Electrification with renewables:
Enhancing healthcare delivery in
Mali

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CONTENTS

FIGURES

TABLES

BOXES

ABBREVIATIONS

AC	air conditioning
AER-Mali	Renewable Energy Agency of Mali (*Agence des Energies renouvelables du Mali*)
AMADER	Malian Agency for Domestic Energy and Rural Electrification (*Agence Malienne pour le Développement de l'Énergie et de l'Électrification Rurale*)
ASACO	community health association (*Association de Santé Communautaire*)
CBA	cost-benefit analysis
CFA	Western African franc – Malian local currency
CMIE	inter-company medical centre (*Centre Médical Inter-Entreprise*)
CREDD	Strategic Framework for Economic Recovery and Sustainable Development (*Cadre Stratégique pour la Relance Économique et le Développement Durable*)
CREE	Electricity and Water Regulatory Commission (*Commission de Régulation de l'Électricité et de l'Eau*)
CSCOM	community health centre (*Centre de Santé Communautaire*)
CSREF	referral health centre (*Centre de Santé de Référence*)
DNS	national health directorate (*Direction Nationale de la Santé*)
DRE	decentralised renewable energy
DRS	regional health directorate (*Direction Régionale de la Santé*)
EDM	national electric utility of Mali (*Energie du Mali – SA*)
IRENA	International Renewable Energy Agency
km	kilometre
kVA	kilovolt ampere
kWh	kilowatt hour
kWp	kilowatt peak
MEE	Ministry of Energy and Water (*Ministère de l'Énergie et de l'Eau*)
MSDS	Ministry of Health and Social Development (*Ministère de la santé et développement social*)
MW	megawatt
MWh	megawatt hour
O&M	operation and maintenance
OOP	out-of-pocket
PRODESS	Health and Social Development Programme (*Programme de Développement Sanitaire et Social*)
PV	photovoltaic
RE	renewable energy
RMS	remote monitoring system
SDGs	Sustainable Development Goals
UHC	universal health coverage
USD	United States dollar
W	watt
WASH	water supply, sanitation and hygiene
Wh	watt hour
WHO	World Health Organization

EXECUTIVE SUMMARY

Reliable and affordable electricity access is a critical bottleneck in the delivery of quality healthcare in Mali, particularly in rural and remote regions. Inadequate access restricts the operation of essential medical equipment, the maintenance of cold chains for vaccines and adequate lighting for critical care. These challenges are further intensified by climate change: extreme weather events such as droughts and floods disrupt health service delivery, damage infrastructure and increase the incidence of diseases requiring immediate attention. The Health and Social Development Programme (*Programme de Développement Sanitaire et Social*, PRODESS), the country's primary health development initiative, prioritises expanding access to primary healthcare, improving maternal and child health, and integrating renewable energy to enhance resilience in health facilities. However, frequent power outages continue to impede essential services and diminish the overall quality of healthcare.

Decentralised renewable energy (DRE) systems offer an effective solution to these challenges, forming a vital part of the infrastructure required in the health sector and providing a sustainable pathway to address Mali's energy needs for healthcare. In particular, solar photovoltaic (PV) systems can deliver consistent energy for lighting, refrigeration and medical equipment. For instance, solar-powered vaccine refrigerators are crucial for maintaining the cold chain in remote facilities. Moreover, solar energy facilitates telemedicine, diagnostics and maternal care, ensuring uninterrupted service even during power outages.

This report assesses the benefits of using DRE solutions to power Mali's healthcare facilities and proposes technical designs along with estimated investment costs. The study focuses primarily on first- and second-level health facilities, namely the community health centres (*Centre de Santé Communautaire*, CSCOMs) and district referral health centres (*Centre de Santé de Référence*, CSREFs) that form the backbone of the public health system in Mali. CSCOMs deliver primary health care at the community level, while CSREFs serve as the first level of referral and technical support for CSCOMs, handling cases that require additional expertise or resources. Hospitals represent the apex of the healthcare system in Mali, providing services typically not available at the CSCOM and CSREF levels.

Based on an assessment of 60 health facilities[1] across Mali, the following findings were made:

- **Health facility ownership and management.** CSCOMs are primarily owned by local communities and operated by community health associations (*Association de Santé Communautaire*, ASACOs), with 90% under local control. In contrast, CSREFs and hospitals are predominantly owned and managed by the government.

1 Forty-eight CSCOMs, ten CSREFs and two regional hospitals (see Annex A for details).

- **Energy sources for health facilities.** Most health facilities in Mali rely on a combination of energy sources, primarily solar PV panels equipped with batteries, grid-connected solar power and diesel generators. In 54% of the surveyed CSCOMs, a solar PV system with batteries was the main source of energy, while approximately 95% of CSREFs and hospitals depend on a mix of grid and solar energy, supplemented by diesel generators. Power outages are frequent across facilities; CSCOMs experience the highest number of disruptions due to inadequate solar PV installations, while CSREFs and hospitals are the most affected by grid-related issues. These disruptions pose significant challenges for both patients and staff, particularly in maternal care and vaccine preservation. A staggering 93% of facilities report compromised services, 96.7% report staff discomfort and 81% note issues with the cold chain.

Based on primary data collection, stakeholder consultations and a secondary desk review, customised system designs have been developed to address the unique energy needs of each facility category. These designs provide a framework to meet the varied energy requirements of healthcare facilities through solar energy, offering various system options tailored to specific health delivery contexts and energy needs. The recommended solar PV system sizes range from 4.2 kilowatts peak (kWp) (critical loads) to 7.8 kWp (entire load) for rural CSCOMs; 4.2 kWp (critical loads) to 10.8 kWp (entire load including air conditioning) for urban CSCOMs; 10.8 kWp (critical loads) to 42 kWp (entire load including air conditioning) for CSREFs; and 26.4 kWp (critical loads) to 90 kWp (entire load) for regional hospitals (Table 1).

Table 1 **Specifications of recommended solar PV systems**

Type of facility	Type of load	Solar panel (kWp)	Battery (kWh)	Inverter (kVA)	No. of facilities
Rural CSCOM	Entire load	7.8	48	8	1 058
	Critical load	4.2	24	6	
Urban CSCOM	Entire load	10.8	60	12.5	570
	Critical load	4.2	24	6	
CSREF	Entire load	42	240	45	61
	Critical load	10.8	60	15	
Regional hospital	Entire load	90	600	100	6
	Critical load	26.4	192	32	

Notes: CSCOM = community health centre; CSREF = referral health centre; kVA = kilovolt ampere; kWh = kilowatt hour; kWp = kilowatt peak.

The proposed designs suggest an investment of USD 42 125 346 to power all healthcare infrastructure (for all regular services, excluding backup for air conditioning) as well as staff quarters using solar PV systems. The cost to power only the critical loads of primary healthcare facilities using solar PV is estimated at USD 18 413 105. Investing in health facilities' solar-powered electricity access is not only imperative for health outcomes but also a key driver of broader rural development and resilience (Table 2).

Table 2 **Estimated costs of recommended solar PV systems**

Type of facility	Type of load	System cost (USD)	O&M (USD)	Remote monitoring system (USD)	Unit cost (USD)	Total cost for all facilities (USD)
Rural CSCOM (1 058)	Entire load	17 246	1 437	353	19 036	20 140 088
	Critical load	9 006	750	353	10 109	10 695 322
Urban CSCOM (570)	Entire load	18 974	1 581	353	20 908	11 917 560
	Critical load	9 006	750	353	10 109	5 762 130
CSREF (61)	Entire load	54 889	4 574	353	59 816	3 648 776
	Critical load	22 627	1 886	353	24 865	1 516 765
Regional hospitals (6)	Entire load	126 625	10 552	353	137 530	825 180
	Critical load	67 195	5 600	353	73 148	438 888

Notes: CSCOM = community health centre; CSREF = referral health centre; O&M = operation and maintenance.

Recommendations

Based on the assessment's findings, the present report outlines several recommendations for the successful implementation of DRE systems in Mali's healthcare services (Box 1). The proposed DRE programme should be tailored to the country's current context and designed for long-term sustainability.

Box 1 **Recommendations for the successful implementation of DRE systems in healthcare**

- Select technologies based on need, efficiency and quality, with a focus on high-quality photovoltaic systems, batteries, inverters and medical equipment, all backed by efficient and cost-effective supply chains.
- Ensure infrastructure is climate resilient, with solar designs incorporating cooling systems to mitigate extreme heat and the operational challenges posed by droughts and floods.
- Electrify facilities in phases, starting with locations that already have good infrastructure and adequate staff, to encourage buy-in and ownership.
- Leverage existing government structures to support the decentralisation of healthcare, thereby bringing health services closer to communities.
- To ensure the effective oversight of technical specifications, system quality, and monitoring and maintenance, set up a dedicated Solar Programme Unit within the Ministry of Health and Social Development (*Ministère de la Santé et Développement social*, MSDS), receiving technical support from the Ministry of Energy and Water (*Ministère de l'Énergie et de l'Eau*, MEE).
- Define quality standards for decentralised renewable energy equipment, prioritising local vendors and encouraging partnerships between local enterprises. Provide regular and ongoing training for all stakeholders, with training costs included in the programme budget. Operation and maintenance (O&M) should extend beyond annual contracts; facility staff should receive training in basic maintenance and reporting, guided by clearly defined standard operating procedures. Maintenance responsibilities for various levels of repair should be clarified across facility staff and local technicians.
- Include long-term O&M clauses in contracts, and O&M costs in health ministry budgets. In regions experiencing instability, third-party accounts may be utilised to safeguard finances, and the Solar Programme Unit should regularly review fund allocation guidelines to ensure effective and sustainable programme implementation.
- Develop policies to support the sustainable integration of decentralised renewable energy in healthcare facilities. These policies would promote inter-sectoral collaboration, prioritise the maintenance of existing facilities and minimise administrative barriers.
- Finally, investigate innovative delivery models, including public, non-profit and private sector approaches. In Mali, public and non-profit models are the most prevalent, but challenges such as asset maintenance and high upfront costs can be mitigated through supportive policy environments. Partnerships between private sector entities and public healthcare facilities may be explored to balance public health priorities with financial sustainability.

1. INTRODUCTION

Primary healthcare centres are the backbone of health service delivery in many rural and underserved regions. However, these facilities often encounter significant challenges due to unreliable energy supply and inadequate infrastructure. The lack of consistent energy access can severely limit their ability to provide essential services such as emergency obstetric care, neonatal care, immunisation and more.

1.1 ENERGY FOR HEALTH

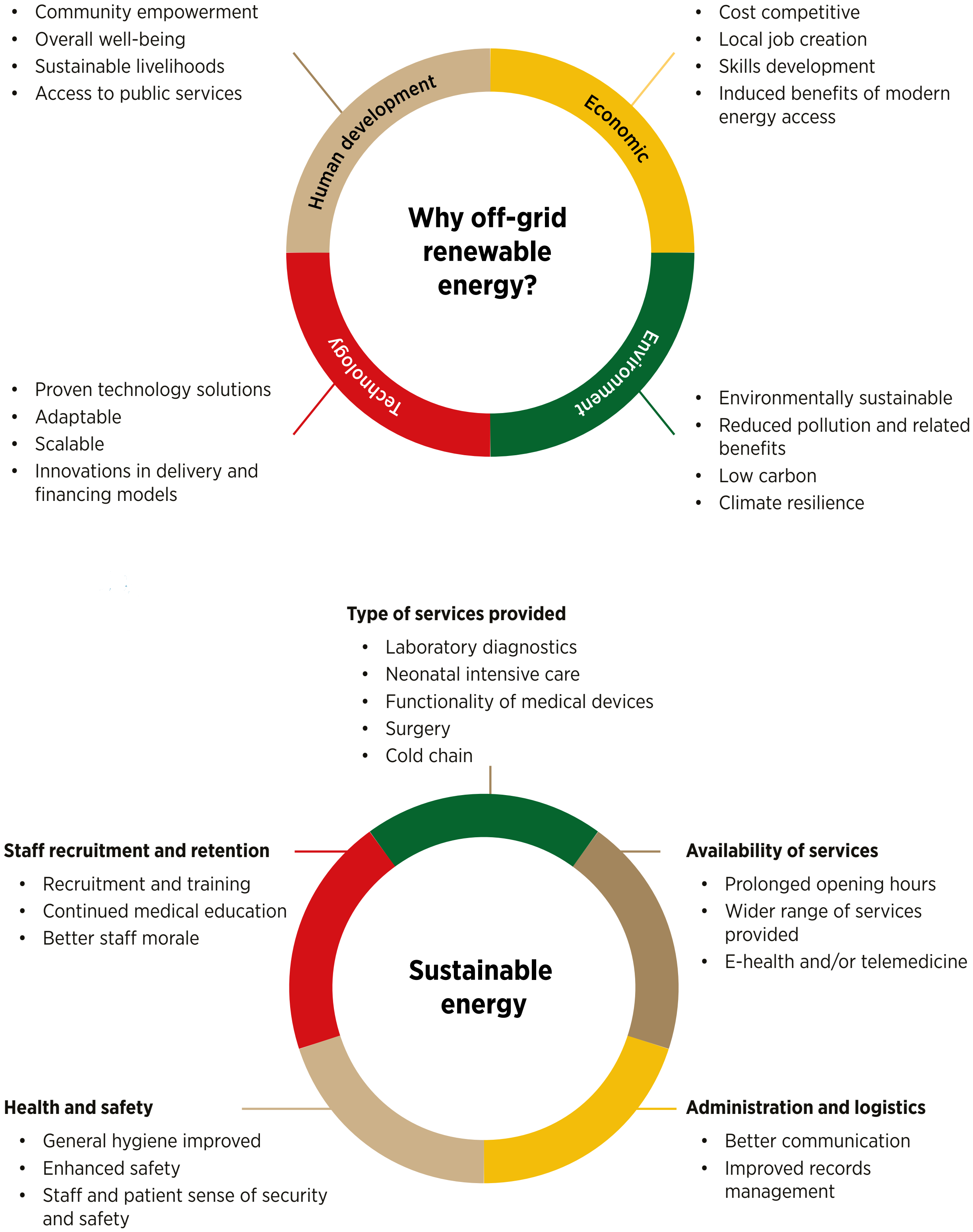
Reliable energy is crucial for the effective functioning of health facilities, especially for key services such as lighting, vaccine refrigeration and the operation of medical equipment. It enables health workers to perform vital tasks safely and efficiently, especially during emergencies. A stable energy supply supports health workers' job satisfaction, extends facilities' operating hours and improves the quality of patient care. In areas with limited access to the power grid, decentralised clean energy systems offer a cost-effective and resilient solution, facilitating affordable, uninterrupted healthcare services and improved health outcomes. Access to affordable and clean energy (Sustainable Development Goal [SDG] 7) can advance good health and well-being (SDG 3) by enabling essential, and often lifesaving, health services (Figure 1). The connection between energy access and health outcomes is particularly significant for primary healthcare systems, especially in developing nations with constrained resources, underfunded facilities and inadequate infrastructure.

Decentralised renewable energy (DRE) technologies, such as those powered by solar energy, present a practical and increasingly affordable solution to these challenges. Solar energy can significantly enhance the operational efficiency of healthcare facilities by providing a consistent and cost-effective power source. This is especially important in areas where conventional energy infrastructure is either lacking or prohibitively expensive. Solar power can support the operation of essential medical equipment, maintain the cold chain for vaccines and facilitate communication technologies such as telemedicine (connecting rural health facilities to specialists), and thereby expand healthcare access. Figure 1 illustrates the case for off-grid renewable energy solutions.

The link between SDGs 3 and 7 underscore the need for integrated approaches to development. Achieving universal health coverage (UHC) and other health-related targets under SDG 3 is closely tied to the availability of sustainable energy. Without a reliable electricity supply, healthcare facilities cannot operate at full capacity, leading to diminished service delivery, lower quality care and, ultimately, poorer health outcomes. Meanwhile, energy access supports the modern healthcare innovations that improve service delivery in marginalised communities (WHO *et al.*, 2023).

Thus, integrating DRE in healthcare systems has the potential to significantly enhance health infrastructure, optimise service delivery and foster healthcare innovation. DRE solutions address immediate energy challenges while aligning with global sustainability goals, providing a pathway to better health outcomes and more resilient healthcare systems. By bridging the gap between energy and health, Mali can achieve both better health outcomes and more resilient healthcare systems.

Figure 1 **The case for decentralised renewables and improved energy access in health services**



Source: (IRENA, 2019a).

1.2 SCOPE OF THE STUDY

The International Renewable Energy Agency (IRENA), in collaboration with the Renewable Energy Agency (*Agence des Energies renouvelables du Mali*, AER-Mali),[2] under the auspices of the Ministry of Energy and Water (*Ministère de l'Énergie et de l'Eau*, MEE) and the Ministry of Health and Social Development (*Ministère de la Santé et Développement Social*, MSDS), assessed the integration of DRE solutions and energy-efficient technologies to enhance the country's healthcare sector. Recognising existing frameworks for a comprehensive energy programme, IRENA is collaborating with the Malian government to co-develop health-energy systems tailored to the needs of healthcare facilities, especially in remote areas. This partnership aims to support decision making and improve healthcare delivery by developing a roadmap for designing and funding resilient DRE solutions across various primary healthcare facilities.

The scope of the study focused primarily on first- and second-tier health facilities, namely community health centres (*Centre de Santé Communautaire*, CSCOMs) and referral health centres (*Centre de Santé de Référence*, CSREFs). These facilities constitute the backbone of Mali's public health system: the CSCOMs provide primary health care, while the CSREFs serve as the first level of referral and technical support for the CSCOMs, managing cases that require additional expertise or resources. The report presents the findings of the assessment and outlines a framework along with tailored recommendations for Mali's ministries of health and energy to accelerate and sustain a country-driven health-energy nexus programme.

2 *Known as the National Agency for Renewable Energy and Bioenergies (Agence Nationale des Energies Renouvelables et des Bioénergies, ANERB) as of 24 December 2024.*

2. OVERVIEW OF MALI'S HEALTH SECTOR

2.1 DEMOGRAPHIC AND GEOGRAPHIC CHARACTERISTICS

Mali is the second-largest country in West Africa, covering an area of 1.24 million square kilometres. It is landlocked and bordered by Senegal and Mauritania to the west; Guinea, Burkina Faso and Côte d'Ivoire to the south; Niger to the east; and Algeria to the north. The country's geography is diverse, featuring the Sahara Desert in the north, the semi-arid Sahel in its central region and tropical savanna in the south. Thus, Mali's climates range widely, from the arid Sahara in the north to a more tropical environment in the south. Mali has three main seasons: a hot, dry period from March to June, a rainy season from June to September and a cooler, dry season from October to February, often marked by the harmattan wind. Temperatures typically vary between 24°C in January and 35°C in May. In recent decades, the average temperature has risen from 28.5°C to 29.5°C, with 2021 being the hottest year on record (World Data, 2023). The country's six agro-ecological zones, ranging from desert to savanna, experience varied temperature and moisture conditions that significantly shape agricultural and pastoralist practices. Increasing temperatures and fluctuating rainfall exacerbate challenges for climate-sensitive sectors, such as agriculture, water, health and infrastructure (Potsdam Institute for Climate Impact Research, 2023).

As of 2024, Mali's population was estimated at 24 million, with an annual growth rate of approximately 3.1% (World Bank, 2024a). The population is predominantly young: 45% are under the age of 15. About 70% reside in rural areas, with significant concentrations along the Niger River (INSTAT, 2024).

2.2 PUBLIC HEALTH PRIORITIES

Government priorities in the health sector include access to services in rural and peri-urban areas, disease prevention, socio-health promotion and family well-being, and the implementation of policies and strategies that ensure comprehensive care and service integration.

Table 3 **Critical health indicators and challenges**

Health indicators	Mali	Global
Maternal mortality ratio (deaths per 100 000 live births), as of 2023	367	197
Births attended by skilled health personnel, 2004-2020	67%	87%
Universal health coverage (UHC) service coverage index, 2021	41	68

Source: (USAID, 2023; World Bank, 2024b).

The indicators in Table 3 highlight systemic gaps in healthcare delivery, such as inadequate infrastructure, limited access to skilled health personnel and resource disparities, all of which directly affect health outcomes across the country. Furthermore, inadequate energy supply hampers the operation of healthcare facilities, including the storage of vaccines.

Progress towards universal health coverage

Mali is making significant strides towards universal health coverage through several key initiatives. The government is enhancing its public healthcare system and decentralising services to village levels with the assistance of community health workers, while also expanding its universal health insurance scheme. Efforts to increase funding, modernise infrastructure and adopt digital technologies are essential for improving both the quality and accessibility of healthcare services. In line with these priorities, Mali recently launched a national digital health strategic plan for 2024-2028 (*Plan Stratégique National de Santé Numérique du Mali*, PSNSNM) with a budget of USD 35 million, aimed at integrating digital tools and enhancing healthcare delivery across the country (Government of Mali, 2024).

Mali's health system is structured into three levels of care: primary, secondary and tertiary. These levels provide varying degrees of service to address the population's healthcare needs. The country is committed to achieving universal health coverage by improving access to quality healthcare services for all its citizens. The Health and Social Development Programme (*Programme de Développement Sanitaire et Social*, PRODESS) serves as Mali's key social and health development initiative, launched to improve healthcare access, social protection and family welfare throughout the country. Initiated in the late 1990s, it has evolved through multiple phases, each focused on strengthening the health system, addressing socio-economic disparities and promoting gender equality. The most recent phase, PRODESS IV (2020-2023), aligns with Mali's broader development goals, including the Strategic Framework for Economic Recovery and Sustainable Development 2019-2023 (*Cadre Stratégique pour la Relance Économique et le Développement Durable*, CREDD). Key priorities include improving health infrastructure, expanding social protection mechanisms and empowering vulnerable populations, all while addressing energy challenges through renewable energy initiatives in health facilities.

The urban/rural divide

The disparity between rural and urban healthcare access is pronounced. Urban centres such as Bamako benefit from established infrastructure, skilled healthcare professionals and ample medical resources. In stark contrast, rural areas face significant challenges, including inadequate healthcare infrastructure, insufficient medical supplies and a shortage of trained medical personnel. Residents of rural areas often have to travel 5 km to 35 km to reach healthcare centres, placing a heavy burden especially on women, children and the elderly. In 2022, 58.6% of Mali's population lived within 5 km of a health centre, while 88.9% lived within 15 km of one. Access is alarmingly low in regions such as Kidal (33.8% within 5 km) and Taoudénit (15.5% within 5 km). Traveling by foot or cart, especially in rural areas, poses significant challenges for the ill, particularly pregnant women. This challenge worsens during rainy seasons when roads become impassable. Additionally, many healthcare workers migrate to urban areas seeking better opportunities, leaving rural clinics understaffed. National health policy is addressing these disparities by decentralising healthcare services, constructing new health posts and deploying mobile health units.

Healthcare infrastructure

According to a report of the World Health Organization (WHO) Health Resources and Services Availability Monitoring System (HeRAMS), of the 3 139 Malian health facilities assessed, 3 086 are operational (Table 4), 53 are non-operational and 196 are either planned or permanently closed (WHO, 2023). In over 400 of these facilities, equipment is not in working condition as it is totally or partially damaged. These infrastructural challenges, coupled with energy deficits, have a direct impact on the quality and availability of healthcare services, especially in rural areas.

Table 4 **Distribution of healthcare facilities by type**

District	Primary				Secondary			Tertiary		
	CSCOM	Cabinet	Clinic	Infirmary	CSREF	CMIE	Poly clinic	Hospital (central and regional)	Other	Total
Bamako	64	365	150	6	5	7	12	9	8	**626**
Gao	110	11	5	3	3	1	–	2	–	**135**
Kayes	274	121	16	2	10	3	1	4	7	**438**
Kidal	17	2	2	–	1	–	–	–	1	**23**
Koulikoro	293	293	44	4	10	2	2	1	4	**653**
Menaka	61	–	–	–	1	–	–	–	–	**62**
Mopti	180	29	–	2	8	1	–	1	5	**226**
Sikasso	275	130	13	–	10	3	2	2	4	**439**
Segou	226	66	13	6	8	5	–	2	12	**338**
Taoudénit	17	–	–	–	–	–	–	–	–	**17**
Tombouctou	111	6	4	2	5	–	–	1	–	**129**
TOTAL	**1628**	**1023**	**247**	**25**	**61**	**22**	**17**	**22**	**41**	**3086**

Source: (WHO, 2024).
Notes: CMIE = inter-company medical centre; CSCOM = community health centre; CSREF = referral health centre.

2.3 SYSTEM STRUCTURE

The healthcare system in Mali functions on three levels (Table 5), based on the services provided and the area: central (national), and regional and sub-regional (district and community levels) (Government of Mali, 2019).

1. **At the central (national) level**, university teaching hospitals and specialised institutions provide tertiary care and manage complex medical cases requiring specialised interventions.

2. **At the regional level**, six regional hospitals offer secondary care. This level also includes private non-profit hospitals such as the Luxemburg "Mother-Child" Hospital in Bamako.

3. **At the sub-regional level** (districts and communities), primary health services are provided by 1628 CSCOMs. These facilities are complemented by other private, faith-based organisations, and facilities operated by non-governmental organisations. Additionally, 61 CSREFs at the district level supply secondary care and manage referrals from the first level.

Table 5 **Overview of health system structure**

Level		Health facility type	Examples of services provided	Responsible authority
National (central) (third referral level) Tertiary care		University Hospital Centre (CHU)	General surgery; traumatology	Ministry of Health and Social Development (MSDS); National Health Directorate (DNS); National Federation of Community Health Associations (FENASCOM)
Regional **(second referral level)** **Tertiary care**		Regional hospitals; polyclinics; clinics	General medicine; specialty medicine (ophthalmology, dermatology, etc.); surgery	Regional Health Directorate (DRS); Regional Federation of Community Health Associations (FERASCOM)
Sub-regional	District (first referral level) Secondary care	Referral health centre (CSREF); inter-company medical centres (CMIEs)	General medicine; caesarean section	District health management team; Local Federation of Community Health Associations (FELASCOM)
	Community (primary care)	Community health centre (CSCOM); dispensary; nursing practice	Childbirth; vaccinations; nursing care	Community health association (ASACO); community health agents (ASC); village health committee

Primary care is delivered at community health centres (CSCOMs), which serve as the first point of contact for the majority of the population, providing basic medical services such as maternal and childcare, vaccinations and treatment for common illnesses. Other primary care providers include cabinets, clinics and garrison infirmaries. Cabinets and clinics deliver primary care services outside the public health system, while infirmaries, associated with the military, offer semi-public primary healthcare.

Secondary care is provided at referral health centres (CSREFs) and regional hospitals, which offer more specialised services, including emergency care and surgical interventions. Inter-company medical centres (*Centre Médical Inter-Entreprise*, CMIEs), which serve specific populations, also fall into this category. They primarily focus on occupational health services for employees of various enterprises, emphasising workplace health, preventive care and basic curative services.

Tertiary care is offered at regional and national hospitals, which provide the most complex and specialised medical services.

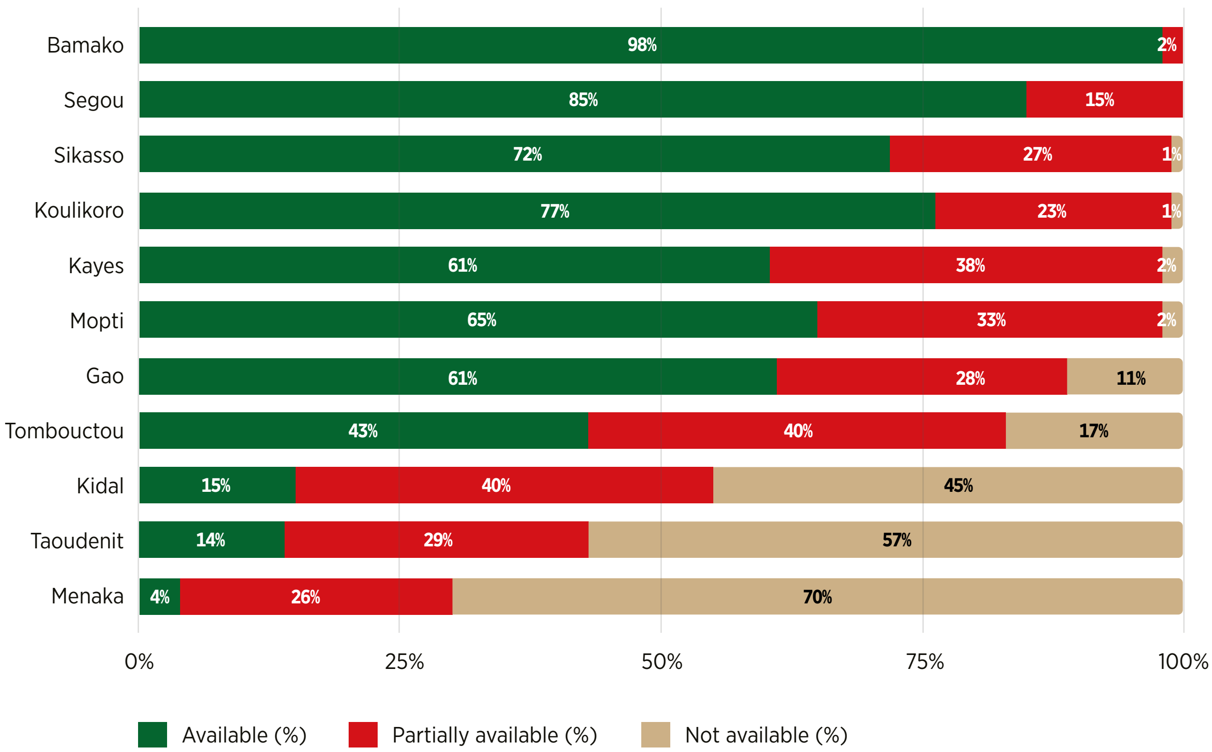
Common services across CSCOMs, CSREFs and hospitals include reproductive health (maternity, family planning), paediatrics, disease management (asthma, diabetes, hypertension), mental health, trauma and injury care, disability services, ante-natal health, basic radiology, laboratory diagnostics and pharmacy services. Advanced diagnostics and research laboratories are primarily located in CSREFs and hospitals, where specialised services, including emergency and intensive care, cater to complex health needs, in contrast to the primary care focus of CSCOMs. Hospitals offer more intensive care, advanced radiology, dialysis, surgical operating blocks, specialised departments and advanced mental health services. The private sector, faith-based organisations and military health services supplement public healthcare.

Although the private health sector has expanded, particularly in urban areas, data on these facilities are not well integrated into national health records. Traditional medicine continues to be widely practiced, with numerous centres offering care in rural areas (Government of Mali, 2014).

2.4 HEALTH FACILITIES' ELECTRICITY ACCESS

Mali's health facilities demonstrate significant disparities in energy access, both nationally and regionally. In 2024, the WHO assessed 2 943 operational health facilities, of which 75% had reliable electricity access, 20% experienced unreliable supply and 4% lacked access to electricity (WHO, 2023). However, these national averages mask stark regional differences. In the capital district of Bamako, 98% of health facilities are electrified, primarily through grid connections. Similarly, health facilities in the southern and central regions – such as Ségou (85%), Koulikoro (77%) and Sikasso (72%) – also have relatively high rates of electrification. In contrast, regions in the north and northeast, including Gao, Tombouctou, Kidal, Taoudénit and Ménaka, face severe challenges. In Taoudénit and Ménaka, for instance, between 57% and 70% of health facilities lack access to electricity, highlighting a pronounced urban-rural divide (Figure 2).

Figure 2 **Health facilities' energy access by region**



Source: (WHO, 2024).

The primary systemic obstacles to energy access include equipment shortages (affecting 80% of facilities) and financial constraints (53%), compounded by a lack of supplies (10%), inadequate training (7%) and limited personnel (5%). Solar photovoltaic (PV) systems are becoming the cornerstone of Mali's health facility energy solutions, reflecting both the country's solar energy potential and the limitations of the grid. Among facilities with access, 59% rely on solar energy, 49% on the public grid and 10% on diesel generators.

2.5 HEALTHCARE FINANCING

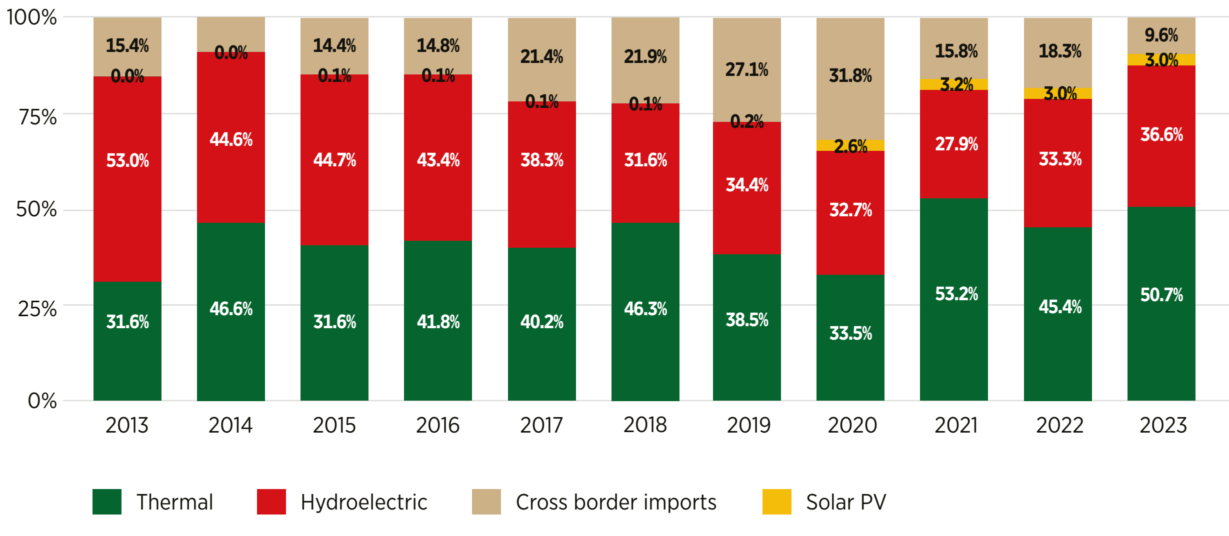
Mali's health system depends on both domestic and external funding sources. In 2020, public spending on health was 4% of the gross domestic product, amounting to USD 16.2 per capita, an increase from USD 8.9 in 2000 (World Bank, 2023). Less than half of this spending comes from public sources, with 55% derived from domestic funding and 45% from external funding, including foreign aid. Total annual health spending per capita stands at around USD 35, with out-of-pocket (OOP) expenditure accounting for 29%. This figure is lower than the average OOP spending in low-income and sub-Saharan African countries. Despite a six-fold increase in public health spending from 2000 to 2020 and ongoing efforts to enhance equity through mechanisms such as national health accounts, Mali faces significant obstacles in achieving universal health coverage. These include inadequate resource allocation to poorer regions and high OOP costs. The country's strategy aims to increase healthcare services' share of the national budget to 15%, while improving local funding; however, external aid remains crucial for sustaining progress (World Bank, 2024c). Addressing healthcare financing challenges amid systemic gaps in service delivery requires sustainable and equitable funding mechanisms. Increasing the healthcare sector's share of national spending while encouraging local funding will be critical for sustaining progress towards universal health coverage.

3. OVERVIEW OF THE ELECTRICITY SECTOR

Mali's electricity sector is organised around a few key players and institutional entities. The national electric utility (*Énergie du Mali*, EDM) plays a central role in electricity generation, transmission and distribution, alongside independent power producers. The main actors at the institutional level include the Ministry of Energy and Water (MEE), the Electricity and Water Regulatory Commission (*Commission de Régulation de l'Électricité et de l'Eau*, CREE) and the Malian Agency for Domestic Energy and Rural Electrification (*Agence Malienne pour le Développement de l'Énergie et de l'Électrification Rurale*, AMADER). EDM is responsible for the provision of electricity service within a concession area that covers Mali's major urban centres, while AMADER is responsible for rural electrification, which is delegated to private concessionaires in defined geographic areas.

In 2023, electricity generation reached 2 838 gigawatt hours: 50.7% from thermal sources, 36.6% from hydroelectric, 9.6% from cross-border imports (from Côte d'Ivoire) and 3% from solar PV (Figure 3). That same year, overall access to electricity was 54.5%, with rural access at 18.3% and urban access at 99.7% (IEA *et al.*, 2024; World Bank, 2024d). The government aims to further enhance the electrical system by hybridising existing diesel power plants with solar PV.

Figure 3 **Evolution of electricity mix by source, 2013-2023**



Source: (EDM, 2025).
Note: PV = photovoltaic.

OVERVIEW OF THE ELECTRICITY SECTOR

Mali possesses vast renewable energy potential; just 2% of its solar resources could meet the entire nation's electricity demand. The National Renewable Energy Action Plan aims for 1 416 megawatts of grid-connected renewable capacity by 2030, representing a nine-fold increase from 2010. The focus would be on both grid-connected and off-grid renewable solutions (Tables 6 and 7), with a special emphasis on decentralised solar PV and biomass (IRENA, 2019b). Although the country has a long history of solar energy programmes for livelihoods and utility services, reliable energy access for health services remains a major challenge.

Table 6 **Targets for grid-connected renewables, 2010-2030**

	2010	2020	2030
Installed capacity for non-hydro RE (MW)	6.3	150.7	201.8
Non-hydro RE* of total installed capacity (%)	2.3	13.8	8.3
Installed capacity for all RE targets including hydro** (MW)	156.5	660.4	1 416
RE targets, including hydro** of total installed capacity (%)	57.71	61.44	58.25
Non-hydro RE* production in the electricity mix (%)	3.12	12.11	8.63
RE targets, including hydro** production in the electricity mix (%)	65.09	49.35	36.88

Source: (IRENA, 2019b).
Notes: *renewable energy targets, excluding small and large hydro (> 30 megawatts);
**renewable energy targets, including small and large hydro; MW = megawatt; RE = renewable energy.

Table 7 **Targets for off-grid renewables, 2010-2030**

	2010	2020	2030
Mini-grids, renewable and hybrid (MW)	0.094	8.063	8.063
Total installed capacity for all other systems (MW)	20.27	234.72	605.01
Rural population with electricity access from renewables (mini-grid and isolated systems) (%)	1.7	36.9	66.64

Source: (IRENA, 2019b).
Note: MW = megawatt.

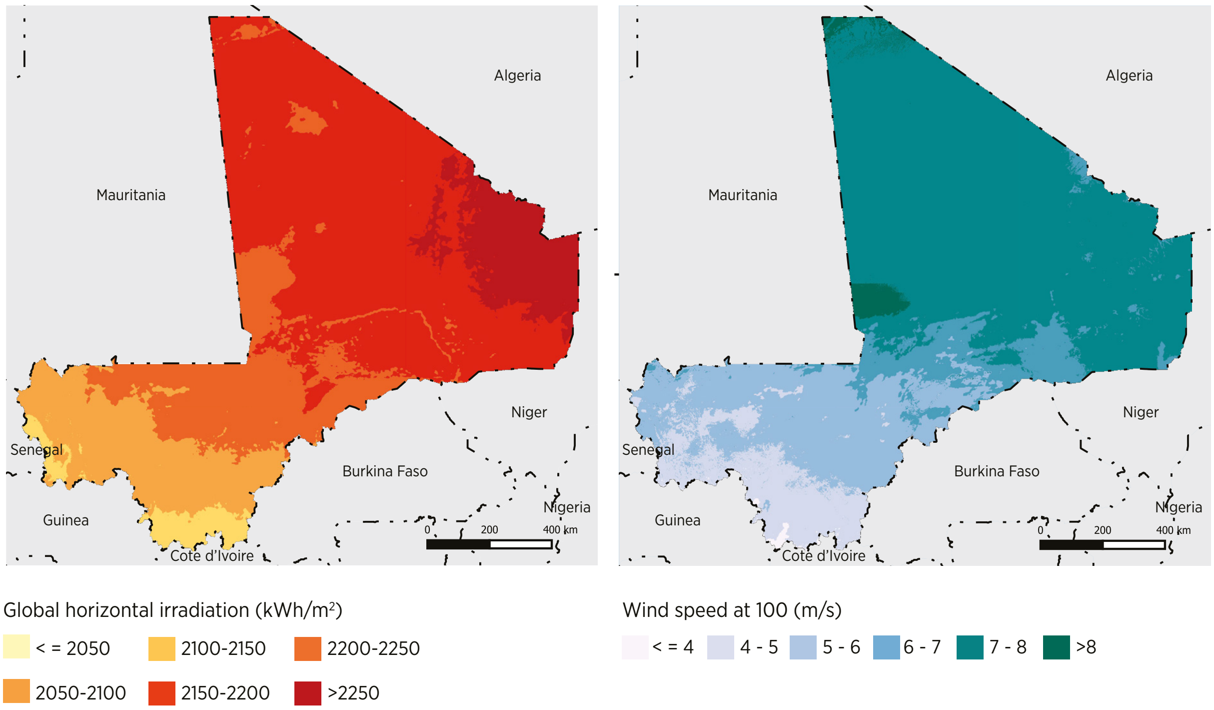
3.1 THE EFFECTS OF ENERGY ACCESS GAPS ON HEALTH SERVICES

Limited access to energy hampers not only daily living but also critical health services that rely on consistent power supply. Energy availability is a pressing issue: only 75% of health facilities have some form of electricity, primarily from solar power (57%) and the grid (49%). Cold chain systems for vaccines and medical storage are highly unreliable, with only 57% of facilities having electricity to support these systems (WHO, 2023). Frequent power outages due to insufficient electricity supply impede essential services like the refrigeration of vaccines and operation of medical equipment. The high cost of thermal power generation from heavy fuel oil – one of the dominant sources of electricity in the country – makes electricity unaffordable for many healthcare facilities, forcing them to rely on expensive diesel generators (World Bank, 2019).

3.2 RENEWABLE ENERGY RESOURCES

Mali receives an annual average direct normal irradiance of 4.8 kilowatt hours per square metre per day ($kWh/m^2/day$), along with an average global horizontal irradiance (GHI) in the range of 5.5–6 $kWh/m^2/day$, as illustrated in Figure 4. The GHI is crucial for evaluating energy production and the efficiency of flat-plate PV systems. The designs proposed are based on an average of 5.5 sunny hours, indicative of Mali's geographical location and tropical climate. Meanwhile, wind energy resources exceeding 6 metres/second (m/s) are more prevalent in the northern part of the country, particularly above 16 degrees latitude.

Figure 4 **Solar (left) and wind (right) resources**



Source: (IRENA, 2025).

Notes: km = kilometre; kWh/m^2 = kilowatt hours per square metre; m= metre; s = second.

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.

4. METHODOLOGY, ANALYSIS AND SURVEY FINDINGS

The study aimed to assess the health-energy ecosystem in Mali to inform DRE solutions that enhance healthcare delivery and address critical gaps. Each phase of the study was tailored to uncover insights regarding health service delivery, energy access and infrastructure needs. This section delves into the study's approach, the sample used and an analysis of the survey data.

A mixed-methods approach was employed for data collection and analysis, involving a thorough examination of both secondary and primary data. The primary data collected from the field were organised into themes for analysis and triangulated with secondary data, providing robust insights into the design of DRE systems and the health-energy ecosystem in Mali. The study had three phases, outlined in Table 8.

Table 8 **Study phases**

Phase 1	**Desk research through mixed methods.**	**Formulated a sampling strategy.**
Phase 2	Interviews conducted at 60 healthcare facilities (48 CSCOMs, 10 CSREFs, 2 regional hospitals; see Annex A for details).	Interviews conducted through a structured questionnaire.
Phase 3	Qualitative analysis: Interviews were coded into numerical data for analysis (included input from staff at health facilities to understand health service delivery, and from 4 DRE suppliers to understand the energy enterprise ecosystem).	Quantitative analysis: Statistical, predictive and prescriptive techniques were used to extract meaningful patterns and conclusions.

Notes: CSCOM = community health centre; CSREF = referral health centre; DRE = decentralised renewable energy.

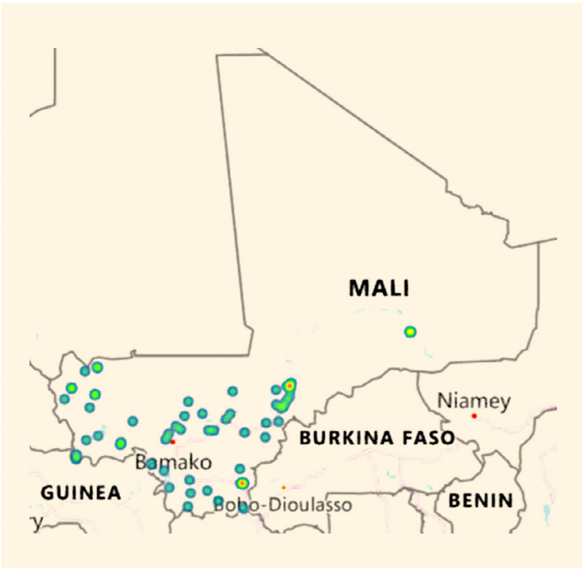
4.1 GEOGRAPHICAL DISTRIBUTION OF SURVEYED HEALTH FACILITIES

To improve healthcare governance and deliver public health services directly to local populations, the government of Mali reorganised its administrative structure in 2023, increasing the total number of regions to 19, in addition to the capital district of Bamako.

The present study adopted a broad sampling strategy to provide representative results at the national level. However, due to security issues in the central and northern parts of the country, the assessment was conducted in only nine of Mali's 19 administrative regions. Table 9 shows the geographical distribution of the 60 health facilities surveyed across these nine regions. Annex A provides detailed information about each health facility.

Health facilities were selected based on criteria set to ensure a representative statistical sample, focusing on electricity access, reliability, geographical distribution, and the type and level of health services provided. Although none of the surveyed facilities was entirely without electricity, 32 of 60 (53.3%) were off-grid and relied on unreliable sources such as diesel generators, solar panels or hybrid systems, while 28 (46.7%) were on-grid though they also experienced unreliable supply. Regarding geographical coverage, 65% of community health centres (CSCOMs) are located in rural areas, whereas most referral health centres (CSREFs) and regional hospitals are located in urban centres. The selection process also considered the range of health services provided and the service level of the facilities, ultimately including 48 CSCOMs, 10 CSREFs and 2 regional hospitals, thus ensuring a well-rounded representation of both primary and secondary healthcare facilities.

Table 9 **Geographical distribution of assessed health facilities**



Regions	CSCOMs	CSREFs	Regional hospitals
Koulikoro	9	-	-
Sikasso	5	1	-
Segou	6	1	-
Kayes	11	2	-
Mopti	8	2	1
San	1	1	-
Bougouni	4	2	-
Kita	3	-	-
Gao	1	1	1
Total	48	10	2

Notes: CSCOM = community health centre; CSREF = referral health centre.

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.

4.2 KEY CHARACTERISTICS OF SURVEYED HEALTH FACILITIES

Conducted across nine regions of the country, the study aimed to evaluate the potential for deploying renewable energy solutions, particularly solar PV systems, in healthcare facilities that currently lack reliable electricity access. CSCOMs primarily serve rural communities, with 65% of surveyed facilities situated in rural areas. They form the foundation of Mali's healthcare system, providing primary care to communities. In contrast, CSREFs serve mostly urban populations, with 80% of surveyed facilities located in urban settings. The hospitals included in the survey were exclusively urban (100%) and function as tertiary care centres for their respective regions.

Accessibility and exposure to natural disasters

The modes of transport used to reach health centres vary widely, depending on local context. The most common modes include motorcycles (98%), on foot (85%), bicycles (78%), cars (67%) and carts (65%). While 95% of health facilities are not affected by major natural disasters, approximately 5% face flooding risks due to their proximity to waterways. Notably, 92% are located in lightning-prone areas, posing a potential hazard to electrical systems and highlighting the need for adequate lightning protection in renewable energy installations.

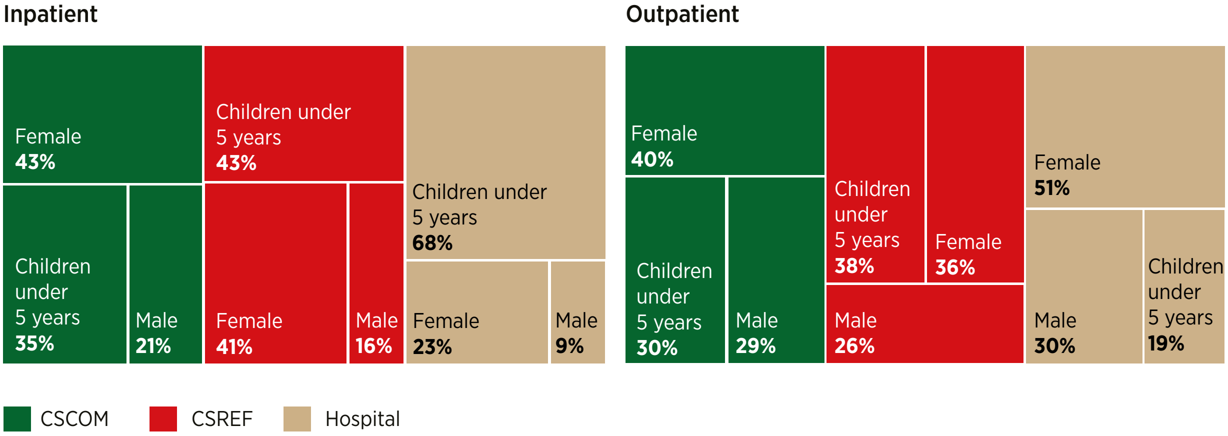
Health services provided and target populations served

The primary health services provided by CSCOMs include reproductive health (maternity, family planning, antenatal care); neonatal and paediatric care; management of chronic diseases, trauma and injuries; support for disabilities and basic intensive care. The study highlighted that while maternity and reproductive health services at both CSCOMs and CSREFs are universally available, they are in urgent need of improvement. Moreover, pharmacy and laboratory services, although not widely available at this facility level, require enhancement. In regional hospitals, key services requiring improvement include intensive care, radiology, neonatal care and laboratory services.

Of the population served by healthcare facilities in Mali, a minimum of 2 500 people are covered per CSCOM, rising to 16 000 people depending on the type of CSCOM (urban vs rural) and its location. These figures rise exponentially for CSREFs, with each serving an average of 330 000 people, and hospitals, each serving up to 1.3 million people.

On average, surveyed CSCOMs receive 27 patients a day, while CSREFs and hospitals accommodate a minimum of 158 and 1 050 patients a day, respectively. The distribution of inpatients and outpatients across various healthcare facilities has a noteworthy pattern, particularly concerning gender and age demographics. A large share of patients at CSCOMs are women, whose share of inpatients and outpatients is remarkably balanced: 40% of outpatients and 43% of inpatients (as illustrated in Figure 5). Taken together, women and children make up a staggering 84% of inpatients. This may be attributed to the maternity services provided at CSCOMs. Also, a significant proportion of patients are children under the age of five. A similar trend is observed at CSREFs: children under the age of five comprise 43% of inpatients and 38% of outpatients, and women make up 41% of inpatients and 36% of outpatients. In contrast, the distribution of inpatients and outpatients within hospital settings (as shown in Figure 5) is considerably divergent, highlighting the distinct nature of hospital care compared with other healthcare facilities. While children under five comprise the majority of inpatients (68%) at hospitals, women make up the largest share of outpatients (51%). Understanding the patient demographics at each facility level helps identify services that need strengthening and tailor DRE solutions accordingly. Recommendations for medical technologies are elaborated in Chapter 6.

Figure 5 **Distribution of patients at CSCOMs, CSREFs and hospitals by demographic group**



Notes: CSCOM = community health centre; CSREF = referral health centre.

Ownership, revenues, operating costs and financing

CSCOMs serve as the primary point of contact for most of the population and are integral to the public healthcare system. Most are community owned ASACOs. Meanwhile, the vast majority of CSREFs (90%) are government owned, as are all regional hospitals. This pattern indicates a trend towards centralisation as the facility level increases, and underscores the significant community ownership present at the CSCOM level. Across all levels of the healthcare system, cost recovery fees are charged at subsidised rates for consultations, laboratory examinations and medicine.

The annual operating costs of health facilities vary among CSCOMs, CSREFs and hospitals (see Table 10). To cover these costs, CSCOMs primarily rely on cost recovery fees (76%), community contributions, and donor support, with government subventions playing a smaller role. In contrast, CSREFs are mainly funded through user fees and government subventions. Hospitals, on the other hand, are primarily financed by the government, with occasional assistance from donors.

Table 10 **Annual operating costs of health facilities**

	CSCOMs	CSREFs	Hospitals
Average (USD)	21 420	255 000	555 900
Maximum (USD)	105 400	680 000	884 000
Minimum (USD)	3 400	28 900	229 500

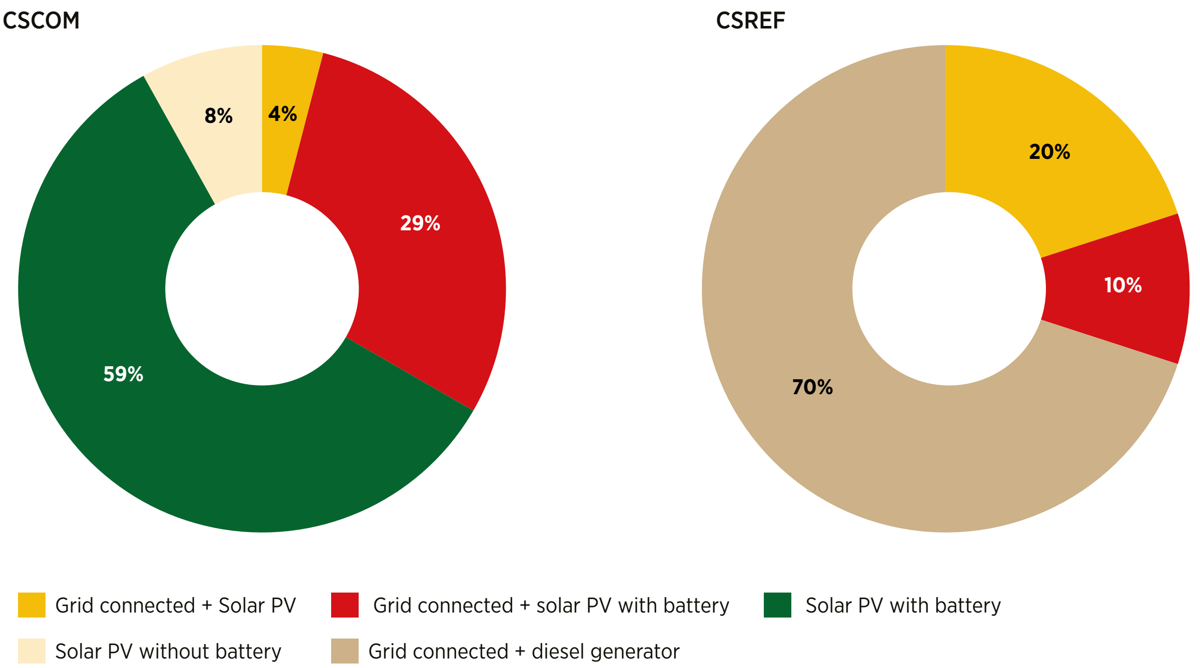
Notes: CSCOM = community health centre; CSREF = referral health centre; USD = United States dollar.

Demand for healthcare services peaks during the rainy season, from May to November. During this period, CSCOMs generate an average of USD 2 789 (CFA 1 640 703) from user fees. For CSREFs, this figure rises to USD 11 990 (CFA 7 052 994), and hospitals earn up to USD 100 876 (CFA 59 339 094).

4.3 AN OVERVIEW OF HEALTH FACILITIES' ELECTRICITY ACCESS

All levels of health facilities rely on a combination of electricity sources to ensure electrification (Figure 6). For CSCOMs, the primary source of electricity is solar PV panels with battery storage (58%). One-third of surveyed CSCOMs are connected to the grid, while only 4% use standby diesel generators as a backup. Where available, grid supply is often unreliable and prone to frequent outages. Of surveyed CSREFs, 100% are connected to the grid, and 70% have standby generators. Frequent outages disrupt critical services, and existing infrastructure often struggles to support modern medical equipment. Meanwhile, diesel generators are expensive to run and maintain. In many cases, facilities supplement their power supply with standalone solar PV systems that provide electricity to specific sections, such as laboratories. Most health facilities have more than 12 hours of grid electricity a day, while 20% of health facilities have only 4-8 hours. Uninterrupted power supply is not common. Although all hospitals are connected to the grid, they still face intermittent supply. While backup generators are standard, challenges related to fuel supply and maintenance persist. The current capacity of solar energy systems is insufficient to meet growing energy demand. Reliance on expensive diesel and petrol to compensate for shortages significantly increases costs, highlighting the urgent need for more reliable and sustainable energy solutions. Box 2 outlines the WHO Multi-Tier Framework for assessing electricity access in primary (CSCOMs) and secondary (CSREFs) health facilities.

Figure 6 **Sources of electricity across surveyed CSCOMs and CSREFs**



Notes: CSCOM = community health centre; CSREF = referral health centre; PV = photovoltaic.

Box 2 **WHO multi-tier measurement of electricity access in health facilities**

Tier 0 (no access). This health facility has no electricity supply, except for dry-cell batteries with a peak power capacity of less than 5 watts (W). Consequently, the facility relies on kerosene lamps or candles and lights powered by dry-cell batteries for lighting.

Tier 1 (minimal access). This facility has access to at least 5 W of peak capacity for a minimum of four hours during the day, primarily for electrical lighting, but experiences inadequate evening supply. It may also encounter challenges with quality, reliability, and operational or environmental sustainability. The daily energy capacity ranges from 20 watt hours (Wh) to 279 Wh.

Tier 2 (basic access). This health facility can access at least 70 W of peak capacity for at least four hours per day, including a minimum of two hours after nightfall if necessary. The supply can support additional applications beyond lighting, such as blood analysers, ultraviolet water purifiers, jaundice lights, very high frequency receivers, light-emitting diode microscopes, air circulators, printers, ultrasound machines and vacuum aspirators. The facility may encounter challenges related to reliability, voltage issues, and operational and environmental sustainability. The daily energy capacity ranges from 280 Wh to 1 599 Wh.

Tier 3 (intermediate access). This facility has access to an electricity supply of at least 200 W of peak capacity for a minimum of eight hours during the day, and at least two hours in the evening. In addition to the applications mentioned in Tier 2, the clinic can utilise most medium-capacity equipment, such as suction apparatus, vortex mixers, CD4 counters and centrifuges. While the facility does not face issues with supply quality or reliability, it may face environmental and operational sustainability problems. The daily energy capacity ranges from 1.6 kilowatt hours (kWh) to 32 kWh.

Tier 4 (advanced access). This health facility has access to an electricity supply of at least 2 000 W and can operate most applications, although it may be constrained in its ability to run numerous high-capacity applications simultaneously (*e.g.* in a large clinic). The supply is available for at least 16 hours per day, including all evening hours, with adequate voltage and rare interruptions. The facility has sufficient funds to cover fuel and electricity costs as well as maintenance costs. Also, the electricity source does not have negative environmental or health impacts in the surrounding area. The daily energy capacity ranges from 32 kWh to 220 kWh.

Tier 5 (full access). This health facility can access virtually unlimited power at all times of the day and night, with no deficiencies in quality or reliability of supply. The facility also has sufficient funds for fuel and electricity bills as well as maintenance costs. Furthermore, the electricity source does not cause any negative environmental health impacts in the local vicinity around the clinic. The daily energy capacity exceeds 220 kWh.

Source: (WHO, 2015).

Electricity and fuel consumption rates

There is a demand for lighting throughout the day, reaching a peak in the evening between 6 p.m. and 12 a.m. It is important that CSCOMs and CSREFs set a plan for lighting management; in hospitals, lighting is used consistently throughout the day, peaking from 12 a.m. to 12 p.m.

Given the unreliable and erratic supply of grid electricity, most health facilities rely on diesel and petrol to power essential medical equipment. Table 11 presents the weekly consumption volume consumed at each facility level. Diesel is used across all types of facilities, resulting in average yearly greenhouse gas emissions estimated at 4.2 tonnes for CSCOMs, 47.3 tonnes for CSREFs and 752.3 tonnes for hospitals. To mitigate these emissions, it is crucial to transition to cleaner energy sources, such as solar (see Chapter 5 for recommended designs for each facility level).

Table 11 **Diesel consumption per week by type of health facility**

Diesel	CSCOMs	CSREFs	Hospitals
Average (litres/week)	30	339	5 404
Maximum (litres/week)	30	1 120	7 000
Minimum (litres/week)	30	25	3 808

Notes: CSCOM = community health centre; CSREF = referral health centre.

Current electricity consumption and expenditure for lighting and electrical devices have been estimated based on facilities' monthly electricity bills. Variations in electricity consumption due to seasonal activity fluctuations are considered negligible in this analysis. Table 12 summarises the average consumption and expenditure of each facility level, revealing that the highest electricity costs are incurred by the smallest and most remote facilities.

Table 12 **Average electricity consumption rates and expenses by type of health facility**

Customer group	Average monthly electricity consumption per facility (kWh)	Average monthly electricity expenses per facility (USD)	Average cost of electricity unit (USD/kWh)
CSCOMs	88.7	36.9	0.42
CSREFs	6 340.4	1 652.9	0.26
Hospitals	38 694.6	10 298.5	0.27

Notes: CSCOM = community health centre; CSREF = referral health centre; kWh = kilowatt hour.

Frequency of electricity cuts and impact on healthcare delivery

Power outages are frequent, with up to two interruptions a day across all facility levels (Table 13). The average duration of these outages is approximately 9 hours, ranging from a minimum of 2 hours to a maximum of 24 hours in some areas. In two-thirds of the assessed health facilities, no correlation was found between the frequency of power interruptions and seasonality (dry versus wet season), while 31% of health facilities reported that most interruptions occur during the rainy season.

Table 13 **Frequency of outages in a typical month by type of health facility**

	CSCOMs	CSREFs	Hospitals
Average (outages/month)	12	27	45
Maximum (outages/month)	60	60	60
Minimum (outages/month)	1	1	30

Notes: CSCOM = community health centre; CSREF = referral health centre.

In CSCOMs, electricity disruptions mainly occur due to poorly constructed PV systems, which account for 67% of power interruptions. This highlights a significant reliance on solar energy at the community level, and underscores issues related to inadequate solar design, installation, and operation and maintenance (O&M). In contrast, CSREFs and hospitals primarily face disruptions caused by grid issues or load-shedding due to insufficient electrical capacity.

Over 90% of the facilities reported that power interruptions frequently compromise maternal care services. Most health facilities noted that the absence of fans during power outages causes discomfort for patients. A CSCOM staff member remarked, *"Almost every evening, we experience a power outage because there is no backup source. We cannot even plug in a fridge."* A substantial majority (96.7%) of the surveyed health facilities indicated that insufficient electricity hinders their work environment, affecting the staff's ability to deliver care. Approximately 51 of 60 facilities need to either replace or repair equipment damaged by electricity fluctuations. Additionally, 81% of these facilities frequently experience challenges with the cold chain, which results in vaccine spoilage and negatively impacts immunisation efforts. At the CSREF and hospital levels, electricity outages affect laboratories, operating theatres, pharmacies and radiology services, as well as maternity wards and cold chains.

4.4 OTHER KEY CHARACTERISTICS

Cooking and heating

Most of the surveyed healthcare facilities (97%) indicated a need for cooking and heating, with the exception of health posts. In facilities where patients are provided with meals, charcoal is the primary energy source for cooking and heating, followed by firewood (67%); solar, electricity and other energy sources (*e.g.* butane) are rarely utilised.

Water supply, sanitation and hygiene

Water supply, sanitation and hygiene (WASH) are crucial components of healthcare facilities that significantly shape individual patient outcomes and overall public health. In Mali, the heightened risk of drought can drive up WASH costs, and thus health facilities' operating expenses. Adequate toilet facilities are vital for preventing infections, maintaining hygiene and ensuring a safe environment for both patients and healthcare staff. Assessing WASH infrastructure helps gauge its role in enhancing patient care and ensuring safety. Effective sanitation not only improves the quality of care, but also promotes patient dignity and contributes to overall comfort, underscoring the importance of prioritising WASH improvements in healthcare systems. The average monthly water consumption is 32 000 litres in CSCOMs, 170 000 litres in CSREFs and 560 000 litres in hospitals. Most health facilities depend on a public water reticulation system, with some relying on independent water supply and treatment (mainly CSCOMs). This situation underscores the need for water conservation measures to ensure adequate water availability, especially during droughts and dry seasons.

Building characteristics

The integration of DRE systems in healthcare facilities is heavily influenced by existing infrastructure, which varies widely across facility types. CSCOMs primarily use iron sheets for roofing (88%) and a combination of unburnt bricks or cement blocks for walls (48% each); their floors are predominantly concrete (57%), and almost all have iron window coverings (94%). However, 24% of CSCOMs lack electrical wiring, underscoring the urgent need for energy access. CSREFs demonstrate slightly superior construction quality, with roofs made of iron sheets (60%) and concrete (40%). Walls are mainly constructed from unburnt bricks with cement (60%) or cement blocks (30%), and various materials are used for floors. Despite their higher-quality buildings, 17% of CSREFs remain unwired, a significant infrastructure gap that must be addressed. Table 14 presents the number of rooms in surveyed health facilities, by type of use.

Table 14 **Number of rooms in surveyed health facilities, by use and facility type**

		CSCOMs	CSREFs	Hospitals
Number of rooms for healthcare services (consultation rooms, wards, labs, *etc.*)	Average	12	135	262
	Maximum	27	210	301
	Minimum	4	17	223
Number of rooms in staff quarters	Average	3	12	11
	Maximum	10	50	14
	Minimum	0	0	7
Rooms for other uses (officers' mess)	Average	1	3	8
	Maximum	3	5	8
	Minimum	0	0	8

Notes: CSCOM = community health centre; CSREF = referral health centre.

Hospitals are generally better equipped, with all surveyed hospitals wired and connected via a three-phase line. These hospitals are also constructed with better-quality materials than CSCOMs and CSREFs, with iron sheets and cement for roofing and unburnt bricks with cement or cement blocks for walls.

CSCOMs, which lack basic electrical infrastructure, face greater challenges in adopting renewable energy technologies compared to well-equipped hospitals. Given the high temperatures throughout the country, it is important to adopt efficient building materials and designs to provide cooling and comfort for patients and staff, as well as to enhance the efficacy of medical equipment and services.

5. RECOMMENDED SOLAR PV SYSTEM DESIGNS AND THEIR COSTS

This chapter outlines the foundational assumptions necessary for designing solar energy systems. To create an effective design, it is essential to understand the energy framework requirements, patient inflow and the distribution of sunlight across areas. Similarly, the cost analysis of the proposed designs is based on price quotes for the various components and activities required to set up and maintain the solar energy system, sourced from local suppliers in the country.

5.1 SOLAR PV SYSTEM DESIGN CATEGORIES

The details of design assumptions and load considerations are elaborated in Annex B. The designs for each facility level are categorised as follows:

- **Entire load.** This category considers medical equipment (including equipment at CSCOMs and CSREFs, as well as select equipment in hospitals), standard equipment for administrative tasks, lighting and ventilation including air conditioning (AC). It also includes battery backup for all connected loads.
- **Entire load with AC** without battery backup for AC. This category includes all loads covered under the entire load category, providing battery backup for all loads except air conditioners. This assumes that AC is only necessary during the day when temperatures soar high and solar PV panels can be directly used to power them.
- **Entire load without AC.** This category considers all loads included under the entire load category, excluding air conditioners. It includes battery backup for all other loads.
- **Critical load.** This category focuses on select medical equipment essential for maternal care, emergency services and vaccine storage, along with essential lighting and ventilation needs (fans). It also includes battery backup for these loads.

Based on the assessment's findings and assumptions, the recommended designs for each health facility type with various options are given in Table 15.

Table 15 **Specifications of recommended DRE system designs**

Type of facility	Type of load	Solar panel (kWp)	Battery (kWh)	Inverter (kVA)	Number of facilities
Rural CSCOM	Entire load w/o AC*	8	48	8	1254
	Critical load	4.2	24	6	
Urban CSCOM	Entire load	11	60	12.5	374
	Entire load with AC without battery backup for AC**	11	48	12.5	
	Entire load w/o AC	7.8	48	8	
	Critical load	4	24	6	
CSREF	Entire load	42	240	45	61
	Entire load with AC without battery backup for AC	42	120	45	
	Entire load w/o AC	18	120	25	
	Critical load	10.8	60	15	
Regional hospital	Entire load	90	600	100	6
	Entire load with AC without battery backup for AC	90	288	100	
	Entire load w/o AC	48	288	50	
	Critical load	26.4	192	32	

Notes: AC = air conditioning; CSCOM = community health centre; CSREF = referral health centre; kVA = kilovolt ampere; kWh = kilowatt hour; kWp = kilowatt peak; w/o = without; *Applicable to rural CSCOM as per services provided under national guidelines; **Applicable to urban CSCOM as per services provided under national guidelines.

Urban CSCOMs are equipped or required to be equipped with AC infrastructure, while rural CSCOMs currently lack AC services. This disparity affects the design of solar energy systems for both types of facilities. As seen in Table 15, the system size of 10.8 kWp is applicable for existing urban CSCOMs that operate with full loads, including AC. In contrast, rural CSCOMs which do not have AC, require a system size of 7.8 kWp to support their entire loads. The critical load for both urban and rural CSCOMs necessitates a system design of 4.2 kWp. To power the first point-of-care with critical load, a system capacity of 4.2 kWp is needed, while the largest facility (*i.e.* hospital) will require a system capacity of 90 kWp to support the entire load with AC.

5.2 DESIGN OPTIONS FOR STAFF QUARTERS

Currently, most staff quarters at rural health facilities lack electrification, leading to dissatisfaction among staff members. To enhance their work efficiency and comfort, the following DRE system designs can be integrated into existing and new health facilities, based on the number of staff quarters. The solar PV design considerations for staff quarters are divided into two categories: entire loads (including lights, televisions, refrigerators, fans, *etc.*) and basic loads (including lights and mobile phone charging).

The designs recommended for staff quarters are informed by data from other countries on the African continent. Typically, health facilities have between three and five staff houses. The most common housing design consists of three bedrooms, a kitchen, a toilet and shower, a laundry area, a living room and a passage area. Taking into account regular loads and staff needs, two design options are proposed for staff quarters (Table 16).

Table 16 **Solar PV design options for staff quarters**

Option A: Entire load **This option covers the entire load required for staff members to feel at home at all times.**	Rooms: Living room and dining + kitchen + laundry + main bedroom + 2 bedrooms + passage + shower + w/c + outdoor Load types: Ceiling/wall/pedestal fan (5) + fridge (1) + LED bulb (10) + mobile charging (4) + television (1) + outdoor light (1)
Option B: Basic load **This option covers the lighting and ventilation systems needed to ensure staff members' basic comfort.**	Rooms: Kitchen + main bedroom + shower + w/c Load types: Ceiling/wall/pedestal fan (1) + LED bulb (4) + mobile charging (1)

Notes: LED = light-emitting diode; w/c = water closet.

Table 17 **Parameters of solar PV system options for staff quarters**

Load type	Design approach	Solar panel capacity (kWp)	Battery bank sizing (kWh)	Solar MPPT inverter sizing (kVA); charge controller
Entire load	1 staff quarter	0.96	7.2	1
	3 staff quarters	3	24	3
	5 staff quarters	4.8	36	5
Basic load	1 staff quarter	0.12	1.8	20 A; 12 V
	3 staff quarters	0.36	4.8	25 A; 24 V
	5 staff quarters	0.72	8.64	1

Notes: A = ampere; kVA = kilovolt ampere; kWh = kilowatt hour; kWp = kilowatt peak; MPPT = maximum power point tracking; PV = photovoltaic; V = volt.

Powering entire loads. According to the designs presented in Table 17, powering a single health staff quarter using DRE as the primary system for regular loads requires a panel capacity of 0.96 kWp, a battery capacity of 7.2 kWh and an inverter size of 1 kilovolt ampere (kVA) per residence. In the case of three staff quarters located together, the combined requirements to power regular loads for all three would include a 3 kWp panel capacity, a 24 kWh battery capacity and a 3 kVA inverter. Similarly, if five staff quarters are in one location, the requirements increase to a panel capacity of 4.8 kWp, a battery capacity of 36 kWh and a 5 kVA inverter. It is important to note that the reliability of this system is enhanced when separate individual systems are installed for each staff quarter.

Powering basic loads. For powering the basic loads of one staff quarter, a panel capacity of 0.12 kWp, a battery capacity of 1.8 kWh and a 20 A, 12 V charge regulator are required. For three staff quarters, total requirements rise to a panel capacity of 0.36 kWp, a battery capacity of 4.8 kWh and a 25 A, 24 V charge regulator. Five staff quarters require panel capacity of 0.72 kWp, a battery capacity of 8.64 kWh and a 1 kVA inverter.

5.3 COST ASSUMPTIONS

The cost of a DRE system includes the supply of panels, batteries, inverters and cabling, in addition to installation and maintenance expenses. The costs estimated below are derived from information provided by three local suppliers and one international supplier, with average component costs stated in US dollars. Assumptions are based on the requirements for installing the system at various health facilities.

System costs

The system costs account for solar panels, batteries and inverters, as well as wiring, module mounting structures and other balance-of-system components.

Beyond these components, 20% of the overall cost is for transport, installation, commissioning and labour. All costs are determined based on the components available regionally, careful consideration of local factors and the use of lithium-ion batteries.

Operation and maintenance costs

Under the maintenance contract, a technician is scheduled to visit twice a year to repair/replace components as and when necessary. When estimating O&M costs, it is essential to consider corrective and preventive maintenance activities, the cost of remote monitoring systems and other co-ordination-related activities. The proportion of O&M costs is estimated as follows:

- Up to 10% of the system cost is allocated to O&M. This can be further divided into scheduled maintenance and corrective maintenance. Also, the cost of a remote monitoring system is set at a flat rate of USD 353 for five years, regardless of system capacity.
    - Scheduled maintenance activities include a minimum of two visits per year, component replacement, travel, labour costs and applicable taxes.
    - Corrective maintenance addresses out-of-warranty issues, including the replacement and repair of components not covered by annual maintenance contracts. It also involves multiple travels and visits for assessment, diagnosis and repair activities, along with associated labour costs and taxes.

Total programme cost

Programme management costs include the expenses of operating a solar programme unit, data monitoring platforms, training, and human resources required for data maintenance and facilitating system performance through interactions with vendors and health facilities. This cost is estimated to be 18-20% of the overall programme cost. It is presented at the end of this section to provide a comprehensive view of the total programme cost and is not included under each facility type.

Table 18 **Cost estimates for 1 628 CSCOMs**

Type of load	No. of facilities*	System size (kWp)	Li-ion battery (kWh)	System cost (USD)	O&M (USD)	RMS (USD)	Total cost (USD)	Total for all facilities (USD)
Entire load with AC (with battery backup for AC)	570	10.8	60	22 288	1 857	353	24 498	13 963 860
Entire load with AC (w/o battery backup for AC) *(Design of standard urban CSCOM)*	570	10.8	48	18 974	1 581	353	20 908	11 917 560
Entire load w/o AC *(Design of standard rural CSCOM)*	1 058	7.8	48	17 246	1 437	353	19 036	20 140 088
Entire load w/o AC	1 628	7.8	48	17 246	1 437	353	19 036	30 990 608
Critical load	1 628	4.2	24	9 006	750	353	10 109	16 457 452

Notes: AC = air conditioning; CSCOM = community health centre; kWh = kilowatt hour; kWp = kilowatt peak; Li-ion = lithium ion; O&M = operation and maintenance; RMS = remote monitoring system; w/o = without; * Based on primary data analysis: 65% (*i.e.* 1 058 facilities) of CSCOMs are present in rural areas, and 35% (*i.e.* 570 facilities) in urban areas. This adds up to a total of 1 628 operational CSCOMs.

Table 18 presents a cost analysis for implementing solar energy systems across 1 628 CSCOMs in Mali under four scenarios: entire load, entire load with AC (with and without battery backup), entire load without AC and critical load.

Design for current services. According to current design standards derived from national guidelines, the most energy-efficient approach is to power the entire load without AC backup for urban CSCOMs and to power the entire load (excluding AC) for rural CSCOMs.

Battery backup for AC is not recommended for urban CSCOMs due to energy efficiency concerns. In rural CSCOMs, AC is entirely excluded, as these facilities do not provide AC services as per the country's guidelines. As a result, USD 32 057 648 would be required to power all CSCOMs, which includes 65% rural facilities (without AC loads) and 35% urban facilities (with AC loads).

For urban CSCOMs with AC, the cost increases by USD 24 498 per CSCOM if battery backup is included for the AC loads. Alternatively, solar-powered AC without backup would cost USD 20 908 per CSCOM. This option may be considered based on programme priorities and financing availability and may also be relevant for rural CSCOMs if service is expanded.

Powering only critical services such as emergency and maternity services at all facilities (without AC), would cost USD 10 109 per CSCOM. Consequently, the total expenditure required to power all of the country's CSCOMs ranges between USD 16 457 452 (for critical loads) and USD 30 990 608 (for all loads excluding AC).

Table 19 **Cost estimates for 61 CSREFs**

Type of Load	System size (kWp)	Li-ion battery (kWh)	System cost (USD)	O&M (USD)	RMS (USD)	Total cost (USD)	Total for all facilities (USD)
Entire load with AC (with battery backup for AC)	42.0	240	88 026	7 336	353	95 715	5 838 615
Entire load with AC (w/o battery backup for AC)	42.0	120	54 889	4 574	353	59 816	3 648 776
Entire load w/o AC	18.0	120	43 234	3 603	353	47 190	2 878 590
Critical load	10.8	60	22 627	1 886	353	24 865	1 516 765

Notes: AC = air conditioning; CSREF = referral health centre; kWh = kilowatt hour; kWp = kilowatt peak; Li-ion = lithium ion; O&M = operation and maintenance; RMS = remote monitoring system; w/o = without.

Table 19 presents four types of CSREF loads along with their associated costs. Powering the entire load without AC would cost USD 47 190. In contrast, powering the entire load with AC would cost USD 95 715. If AC is powered solely on solar energy without battery backup, the cost would be USD 59 816. Powering only the critical load (excluding AC) would cost USD 24 865. Consequently, the total cost to power all urban CSREFs in the country would range between USD 1 516 765 and USD 5 838 615 depending on whether the entire load or only the critical loads are powered.

Table 20 **Cost estimates for 6 regional hospitals**

Type of load	System size (kWp)	Li-ion battery (kWh)	System cost (USD)	O&M (USD)	RMS (USD)	Total cost (USD)	Total for all facilities (USD)
Entire load with AC (with battery backup for AC)	90.0	600	212 781	17 732	353	230 866	1 385 196
Entire load with AC (w/o backup for AC)	90.0	288	126 625	10 552	353	137 530	825 180
Entire load w/o AC	48.0	288	104 195	8 683	353	113 231	679 386
Critical load	26.4	192	67 195	5 600	353	73 148	438 888

Notes: AC = air conditioning; kWh = kilowatt hour; kWp = kilowatt peak; Li-ion = lithium ion; O&M = operation and maintenance; RMS = remote monitoring system; w/o = without.

Table 20 presents the cost of powering hospitals at the regional level for four types of loads. The cost of powering all the loads, excluding AC, amounts to USD 113 231. In contrast, powering the entire load with AC would cost USD 230 866. If AC is powered solely by solar energy without battery backup, the cost would be USD 137 530. The expense for powering only the critical load (excluding AC) is USD 73 148. Therefore, to power all six regional hospitals in the country, the total cost would range from USD 438 888 to USD 1 385 196, depending on whether the entire load or only the critical loads are powered. The maximum cost for powering all energy systems at all facility levels, excluding AC for rural CSCOMs, would be USD 36 531 604 for the entire load. However, if only the critical load is powered at each facility, the cost would be USD 18 413 105.

Table 21 **Cost estimates for staff quarters**

Design approach		System size (kWp)	Battery capacity (kWh)	System cost (USD)	O&M (USD)	RMS (USD)	Total cost (USD)
Entire load	1 staff quarter	0.96	7.2	2 482	207	353	3 041
	3 staff quarters	3	24	8 152	679	353	9 184
	5 staff quarters	4.8	36	12 408	1 034	353	13 795
Basic load	1 staff quarter	0.12	1.8	610	51	353	1 013
	3 staff quarters	0.36	4.8	1 527	127	353	2 008
	5 staff quarters	0.72	8.64	2 790	232	353	3 375

Notes: kWh = kilowatt hour; kWp = kilowatt peak; O&M = operation and maintenance; RMS = remote monitoring system.

The cost of electrifying staff quarters using solar PV ranges between USD 1 013 and USD 13 795 depending on the loads it powers and the number of staff quarters (Table 21). The total costs consider one staff quarter at CSCOMs, three at CSREFs and five at regional hospitals. For basic loads across all facilities, the total investment would be USD 1 791 902, while powering the entire load for all staff quarters would cost USD 5 593 742.

The total programme cost for implementing DRE systems to ensure effective service delivery at all facilities and staff quarters, based on current needs that include AC in all locations (excluding rural CSCOMs), is USD 42 125 346. These designs do not include solar backup for AC as they assume a limited number of operational hours (*i.e.* during daytime) for utilising the air conditioner, thus prioritising energy efficiency.

However, if the focus were to shift to powering critical loads – specifically maternity and emergency services – along with basic load support for staff quarters at each facility, the estimated investment outlay would be USD 20 205 007.

In light of the increasing heat stress due to climate change, it is also essential to consider adding air conditioners to rural CSCOMs. An additional 20% should be factored in for programmatic activities, such as establishing a technical unit and managing out-of-warranty repairs and system replacements at the end of the system's lifecycle (beyond standard maintenance contracts).

5.4 COST-BENEFIT ANALYSIS: A FUEL SHIFT FROM DIESEL TO SOLAR PV

The energy provided by existing solar systems to health facilities has been unreliable. The proposed plan for DRE systems addresses this issue by allocating funds for long-term maintenance. Moreover, the plan is designed to meet the entire energy needs of health facilities at the last mile, rather than relying on individual, equipment-based solar systems. This approach indicates that DRE can serve as a reliable and cost-effective solution, irrespective of the availability of grid electricity. To illustrate the cost savings of transitioning to decentralised, need-based clean energy systems for health facilities, a cost-benefit analysis (CBA) has been conducted for a CSREF health facility that addresses the primary healthcare requirements of Mali's population (see Box 3).

Box 3 **Assumptions for the cost-benefit analysis (CBA)**

Total energy requirement: 120 kilowatt hours (kWh)/day (according to energy system designs for powering entire loads of referral health centres [CSREFs])

Cost of electricity: USD 0.25/kWh

Minimum diesel consumption: 3 litres (L)/day

Maximum diesel consumption: 30 L/day

Cost of diesel: USD 1.27/L (CFA 800/L)

Installed solar capacity: 42 kilowatts peak (as per system design for powering all loads)

Cost of system: USD 95 715

Notes: The assumptions are based on sampled site survey data regarding energy consumption patterns across various facility levels. The collected data were sufficient to perform a CBA analysis for CSREF facilities. However, for a CBA of CSCOMs and hospitals, further energy consumption information will need to be sourced from relevant primary sources.

The CBA presents two scenarios. Case 1 examines a situation where minimum levels of diesel are consumed, based on preliminary estimates of respondents from health facilities. Case 2 considers maximum diesel consumption. Both cases focus on the CSREF facility level.

Case 1: Considering minimum diesel consumption of 3 litres per day

The generator is estimated to produce 9.9 kWh/day, consumed at the facility level, based on the assumption that 1 litre of diesel generates 3.3 kWh of electricity. The remaining energy demand of 110.1 kWh/day is reported to be met through the grid. The annual expenditure on diesel and grid electricity is projected to be USD 14 636. Transitioning to solar energy is expected to allow a payback of the initial investment in approximately 6.5 years.

Case 2: Considering maximum diesel consumption of 30 litres per day

The generator is estimated to produce 99 kWh/day, which is reportedly consumed at a sampled CSREF facility, also based on the assumption that 1 litre of diesel generates 3.3 kWh of electricity. The remaining energy demand of 21 kWh/day is met through the grid. The annual expenditure on diesel and grid electricity is projected to be USD 47 808. Transitioning to solar energy is expected to allow a payback of the initial investment in approximately 2 years.

Since an unreliable grid prompts high diesel consumption, it is essential to consider both the cost of diesel and the CBA of shifting to solar energy. Thus, the above analysis indicates that in Mali, owing to the high cost of diesel, DRE results in a positive return on investment across various levels of diesel consumption.

6. RECOMMENDATIONS FOR THE DESIGN OF A HEALTH-ENERGY PROGRAMME IN MALI

This chapter outlines the key recommendations for designing and implementing a sustainable programme for the solar electrification of health facilities. These recommendations are grounded in real-world experiences and practices observed in the region. The emphasis is on creating a climate-resilient built environment, utilising medical technologies that address the country's disease burden, ensuring effective service delivery, providing training, planning for O&M and engaging stakeholders. The recommendations are categorised into three areas: technology solution design, programme design considerations and sustainability aspects (detailed below).

Implementing these recommendations requires co-ordinated action across multiple sectors, including health, energy, finance and telecommunications. By prioritising the energy access of healthcare facilities, adopting suitable technologies, fostering supportive policy environments and exploring innovative delivery models, significant improvements in healthcare delivery can be realised. The integration of energy access with healthcare planning represents a vital opportunity to strengthen health systems and enhance patient outcomes, particularly in underserved communities.

6.1 APPROPRIATE TECHNOLOGY SELECTION

Benchmarking technology based on need, efficiency and quality is essential for Mali's health facilities, particularly given the non-operability of many existing solar systems. As highlighted in Chapter 4, voltage fluctuations from unreliable grids have damaged medical equipment in 85% of the health facilities surveyed, while poorly designed and installed PV systems have led to frequent disruptions. National guidelines should be developed to standardise technical specifications for PV panels, inverters and batteries, by mapping local and global supply chains and benchmarking products that meet established quality and pricing standards.

Climate-resilient infrastructure is essential, as droughts and floods in Mali push up operational costs and damage infrastructure. Solar designs that incorporate both active and passive cooling mechanisms would help effectively manage high heat stress (up to 50°C). Also, energy-efficient appliances and building design can optimise energy use and reduce costs.

Health facility solarisation programmes must include design considerations for staff living quarters. As noted earlier, over 95% of respondents reported that a lack of electricity led to physical discomfort (*e.g.* fans being inoperable). Programmes in India and Uganda have demonstrated that powering staff quarters with solar energy improves physical comfort, thus facilitating greater work efficiency (WHO *et al.*, 2023).

Enhancing service delivery through medical technologies is critical, as 86% of health facilities surveyed reported equipment shortages affecting services such as communication, cold chains for vaccinations and sterilisation. The Mali Action Plan supports decentralised care models, including telemedicine and tele-diagnostic kits, to extend quality care to remote regions. DRE-based cold chain solutions, such as solar-powered active vaccine carriers, are essential for improving immunisation coverage, particularly in rural areas, and can be developed in partnership with organisations such as GAVI.

6.2 PROGRAMME DESIGN APPROACH

Programme design is best phased, starting with facilities that have robust infrastructure and adequate staff to create effective models that foster trust in DRE solutions. The second phase should then focus on addressing infrastructural and human resource challenges before implementation proceeds. Leveraging existing government structures and priorities will help integrate solar power in national health goals. The upgrade of health centres and introduction of mobile health units should integrate energy efficient design and solar solutions for cost-effectiveness and service reliability.

Establishing multiple stakeholder engagements through a working group that includes multilaterals is vital for assisting Mali in benchmarking the cost of components, ensuring component quality and securing funding for both capital and O&M costs. Many assets from donor-driven programmes often remain unused and dysfunctional after the first year of installation due to a lack of ownership and allocation of adequate funds for maintenance. The working group could help raise funds for maintenance to support the government's objective of maintaining and rehabilitating existing equipment.

Establishing a solar programme unit as a third-party technical audit cell under the Ministry of Health and Social Development, with technical support from the Ministry of Energy and allied agencies, is advisable. This unit would oversee technical specifications, system quality, monitoring and maintenance, and ensure co-ordination among stakeholders.

To promote regional equity and lessen the urban-rural divide, targeted investments in equipment, funding and skilled personnel for Mali's northern and rural regions should be prioritised. This initiative would foster decentralised electrification programmes (such as mini-grids and solar home systems) managed by local operators and supported by AMADER. A larger share of national and international funding must be allocated to these underserved areas, alongside capacity-building initiatives to ensure local communities and operators can effectively manage and maintain the new infrastructure.

6.3 OPERATION, MAINTENANCE, TRAINING AND FINANCING FOR SUSTAINABILITY

Sustainability requires the establishment of quality standards for DRE equipment through national guidelines, which should include specifications and processes for quality checks on imported equipment. It is important to standardise the electrical parameters of this equipment and to promote partnerships between international suppliers and local enterprises for ongoing O&M and capacity building. Local vendors can be incentivised to enhance their technical capacity and develop supply chains for replacement parts.

Training is an integral part of ensuring the long-term sustainability of any solar electrification programme. Strengthening the skills and knowledge of stakeholders in the health and energy sectors is essential for effective resource planning, implementation and O&M of energy and health infrastructure.

During the programme conceptualisation stage, it is essential to demonstrate DRE systems' potential to improve health outcomes to key health and energy stakeholders at the national, regional and district levels. This will help raise awareness of the benefits, and facilitate the budget allocations necessary for the programme's long-term sustainability. Training must be conducted before and after installation (with periodic refreshers), and should be included in the programme's budget.

O&M extends beyond just signing annual maintenance contracts with vendors; it requires the involvement of multiple stakeholders to address issues as they arise so as to minimise service disruption. Health facility staff must be trained to operate energy systems, conduct basic maintenance and report issues related to the solar energy system. Standard operating procedures should be clearly defined and localised for verification, with a transparent allocation of funds and a clear delineation of the roles and responsibilities of all involved stakeholders.

Roles and responsibilities for the various O&M functions must be clearly defined. The first line of maintenance consists of facility staff, including nurses and security guards, who must be trained to identify and troubleshoot basic issues and to report more complex problems. The second line of maintenance involves local technicians, associated with local service providers or non-governmental organisations, who should be trained to carry out minor repairs and recognise the need for component replacement. The third line of maintenance comprises well-trained technical members capable of carrying out major repairs and replacing system components.

Planning for regional differences is essential, as geography impacts service access, system design, maintenance frequency and O&M costs. Northern Mali's remote and dusty regions are difficult to access, while the tropical south experiences higher rainfall, necessitating panels with greater capacities, lightning rods and robust mounting structures. Areas prone to thunderstorms and sandstorms require additional monitoring of system functionality, and the inconsistent quality of road infrastructure may lengthen turnaround times. Considering seasonality, annual maintenance contracts should encourage contractors to schedule activities before and after monsoons. Effective remote monitoring can track battery capacity and inverter functionality, with staff trained to address issues and follow escalation processes during adverse weather conditions.

Financing for O&M must be integrated from the programme's inception, and involve all relevant stakeholders including the ministries of finance, health and energy. O&M costs encompass expenses beyond the annual maintenance contract, such as programme management and out-of-warranty components. The PRODESS IV's focus on maintenance should be leveraged to raise funds for O&M, ensuring health-facility-level ownership of asset maintenance.

Strengthening the local energy ecosystem is crucial, as the renewable energy sector largely depends on imported products. Most activities are donor driven or rely on international partners, resulting in a shortage of skilled local technicians and a lack of confidence in DRE-based solutions. Significant efforts are needed to develop the energy ecosystem through skilling programmes that make the DRE sector appealing to communities, requiring the collaboration of multiple stakeholders to facilitate incubation, training and financing.

Creating an enabling environment

The electrification of healthcare facilities should be incorporated into overall energy sector strategies. The energy requirements of these facilities need to be included into national and local electrification planning frameworks. It is essential to develop policies to support DRE-enabled healthcare, particularly as the off-grid sector is still emerging. The government would do well to regulate sector growth through policies that incentivise energy-enabled healthcare services, aiming to enhance health infrastructure and improve primary health services. These policies would address the financing of O&M, training frameworks for technicians and health staff, and procurement processes.

Policies and plans for powering healthcare facilities require greater integration across sectors to ensure co-ordinated implementation and efficient resource allocation. This integrated approach addresses both immediate needs and long-term sustainability goals. Investment priorities include maintaining existing healthcare facilities, not just constructing new ones. A maintenance-oriented approach helps preserve critical infrastructure and extends the operational lifespan of healthcare facilities.

Central government agencies should actively co-ordinate with local communities to identify and leverage synergies among multiple projects, including electrification of healthcare facilities, development of telecommunications towers and community-wide electrification initiatives. Administrative barriers are minimised by streamlining permit and authorisation processes for healthcare facilities, which enables the faster implementation of energy solutions and reduces bureaucratic delays.

International donors may be encouraged to support the electrification of healthcare facilities on a much larger scale, recognising their fundamental role in achieving broader health and development objectives. Regulatory frameworks and investment strategies would do well to balance the support of new installations and the upgrade of existing facilities, ensuring comprehensive coverage across the healthcare system. The financial gap between service costs and income poses a significant risk for private off-grid energy providers. Policy mechanisms need to address this gap to promote private sector participation in electrifying remote healthcare facilities.

Innovative delivery models

There are three primary delivery models for healthcare facility electrification: the public delivery model (traditional ownership model), the non-profit delivery model and the private sector model. In Mali, the public and non-profit delivery models are the most prevalent. Key factors affecting the viability of these delivery models include asset maintenance requirements, high upfront investment costs and the ability of healthcare facilities to pay for services (*i.e.* off-taker risk). These challenges can be addressed by creating a supportive policy environment for private sector engagement and developing frameworks for public-private partnerships (PPPs) in the health and energy sectors.

For effective implementation of a private or PPP delivery model, energy service providers, rather than healthcare facilities, should maintain energy assets to achieve long-term sustainability. New income-generating activities should be integrated with healthcare facilities to enhance financial sustainability and expand service offerings. Potential partnerships between private sector actors and healthcare facilities should be explored under PPP models that balance public health priorities with financial sustainability.

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ANNEX A. HEALTH FACILITIES SURVEYED FOR THE STUDY

Region	Name of the health facility (village)	District	Latitude	Longitude	Type of facility	Rural/ urban	Year of establishment
Bougouni	Kadiana	Kolondieba	10.744708	-6.503174	CSCOM	Rural	1997
Bougouni	Centre de Santé Communautaire de Mafélé	Bougouni	10.557653	-7.530455	CSCOM	Rural	2002
Bougouni	Centre Sanitaire de Garalo	Bougouni	10.994490	-7.436884	CSCOM	Rural	1997
Bougouni	Centre de Santé Yanfolila Centrale	Yanfolila	11.179701	-8.155724	CSCOM	Urban	2001
Bougouni	CSRF de Kolondieba	Kolondieba	11.079024	-6.876939	CSREF	Rural	1994
Bougouni	Centre de Santé de Bougouni	Bougouni	11.429351	-7.472771	CSREF	Urban	1999
Gao	CSCOM Château	Gao	16.261768	-0.037634	CSCOM	Urban	1996
Gao	CSREF de Gao	Gao	16.283617	-0.046512	CSREF	Urban	1996
Gao	Hôpital Régional de Gao	Gao	16.272474	-0.043247	Hospital	Urban	2003
Kayes	Aire de Santé Lafiabougou	Kayes	14.438820	-11.446521	CSCOM	Urban	2004
Kayes	Sangafara	Sadiola	14.083919	-11.681035	CSCOM	Rural	2021
Kayes	Aire de Santé Kersignané Diafounou	Yelimani	14.992243	-10.990960	CSCOM	Urban	1996
Kayes	Aire de Sante Yelimani CSCOM	Kayes	15.114803	-10.576947	CSCOM	Rural	2020
Kayes	Aire de Santé Bafoulabé	Bafoulabé	13.809484	-10.831842	CSCOM	Rural	2005
Kayes	CSCOM de Madalaya	Oussoubidiagna	14.220836	-10.661632	CSCOM	Rural	1998
Kayes	Aire de Santé Godi	Oussoubidiagna	14.243850	-10.645251	CSCOM	Rural	2021
Kayes	Aire de Santé Kamagalamadji	Bafoulabé	12.883674	-10.549102	CSCOM	Rural	2012
Kayes	Aire de Santé Faléa	Kéniéba	12.264065	-11.275912	CSCOM	Rural	2005
Kayes	CSREF de Kaye	Kayes	14.451213	-11.438954	CSREF	Urban	2001
Kayes	CSREF de Yelimani	Yelimani	15.122968	-10.575145	CSREF	Rural	1984

Region	Name of the health facility (village)	District	Latitude	Longitude	Type of facility	Rural/ urban	Year of establishment
Kayes	Aire de SekoToba	Kéniéba	12.745694	-10.947887	CSCOM	Rural	2023
Kayes	Aire de Santé Darsalam	Falea	12.118810	-11.297027	CSCOM	Rural	2022
Kita	Centre de Santé Communautaire Namala	Kita	13.360152	-9.385905	CSCOM	Urban	2015
Kita	Aire de santé Sagabari	Sagabari	12.589772	-9.804690	CSCOM	Rural	2009
Kita	Aire de santé Gakouroukoto	Sagabari	12.670018	-9.776213	CSCOM	Rural	2017
Koulikoro	Selefougou	Kangaba	11.742413	-8.334685	CSCOM	Rural	2002
Koulikoro	Kourémalé	Kangaba	11.958172	-8.776295	CSCOM	Rural	2011
Koulikoro	Kalifabougou	Kati	12.952183	-8.175769	CSCOM	Rural	2002
Koulikoro	Dombila	Kati	12.762714	-8.278221	CSCOM	Rural	2005
Koulikoro	Toukoroba	Banamba	13.610960	-7.040516	CSCOM	Rural	1997
Koulikoro	CSCOM de Boron	Banamba	14.005520	-7.514940	CSCOM	Rural	1996
Koulikoro	Centre de Santé de Sirakoroba	Kolokani	13.535343	-7.642770	CSCOM	Rural	2005
Koulikoro	Ouolodo	Solokani	13.204634	-7.931495	CSCOM	Rural	1998
Koulikoro	CSCOM de Tombougou	Koulikoro	13.091733	-7.767938	CSCOM	Rural	2002
Mopti	Hôpital Régional de Mopti (Sominé Dolo)	Mopti	14.539782	-4.084384	Hospital	Urban	2012
Mopti	CSCOM de Soufroulaye	Soufroulaye	14.406430	-4.084097	CSCOM	Rural	1996
Mopti	CSCOM Sévaré 3	Mopti	14.517343	-4.095194	CSCOM	Urban	2003
Mopti	Madiama	Djenné	13.791981	-4.393260	CSCOM	Rural	1995
Mopti	Fatoma	Mopti	14.616398	-4.046972	CSCOM	Rural	1996
Mopti	Aire de Santé Bounguel	Djenné	14.166004	-4.103998	CSCOM	Rural	2010
Mopti	Torokoro	Djenné	13.850964	-4.307104	CSCOM	Rural	2014
Mopti	CSCOM Djenne	Djenné	13.904055	-4.556202	CSCOM	Urban	1995
Mopti	CSCOM de Sophara	Djenné	14.020118	-4.220351	CSCOM	Rural	1996
Mopti	CSREF Djenné	Djenné	14.390588	-4.561562	CSREF	Urban	1947
Mopti	CSREF de Mopti	Mopti	14.503972	-4.196668	CSREF	Urban	1968
San	Aire de Santé de Monisso	Tomian	13.351926	-4.476203	CSCOM	Rural	2003
San	CSREF de San	SAN	13.307746	-4.893679	CSREF	Urban	1968
Segou	CSCOM Cocody	Niono	14.337933	-6.020843	CSCOM	Rural	1993
Segou	CSCOM de Diédala	Bla	12.990904	-5.616389	CSCOM	Rural	2002
Segou	Aire de Santé Kimparana	San	12.836685	-4.924002	CSCOM	Rural	1999

Region	Name of the health facility (village)	District	Latitude	Longitude	Type of facility	Rural/ urban	Year of establishment
Segou	Aire de Santé Tigui	Segou	13.058840	-6.647118	CSCOM	Rural	2006
Ségou	CSCOM Soumabougou	Markala	13.604741	-6.102594	CSCOM	Rural	2009
Ségou	Aire de Santé Sido-Soninkoura	Segou	13.428221	-6.245735	CSCOM	Urban	2017
Ségou	CSREF de Baraoueli	Baraoueli	13.070598	-6.838362	CSREF	Urban	1996
Sikasso	Banankoda	Sikasso	11.317613	-5.753827	CSCOM	Urban	2013
Sikasso	Centre Sanitaire de Wayerma II	Wayerma II	11.329709	-5.660801	CSCOM	Urban	2001
Sikasso	CSCOM de Zegoua	Kadiolo	10.488147	-5.654170	CSCOM	Rural	1996
Sikasso	Aire de Santé de Foh	Sikasso	11.794427	-5.776669	CSCOM	Urban	2010
Sikasso	Hamdallaye	Sikasso	11.308822	-5.693697	CSCOM	Rural	2001
Sikasso	CSREF de Sikasso	Sikasso	11.316782	-5.668592	CSREF	Urban	1964

Note: CSCOM = community health centre; CSREF = referral health centre.

ANNEX B. SOLAR ENERGY SYSTEM DESIGN ASSUMPTIONS AND CONSIDERATIONS

Based on the needs identified through primary consultations and secondary data, the following parameters were used to calculate and propose customised decentralised renewable energy system designs for different levels of health facilities in Mali.

Solar photovoltaic system design parameters

Factors determining energy needs	Load specifications	System design considerations
Health facility specificities	Standard designs with typical operational hours	Peak sunshine hours
Health facility level		Days of autonomy
Number of rooms	**Customisation based on services**	Depth of discharge
Services delivered	Critical and non-critical equipment loads	Energy efficiency of equipment
Future growth needs		
Safety and well-being needs	Climate disasters	Load requirements at each level

Using the above parameters, technical design solutions are provided for each facility. These include solar power for regular loads (lights, fans, charging devices, *etc.*) as well as medical equipment powered primarily by the solar energy system. It is assumed that 100% of the energy generated will come from solar sources (based on the assumed hours of operation).

Solar energy system design considerations

Regular load with medical equipment

Refers to the minimum infrastructure and equipment required to provide services at the CSCOMs and CSREFs – the equipment considered regular loads for mainly luminaries and laptop and mobile charging loads.

Option A

Powering entire load including AC in urban CSCOMs

Rooms: Entrance, waiting area and reception, 2 OPD/consultation, observation room, CPN room, pharmacy/drug storeroom, medical care/nursing room, medical officer room, labour room, LAB, staff/bedroom (5 rooms), storeroom, toilet, outdoor courtyards

Loads: AC (1), air cooler (2), ceiling/wall/pedestal fan (20), centrifuge (1), desktop (3), portable examination lamp (1), fridge (1), infant phototherapy unit (1), Hb analyser, laptop (2), LED bulb (20), LED tube light (9), microscope (1), mobile charging (2), nebuliser (1), needle cutter (1), orbital shaker (1), outdoor light (1), printer (3), radiant warmer/baby warmer (1), suction apparatus (1), spotlight/examination lamp, TV (1), ultrasonic device (1)

Powering entire load including AC in CSREFs

Rooms: Entrance, waiting area and reception, 2 OPD/consultation, 2 observation rooms, CPN room, pharmacy/drug storeroom, immunisation room, blood bank, medical care/nursing room, medical officer room, manager/admin room, ophthalmology room, delivery room, labour room, emergency room, minor OT, imaging room, dental, laboratory, server room, toilet, staff/bedroom (10 rooms), storeroom, outdoor courtyard

Loads: AC (7), anaesthesia machine (1), blood bank refrigerator (1), ceiling/wall/pedestal fan (37), dental chair (1), dental chair compressor (1), centrifuge (1), desktop (5), fridge (3), portable examination lamp (1), incubator (3), imager scanner (1), Hb analyser (1), GeneXpert (COVID/TB test) (1), haematology analyser (1), infant phototherapy unit (1), laptop (6), LED bulb (31), LED tube light (39), microscope (2), mini rotary shaker (1), mobile charging (20), nebuliser (1), needle cutter (2), OT light (1), outdoor light (10), patient monitor (1), oxygen concentrator (2), printer (7), radiant warmer/baby warmer (2), suction apparatus (5), spotlight/examination lamp (1), TV (1), ultrasonic device (1), X-ray (1), Wi-Fi modem (1)

Powering entire load including AC in regional hospitals

Rooms: Entrance, waiting area and reception, 2 OPD/consultation, 2 observation rooms, male ward, female ward, CPN room, pharmacy/drug store room, immunisation room, blood bank, medical care/nursing room, medical officer room, manager/admin room, ophthalmology room, delivery room, labour room, emergency room, OT, ICU, radiology/imaging room, dental, 2 LABs, server room, staff/bedroom (10 rooms), store room, toilet, outdoor courtyard

Loads: AC (12), anaesthesia machine (1), syringe driver pump (1), auto haematology analyser machine (2), biochemistry analyser (2), biochemistry analyser cuvettes (2), biochemistry small refrigerator (2), blood bank refrigerator (2), blood collection monitor (2), blood gas analyser (1), cardiac monitor (2), ceiling/wall/pedestal fan (82), CELL-DYN haematology analyser (2), dental chair (1), dental chair compressor (1), desktop (6), ventilator (1), portable examination lamp (1), immunoassay analyser microtiter plates (2), fridge (6), GeneXpert (COVID/TB test) (2), Hb analyser (2), haematology analyser (2), incubator (3), imager scanner (1), infant phototherapy unit (2), electrosurgical unit (1), lab centrifuge (2), laparoscopic display TV (1), laptop (7), LED bulb (73), LED tube light (79), Lisa scan (2), microplate reader (2), microplate washer (2), microscope (4), microscope printer (2), mini rotary shaker (2), mobile charging (50), nebuliser (2), needle cutter (3), needle destroyer (2), OT light (1), OT table (1), oxygen concentrator (6), patient monitor (16), defibrillator (1), plasma thawing bath (2), platelet agitator and incubator (2), printer (10), radiant warmer/baby warmer (2), semi auto coagulation analyser (2), serology water bath (2), spotlight/examination lamp (1), suction apparatus (6), TV (7), ultrasonic device (4), ventilator (1), Wi-Fi modem (1), X-ray (1), outdoor light (10)

Option B

Powering entire load in CSCOMs, CSREFs and regional hospitals, where AC will be run on solar during daytime and there is no battery backup for AC

Option C

Powering entire load except AC and air coolers in urban CSCOMs

Rooms: Entrance, waiting area and reception, 2 OPD/consultation, 2 observation rooms, CPN room, pharmacy/drug storeroom, medical care/nursing room, medical officer room, labour room, LAB, staff/bedroom (5 rooms), storeroom, toilet, outdoor courtyards

Loads: ceiling/wall/pedestal fan (20), centrifuge (1), desktop (3), portable examination lamp (1), fridge (1), infant phototherapy unit (1), Hb analyser (1), laptop (2), LED bulb (20), LED tube light (9), microscope (1), mobile charging (2), nebuliser (1), needle cutter (1) orbital shaker (1), outdoor light (1), printer (3), radiant warmer/baby warmer (1), suction apparatus (1), spotlight/examination lamp (1), TV (1), ultrasonic device (1)

Powering entire load without AC in CSREFs

Rooms: Entrance, waiting area and reception, 2 OPD/consultation, 2 observation rooms, CPN room, pharmacy/drug storeroom, immunisation room, blood bank, medical care/nursing room, medical officer room, manager/admin room, ophthalmology room, staff/bedroom (10 rooms), storeroom, toilet, delivery room, labour room, emergency room, minor OT, imaging room, dental, LAB, server room, outdoor courtyard

Loads: Anaesthesia machine (1), blood bank refrigerator (1), ceiling/wall/pedestal fan (37), dental chair (1), dental chair compressor (1), centrifuge (1), desktop (5), fridge (3), portable examination lamp (1), incubator (3), imager scanner (1), Hb analyser (1), GeneXpert (COVID/TB test) (1), haematology analyser (1), infant phototherapy unit (1), laptop (6), LED bulb (31), LED tube light (39), microscope (2), mini rotary shaker (1), mobile charging (20), nebuliser (1), needle cutter (2), OT light (1), outdoor light (10), patient monitor (1), oxygen concentrator (2), printer (7), radiant warmer/baby warmer (2), suction apparatus (5), spotlight/examination lamp (1), TV (1), ultrasonic device (1), X-ray (1), Wi-Fi modem (1)

Powering entire load without AC in regional hospitals

Rooms: Entrance, waiting area and reception, 2 OPD/consultation, 2 observation rooms, male ward, female ward, CPN room, pharmacy/drug store room, immunisation room, blood bank, medical care/nursing room, medical officer room, manager/admin room, ophthalmology room, delivery room, labour room, emergency room, OT, ICU, radiology/imaging room, dental, 2 LABs, server room, staff/bed room (10 rooms), store room, toilet, outdoor courtyard

Loads: Anaesthesia machine (1), syringe driver pump (1), auto haematology analyser machine (2), biochemistry analyser (2), biochemistry analyser cuvettes (2), biochemistry small refrigerator (2), blood bank refrigerator (2), blood collection monitor (2), blood gas analyser (1), cardiac monitor (2), ceiling/wall/pedestal fan (82), CELL-DYN haematology analyser (2), dental chair (1), dental chair compressor (1), desktop (6), ventilator (1), portable examination lamp (1), immunoassay analyser microtiter plates (2), fridge (6), GeneXpert (COVID/TB test) (2), Hb analyser (2), haematology analyser (2), incubator (3), imager scanner (1), infant phototherapy unit (2), electrosurgical unit (1), lab centrifuge (2), laparoscopic display TV (1), laptop (7), LED bulb (73), LED tube light (79), Lisa scan (2), microplate reader (2), microplate washer (2), microscope (4), microscope printer (2), mini rotary shaker (2), mobile charging (50), nebuliser (2), needle cutter (3), needle destroyer (2), OT light (1), OT table (1), oxygen concentrator (6), patient monitor (16), defibrillator (1), plasma thawing bath (2), platelet agitator and incubator (2), printer (10), radiant warmer/baby warmer (2), semi-auto coagulation analyser (2), serology water bath (2), spotlight/examination lamp (1), suction apparatus (6), TV (7), ultrasonic device (4), ventilator (1), Wi-Fi modem (1), X-ray (1), outdoor light (10)

Option D

Powering critical + some regular loads in CSCOMs

Rooms: Entrance, 2 OPD/consultation, pharmacy/drug storeroom, medical care/nursing room, labour room, LAB, toilet, outdoor courtyard

Loads: Ceiling/wall/pedestal fan (8), centrifuge (1), desktop (2), portable examination lamp (1), fridge (1), infant phototherapy unit (1), Hb analyser (1), laptop (1), LED bulb (12), LED tube light (7), microscope (1), nebuliser (1), needle cutter (1), orbital shaker (1), outdoor light (2), printer (2), radiant warmer/baby warmer (1), suction apparatus (1), spotlight/examination lamp (1) ultrasonic device (1)

Powering critical loads in CSREFs

Rooms: Entrance, waiting area and reception, 2 OPD/consultation, 2 observation rooms, CPN room, pharmacy/drug storeroom, immunisation room, blood bank, medical care/nursing room, medical officer room, manager/admin room, ophthalmology room, staff/bedroom (10 rooms), storeroom, toilet, delivery room, labour room, emergency room, minor OT, imaging room, dental, LAB, server room, outdoor courtyard

Loads: Anaesthesia machine (1), blood bank refrigerator (1), ceiling/wall/pedestal fan (12), centrifuge (1), desktop (3), portable examination lamp (1), fridge (3), incubator (3), Hb analyser (1), GeneXpert (COVID/TB test) (1), haematology analyser (1), infant phototherapy unit (1), laptop (4), LED bulb (19), LED tube light (16), microscope (2), mini rotary shaker (1), nebuliser (2), needle cutter (2), OT light (1), patient monitor (1), oxygen concentrator (2), printer (4), outdoor light (10), radiant warmer/baby warmer (2), suction apparatus (5), spotlight/examination lamp (1), ultrasonic device (1), Wi-Fi modem (1)

Powering critical loads in regional hospitals

Rooms: Entrance, waiting area and reception, 2 OPD/consultation, 2 observation rooms, male ward, female ward, CPN room, pharmacy/drug store room, immunisation room, blood bank, medical care/nursing room, medical officer room, manager/admin room, ophthalmology room, delivery room, labour room, emergency room, OT, ICU, radiology/imaging room, dental, 2 LABs, server room, staff/bed room (10 rooms), store room, toilet, outdoor courtyard

Loads: Syringe driver pump (1), anaesthesia machine (1), auto haematology analyser machine (2), biochemistry analyser (2), biochemistry analyser cuvettes (2), biochemistry small refrigerator (2), blood bank refrigerator (2), blood collection monitor (2), blood gas analyser for point of care testing (1), cardiac monitor (2), ceiling/wall/pedestal fan (15), CELL-DYN haematology analyser (2), desktop (4), ventilator (1), portable examination lamp (1), immunoassay analyser microtiter plates (2), fridge (6), GeneXpert (COVID/TB test) (2), Hb analyser (2), haematology analyser (2), infant phototherapy unit (2), incubator (1), electrosurgical unit (1), lab centrifuge (2), LCD TV (1), laptop (5), LED bulb (19), LED tube light (20), Lisa scan (2), microplate reader (2), microplate washer (2), microscope (4), microscope printer (2), mini rotary shaker (2), nebuliser (2), needle cutter (3), needle destroyer (2), OT light (1), OT table (1), oxygen concentrator (3), patient monitor (2), defibrillator (1), plasma thawing bath (2), platelet agitator and incubator (1), printer (7), radiant warmer/baby warmer (2), semi-auto coagulation analyser (2), serology water bath (2), spotlight/examination lamp (1), suction apparatus (6), TV (2), ultrasonic device (3), ventilator (1), Wi-Fi modem (1), outdoor light (10)

Note: AC = air conditioning; CPN = complex physical needs; CSCOM = community health centre; CSREF = referral health centre; Hb = haemoglobin; ICU = intensive care unit; LCD = liquid-crystal display; LED = light-emitting diode; OPD = outpatient department; OT = operation theatre; TB = tuberculosis; TV = television.

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