systems are in proper working condition; it helps to identify potential issues or damage before they escalate and start affecting systems' power generation capacity. In sum, AMC services cover all aspects – predictive, preventive and corrective – of solar system installation and ensure optimum performance throughout the expected duration.

Effective scheduled maintenance requires clear service-level agreements with providers, highlighting the essential components to be maintained and the process of communication for work beyond the agreement's scope.

Factors influencing O&M model selection

Multiple factors affect O&M. Broadly, the factors fall under the following parameters:

Connectivity and logistics. The geography of a region determines the ease of access to services, the frequency of maintenance/repair and the cost of O&M. The specific geographic factors are:

- **Terrain.** Assess whether a region is made up of plains or valleys, or is mountainous, and whether it has forests or islands, which affect the cost and turnaround time for O&M.
- **Disaster vulnerability.** Identify thunderstorm-, sandstorm- or flood-prone regions, where systems require greater monitoring and maintenance to ensure seamless operation.
- **Connectivity.** Evaluate access to the internet and to road infrastructure for transportation to determine ease of contact and turnaround time for O&M. Improved connectivity can facilitate better monitoring and timely support.

Technical capacity. The technical capacity within a region determines the ease of accessing services and influences the cost of O&M:

- **Existing institutional capacity (human resources).** Assessing the availability of trained human resources and technical departments for O&M within a country's institutional governmental framework helps reveal capacity gaps.
- **Availability of clean energy enterprises.** Assessment of the skill landscape requires competent technical support and issue-management enterprises to be present.
- **Presence of training academies.** Identify the availability of local training facilities to build the necessary O&M skills.

Supply chain. Market maturity for clean energy is reflected by the supply chain for solar technologies as well as the spread of enterprises across a region. This influences the cost of O&M and the turnaround time:

- **Market maturity for clean energy.** Evaluate the supply chain for solar technologies and the spread of enterprises; this influences costs and the turnaround time.
- **Spread/network.** Determine whether energy enterprises are spread out or concentrated; this affects costs and ease of access to trained technicians.
- **Supply chain for solar technology.** Assess the availability of technologies and spares, and the ease of providing services; this assessment is to consider the cost of local availability versus import.

Institutional capacity

- **Existing structure.** Identify public health departments and energy departments that can integrate O&M for energy systems.
- **Governance system.** Analyse decision makers' roles, involvement levels and collaboration; this impacts model choices.
- **Private institutions and capacity.** Evaluate non-governmental organisations' (NGOs) and Clean Energy Enterprises (CEEs') capacity to manage and execute O&M; this evaluation is to consider possible shared responsibilities and collaborations.

Finance

- **Fund availability.** Determine whether funding is through government or philanthropy; this influences O&M model choices. Understand which stakeholders are involved in financing O&M.

Role of stakeholders in O&M model selection

A programme may have multiple stakeholders, and specifically in O&M, the stakeholders can be a country's government, the private sector and civil society organisations. They have a role in decision making, fund allocation, process execution and maintaining the programme in the long run. The following are the roles involved in O&M:

- **Ownership.** The energy systems at healthcare facilities can be owned by a public entity (government/state), which is the Ministry of Health or the Ministry of Energy, or a private entity (energy company, NGOs), or the government can enter into a partnership with private companies/NGOs, including to receive energy as a service. Each of these ownership models is determined based on the initial investment and the place where energy is generated.
- **Management.** The management of the energy systems at the facilities can be the responsibility of a private or a government entity, or both. Who runs the facility daily determines the level of involvement and participation. It also shows the decision flow for finance and for the procurement of other resources at the facility level.
- **Execution.** O&M can be carried out using the resources available with a government entity or a private entity. The corresponding decision is based on the availability and accessibility of resources within the ecosystem.

- **Financing.** The total O&M cost is generally considered to constitute 3-5% of the annual system cost. These costs include operating the solar system and maintaining a monitoring mechanism. The costs for each of these components vary by the context. The sustainable running of the systems depends on who funds O&M and when O&M funds are allocated. O&M can be funded by the government/state or any private entity, or it can be corporate social responsibility/donor/grant funded.

Financing and business models for capital expenditure and operating expenditure

The assessment suggests options for financing and business models for the long-term operation and sustainability of renewable energy solutions. These models include the ones listed below:

1. **Capital expenditure (CAPEX) subsidy with O&M primarily through local private sector operators.** CAPEX is typically covered by the public sector or philanthropy, which is where O&M financing also comes from. O&M responsibilities are handled by local private sector operators. The system is owned and managed by the healthcare facility or a public agency.

2. **CAPEX subsidy with O&M primarily through public sector energy agencies.** Capital expenditure is covered by the public sector or philanthropy, which is where O&M financing also comes from. O&M responsibilities are managed by local public sector energy agencies. The system is owned and managed by the facility or a public agency.

3. **CAPEX subsidy and O&M primarily through healthcare facility staff, or local community groups or NGOs.** Capital expenditure is typically covered by the public sector or philanthropy, which is where O&M financing also typically comes from. O&M responsibilities are handled by healthcare facility staff, local community groups (*e.g.* patient welfare committees in India) or local NGOs. The system is owned by the healthcare facility or a public agency and managed by healthcare facility staff, local community groups or NGOs.

4. **Energy as a service.** The system is owned by a private sector operator, and the healthcare facility pays a fixed or per-unit cost for the electricity consumed. O&M responsibilities rest with the private sector operator.

4.5 RECOMMENDATIONS FOR INTEGRATING DRE IN MOZAMBIQUE'S HEALTHCARE SYSTEM

The integration of DRE systems into Mozambique's healthcare sector represents a critical step towards making health services more reliable and sustainable nationwide. This section provides detailed recommendations specifically to ensure DRE systems are implemented successfully. The recommendations cover important aspects such as government co-ordination, site-specific assessments, financing strategies, procurement planning, capacity building and O&M, and they are designed to create a robust framework that not only addresses immediate energy needs but will also help make Mozambique's healthcare infrastructure resilient and effective in the long term.

1. Strengthen government co-ordination and forge partnerships

Effective integration of DRE systems into Mozambique's healthcare facilities requires robust collaboration between the Ministry of Health (Ministério da Saúde) and the Ministry of Mineral Resources and Energy (Ministério dos Recursos Minerais e Energia). These ministries must work closely with relevant sub-departments and key stakeholders to ensure cohesive and streamlined efforts.

Action steps:

- **Establish an inter-ministerial task force.** Form a dedicated task force consisting of representatives from the Ministry of Health, Ministry of Mineral Resources and Energy, Electricidade de Moçambique, Mozambique Energy Fund (FUNAE) and other key bodies. This task force should meet regularly to align strategies, share data, and co-ordinate efforts for the deployment and maintenance of DRE systems.
- **Facilitate joint studies and data sharing.** Conduct joint studies to assess the specific energy needs of healthcare facilities and the potential for integrating DRE. Create a centralised database to help ministries and their sub-departments access and share critical information on energy infrastructure, healthcare facilities' requirements and project progress.
- **Secure high-level political buy-in.** Engage ministers and high-ranking officials to secure their commitment to the DRE initiative. Establish a political co-ordination team to advocate for DRE in healthcare and ensure that these projects remain a national priority.
- **Develop public sector budget provisions.** Both ministries named above should collaborate to allocate annual budgets specifically for DRE projects in healthcare facilities. This budget should be supplemented by international donor funds. This will in turn create a stable financial base for ongoing and future initiatives.
- **Form an integrated technical team.** Assemble a multi-disciplinary technical team responsible for conducting feasibility studies, designing energy systems and overseeing the implementation of DRE projects. This team should include experts in energy, healthcare, finance and project management to ensure a holistic approach to DRE integration.

2. Conduct site-specific assessments

While this report provides a general investment estimate for DRE integration, the actual implementation of systems requires detailed, site-specific assessments to tailor solutions to each facility's unique needs.

Action steps:

- **Initiate facility-level energy assessments.** Conduct comprehensive energy audits at each healthcare facility to determine the current energy consumption, equipment needs and service delivery requirements. This will provide the data needed to accurately size DRE systems.
- **Develop a standardised assessment protocol.** Create a standardised protocol for assessments, ensuring consistency across facilities. The protocol should include guidelines for evaluating energy demand, the existing infrastructure and potential future growth.
- **Incorporate local context and needs.** Ensure that assessments consider the local context, including geographic, climatic and socio-economic factors. Engage local healthcare facility staff in the assessment process to gather insights on daily operations and specific energy challenges.
- **Use assessment data to inform system design.** Utilise the data from these assessments to inform DRE system design and specifications so that they meet each facility's unique needs.

3. Develop a comprehensive financing strategy

A successful transition to DRE systems in Mozambique's healthcare sector requires a well-structured financing strategy that combines government resources with external funding and private sector involvement.

Action steps:

- **Identify funding sources.** Explore different funding avenues, including government budgets, international development grants, concessional loans and philanthropic contributions. Engage with international agencies such as the World Bank, Global Fund, United Nations Children's Fund, World Health Organization and United States Agency for International Development to secure financial and technical support.
- **Establish a dedicated DRE fund.** Create a dedicated fund for DRE projects within the Ministry of Economy and Finance (Ministério da Economia e Finanças) or the Ministry of Health. This fund should pool resources from multiple sources and should be managed transparently for efficient fund allocation.
- **Leverage PPPs.** Develop PPP models that incentivise private sector investment in DRE systems. This could include tax incentives, risk-sharing mechanisms or specialised financing packages for companies that provide solar solutions to healthcare facilities.
- **Implement a blended financing approach.** Combine grants, concessional loans and private sector investments to reduce the overall cost of capital for DRE projects. This approach can increase the financial viability of projects and make them more attractive to investors.
- **Develop a long-term sustainability plan.** Ensure that the financing strategy includes provisions for long-term sustainability, such as funding for ongoing O&M, battery replacement and system upgrades.

4. Formulate a robust procurement plan

Ensuring the long-term sustainability and effectiveness of DRE systems requires a carefully designed procurement plan that emphasises quality and reliability.

Action steps:

- **Assess local market capabilities.** Evaluate the capabilities of local suppliers and installers to determine whether they can meet the quality standards required for DRE systems. Where gaps exist, consider importing equipment from reputable international suppliers.
- **Establish strict quality standards.** Develop stringent quality control measures for the procurement process, including criteria for selecting equipment, installers and service providers. All equipment should meet international standards and be tested for durability and performance in Mozambique's climate.
- **Create a transparent procurement process.** Ensure that the procurement process is transparent, competitive and aligned with national and World Health Organization guidelines. This includes clear tendering procedures, evaluation criteria and contract management processes.
- **Develop long-term supplier relationships.** Build long-term relationships with reliable suppliers and service providers that can provide ongoing support and maintenance services. This will help ensure the continuity and reliability of systems over time.

5. Implement comprehensive capacity-building programmes

The successful implementation and sustainability of systems requires capacity building for all stakeholders involved in DRE projects – from government officials to healthcare staff.

Action steps:

- **Design and institutionalise training modules.** Develop comprehensive training modules covering the basics of renewable energy, system O&M, procurement best practices and the healthcare-energy nexus. These modules should be tailored to the needs of different stakeholder groups, including healthcare facility staff, technicians and government officials.
- **Enhance training for maintenance personnel.** Collaborate with the National Directorate for the Training of Health Professionals and the National Directorate of Energy to provide specialised training for maintenance personnel. This training should focus on equipping personnel with the skills needed to perform repairs and manage energy systems effectively.
- **Implement on-the-job training.** Provide on-the-job training to healthcare facility staff and local technicians to fully equip them to operate and maintain DRE systems. The training should include hands-on workshops, regular refresher courses and mentorship programmes.
- **Develop certification programmes.** Introduce certification programmes for technicians and service providers to help them acquire the skills and knowledge for maintaining DRE systems to high standards.
- **Promote awareness and engagement.** Launch awareness campaigns to educate healthcare staff and local communities on the benefits of DRE systems and the importance of proper maintenance. This will help build a culture of ownership and responsibility around the new infrastructure.

6. Establish a robust O&M framework

The long-term success of DRE systems depends on a well-structured O&M strategy that ensures systems remain operational and efficient over their lifespan.

Action steps:

- **Integrate DRE maintenance into existing structures.** Embed DRE system maintenance within the existing maintenance framework of the Ministry of Health. This will leverage existing resources and expertise, ensuring that DRE maintenance is part of routine healthcare infrastructure management.
- **Develop a remote monitoring system.** Implement a remote monitoring system for the real-time tracking of DRE systems' performance. This system should be linked to a central control room managed by the Provincial Health Directorate (DPS), where data can be analysed, for the prompt identification of maintenance needs.
- **Create a clear asset management process.** Ensure that DRE systems are included in asset registers at the provincial as well as facility levels. This will help track equipment and allocate the maintenance budget better and increase accountability for system performance.
- **Establish O&M funding mechanisms.** Allocate dedicated funds for O&M activities, including regular system checks, battery replacements and emergency repairs. Consider creating an escrow account, managed by the Ministry of Economy and Finance, to ensure funds are available when needed.
- **Engage service providers with long-term contracts.** Enter into long-term contracts with service providers that include detailed maintenance schedules, performance guarantees and penalties for non-compliance. This will ensure that providers are accountable for the ongoing upkeep of systems.
- **Monitor and evaluate maintenance activities.** Implement a robust monitoring and evaluation framework to track the effectiveness of O&M activities. This should include regular audits, performance assessments and feedback mechanisms to ensure continuous improvement.

Implementing these recommendations will position Mozambique to effectively harness the power of DRE in strengthening its healthcare system. A focus on co-ordinated government efforts, thorough site assessments, sustainable financing and comprehensive capacity building can help Mozambique equip its healthcare facilities with reliable, sustainable energy sources, not only improving the delivery of essential health services, but also advancing broader national goals of energy resilience and economic development. As Mozambique moves forward with these initiatives, the continued commitment to quality, sustainability and collaboration will be key to achieving lasting success

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ANNEXES

ANNEX 1 DETAILS OF SAMPLED FACILITIES

S.No.	Facility name	Type of health facility	District	Province
1	Centro de Saude de Vanduzi	Rural health centre Type I	Vanduzi	Manica
2	Centro de Saúde de Matsinho	Rural health centre Type II		
3	Centro de Saúde Inchope	Rural health centre Type II	Gondola	
4	Centro de saúde de musserepa	Rural health centre Type II	Mandimba	
5	Centro de saúde de Lussangasse	Rural health centre Type II		
6	Centro de Saúde Micoco	Rural health centre Type I	Lichinga	
7	Centro de Saude Pungue Sul	Rural health centre Type II	Vanduzi	
8	Centro de Saúde de Mucombezi	Rural health centre Type II		
9	Centro de Saúde de Anchilo	Urban health centre Type B	Nampula	Nampula
10	Centro de saúde de Namialo	Rural health centre Type I	Meconta	
11	Centro de Saúde de Nacavala	Rural health centre Type II	Nacavala	
12	Centro de saúde de Carapira	Rural health centre Type I	Monapo	
13	Centro de Saúde Monapo_Rio	Rural health centre Type II		
14	Centro de saúde de Namitatar	Rural health centre Type II	Mossoril	
15	Centro de Saúde de Chocas Mar.	Rural health centre Type II		
16	Centro de saúde de Lumbo	Rural health centre Type II	Ilha de Moçambique	
17	Ilha de Moçambique	Rural health centre Type I		
18	Centro de Saúde Chicá _ Ribaúe	Rural health centre Type II	Ribaúe	
19	Centro de saúde Namiconha	Rural health centre Type II		
20	Centro de saúde de Nacata	Rural health centre Type II	Malema	
21	Centro de Saúde de Mutual	Rural health centre Type II		

22	Centro de saúde de Mepolage	Rural health centre Type II	Cuamba	**Niassa**
23	Centro de Saúde de Mujaua	Urban health centre Type B		
24	Centro de Saúde de Mecanhelas	Rural health centre Type I	Mecanhelas	
25	Centro de Saúde de Chissaua	Rural health centre Type II		
26	Centro de Saude de Manga Mascarenhas	Urban health centre Type A	Beira	**Sofala**
27	Centro de Saude de Tica	Rural health centre Type II	Nhamatanda	
28	Centro Saude de Gorongosa	Rural health centre Type I	Gorongosa	
29	Centro de Saude de Ndoro	Rural health centre Type II	Caia	
30	Centro de Saude de Deve	Rural health centre Type II		
31	Centro de Saude Numero 1	Urban health centre Type B	Tete	**Tete**
32	Centro de Saúde de Moatize	Rural health centre Type I	Moatize	
33	Centro de Saude de Madzimaera	Rural health centre Type II		
34	Centro de Saúde de Changara Sede	Rural health centre Type I	Changara	
35	Centro de Saúde de Dzunga	Rural health centre Type I		
36	Centro de Saude de Namacata	Rural health centre Type II	Nicoadala	**Zambézia**
37	Centro de Saude de Amoro	Rural health centre Type II		
38	Centro de Saude de Boroma	Rural health centre Type II	Morrumbala	
39	Centro de Saude de Muera	Rural health centre Type II		
40	Centro de Saude de Chimuara	Rural health centre Type II	Mopeia	

ANNEX 2 LIST OF RESPONDENTS IN SAMPLE FACILITIES

Respondent type	No. of respondents	Purpose for selection	Tools used
Director	16	To gain an understanding of energy requirements at the facility level, and to understand how energy affects the experiences of health staff in delivering services	✓ **Key Informant Interview (KII) Guide**
Doctor	3		
Administrative	2		
Nurse	12		
Health technician	6		
Pharmacist	1		

Facility name	Type of health facility	Role
Centro de Saude de Manga Mascarenhas	Urban health centre Type A	**Administrative**
Centro de Saúde de Anchilo	Urban health centre Type B	**Director**
Centro de Saude de Tica	Rural health centre Type II	**Director**
Centro de saúde de Namialo	Rural health centre Type I	**General nurse (substitute of the clinical director)**
Centro de Saúde de Nacavala	Rural health centre Type II	**General medicine Technique**
Centro de saúde de Carapira	Rural health centre Type I	**Administrative**
Centro de Saúde Monapo_Rio	Rural health centre Type II	**Director**
Centro Saude de Gorongosa	Rural health centre Type I	**Director**
Centro de Saude de Ndoro	Rural health centre Type II	**Director**
Centro de saúde de Namitatar	Rural health centre Type II	**Technique of general medicine (Substitute of the director)**
Centro de Saúde de Chocas Mar.	Rural health centre Type II	**General nurse**
Centro de Saude de Deve	Rural health centre Type II	**Pharmacist**
Centro de saúde de Lumbo	Rural health centre Type II	**Head nurse**
Ilha de Moçambique	Rural health centre Type I	**Clinical director**
Centro de Saude de Namacata	Rural health centre Type II	**Responsible for gender-based violence and tuberculosis**
Centro de Saude de Amoro	Rural health centre Type II	**Director**
Centro de Saúde Chicá _ Ribaúe	Rural health centre Type II	**Nurse (director of the centre)**
Centro de saúde Namiconha	Rural health centre Type II	**Technique of medicine**
Centro de Saude de Boroma	Rural health centre Type II	**Technician of preventive medicine**
Centro de Saude de Muera	Rural health centre Type II	**Maternal and child health nurse**
Centro de Saude de Chimuara	Rural health centre Type II	**Director**
Centro de saúde de Nacata	Rural health centre Type II	**Director**

Centro de Saúde de Mutual	Rural health centre Type II	**Doctor**
Centro de saúde de Mepolage	Rural health centre Type II	**Director**
Centro de Saúde de Mujaua	Urban health centre Type B	**Serious mental illness (SMI) nurse (substitute for director)**
Centro de Saude Numero 1	Urban health centre Type B	**Head nurse**
Centro de Saúde de Moatize	Rural health centre Type I	**Doctor**
Centro de Saude de Madzimaera	Rural health centre Type II	**Director**
Centro de Saúde de Changara Sede	Rural health centre Type I	**Director**
Centro de Saúde de Dzunga	Rural health centre Type I	**Substituto do Director(enfermeiro geral)**
Centro de Saúde de Mecanhelas	Rural health centre Type I	**Head nurse**
Centro de Saúde de Chissaua	Rural health centre Type II	**Clinical director**
Centro de Saude de Vanduzi	Rural health centre Type I	**Director**
Centro de Saúde de Matsinho	Rural health centre Type II	**Doctor**
Centro de Saúde Inchope	Rural health centre Type II	**Director**
Centro de saúde de musserepa	Rural health centre Type II	**SMI nurse**
Centro de saúde de Lussangasse	Rural health centre Type II	**Health technician**
Centro de Saúde Micoco	Rural health centre Type I	**SMI nurse**
Centro de Saude Pungue Sul	Rural health centre Type II	**Maternal health nurse**
Centro de Saúde de Mucombezi	Rural health centre Type II	**Director**

ANNEX 3 ENTERPRISE COST QUOTATIONS FOR SOLAR ENERGY SYSTEMS

The following is the list of vendors from where costs for solar energy system components of panels, batteries and inverters were mapped to calculate the cost of a recommended decentralised renewable energy (DRE) system.

- The cost as of 6 August 2024, excludes mounting structures, earthing rods, lightning arresters, junction boxes and wiring, with additional charges for installation, remote monitoring system, transportation and maintenance.
- For the costing, panel capacity of 555 watts peak was considered.

Enterprise name	Websites
SiW	www.inverter-warehouse.co.za/
GC Solar	www.onlineshop.gcsolar.co.za/
Solar Shop	www.solar-shop.co.za/

Reference quotations from different vendors

					SiW			GC Solar			Solar Shop		
Health facility type	Design approach	Solar panel (kWp)	$LiPo_4$ battery (Ah)	Solar inverter (kVA)	Total panel cost (US D)	Inverter cost (USD)	Battery price (USD)	Total panel cost (USD)	Inverter cost (USD)	Battery price (USD)	Total panel cost (USD)	Invert er cost (USD)	Battery price (USD)
RHC – Type 2	**Option 1 – All loads**	3.2	1 000	5	535	485	2 834	745	714	3 940	599	971	3 110
		2.5	650	4	446	485	1 842	621	7	2 561	500	971	2 022
	Option 2 – Critical loads	2	600	3	356	485	1 700	497	342	2 364	400	620	1 866
		1	350	2	178	485	992	248	342	1 379	200	620	1 089
RHC – Type 1	**Option 1 – All loads**	11	3 500	15	1 782	4 145	9 919	2 484	#N/A	13 789	1 998	4 016	10 886
		7	2 000	10	1 158	3 241	5 668	1 615	1 236	7 880	1 299	3 149	6 221
	Option 2 – Critical loads	9	2 800	12.5	1 515	4 145	7 935	2 111	#N/A	11 032	1 698	993	8 709
		6	1 800	10	980	3 241	5 101	1 366	1 236	7 092	1 099	3 149	5 599
UHC – Type C	**Option 1 – All loads**	4	1 000	6	713	3 241	2 834	994	714	3 940	799	518	3 110
		2.5	650	4	446	485	1 842	621	7	2 561	500	971	2 022
	Option 2 – Critical loads	2	600	3	356	485	1 700	497	342	2 364	400	620	1 866
		1	350	2	178	485	992	248	342	1 379	200	620	1 089
UHC – Type B	**Option 1 – All loads**	8	2 500	12	1 337	4 145	7 085	1 863	#N/A	9 850	1 499	4 016	7 776
		5	1 400	7.5	891	3 241	3 967	1 242	714	5 516	999	2 415	4 355
	Option 2 – Critical loads	5	1 600	7.5	891	3 241	4 534	1 242	714	6 304	999	2 415	4 977
		3	850	5	535	485	2 409	745	714	3 349	599	971	2 644
UHC – Type A	**Option 1 – All loads**	14	4 300	20	2 317	6 481	12 186	3 229	#N/A	16 941	2 597	#N/A	13 375
		9	2 700	15	1 515	4 145	7 652	2 111	#N/A	10 638	1 698	4 016	8 398
	Option 2 – Critical loads	11	3 350	15	1 782	4 145	9 494	2 484	#N/A	13 198	1 998	4 016	10 420
		8	2 300	12	1 337	4 145	6 518	1 863	#N/A	9 062	1 499	993	7 154

* Prices are as of 31 August 2024.

Notes: Ah = ampere hour.; kVA = kilovolt-ampere; kWp = kilowatt peak; $LiPO_4$ = lithium phosphate; N/A = not available; RHC = rural health centre; UHC = urban health centre.

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