International Renewable Energy Agency

Electrification with renewables: Enhancing healthcare delivery in

São Tomé and Príncipe

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ABBREVIATIONS

AC	alternating current
Ah	ampere hour
CO_2	carbon dioxide
DC	direct current
DOD	depth of discharge
DRE	decentralised renewable energy
GHG	greenhouse gas
hrs	hours
ILR	ice-lined refrigerator
$kgCO_2eq$	kilogramme of CO_2 equivalent
km	kilometre
km^2	square kilometre
kVA	kilovolt ampere
kW	kilowatt
kWp	kilowatt peak
NGO	non-governmental organisation
O&M	operations and maintenance
OPD	outpatient department
OT	operation theatre
PV	photovoltaic
RE	renewable energy
SDG	Sustainable Development Goal
SDG3	Third Sustainable Development Goal
SDG7	Seventh Sustainable Development Goal
SIDS	small island developing state
SOP	standard operating procedure
SSA	Sub-Saharan Africa
UNDP	United Nations Development Programme
V	volt
W	watt
WHO	World Health Organization
Wp	watt peak

EXECUTIVE SUMMARY

Access to affordable, reliable and modern energy is essential for the delivery of quality health services, whether that is to power critical life-saving equipment, such as incubators and lighting in labour rooms, or basic diagnostics and administrative needs. Energy access can be more challenging in the context of island countries as they are highly vulnerable to the adverse effects of climate change and some of them lack a reliable and affordable energy supply. Decentralised renewable energy (DRE) can play a vital role in ensuring essential social services such as health care in island countries.

São Tomé and Príncipe, an island State off the west coast of Africa, is the continent's second smallest country, with a population of around 225 000 (World Bank, 2023) and an area of less than 900 square kilometres (km^2) (World Bank, 2023). It is extremely vulnerable to climate change impacts. In the last decade there has been a steady increase in global sea level and temperature, which disproportionately affect communities living in small island developing states (SIDS) like São Tomé and Príncipe (IRENA, 2023a). Additionally, the country is dependent on external interventions for the supply of fuel and other essential needs of the population, with a significant percentage of the State budget dependent on foreign assistance (WHO, 2023).

The Government of São Tomé and Príncipe is focused on addressing these challenges and has renewed its commitment to **reduce greenhouse gas emissions by 27% through the production of renewables by updating its nationally determined contribution in 2021**. This provides a clear opportunity to leapfrog the traditional sources of electricity and equip health facilities with DRE technologies to meet community needs in a sustainable manner.

> Maternal, neonatal and nutritional deficiencies contribute to the country having the second-highest disability-adjusted life-years among small island developing states. **São Tomé and Príncipe has an infant mortality rate of 32.4 per 1000 live births.**

São Tomé and Príncipe has a total of 40 health-care facilities: 2 hospitals, 6 health centres, 31 health posts and a warehouse to store vaccines. In addition to analysis of secondary data, this report draws findings from primary data collected from 14 facilities, mainly health centres and health posts. Key learnings were also derived from interviews with stakeholders, including energy and health experts from the Government and from development partners in the country. The report details the gaps in the health system from an energy delivery perspective and provides options to make the health-care facilities in São Tomé and Príncipe more efficient and reliable.

Due to the widespread lack of electrification, many health-care facilities worldwide suffer from insufficient power, impeding their ability to provide fundamental and emergency medical services. Essential emergency medical procedures, such as laboratory testing, X-ray imaging and use of ventilators, heavily rely on electricity. However, with unreliable electrical supply, medical equipment is prone to malfunction or is often inaccessible (World Bank, 2023). The same applies to the health infrastructure of São Tomé and Príncipe due to unreliable electricity and power outages. Reliable electricity infrastructure is a crucial enabling factor in improving health systems and achieving Sustainable Development Goal 3 (SDG 3) goals. Table S.1 provides an overview of the designs and costs for powering the different types of health facility in the country with renewable energy for ten years, as the primary source of energy for all loads or, alternatively, as a backup source of energy for powering facilities during power outages.

Table S.1 **Summary of designs and costs for DRE systems in all health facilities in São Tomé and Príncipe**

		Design size (kWp)	Cost for one system (USD)	Total cost: all systems (USD)
Health post (São Tomé - 26 posts)	Solar as primary for regular loads and lab services	6	76 995	**2 001 881**
	Solar as backup for basic loads	1.4	27 663	**719 241**
Health post (Príncipe - 5 posts)	Solar as primary for regular loads	3	65 681	**328 406**
	Solar as backup for basic loads	0.1	27 907	**139 536**
Health centre (only present in São Tomé - 6 centres)	Solar as primary for regular loads and lab services	26	294 787	**1 768 722**
	Solar as backup for basic loads	6	76 996	**461 976**
Hospital on São Tomé	Solar as primary for regular loads and lab services	349		**4 105 256**
	Solar as backup for basic loads	97		**1 148 577**
Hospital on Príncipe	Solar as primary for regular loads and lab services	172		**2 042 312**
	Solar as backup for basic loads	64		**778 789**

Assessments indicate that it would require an initial investment of USD 10 246 581 to power the entire health sector in São Tomé and Príncipe with solar PV as a primary source of electricity for a period of ten years.

An investment of USD 3 468 309 would be required to power the basic loads of all health facilities as a backup option that accounts for the functioning of basic facility services during daily power outages and disruptions for a period of ten years.

Health posts and health centres make up 37 of the total 40 health facilities in the country. Strengthening these facilities would help provide more services at the first point of care, reducing the need to refer to the country's larger hospitals. To equip all health posts and health centres with affordable and reliable solar energy as a primary source for ten years would take an initial investment of USD 4 099 009.

In addition to the supply of reliable and clean energy, efficient and modern medical appliances, better building designs and dedicated human resources are some of the key factors required for a robust health system in the country. The key steps and processes outlined in the report to enable better planning, design and implementation of health–energy solutions in São Tomé and Príncipe are:

- **Energy-Health assessment:** Clear understanding of the energy needs in the facility given the specific health situation, population catered, disease burden and human resource capacity.

- **System design and costing:** Developing customised DRE system designs, including efficient medical and electrical appliances, based on the assessments conducted and templatising these designs for different levels of healthcare and service provision. Based on these, cost estimations can be developed.

- **Procurement and installation:** Using procurement guidelines that incentivise quality and timely after-sales service and strengthen local entrepreneurship for installations and maintenance.

- **Ownership and maintenance:** Establishing financial and ownership models that ensure maintenance and proper utilisation of the energy system. These should include maintenance contracts with local energy enterprises.

- **Capacity building and training:** Building capacity by equipping local staff, vendors, and other designated personnel to use medical appliances for service delivery and to manage the energy system, including aspects of basic maintenance.

- **Energy-efficient design:** Coupled with DRE systems, designing for energy-efficient machines at healthcare facilities have positive implications on overall cost saving, system resilience, as well benefits from a climate adaptation lens.

- **Built environment:** Built environment are passive techniques for enabling energy efficiency that work on aspects related to heating, cooling, light, and other factors.

SUSTAINABLE ENERGY FOR UNIVERSAL HEALTH COVERAGE

Health services are highly dependent on reliable and uninterrupted energy supply to enable life-saving procedures. Access to reliable energy catalyses the delivery of health services and, when combined with appropriate medical and electrical appliances, improves the efficacy and impact of health-care provision. Studies show that in some least-developed countries, an unreliable grid results in almost 70% of medical devices failing or not being procured at all (IRENA and SELCO Foundation, 2022).

The health-care services that are dependent on reliable energy access include:

Basic administrative services: general needs including lighting, fans, laptops, computers and printing, and mobile charging for staff and patients.

Maternity and child care: diagnostic equipment used in identification of high-risk pregnancies and equipment used during and after delivery, including suction machines, radiant baby warmers, operation spotlights and phototherapy.

Immunisation: cold chain and refrigeration using deep freezers; ice-lined refrigerators for storing medicines, drugs and vaccines.

Basic diagnostics, laboratory testing and medical care: lighting for operations; energy for microscopes and centrifuges, instrument sterilisers and non-communicable disease kits.

Preventive and therapeutic care: energy and built environment for space heating and cooling; basic energy for testing and for quarantine facilities; cold chains for vaccine storage and delivery.

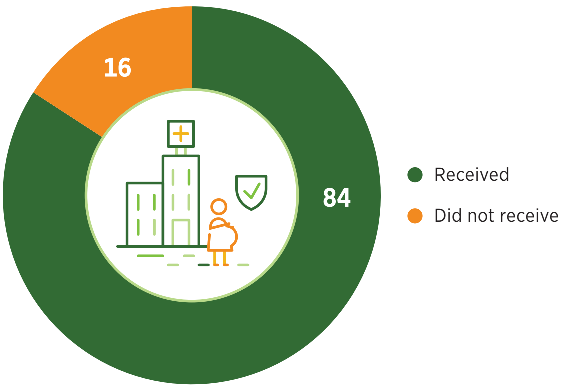
1.1 CONTEXT OF HEALTH CARE IN SÃO TOMÉ AND PRÍNCIPE

São Tomé and Príncipe, an archipelago off the west coast of Africa, is the continent's second smallest country, with a population of around 225 000 (UNFCCC, 2023). Comprising two main islands, São Tomé Island and Príncipe island, and some rocky islets, with a total area of approximately 900 km^2, the country is categorised as a small island developing state (SIDS).

SIDS have suffered immeasurably due to decades of recurring natural disasters that have continued to worsen as a result of the impacts of climate change (WHO, 2023). The increase in global temperatures has made islands extremely sensitive to inundation and to extreme weather conditions, such as hurricanes and cyclones, that are disastrous at scale to lives and livelihoods. As established by the Johannesburg Declaration, climate change is to be a risk multiplier for already economically vulnerable communities (OECD, *et al.*, 2009).

SIDS also face serious and urgent health threats owing to the increased risks attributed to climate change. With increased unpredictability of weather patterns and associated conditions, SIDS now face rapidly increasing rates of non-communicable diseases, malnutrition and shortage of medicines. Universal health coverage becomes challenging to achieve under such conditions, making it critical to converge all Sustainable Development Goal pathways to ensure health and other goals can be met.

Figure 1.1 **Percentage of women in São Tomé and Príncipe who received postnatal care after giving birth.**



Source: UNICEF Country Fact Sheet (UNICEF, 2024).

At a glance: Key health indicators in São Tomé and Príncipe

Life expectancy: The current life expectancy in São Tomé and Príncipe is 70.4 years (2024).

The country has a maternal mortality rate of 146 per 100 000 live births (WHO, *et al.*, 2023).

The country has an under-5 mortality rate of 15.43 per 1000 live births. Only 33% of children receive the mandated two-dose vitamin A supplement; 69% of children receive the mandated second dose of measles-containing vaccine (UNICEF, 2024).

Health-care delivery in São Tomé and Príncipe

Forty public health facilities in São Tomé and Príncipe cater to the health-care needs of the population. These facilities are categorised based on the services they provide, their geographic spread and remoteness, and their proportionality to the population served. The categories are:

- Health posts (*posto de saúde*) (31)
- Health centres (*centro de saúde*) (6)
- Hospitals (2)
- Warehouses (1)

1. **Health posts (*posto de saúde*):** Thirty-one health posts spread across the two islands are the primary point of care for the populations, offering basic services, consultations and medical care. Health posts provide multiple services, including laboratory analysis, maternity consultation and 24/7 emergency services to the entire population of the two islands.

2. **Health centres (*centro de saúde*):** Six health centres, being the intermediate point of care, offer services including emergency care without hospitalisation, general and family medicine, and immunisation. The data collected as a part of this assessment, shows that health centres serve 20–60 patients per day, and manage 13 births on average every month.

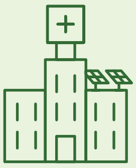
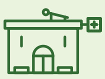
3. **Hospitals:** Two hospitals, one on each island, offer specialised critical services to the population. The hospital in São Tomé directly serves the Agua Grande District population of 84 300 as well as receiving patients from all other parts of the island, typically after they have undergone primary medical consultations at the health posts or health centres in their local districts. The hospital on São Tomé is the only facility in the country that provides X-ray services and has an oxygen generation unit.

4. **Warehouse:** Under the National Fund of Machines, one warehouse facility exists for storage of medicines, vaccines and other medical products for the country. The facility has one large and two small refrigerators.

Health centre in the Caué District.
Photo: A. Sánchez/IRENA.

Health post Agua Arroz in the Agua Grande District.
Photo: A. Sánchez/IRENA.

Table 1.1 **Distribution of health-care facilities in São Tomé and Príncipe**

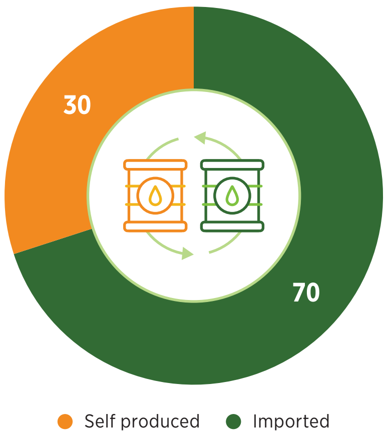
Level	Type of facility	Services provided	Human resources (average)	Total no. of facilities
National	Hospital 	· Emergency · Medical consultation · Maternity · Surgery · Family planning · Immunisation · Pharmacy · Laboratory · Ambulance	**São Tomé island hospital:** · 9 doctors (permanent) · 49 nurses (emergency block: 8, maternity: 10, paediatrics: 7, CCHEM: 8, psychiatry: 8, respiratory: 4, physiology: 4) · 30 technicians (pharmacy: 11, stomatology: 3, laboratory: 10, blood bank: 6) **Príncipe island hospital:** · 4 doctors (permanent) · 5 nurses (permanent) · 5 technicians (3 permanent, 2 as per requirement)	2
District	Health centre *(centro de saúde)* 	**Basic services:** · Emergency · Medical consultation · Maternity · Family planning · Immunisation · Pharmacy · Laboratory **Additional:** · Minor surgery · Ambulance	· 3–5 doctors (permanent) · 5–10 nurses (permanent) · 2 midwives (permanent) · 2 laboratory technicians (permanent) · 2 pharmacy technicians (permanent) · 5 administrative staff	6
Last-mile	Health post *(posto de saúde)* 	**Basic services:** · Emergency · Medical consultation · Family planning · Immunisation **Additional:** · Pharmacy · Laboratory	3 nurses (permanent) 1 doctor (available 2–3 days/week)	31
National	Warehouse	**Basic services:** · Storage of vaccines and medicines	5 workers	1

The services provided at each facility level from an energy point of view have been detailed in further sections of the report.

The 40 health-care facilities in São Tomé and Príncipe are currently dependent on grid infrastructure in the country that was installed over 70 years ago and needs an upgrade and advancement. It is prone to severe voltage fluctuations that exacerbate the inefficient supply of electricity, affecting the delivery of services across core sectors of health and impeding both lives and livelihoods. According to the health officials from Príncipe Island, diagnostic services, specifically X-ray examinations, are at times unavailable from 12 a.m. to 2 p.m. due to the absence of power supply. This disruption forces all patients awaiting these essential diagnostic tests to reschedule their appointments to the following week, causing significant delays in their medical care and treatment plans. Also, a nurse from a health post in São Tomé reports that during night-time blackouts, specifically between 5.30 p.m. and 9 p.m., the medical staff waits for 30 minutes in hopes of power restoration. If electricity is not resumed within this window, they are compelled to shut down the facility. Such closures during power outages often lead to frustration and anger among patients.

Need for decentralised renewable energy solutions

Figure 1.2 **Percentage of fuel imported for use in São Tomé and Príncipe**



Source: (IRENA, 2023b).

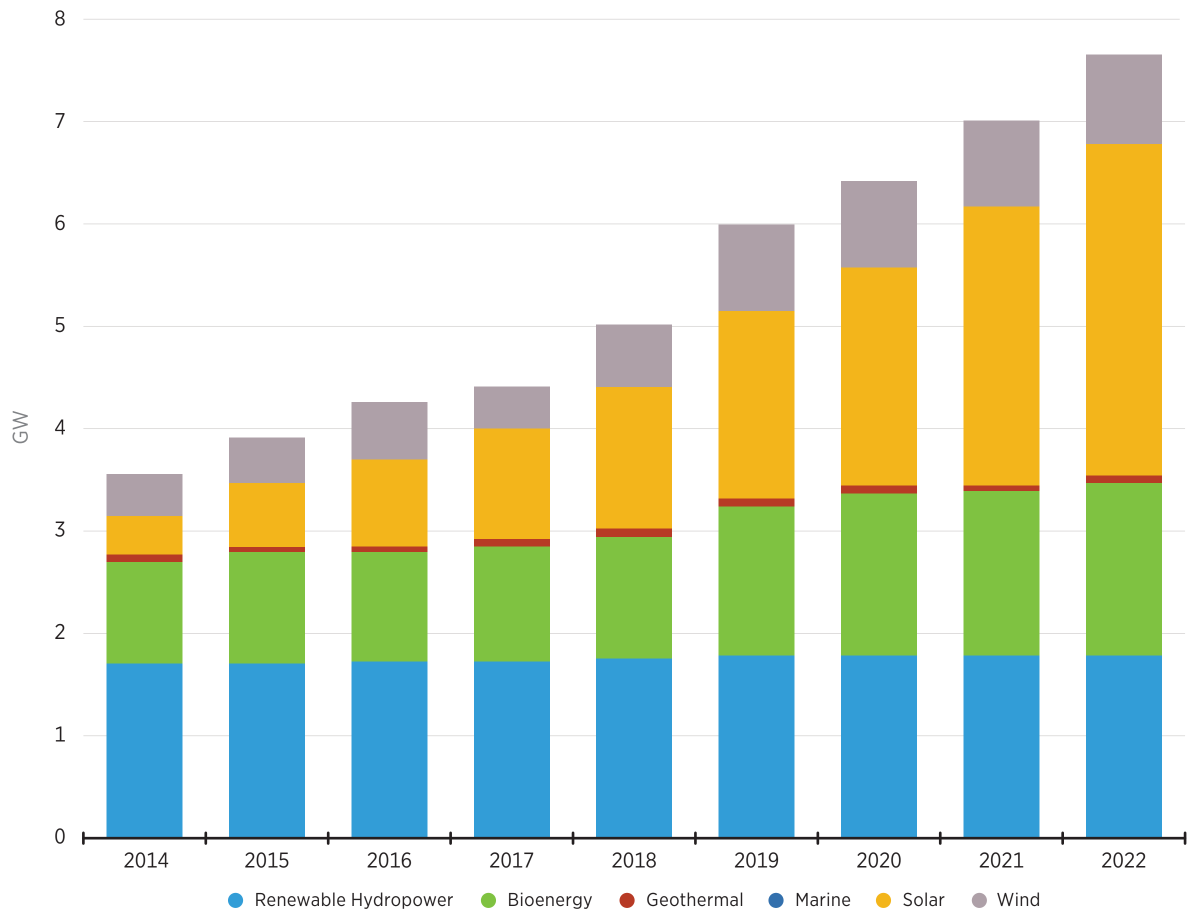
São Tomé and Príncipe is dependent on imports for the supply of most of the essential needs of the population (Government of São Tomé and Príncipe, 2021). About 70% of the total energy supply in the country comes from imports (IRENA, 2023b). Power outages, whether programmed or not, are sometimes a direct consequence of the local utility not being able to purchase enough fuel for a continuous supply of electric power. Similarly, climate disasters also affect the supply of fuel for operations. An administrator of the health centre in Caué district stated that the share of electrical energy supplied by the generator is significant. However, even with that high use of the generator, the staff tries to turn off equipment that is not indispensable, sometimes sacrificing thermal or lighting comfort, to save fuel during blackouts, aiming to ensure that fuel is present for essential use.

Furthermore, the Minister of Health of São Tomé and Príncipe stated that a substantial portion of the national health budget is allocated to procuring diesel fuel and meeting the energy demands of the sector. This expenditure underscores the significant reliance on diesel-powered generators for electricity in health-care facilities nationwide, reflecting the challenges faced in the health sector due to the lack of a reliable power supply. This points to an urgent need to plan for self-sufficiency and energy security in order to make social and economic gains. Decentralised renewable energy (DRE) systems will be a vital means to achieve self-sufficiency of energy, with the added benefits of being reliable, modern and affordable.

1.2 POTENTIAL OF RENEWABLE ENERGY FOR POWERING HEALTH CARE IN SÃO TOMÉ AND PRÍNCIPE

São Tomé and Príncipe was observed to have the capacity to power all electricity requirements from different renewable energy technologies like solar photovoltaic (PV) and hydroelectric power. However, because of the lack of means to harness renewable resources, the country met 93.5% of its total energy supply from fossil fuels in 2020 (Government of São Tomé and Príncipe, 2021). The Government of São Tomé and Príncipe is committed to addressing these challenges and has renewed its commitment to reduce greenhouse gas emissions by 27% through the production of renewables by updating its nationally determined contribution in 2021 (Government of São Tomé and Príncipe, 2021).

Figure 1.3 **Total installed renewable energy capacity by technology (GW, 2014–2022)**



Source: (IRENA, 2023a).

1.3 POTENTIAL OUTCOMES OF THE HEALTH–ENERGY PROGRAMME

The impacts of integrating renewable energy for improved health care will be experienced at the patient, health facility and system levels. The following expected outcomes are based on primary consultations with key stakeholders in the country, as well as organisations experienced in implementing DRE for health programmes.

Patient-level outcomes

- **Timely and reliable access to health facilities:** DRE solutions strengthen health-care ecosystems, provide last-mile communities with 24/7 access to quality care and reduce mortality rates.

- **Improved maternity and child care services:** Strengthened health-care facilities lead to higher immunisation rates, early identification of high-risk pregnancies, and improved well-being.

- **Reduced out-of-pocket expenditure:** Improved access to health care closer to home reduces income loss, transportation costs and out-of-pocket expenses for patients seeking medical treatment.

- **Improved feelings of well-being in patients:** Reliable electricity in health care enhances patient well-being by ensuring lighting, ventilation and phone charging. Solarisation ensures constant essential services for a safer environment, more conducive to recovery.

Facility-level outcomes

- **Improved staff retention, well-being and productivity:** Reliable electricity enhances health-care work environments, promoting comfort, safety and access to equipment. Better facilities boost job satisfaction, confidence and staff retention in distant areas, resulting also in financial savings for health centres.

- **Financial savings for the health facility:** Solarisation can save energy costs by avoiding procurement of grid electricity and diesel fuel as well as wastage of vaccines. As per t the primary data collected, almost half of the health facilities (43%) are equipped with a diesel generator, which consumes an average of approximately 210 litres of fuel per month, with the actual usage varying from 80 to 300 litres. On average, these generators produce about 706 kilowatt hours (kWh) of electricity per month, though the output can range from 256 kWh to 1 111 kWh.

- **Reduction in health appliance damages:** Reliable electricity enhances service quality, reduces waste and extends operational hours.

- **Reduced wastage of medicine and vaccines:** Solar-powered refrigeration provides a constant and reliable temperature for the storage of vaccines and medicines, ensuring their efficacy and reducing wastage (Burton and Alers, 2020).

System-level outcomes

- **Improvements in societal and- community health outcomes:** Energy solutions can improve the service provided by health-care facilities, reducing risks in maternity and childcare and improving health outcomes for the country as a whole, helping achieve country targets for sustainable development.

- **Independence from carbon-based fuels:** Decentralised sustainable energy systems can reduce greenhouse gas emissions caused by traditional energy sources like diesel.

- **Job creation and local entrepreneurship:** Solar energy solutions can create job opportunities and promote local entrepreneurship by involving local enterprises in the design, implementation and maintenance of the system.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APPROACH AND METHODOLOGY ADOPTED FOR THE ASSESSMENT

This chapter provides an overview of the methodology used for the assessment. Beginning with the conceptual framework that outlines the key factors considered in the study, the assessment follows an ecosystem approach to assess energy needs, challenges in energy service supply and financing for energy interventions. It then identifies renewable-powered system designs and funding needs, as well as recommendations on local skill development and on ownership and policy-level action. The assessment relies on both primary and secondary data.

The overarching **objectives** of the assessment were:

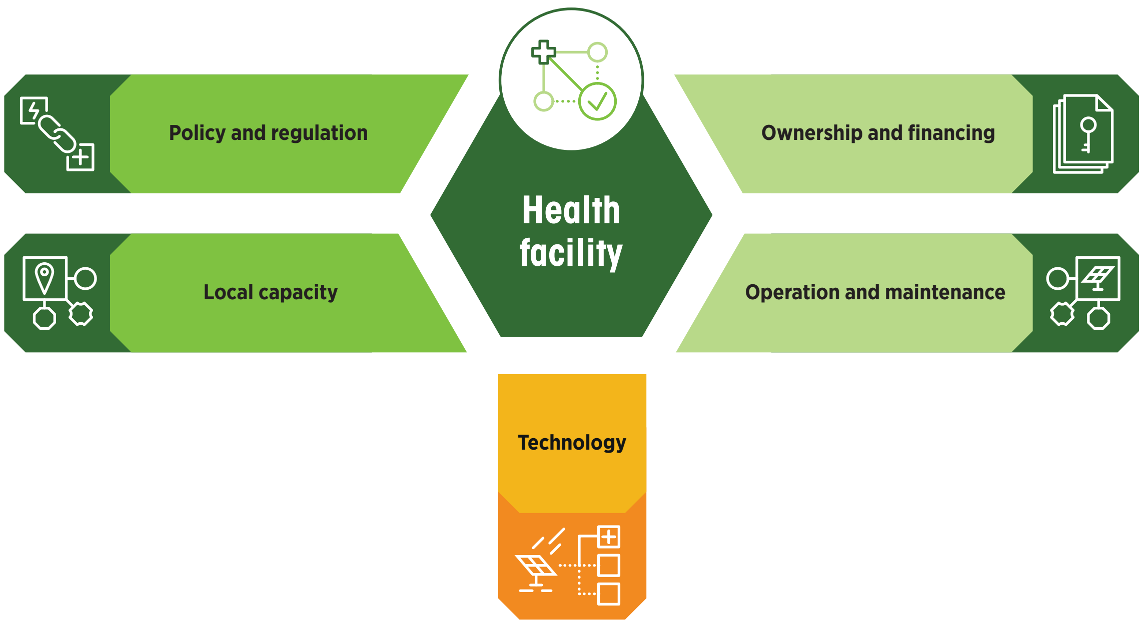
- to gain a comprehensive understanding of the health–energy ecosystem in São Tomé and Príncipe, including the current energy situation, energy needs, staff well-being and other key indicators;
- to gather key information for further planning of an evidence-based health–energy programme customised to the needs of São Tomé and Príncipe;
- to design a comprehensive plan and estimate the required investment;
- to ensure effective asset management and long-term sustainability;
- to identify gaps and opportunities for skills development of health staff for the operation and maintenance of DRE systems at health facilities; and
- to develop a detailed cost structure for programme implementation.

2.1 CONCEPTUAL FRAMEWORK FOR ASSESSMENT

An **ecosystem approach** was used in the process of inquiry. The approach, based on the principles of systems thinking, recognises the cause and effect between parts of a system and how they interact to influence and form the whole. This approach enhances understanding of the enablers and barriers important to the establishment, quality of functioning and sustainability of any system. The approach takes into account the current status of system components, overlaps between crucial aspects, and gaps and challenges attributed to different system components and provides key pathways for increasing relevance and efficiency in solution design, deployment and sustainability. The approach centres the end user, in this case the health-care facility, and accounts for the interconnections and interactions between these end users that make up the health-care system. The system components considered for examining the health–energy nexus were:

- technology – quality and compatibility of the DRE system with equipment
- ownership of the DRE system
- processes for installation, operation and maintenance of the DRE system
- local capacity for installation, operation and maintenance
- financing for installation, operation and maintenance
- policy and regulation around the health–energy nexus

Figure 2.1 **Key components of ecosystem approach to understanding health context and designing DRE systems**



2.2 ASSESSMENT METHODOLOGY

Assessment approach

The assessment followed a mixed-methods approach to data collection and analysis, wherein an in-depth analysis of secondary and primary data was conducted. The study followed key steps, as detailed in Figure 2.2.

Figure 2.2 **Assessment approach to data collection and analysis**

Step 1	· In-depth understanding of health-energy landscape through primary consultations and secondary findings
Step 2	· Selection of sample for primary data collection based on key criteria
Step 3	· Training of local health-energy persons to collect primary data
Step 4	· On-ground assessment of all types of selected health facilities
Step 5	· DRE solutions designs and costs
Step 6	· Developing overall DRE-based health-ecosystem reccomendations

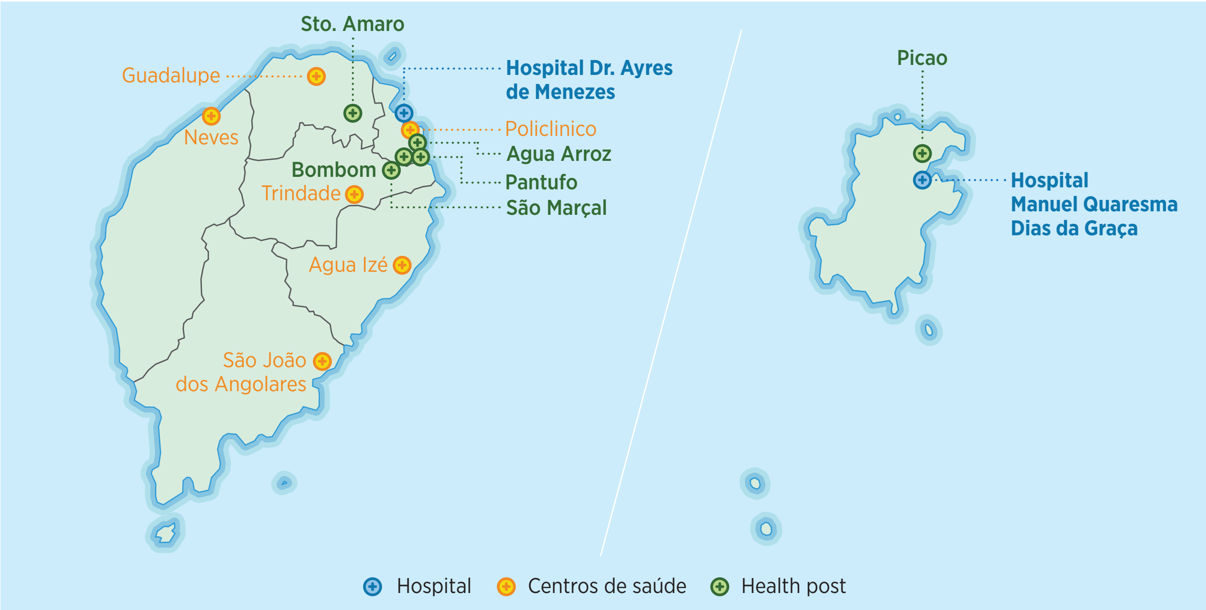
Source: (IRENA, 2023a).

Assessment sample

To ensure the assessment reflected the on-ground realities of the country, of the 40 health facilities in São Tomé and Príncipe, **14 health facilities were selected for the health–energy audit and for key interviews at the facility level.** The selection of facilities used the following criteria:

- All types of public health facilities, providing varied services (*i.e.* health posts, health centres and hospitals) should be represented.
- The locations should represent geographic and other variances on both islands.
- Number of patients treated per day at the facility.
- Different electrification scenarios should be represented.

Figure 2.3 **Facilities selected for the health–energy assessment on both islands**



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.

Respondents and tools

Beside the facility-level audits, the following matrix provides an overview of the respondents selected for the study, and the tools used to obtain information.

Table 2.1 **Overview of the respondents and the tools used**

Respondent type	Respondents (no.)	Reason for selection	Tools used
Facility-level staff: nurses, doctors, electricians, facility administrators	14	To gain an understanding of the energy requirement at the facility level, and to understand how energy affects the experiences of health staff in delivering services	✓ Facility observation checklist ✓ Key informant interview guide
Local DRE component suppliers	6	To get realistic cost estimates of DRE components to ensure appropriate representation of the same	✓ Key informant interview guide
Ministry of Health, Ministry of Infrastructure, bilateral organisations in the country	4	To gain key documents that provide insights on the status of health and energy in the country and on any ongoing programmes	✓ In-depth desk review

The information received through the primary data collection was categorised into themes for analysis as per the ecosystem approach described in Section 2.1. Primary and secondary data were triangulated to provide strong insights for the DRE system design and the health–energy ecosystem in the country. The findings from the assessment are presented in this report to enhance understanding of the context and problem statements and to provide accurate and reliable solution designs.

SOLAR ENERGY SYSTEM DESIGNS AND COSTS

This chapter lays out the assumptions considered for solar energy system designs, taking into consideration variances in conditions on both islands. Pertinent information that could help provide accurate and relevant estimates include the specific services provided at the facilities, which affect their energy requirements; possible expansions in infrastructure; the footfall at the facility; and the sunshine conditions in different parts of the islands. The costings of the proposed designs are based on quotations for the various components and processes involved in installing and maintaining the solar energy system, provided by local vendors and entrepreneurs in the country. The findings are presented based on variances in the two islands of São Tomé and Príncipe, as well as across the three levels of health posts, health centres and hospitals.

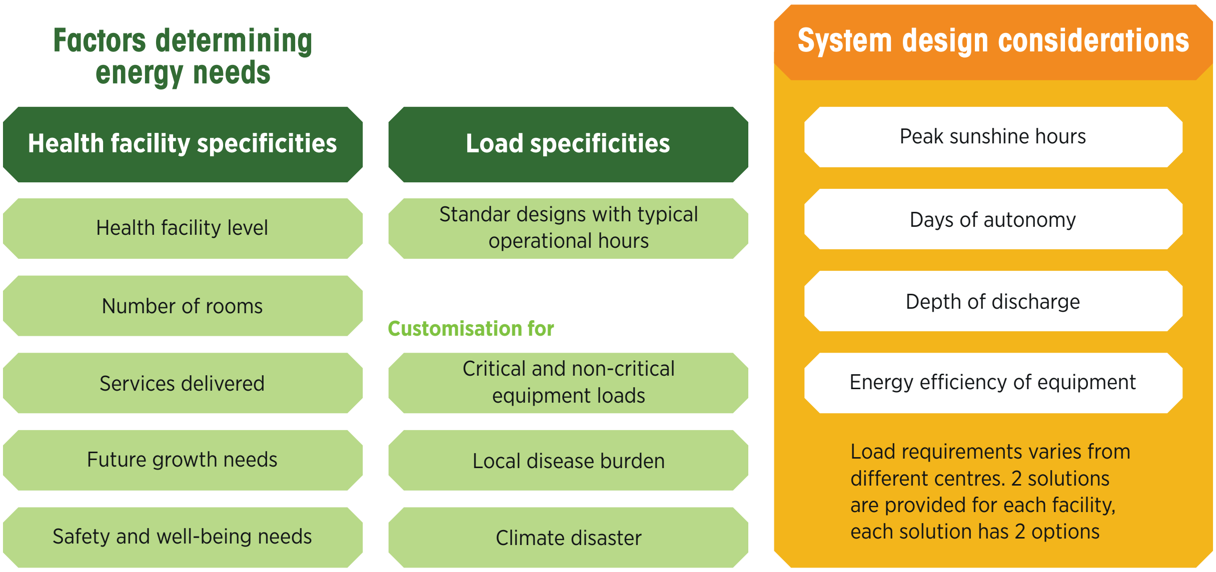
The health posts and health centres offer basic and emergency services to all residents of the country; patients are commonly referred to the two hospitals for more complex and critical services. To account for the vast differences in levels of infrastructure at each type of facility, the DRE system design and costing have been presented separately for (1) health posts and health centres and (2) hospitals.

Various options for installing DRE systems have been made for the three levels of facility, which can assist stakeholders in making critical decisions regarding health–energy programmes in São Tomé and Príncipe.

3.1 SOLAR ENERGY SYSTEM DESIGN PARAMETERS

Based on the needs identified from primary consultations and secondary data, the parameters for determining energy needs described in Figure 3.1 were used to calculate and propose custom DRE system designs for the different levels of health facility in the country.

Figure 3.1 **Overarching factors considered for solar energy system design**



3.2 SOLAR ENERGY SYSTEM DESIGN ASSUMPTIONS

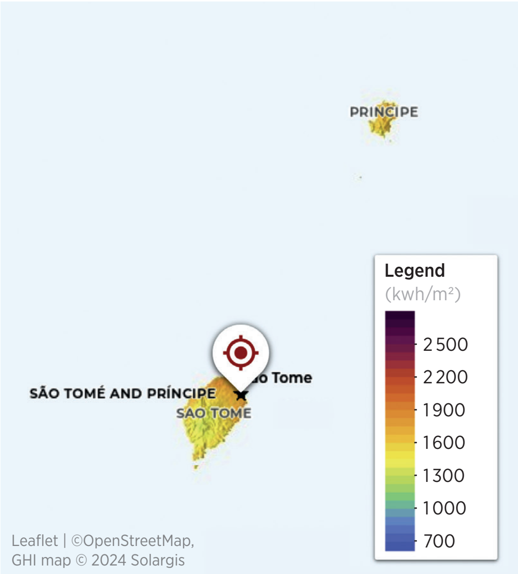
This section broadly outlines the assumptions used in estimating the designs of the solar energy system components: solar panel, battery and inverter.

These assumptions have been made for the purpose of analysing the health-care system from a point of view of DRE integration. However, customised designs are encouraged for specific geographical areas within the country based on more nuanced requirements. For example, the capacity of each component, including individual battery and panel size, needs to be based on the availability of and access to that a component of that specification in the local market (as well as servicing and spare part provision). Additionally, the results are based on a sample of the existing facilities. It is imperative that a site-level assessment is conducted for any facility that is considering as part of an implementation program, using the design templates as reference.

Solar irradiation

São Tomé and Príncipe receives an **annual average direct normal irradiance of around 3 kWh per square metre (m^2) per day** and an **annual average global horizontal irradiance of around 3–4.9 kWh/m^2/day** (ESMAP, 2024). Average global horizontal irradiance is the appropriate parameter for calculating electricity yield and evaluating the performance of flat plate PV technologies. For the designs in this report, sunshine hours are considered to be 3 hours per day (as per the annual average direct normal irradiance) (World Bank, 2019) based on the geographical presence and climatic conditions of the country in the tropical region, as seen in Figure 3.2.

Figure 3.2 **Global horizontal irradiation of São Tomé and Príncipe**



Map data

Specific photovoltaic power output	PVOUT specific	3 982	kWh/kWp per day
Direct normal irradiation	DNI	3 056	kWh/m² per day
Global horizontal irradiation	GHI	4 955	kWh/m² per day
Diffuse horizontal irradiation	DIF	2 686	kWh/m² per day
Global tilted irradation at optimum angle	GTI opta	4 957	kWh/m² per day
Optimum tilt of PV modules	OPTA	2 / 180	°
Air temperature	TEMP	26.0	°C
Terrain elevation	ELE	8	m

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

Days of autonomy

Autonomy is the length of time that a battery bank can support a specific load without charging. It is used in determining battery reserve capacity and system reliability. Autonomy enables the system to perform as required even under monsoon season or cloudy conditions for specified days of autonomy and enhances battery life (depth of discharge (DOD) versus cycle life). **For the designs for both health posts and health centres, a two-day autonomy has been incorporated to operate the design loads at those health facilities** and enabling the facilities to be resilient to power outages on cloudy days. **For hospitals, a 1.5-day autonomy has been incorporated when solar is the primary source of energy and a one-day autonomy when solar is the backup source, as the system sizes are considerably larger.**

Solar PV panel

The required solar PV panel wattage is calculated using the energy required to operate the connected load, the available sunshine hours and other parameters, including battery charging efficiency, load efficiency and dust factor. The PV panel calculation is as follows:

panel wattage required = (total energy required (watt-hours)) / (sunshine hours × battery charging efficiency × load efficiency × dust factor)

Assumptions:

Battery charging efficiency = 90%
Battery discharging efficiency = 90%
Load efficiency* = 85%
Dust factor = 95%

* The load efficiency of a system is defined as the useful power output available out of the total electrical power generated.

Battery

The battery or energy that must be stored is determined by the total energy required to operate the connected load, the battery's efficiency, the days of autonomy required, and the battery DOD. Lithium-ion batteries have been incorporated into the designs based on primary findings from consultations with vendors in the country, who confirmed that lithium-ion are the batteries most procured, installed and used on the islands in this context. The battery capacity calculation is as follows:

battery capacity required = (days of autonomy × total load (watt-hours)) / (load efficiency × system voltage × DOD × discharging efficiency)

Assumptions:

Battery discharging efficiency = 90%
Load efficiency = 85%
DOD = 90%

Solar inverter

The solar inverter is chosen based on the power consumption and type of connected load, as well as the capacity of the solar PV system and the battery bank voltage.

Solar energy assumptions summary

The assumptions used in the solar energy system designs for the health facilities in São Tomé and Príncipe are shown in Table 3.1.

Table 3.1 **Summary of assumptions for solar energy system design**

S.No.	Parameter	Assumption
1	Battery charging efficiency	90%
2	Load efficiency	85%
3	Dust factor	95%
4	Sunshine hours	3 hours per day
5	Battery discharging efficiency	90%
6	Depth of discharge (DOD)	90%
7	Temperature coefficient*	0.8
8	No. of days of autonomy (health posts and health centres)	2
9	No. of days of autonomy (hospitals – primary)	1.5
10	No. of days of autonomy (hospitals – backup)	1

* The temperature coefficient represents the rate at which resistance varies with temperature, denoting the alteration in resistance value as the component's temperature changes.

The number of days of autonomy for the various types of health facilities have been allocated as per the differing needs and contexts of the facilities with regards to power usage and outages. For Health Posts and Health Centres, 2 days of autonomy have been considered as they are the primary care facilities that serve most of the population of the country as the first point of care. As the requirements at these levels are limited, and given the islands face long power outages regularly, 2 days have been considered. For the hospitals, as the system requirements are much larger, a minimum 1 day of autonomy has been considered for the hospital on Príncipe island. An autonomy duration of 1.5 days has been considered for São Tomé island hospital, as it serves a larger population for more critical needs from both the islands.

Average number of rooms

For the different types of facility, the number of rooms assumed for various solutions were based on the number of rooms typically present in that type of facility. The average rooms considered for health posts and health centres is shown in Table 3.2. Details beyond those provided in the table for hospitals are presented in the design sections for the two hospitals.

Table 3.2 **Assumptions of number of rooms used for health posts and health centres**

Type of facility	No. of Rooms	Types of Room	
Health post	· Range: 5–10 · Average: 8	· Waiting area · Medical rooms · Nursing rooms · Laboratory	· Pharmacy · Administration room · Storage · Toilet
Health centre	· Range: 8–37 · Average: 18	· Reception · Waiting area · Medical rooms · Nursing rooms · Emergency unit · Paediatrics unit · Stomatology unit · Reproductive health unit · Laboratory	· Sterilisation unit · Bacteriology unit · Gynaecology unit · Administration rooms · Kitchen · Toilets · Laundry · Storage · Staff accommodation
Hospitals	· Large facilities, multiple buildings and rooms · São Tomé hospital: 4 buildings · Príncipe hospital: 2 buildings	All included for health centres, plus: · Operating blocks · X-ray testing · Intensive care unit* · Oxygen generation unit* · Medical air unit*	· Emergency bank* · Autoclave* · Incinerator* · Centralised air conditioning*

* Facilities listed are in reference to São Tomé hospital

Disruptions in energy

From primary consultations with key informants at the facility level, variances in load shedding and power outages for different areas were considered. The durations of power outages were noted to be different on the two islands of São Tomé and Príncipe and to affect types of health facility differently depending on their hours of operation. The details are shown in Table 3.3 for each type of facility.

Table 3.3 **Details of power outages by island and type of facility (hours/day)**

	São Tomé island (average)		Príncipe island (average)	
Type of facility	Hours of operation	Duration of power outages	Hours of operation	Duration of power outages
Health post	12	3	8	2
Health centre	10	3	NA	NA
Hospital	24	4	24	4

Health posts are open only on weekdays, while health centres and hospitals are also open on all days of the week.

Designing for energy efficiency

A number of old fluorescent tube lights, bulbs, incandescent lamps and ceiling fans were identified at facilities for replacement, which would result in a significant amount of energy savings, as seen in Table 3.4. New efficient variants were used for the purposes of system design.

Table 3.4 **Comparison of existing loads and efficient loads**

		Energy-efficient replacement	
Existing component	Power consumption (W)	Type	Power consumption (W)
Tubular fluorescent lamp	50	LED tube light	20
Tubular fluorescent lamp	32	LED tube light	9
CFL light bulbs	15	LED tube light	9
Fan: ceiling mounted	100	Energy-efficient fan: ceiling mounted	50

Designing for current needs and future expansion

The future expansion needs of specific facilities were taken into consideration. As identified in key informant interviews, there is a plan to expand the hospital on Príncipe island, and the additional buildings and equipment would add to the energy requirement at the facility. The designs for the hospital have been made to account for this expansion.

3.3 SOLAR ENERGY SYSTEM DESIGN OPTIONS

To best represent the facility types and requirements in the country, DRE system design templates have been developed for the following types of health facility and load. These are shown in Table 3.5.

Table 3.5 **Details of power outages by island and type of facility (hours/day)**

Type of facility	Solar as primary source of energy	Solar as backup source of energy
Health post	✓ Basic loads ✓ Regular loads ✓ Regular loads with laboratory services	✓ Basic loads ✓ Regular loads ✓ Regular loads with laboratory services
Health centre	✓ Basic loads ✓ Regular loads with laboratory services	✓ Basic loads ✓ Regular loads with laboratory services
Hospital	✓ Regular loads with laboratory services	✓ Regular loads with laboratory services excluding autoclave and steriliser

Based on the services offered by each facility, different types of solution have been provided to power basic loads, regular loads and regular loads with laboratory services. A basic description of the load options is presented in Table 3.6.

Table 3.6 **Design solutions per type of load**

<table>
<tr><td rowspan="2">Option A
—
Basic loads</td><td colspan="2">Includes the minimum infrastructure and equipment required to provide services at the health facility. The equipment considered as basic loads for are mainly illumination of different types and fans in the various rooms of the facility.</td></tr>
<tr><td>Basic loads considered for health posts on São Tomé island:

Rooms: 1 entrance + 1 waiting area + 1 outpatient department/consultation room + 1 nursing room + 1 medical officer room + 1 dispensary + 1 storage + 1 laboratory + 1 toilet

Loads: 7 LED bulbs + 6 tube lights + 6 fans

Basic loads considered for health posts on Príncipe island:

Rooms: 1 reception + 1 pharmacy + 1 storage + 1 toilet

Loads: 2 LED bulbs + 2 tube lights + 1 pedestal fan

Note: The loads for health posts differ between the two islands based on available infrastructure found at the facilities during the primary data collection for the assessment.</td><td>Basic loads considered for health centres:

Rooms: 1 entrance + 1 reception + 1 waiting area + 2 outpatient department/ consultation rooms + 2 nursing rooms + 2 medical officer rooms + 1 maternity room + 1 inpatient department + 1 dispensary + 1 storage + 1 laboratory + 1 toilet + 1 outside

Loads: 18 LED bulbs + 23 tube lights + 21 fans + 7 laptops + 4 printers + 2 negatoscopes + 2 fridges + 1 baby warmer + 1 ultrasound + 1 suction machine + 1 exploration light + 1 focus light + 1 ice-lined refrigerator + 1 vaccine fridge + 1 microscope + 1 centrifuge + 1 automatic analyser + 1 vortex mixer + 1 portable examination light + 1 oxygen concentrator + 1 automatic haematology analyser + 1 micro-haematocrit centrifuge</td></tr>
</table>

<table>
<tr>
<td rowspan="2">Option B
—
Regular loads</td>
<td colspan="2">Includes basic loads and administrative equipment like laptops and printers, as well as common equipment required to service the population at large, such as negatoscopes and fridges. This intermediate design option is only applicable for health posts, as explained in the subsequent section.</td>
</tr>
<tr>
<td colspan="2">Regular loads for health posts on São Tomé island:

Rooms: 1 entrance + 1 waiting area + 1 consultation room + 1 nursing room + 1 medical officer room + 1 dispensary + 1 storage + 1 toilet

Loads: 8 LED bulbs + 4 tube lights + 4 fans + 1 negatoscope + 1 fridge + 1 portable examination lamp + 1 desktop + 1 printer

Regular loads for health posts on Príncipe island:

1 reception + 1 pharmacy + 1 storage + 1 toilet

2 LED bulbs + 2 tube lights + 1 pedestal fan + 1 refrigerator + 1 negatoscope + 1 portable examination lamp + 1 desktop + 1 printer

Note: The loads for health posts differ between the two islands based on available infrastructure found at the facilities during the primary data collection for the assessment.</td>
</tr>
<tr>
<td rowspan="2">Option C
—
Regular loads with laboratory services</td>
<td colspan="2">Accounts for multiple services being offered, per the facility's mandate. The services have been categorised as life-saving critical services or other services that enhance the delivery of health care. Critical equipment that has higher energy requirements, such as labour room equipment, vaccine fridges, oxygen concentrators, and other equipment, are included.</td>
</tr>
<tr>
<td>Regular loads + laboratory services for health posts:

Rooms: 1 entrance + 1 waiting area + 1 outpatient department/consultation room + 1 nursing room + 1 medical officer room + dispensary + 1 storage + 1 laboratory + 1 toilet

Loads: 8 LED bulbs + 6 tube lights + 6 fans + 1 negatoscope + 1 fridge + 1 portable examination lamp + 1 laptop + 1 printer + 2 microscopes + 2 centrifuges</td>
<td>Regular loads + laboratory services for health centres:

Rooms: 1 entrance + 1 reception + 1 waiting area + 2 outpatient department/ consultation rooms + 2 nursing rooms + 2 medical officer rooms + 1 maternity room + 1 inpatient department + 1 cold chain unit + 1 dispensary + 1 storage + 1 laboratory + 1 toilet + 1 outside

Loads: 18 LED bulbs + 23 tube lights + 21 fans + 7 laptops + 4 printers + 2 negatoscopes + 2 fridges + 1 baby warmer + 1 ultrasound + 1 suction machine + 1 exploration light + 1 focus light + 1 ice-lined refrigerator + 1 vaccine fridge + 1 microscope + 1 centrifuge + 1 automatic analyser + 1 vortex mixer + 1 portable examination light + 1 oxygen concentration + 1 automatic haematology analyser + 1 micro-haematocrit centrifuge</td>
</tr>
</table>

All three types of loads differ depending what services a particular facility offers. This has been detailed in the sections on the designs for each type of facility. For each solution, two options have been included to provide a choice of design, and therefore cost, options that can inform programme design for relevant stakeholders:

- DRE system as a primary source of energy
- DRE system as a backup source of energy

Solution 1: DRE system as primary source of energy

Aligned with the commitment of the Government of São Tomé and Príncipe to increase the share of renewable energy in the national mix, a solar energy system with battery backup option is being proposed to power the entire load of each facility for the complete operating hours of that facility. This option would be most relevant on Príncipe island as power outages for the island's health facilities connected to the grid occur for almost 50% of their operational hours and as the primary source of energy on the island is diesel generators (per interviews with facility staff). Assumptions for the energy consumption or usage hours of each load are based on the general usage pattern, and illumination and ceiling fan loads have been replaced with energy-efficient equivalents.

Solution 2: DRE system as a backup source of energy

For the 14 health facilities assessed for the purpose of this study that were connected to utility grid, solar energy system designs have been provided that can serve as a backup in case of power outages. The backup design is customised to cater to the outages at each facility type, taking into consideration the varying hours of power outages on both islands, as seen in Table 3.3. Illumination and ceiling fan loads have been replaced with efficient equipment loads.

Backup system assumptions for hospitals

- Operational hours considered for lights and fans is **four hours**, air conditioner, medical equipment and administrative equipment (laptop/desktop) is **two hours**.
- In the case of medical equipment that are running for less than two hours as considered above, the actual operational hours *i.e.* < 2 hours will be considered for the design.
- Exclusion of the autoclave from the solar system design at the Hospital in São Tomé island.
- The autoclave is excluded from the solar energy system design at the hospital on São Tomé island, as the autoclave consumes 34% of the hospital's total energy; it has been categorised as non-critical for the delivery of health services for the purposes of this assessment. Additionally, the autoclave was found to be in a non-working condition at the time of the assessment.
- The autoclave, steriliser and oxygen plant have been excluded from the solar energy system design at the hospital on Príncipe island, as the equipment consumes 42% of the hospital's total energy; it has been categorised as non-critical for the delivery of health services for the purposes of assessment. Additionally, the autoclave and oxygen plant at this hospital were found to be in non-working condition at the time of the assessment.

3.4 SOLAR ENERGY SYSTEM DESIGN TEMPLATES: HEALTH POSTS AND HEALTH CENTRES

Design templates for health posts

Based on the assessment findings and assumptions presented, the following design templates are recommended for health posts. **As the services offered at health posts on both islands differ, the designs account for the variances in conditions on São Tomé island and Príncipe island**.

Table 3.7 **Load considerations and DRE system designs for health posts on São Tomé island**

	Basic load		Regular load		Regular load + laboratory services	
System designs and requirements	**Solar as primary**	**Solar as backup**	**Solar as primary**	**Solar as backup**	**Solar as primary**	**Solar as backup**
Maximum Load Connected	0.49 kW	0.49 kW	1.07 kW	1.07 kW	1.67 kW	1.67 kW
Maximum units that can be used per day	3.05 kWh	1.8 kWh	6.49 kWh	3.4 kWh	8.24 kWh	4.74 kWh
Components						
Solar panel capacity	**2.25 kWp**	**1.4 kWp**	**5 kWp**	**2.5 kWp**	**6 kWp**	**3 kWp**
Solar battery	9.6 kWh	5.76 kWh	19.2 kWh	9.6 kWh	26.88 kWh	14.4 kWh
Solar inverter	3 kVA	2 kVA	6 kVA	3 kVA	7.5 kVA	4 kVA

As indicated in Table 3.7, powering the health posts on São Tomé Island with DRE for **all loads for the complete facility operating hours requires a panel capacity of 6 kilowatt peak (kWp), a battery capacity of 26.88 kWh, and an inverter size of 7.5 kilovolt-amperes (kVA)** for each facility. If one were to consider powering the health posts on the island for **basic loads as a backup system** to work during power outages, then the panel capacity requirement would be **1.4 kWp, with a battery capacity of 5.76 kWh and an inverter size of 2 kVA, 48 V,** per facility.

Table 3.8 **Load considerations and DRE system designs for health posts on Príncipe island**

	Basic load		Regular load	
System designs and requirements	**Solar as primary**	**Solar as backup**	**Solar as primary**	**Solar as backup**
Maximum Load Connected	0.12 kW	0.12 kW	0.842 kW	0.842 kW
Maximum units that can be used per day	0.4 kWh	0.23 kWh	4.6 kWh	2.5 kWh
Components				
Solar panel capacity	**0.2 kWp**	**0.1 kWp**	**3 kWp**	**1.4 kWp**
Solar battery	1.2 kWh	0.7 kWh	14.4 kWh	8 kWh
Solar inverter	1.25 kVA	1.25 kVA	4 kVA	2 kVA

As shown in Table 3.8, for Príncipe island the design considers two types of facility: health post with basic load and health post with regular load. Designs intended for regular load health posts that include laboratory services are deemed unsuitable for Príncipe island. Powering the health posts on Príncipe Island with DRE for **all loads for the complete facility operating hours requires a panel capacity of 3 kWp, a battery capacity of 14.4 kWh, and an inverter size of 1.25 kVA** for each facility. If one were to consider powering the health posts on the island for **basic loads as a backup system** to work during power outages, then the **panel capacity requirement would be 0.1 kWp, with a battery capacity of 0.7 kWh and an inverter size of 1.25 kVA,** per facility.

Design templates for health centres

Health centres are **only present on São Tomé island**. Thus, the design options for health centres reflect the conditions on the island. For the health centres, two design options have been provided, based on load requirements. Basic loads account for more services than the smaller health posts, and regular loads include the laboratory services provided at the health centres.

The DRE system design options as well as the load considerations for health centres are shown in Table 3.9:

Table 3.9 **Load considerations and DRE system designs for health centres on São Tomé island**

	Basic load		Regular load with laboratory services	
System designs and requirements	**Solar as primary**	**Solar as backup**	**Solar as primary**	**Solar as backup**
Maximum load connected	1.54 kW	1.54 kW	6.42 kW	6.42 kW
Maximum units that can be used per day	12.42 kWh	7.91 kWh	34.84 kWh	20.12 kWh
Components				
Solar panel capacity	**10 kWp**	**6 kWp**	**26 kWp**	**14 kWp**
Solar battery	36 kWh	26.88 kWh	102 kWh	54 kWh
Solar inverter	12.5 kVA	7.5 kVA	35 kVA	15 kVA

As seen in Table 3.9, powering all health centers in the country with DRE for **all loads for the complete facility operating hours requires a panel capacity of 26 kWp, a battery capacity of 102 kWh, and an inverter size of 35 kVA** for each facility. If one were to consider powering the health centres for **basic loads as a backup system** to work during power outages, then the **panel capacity requirement would be 6 kWp, with a battery capacity of 26.88 kWh and an inverter size of 7.5 kVA**, per facility.

3.5 SOLAR ENERGY SYSTEM COST ASSUMPTIONS

The cost of the DRE system including supply of panels, batteries, inverters and cabling, installation, and maintenance are based on six quotations received from local service providers. The average costs for various components are provided in US dollars (EUR 1 = USD 1.09 as of 20 January 2024). Based on the requirements for installing a reliable DRE system and implementing processes for sustainability of the system, the assumptions shown in Table 3.10 have been made for estimating the costs of the design solutions.

Table 3.10 **Details of power outages by island and type of facility (hours/day)**

Cost component	Assumptions	Average proportion of cost
System costs	System components, installation and commissioning, labour, remote monitoring system	80%
Operation and maintenance costs	Cleaning the panels, servicing the system once every three months for ten years	14%
Replacement of spare parts	Spare parts for solar panel, battery, inverters and cabling	
Transportation costs	Import and transportation of system components	São Tomé island: 7% Príncipe island: 9% Standard rate: USD 2 998* + USD 172.4/kWp for Príncipe island

* The transportation costs are accounting for the import of parts from other countries by sea. The transportation cost for the hospital on Príncipe island is comparatively high due to the extra transport cost from São Tomé to Príncipe island.

System costs (capital expenditures)

The cost of system components include costs for solar panels, batteries, inverters, charge regulators, wiring and rooftop mounting structures, as well as for installation, commissioning and local transportation. For ground-mounting structures, an additional cost of USD 216.11/kWp has to be included.

Lithium-ion batteries are included in the designs in this report, in accordance with their availability on the island. Depending on usage and maintenance, the average life cycle of a lithium-ion battery is ten years.

The system costs were considered as per availability of system components at São Tomé and Príncipe. The minimum cost taken is for a system size of 1.4 kWp – as this is the smallest system available, as per quotations from six vendors in the country. CAPEX costs are likely to reduce for smaller system requirements, such as for the Príncipe health posts which is of 0.1 kWp.

Operation and maintenance costs (operating expenses)

These costs are provided for a ten-year period, with servicing visits once every three months. Since the islands see heavy rainfall and high wind speeds for a major portion of the year, regular clearing of panels and batteries is paramount to remove accumulated dust that might impede the ability of the system to performance at highest efficiency. The companies consulted estimated that the average maintenance cost for ten years is 14% of the total cost of the system. That cost includes periodic inspections and the replacement of damaged spare parts, as well as a ten-year warranty for lithium-ion solar batteries. During that period, any maintenance required for the battery is typically covered by the manufacturer.

Remote monitoring cost

An average cost for monthly remote monitoring of DRE systems has been considered as part of the system supply and installation cost as a means to ensure effective monitoring and subsequent planning for troubleshooting.

Transportation costs

São Tomé and Príncipe, being a SIDS, is highly dependent on the import of basic facilities from other countries. The transportation of imported goods, including DRE system components, accounts for an average of 7% of the total cost of installing DRE systems on São Tomé island.. The transportation costs for Príncipe island are slightly higher, making up 9% of the system cost, as materials and services have to be transported from São Tomé island to Príncipe island. This has been considered in the cost estimates as it has a significant bearing on the overall programme costs.

3.6 SOLAR ENERGY SYSTEM COSTS: HEALTH POSTS AND HEALTH CENTRES

Cost for DRE system solutions for health posts

Costs for health posts on São Tomé island

Table 3.11 provides the indicative costs for the various system design options for health posts on São Tomé island presented in Section 3.4, using the cost assumptions detailed in Section 3.5.

Table 3.11 **Cost of DRE solutions for health posts on São Tomé island**

	Basic load		Regular load		Regular load + laboratory services	
Cost component	**Solar as primary**	**Solar as backup**	**Solar as primary**	**Solar as backup**	**Solar as primary**	**Solar as backup**
Supply and installation (USD)	29 561	21 637	54 221	31 435	64 911	38 283
Remote monitoring for ten years	Included	Included	Included	Included	Included	Included
Transportation to São Tomé (USD)	2 998	2 998	2 998	2 998	2 998	2 998
Maintenance for ten years (USD)	4 139	3 029	7 591	4 401	9 087	5 360
Total estimated cost (USD)	36 697	27 663	64 809	38 883	76 995	46 640
Unit	for 1 facility	for 1 facility	for 1 facility	for 1 facility	for 1 facility	for 1 facility
For all 26 health posts (USD)	**954 123**	**719 241**	**1 685 040**	**1 009 669**	**2 001 881**	**1 212 640**

As seen in Table 3.11, the cost range for powering a **single health post on São Tomé island is between USD 27 663 and USD 76 995**, depending on whether the DRE system is installed as a backup or primary source and for basic loads, regular loads or regular loads with laboratory services.

Health posts are the first point of care in the country's health-care system, making them the backbone of the health-care infrastructure. To equip **all the health posts on São Tomé island** with long-term, cost-effective DRE systems, the cost range is **between USD 719 241 and USD 2 001 881**, depending on whether the DRE system is installed as a backup or primary source and for basic loads, regular loads or regular loads with laboratory services. These totals include costs for sustainability of the system for a period of ten years, as the battery has an average life cycle of ten years and system maintenance costs for 10 years have been included. Beyond this period, working capital will be required to replace the battery, as well as to account for inverter replacement, if required.

Costs for health posts on Príncipe island

Table 3.12 provides the indicative costs for the two system design options for health posts in Príncipe island.

Table 3.12 **Cost of DRE solutions for health posts in Príncipe island**

	Basic load		Regular load	
Cost component	**Solar as primary**	**Solar as backup**	**Solar as primary**	**Solar as backup**
Supply and installation (USD)	29 561	21 637	54 221	31 435
Remote monitoring for ten years	Included	Included	Included	Included
Transportation to Príncipe (USD)	3 390	3 242	3 870	3 434
Maintenance for ten years (USD)	4 139	3 029	7 591	4 401
Total estimated cost (USD)	37 089	27 907	65 681	39 269
Unit	for 1 facility	for 1 facility	for 1 facility	for 1 facility
For all 5 health posts (USD)	185 447	139 536	328 406	196 347

The cost range for powering a **single health post on Príncipe island is between USD 27 907 and USD 65 681,** depending on whether the DRE system is installed as a backup or primary source and for basic loads, or regular loads.

To equip **all five health posts on Príncipe island** with long-term, cost-effective DRE systems, the cost range is **between USD 139 536 and USD 328 406.** These totals include costs for sustainability of the system for a period of ten years.

Thus, from the above cost estimates for all health posts in the country, it would take an initial investment of **USD 2 330 287** to equip all 31 facilities across the two islands with renewable energy for all loads for the complete operating hours of the facilities.

To equip all loads with renewable energy as a backup system to account for basic loads during power outages, it would take an initial investment of **USD 858 777** to power all 31 health posts on both islands.

Cost for DRE system solutions for health centres

Table 3.13 provides the indicative costs for the various system design options for health centres on São Tomé island presented Section 3.4, using the cost assumptions detailed in Section 3.5.

Table 3.13 **Cost of DRE solutions for health posts in Príncipe island**

	Basic load		Regular load with laboratory services	
Cost component	**Solar as primary**	**Solar as backup**	**Solar as primary**	**Solar as backup**
Supply and installation (USD)	96 566	64 911	255 955	146 118
Remote monitoring for ten years	Included	Included	Included	Included
Transportation to Príncipe (USD)	2 998	2 998	2 998	2 998
Maintenance for ten years (USD)	13 519	9 087	35 834	20 456
Total estimated cost (USD)	113 083	76 996	294 787	169 572
Unit	for 1 facility	for 1 facility	for 1 facility	for 1 facility
For all 6 health posts (USD)	**678 498**	**461 976**	**1 768 722**	**1 017 432**

Health centres are the intermediate level of health-care delivery and offer more care services to the population than the smaller health posts, such as treating minor injuries and delivering basic care to pregnant women. The cost range for powering a **single health centre on São Tomé island** is **between USD 76 996 and USD 294 787**, depending on whether the DRE system is installed as a backup or a primary source and for basic loads or regular loads with laboratory services. To equip **all six health centres on São Tomé island** with long-term, cost-effective DRE systems, the cost is **between USD 461 976 and USD 1 768 722**, depending on whether the DRE system is installed as backup or primary source and for basic loads or regular loads with laboratory services. These totals include costs for sustainability of the system for a period of ten years. (There is no health centre on Príncipe island.)

Health posts and health centres make up 37 of the 40 health facilities in the country. Strengthening these facilities would help provide more services at the first point of care, reducing the need to refer to the country's larger hospitals. To equip all health posts and health centres with affordable and reliable energy as a primary source for all medical services, including ten years of operations and maintenance costs, would take an initial investment of **USD 4 099 009**.

3.7 SOLAR ENERGY SYSTEM DESIGN TEMPLATES: HOSPITALS

Hospitals are relatively larger facilities in the health-care system of São Tomé and Príncipe. Two hospitals, one on each island, cater to the population's needs for critical life-saving services. The hospitals, being much bigger in size owing to the variety of health services they offer, have considerably larger energy requirements than the health posts and health centres. Furthermore, the system designs have to be tailored to each hospital, as the services offered at both facilities, along with the energy disruption patterns on the two islands, vary considerably.

Design templates for hospital on São Tomé island

Hospital Dr. Ayres de Menezes is the reference health facility of the country. It is also referred to as HAM (Hospital Area Metropolitana). It is strategically located ten minutes from the airport and ten minutes from downtown São Tomé. This enables the hospital to provide specialised services to the residents of both islands. The hospital on Príncipe island does not have an operating block , so all patients requiring surgery are served by the Hospital Dr. Ayres de Menezes.

The key infrastructure of Hospital Dr. Ayres de Menezes that offers the maximum services were included in the assessment. The energy requirements are shown in Table 3.14. A basic overview of the energy requirement is as stated below, while much details were collected a part of the data gathering exercise.

Table 3.14 **Energy consumption of infrastructure in the hospital on São Tomé island**

	Energy consumption (kWh/day)	
Infrastructure	**Current**	**After replacing with efficient illumination**
Operating block A	248	242
Operating block B	192	181
Operating block C	120	117
Emergency bank	128	124
Incinerator	52	52
Total	**740**	**716**

Based on the identified needs at the hospital, two design options have been proposed for providing DRE to the hospital's five blocks: a primary system for all loads for all hours of operation, and a backup system for the duration of power outages. As explained in the design assumptions, the backup option excludes the autoclave equipment.

The indicative solar designs for Hospital Dr. Ayres de Menezes on São Tomé island is shown in Table 3.15 and Table 3.16.

Table 3.15 **DRE system designs for hospital on São Tomé island**

Block	Design option	Type of system	Total load (kW)	Total energy (kWh/day)	Solar panel (kWp)	Battery (kWh)	Solar inverter (kVA)
A	**Option 1** full loads	Solar primary	54	242	80	560	100
	Option 2 excluding autoclave	Solar backup	18	47	16	72	20
B	**Option 1** full loads	Solar primary	36	181	60	420	75
	Option 2 excluding autoclave	Solar backup	30	91	30	140	40
C	**Option 1** full loads	Solar primary	51	117	40	272	50
	Option 2 excluding autoclave	Solar backup	15	48	16	74	20
Emergency	**Option 1** full loads	Solar primary	51	124	40	286	50
	Option 1 full loads	Solar backup	51	104	35	160	45
Incinerator	**Option 1** full loads	Solar primary	8	52	17	120	20
	Option 1 full loads	Solar backup	8	27	10	42	15

Table 3.16 **Summary of the overall system design for hospital on São Tomé island**

Design option	Total load (kW)	Total energy (kWh/day)	Solar panel (kWp)	Battery (kWh)	Solar inverter (kVA)
Option 1 Solar primary	200	716	237	1657	295
Option 2 Solar backup	122	316	107	488	140

Design templates for hospital on Príncipe island

Located in Santo António, Príncipe island, Hospital Manuel Quaresma Dias da Graça provides advanced services to the population of Príncipe island, as compared to the smaller health posts that exist on the island. However, it offers fewer services than the hospital on São Tomé island and therefore has lower energy requirements. Currently, Hospital Manuel Quaresma Dias da Graça does not have an operating block and or some other key equipment found in the hospital on São Tomé island.

According to key informant interviews with hospital staff, as well as Ministry of Health Department, there is a plan to expand the hospital infrastructure to provide upgraded laboratory services, such as a centrifuge, bio-systems and water filtration. It is expected that the new section of the hospital will have a central air conditioning unit(chiller, cooling tower, pumps, air diffusers), which could add another 20 kilowatts of electric load. As the plan for expansion is still in the initial stages, specific information regarding total loads were unavailable at the time of the assessment. An estimation was made based on information collected from various sources in the field.

Current energy consumption: Data based on observations of energy consumption of the year prior to the point of the assessment indicated an average consumption of 10 980 kWh/month. That average is from before the scheduled power outages that started in June 2022.

Energy consumption after proposed expansion: As the plan for expansion is still in the initial stages, specific information regarding total loads was unavailable at the time of the assessment. An estimation was made based on information collected from various sources in the field.

A basic overview of the energy requirements is as stated in Table 3.17. A detailed list of blocks, rooms and equipment loads per block were collected as a part of the data gathering excercise.

Table 3.17 **Energy consumption of infrastructure in the hospital on Príncipe island**

	Energy consumption (kWh/day)	
Loads	**Current**	**After replacing with efficient illumination**
Existing loads	366	353
Existing loads with new expansion units	466	453

Based on the identified needs at the hospital, two design options have been proposed for providing DRE to the hospital: a primary system for all loads for all hours of operation, and a backup system for the duration of power outages. The two options have been proposed both for hospital both before and after the planned expansion. As explained in the design assumptions, the backup option excludes the autoclave, steriliser and oxygen plant equipment, as they were non-functional at the time of the assessment.

Table 3.18 **DRE system designs for hospital on Príncipe island**

Design option	Type of system	Total load (kW)	Total energy (kWh/day)	Solar panel (kWp)	Battery (kWh)	Solar inverter (kVA)
Option 1 regular loads (existing)	Solar primary	64	353	120	817	150
Option 1 basic loads (existing) excluding autoclave, steriliser and oxygen plant	Solar backup	61	228	75	352	95
Option 2 regular loads (existing + expansion)	Solar primary	142	453	150	1049	190
Option 2 basic loads (existing + expansion) excluding autoclave, steriliser and oxygen plant	Solar backup	100	277	92	427	120

3.8 SOLAR ENERGY SYSTEM COSTS: HOSPITALS

Cost for DRE system solutions for hospital on São Tomé island

Table 3.19 provides the indicative costs for the two system design options for the hospital on São Tomé island presented in Section 3.7, as per the cost assumptions detailed there.

Table 3.19 **Cost of DRE solutions for hospital on São Tomé island (regular load)**

Cost component	Solar as primary	Solar as backup
Supply and installation (USD)	2 508 853	694 843
Remote monitoring for ten years (USD)	22 236	22 236
Transportation cost to São Tomé (USD)	2 998	2 998
Maintenance for ten years (USD)	1 571 170	428 501
Total estimated cost (USD)	**4 105 256**	**1 148 577**

As shown in Table 3.19, the cost for powering the hospital on São Tomé Island with **DRE as a primary source of energy is USD 4 105 256**. The cost for powering the hospital with **DRE as a backup source of energy is USD 1 148 577**. These totals include costs for sustaining the system for a period of ten years.

The cost for transporting the system components is below 1%, as more components are being shipped at one time than for the health centre and health post designs. System maintenance costs form the largest proportion of the cost estimates, after installation, and run for ten years.

As the DRE system sizes are larger than in the design options for powering the smaller health posts and health centres, the maintenance costs are higher as a proportion, at an average of around 40% of the total cost of the system.

Cost for DRE system solutions for hospital on Príncipe island

Table 3.20 provides the indicative costs for the various system design options for the hospital on Príncipe Island presented in the Section 3.7, as per the cost assumptions detailed there.

Table 3.20 **Cost of DRE solutions for hospital on Príncipe island**

	Existing		Existing + expansion	
Cost component	Regular load (solar primary)	Basic load (solar backup)	Regular load (solar primary)	Basic load (solar backup)
Supply and installation (USD)	1 234 616	457 250	1 594 665	591 897
Remote monitoring for ten years (USD)	22 236	22 236	22 236	22 236
Transportation cost to Príncipe (USD)	14 159	13 636	20 786	27 762
Maintenance for ten years (USD)	771 301	285 667	999 835	357 084
Total estimated cost (USD)	**2 042 312**	**778 789**	**2 637 522**	**998 979**

As shown in Table 3.20, the cost for powering the hospital on Príncipe Island with **DRE as a primary source of energy for all existing loads for a period of ten years is USD 2 042 312**.

Costs for DRE systems have also been calculated to reflect the planned hospital expansion, and therefore expansion of services and energy requirements. The cost for powering the hospital with expanded loads with **DRE as a backup source of energy is USD 998 979**. These totals include costs for sustaining the system for a period of ten years.

As mentioned earlier, the maintenance costs for hospitals is estimated to be around 40% of the total cost of the solution, owing to the large size of the required system.

The maintenance costs account for regular maintenance as well as the replacement of spare parts. Thus, it would be recommended to procure and store a pre-decided number of the spare parts most frequently in need of replacement, as well as build local capacity for catering to servicing needs.

3.9 COST SUMMARY FOR POWERING ALL TYPES OF HEALTH FACILITIES WITH DECENTRALISED RENEWABLE ENERGY

The funding requirements of powering the different types of facilities of varying loads options with decentralised solar energy have been highlighted in previous sections. Table 3.21 provides a snapshot of the investment required to power all levels of healthcare facilities in the country.

Table 3.21 **Summary of investment requirement for powering all health facilities with DRE, distributed by type of facility and load type (in USD)**

		Solar as a back-up energy source for basic load	Solar as a primary energy source for regular load
Health Posts	São Tomé island	719 241	2 001 885
	Príncipe island	139 536	328 406
Health Centre	São Tomé island	461 976	1 768 722
Hospital	São Tomé island	1 148 577	4 105 256
	Príncipe island	998 979	2 042 312
Total		**3 468 309**	**10 246 581**

The total cost of powering the complete health infrastructure of São Tomé and Príncipe – two hospitals, six health centres and 31 health posts – with solar as a primary source of energy for regular loads is USD 10 246 581.

The total cost of powering the health infrastructure of São Tomé and Príncipe with solar as a back-up source of energy for basic loads is USD 3 468 309.

04 STRENGTHENING ECOSYSTEM FOR ENERGISING HEALTH CARE IN SÃO TOMÉ AND PRÍNCIPE

Health–energy programmes are aimed at strengthening health-care systems in a country by using energy as a means to improve both access to quality services and reliability of the health-care system. Chapter 3 laid out various needs-based system design options and costs for powering different levels of health facility with renewable energy in São Tomé and Príncipe. Enablers and barriers need to be accounted for to ensure that any programme is achieving its intended outcomes; therefore, custom DRE system design forms a crucial part of any health–energy programme. As per the conceptual framework laid out in Chapter 2, ensuring that health–energy programmes are needs based and resource efficient requires context-specific consideration of components of technology, financing of the technology, ownership of the DRE systems at the facility level, available mechanisms and capacity for maintenance and servicing, and policy and regulatory frameworks.

Thus, as part of the assessment, essential activities for ensuring smooth operations of an health–energy programme in São Tomé and Príncipe – such as the asset management activities of procurement, installation, maintenance and vendor management – are detailed in this chapter. Additionally, budget considerations and allocations, as well as training and capacity-building focus areas and mechanisms, are outlined in the chapter to provide a holistic support framework for the planning and execution of a sustainable health–energy programme.

4.1 PROCUREMENT AND INSTALLATIONS

Once the design templates are finalised and the budget allocation has been established for the programme, installation processes for the DRE systems and efficient medical equipment would have to be initiated. The guidelines for these installations are outlined below.

Accounting for SIDS context: Diverse procurement strategies

São Tomé and Príncipe, being a SIDS, would require an approach that accounts for the unique challenges that arise from being a remote island. DRE systems already have a long-term cost advantage over the use of diesel as a power source, and the procurement and installation processes of DRE systems can be diversified to best suit the country's needs and further contribute to the systems' viability for powering health-care facilities.

Needs-based procurement strategies: Based on existing local capacity in the country, a procurement strategy can be designed separately for the following:

- Supply of DRE system components – In this assessment, the cost for procurement of the DRE components accounted for around 60% of the total cost of the system. According to the interviews undertaken, almost all solar energy system components are imported into São Tomé and Príncipe by maritime freight. Being a one-time activity, a centralised system for procuring the system components could be advantageous and could cater to all health facilities on the island. A cost analysis of this approach would need to be pursued.

- Installation services – Depending on the local capacity to install DRE systems, local procurement could be considered. From primary interviews with health staff and DRE system vendors in the country, it was found that there is capacity on the island for local installation.

- Servicing and maintenance of DRE systems – Maintenance of the panels, batteries and inverters and of the cabling and earthing and provision of other spare parts are regular activities that require human resources with basic knowledge and technical expertise. Maintenance includes a range of activities, such as cleaning dust off panels, maintaining the level of distilled water in the batteries and repairing damaged wires. Given the need for regular maintenance that does not require highly skilled technical expertise, it would be advisable to appropriately train local technical staff to carry out such servicing and maintenance activities.

Technology and product benchmarking

To start, it would be critical to review and benchmark the existing technology for health care in São Tomé and Príncipe. This review should involve the current energy system components, models of electrical and medical equipment, and the health-care needs in the country. Benchmarking should take into consideration the efficiency, quality and pricing of DRE system components and efficient appliances.

Benchmarking DRE system components: DRE system components including the panel, battery and inverter will have to be benchmarked based on factors of quality that include the annual maintenance costs, the warranty conditions, the lifespan of the components, and the price. These can be done keeping a centralised procurement in mind, to account for the lack of in-country manufacturing of the components. Solar panels should be benchmarked for a lifespan of 25 years, as most manufacturers offer warranties for a period of 25 years. Lithium-ion batteries have an average lifespan of ten years, and warranties for the same period must be procured. Inverter suppliers provide warranties for a minimum of one year and should be benchmarked accordingly.

Benchmarking medical technologies and other appliances: Other electrical appliances and medical technologies also need to be benchmarked for quality. However, the quality of appliances will depend on factors such as certifications and testing processes that ensure standardisation of quality. The supply chains for appliances will vary, and benchmarking will have to account for this. Service agreements with local dealers of overseas manufacturers must be made for the basic maintenance of the appliance, as this requires a more technical approach than the basic maintenance of DRE components.

The scaling of DRE: Health programme facilities would require a strong ecosystem of suppliers of solar components and efficient medical equipment. A mapping of the relevant vendors (for energy systems and efficient medical and electrical appliances) should also be conducted. The exercise would provide increased understanding of the supply chain within São Tomé and Príncipe and neighbourhood countries. As São Tomé and Príncipe is a SIDS, specific challenges on types of products available and services availability in-country need to be accounted for. The benchmarking is therefore critical in this scenario.

Vendor identification and tendering

Vendors of solar energy systems and medical equipment can be identified through a tender process. The implementers of the health–energy solutions, whether local energy enterprises, local construction agencies or contractors, are extremely important to the functioning of a system. For any such procurement, certain aspects should be considered, as follows:

Procuring energy-efficient medical equipment

The tender for medical equipment should pertain to the specification of the equipment as per national and WHO guidelines, particularly the energy-efficiency specification. As that the equipment might not be available locally and will be procured from an overseas supplier, it is critical to establish the technical capacities of local personnel to provide servicing and maintenance of the equipment. The specification can further be reviewed by health experts, energy-efficiency experts and any other relevant expert. It is also suggested that an inter-ministerial approach is taken to initiate a programme or schemes with a focus on promoting the setting of standards for energy efficiency in medical equipment. A collaborative approach between the Ministries of Health, Infrastructure (Energy) and Finance is recommended to ensure robust ownership mechanisms. As the overall objective is to strengthen health-care systems, final selection of vendors can use the Ministry of Health tendering and procurement guidelines.

Ensuring effective maintenance and after-sales service

Strengthening processes for maintenance, including replacement of batteries and provision of spare parts, is key to the sustainability of DRE systems. The procurement process should therefore account for the local service network and spare part availability, such as:

- proof of local presence of the vendor (either directly or through associated local technical agencies), showcasing its ability to provide prompt, quality service in the project area;
- availability of local supply chain for spare parts for service and maintenance; and
- past performance of the vendor with respect to providing design, installation and post-installation services, especially on DRE.

4.2 OWNERSHIP, MAINTENANCE AND MONITORING

Ownership and responsibility for the DRE systems and their continued functioning needs to be built into programme design to ensure system sustainability. *Ownership* in this case means that decision-making is clear, financing capacity and costing for O&M are in place, and mechanism exits to account for year-on-year handover between concerned entities, such as maintenance of asset registries.

Establishing ownership through decision-making structure

A clear structure that accounts for decision-making processes for functions of procurement, installation and servicing of DRE systems will be required to spearhead inter-ministerial collaboration for sustainability of the solution. In the case of Sao Tomé e Príncipe, it is the District Health delegation that is in charge of managing electrical devices and health facility maintenance – and works at the behest of the facility staff. For instance, for the change of electrical consumables, the staff makes a request to the Health delegation of the District which then validates, purchases and instals required equipment. The capacity of the concerned personnel can be built by the existing structures within the Ministry of Infrastructure.

Financial allocations and budgeting

Budgeting for DRE system maintenance

It is important to have resources unlocked for the maintenance of the systems either through untied funds present in the district or national governance structures or including it in the installation contract for the enterprises. The following are the options in which the operational and maintenance models could be established:

- **Option A: Operational and maintenance expenditure and responsibility built into tenders to local energy enterprises as part of DRE installation programme**
  This would ensure the availability of service as part of the long-term contract itself. However, it is important to consider that the vendors without local presence may need incentives to undertake O&M responsibilities, especially when installations are few and far apart, as the transaction costs are higher for them to provide these services.

- **Option B: Operational and maintenance expenditures built into health system budgets allocated for use by the local/responsible administration**
  This would bring in local ownership of systems, and thus, timely maintenance activities and appropriate utilisation of health system funds available at local level.

Budgeting for spare parts

Along with ownership models, and institutionalisation of operations and maintenance responsibilities, it is also important to anticipate spare replacement by budgeting costs, in order to ensure the sustainability of systems installed. Following are the ways of budgeting spare replacement.

- **Option A: Budgeting for DRE to be included in the infrastructure costs while setting up or upgrading a health facility**
  It is recommended that the ministry of health makes it a practice to account for DRE costs as capital infrastructure of the health facility, along with efficient appliances. Such an approach would save the ministry expenses in the long run.

- **Option B: Budgeting for maintenance costs**
  In numerous cases around the world, decentralised solar systems have failed because of lack of financial resources to maintain the system and replace the batteries after five years of operations in the case lead-acid batteries (UN Foundation and SEforALL, 2019). Thus, it is critical to plan out the financial outflow for maintenance and replacement during the planning phase by allocating resources from savings or other available funds. For example, a contract between the local regional level authority and local energy enterprises is set up, which lays out conditions of servicing and maintenance contracts.

Monitoring for better understanding and planning

Once the installation is completed, an immediate implementation of a robust monitoring and evaluation process is necessary to constantly follow up on the utility, impact and develop steps towards rectification if necessary. Concurrent monitoring systems need to be in place to monitor the service uptake of Health centres, post installation. This should be done in co-ordination with the National Health Ministry and District authorities. Meetings with all personnel from regional/district authorities should be conducted once the installation of DRE and deployment of medical equipment is done.

Furthermore, community level champions such as local health workers at each centre could be created, to speak on the value addition of the DRE system in improving the services uptake. It is critical to create documentation of case studies from each region focusing on the patients end user to share their experience of accessing services from the improved Health centre. Along with champions at health facility level, creation of champions from the regional community-based organisation or individuals, civil society organisations etc who would speak on the value addition of DRE solutions would help in larger outreach of the programme's impact.

4.3 TRAINING AND CAPACITY-BUILDING

Overall training and capacity-building map

Building the capacity of the health and energy stakeholders is a key requisite for the effective planning (resources), implementation, and utilisation (operation maintenance) of the energy and health infrastructure. These training programmes, which should take place during the systems' implementation phases, are critical for overall sustainability of the systems. Thus, the Ministry of Health is recommended to develop and integrate the following skill- and awareness-building components within the –health–energy programme.

Table 4.1 **Training needs identified across the implementation phases in São Tomé and Príncipe**

Phase of implementation	Key stakeholder	Details
Programme conceptualisation	Health and energy department(s) from national and district levels	**Large scale awareness- and perspective-building exercise with energy and health stakeholders.** Ministry-led effort to gain key buy-in, introducing DRE and its potential to enhance Sustainable Development Goal 3 delivery, addressing energy access challenges in health facilities and highlighting the socio-economic impacts.
Assessments	Health delegation in district and NGOs	Detailed assessment of health-care facilities for system design. Training on importance of site assessment, documentation of site-specific nuances and consideration of energy and health-care service gaps in programme planning.
Procurement	Health and energy department(s) from national and district levels	Training on best practices in procurement, adhering to national/WHO guidelines. Includes tendering, energy-efficiency considerations and criteria for selecting local enterprises capable of procuring, installing and maintaining medical equipment and clean energy systems.
Installation of solutions	Local clean energy enterprises	Training local energy enterprises on standard operating procedures for DRE installations in health facilities. Includes detailed installation aspects, checklist creation, handover documents and establishment of partnerships with health sector stakeholders for service and maintenance contracts.
Post-installation operation and maintenance	Health facility staff, and electricians	Training health centre staff and community members on basic awareness, technicalities, and operation and maintenance of solar energy systems and medical equipment. Objectives include improving use of DRE-powered medical equipment and incorporating basic operation and maintenance practices for solar components.

Way forward to provide effective training and build capacities

To enable the above-mentioned training activities, it is critical to develop training modules and institutionalise the training process within relevant ministries, among health facility staff and in local technical training institutes.

i. Strengthen training departments in the ministries of health and energy ministries

It is important that a training department or a mechanism for training is created to facilitate implementation of the guidelines to ensure quality. This could be housed under the Ministry of Health or Ministry of Energy, depending on the decentralised structure of the ministries, and the chosen training structures and modalities.

ii. Developing training modules

Following are some of the key modules that need to be incorporated along with the implementation programme within the training departments under the health and energy ministries.

Basics of renewable energy and its criticality in the healthcare sector: This training should cover the basics of renewable energy uses, types, components and its working, role of sustainable energy for better health care facilitation and its various impacts on the health care system, on the staff and on the patients. It also covers the basics and selection of energy efficient medical equipment and its impacts on energy requirements for powering it as well as the broader aspects of savings from a solar powered health care facility and how it can be budgeted (Capex and Opex) for a new or existing health care facility.

Role of decentralised renewable energy in various health care models: This training should cover various types of healthcare models where energy can play a role. For example solar powering various health facilities such as hospitals, health clinics, health posts etc, solar powering various mobility-based health care - mobile clinic, health boat, portable health kits *etc.*, addressing various types of health needs such as Geriatric care, speciality care - dental, ophthalmic *etc.*, diagnosis, preventive care *etc.* This session covers examples of various interventions globally.

Health - Energy nexus programme implementation guidelines: This training module should cover the guidelines for implementation of Health energy nexus programmes. It covers the approach, tools at various stages, stakeholder mapping and their roles, procurement guidelines, standards and certifications, implementation SOPs and best practices, service and maintenance, monitoring and evaluation, capturing learning and sharing knowledge *etc.*

Operation and maintenance of renewable energy systems: This training should cover the operations, maintenance and troubleshooting (weekly, monthly, yearly) of the solar system. It covers the Do's and Don'ts and safety measures to be taken while using the system.

Usage of new technologies and medical equipment: This training should provide hands-on training to health care professionals on existing and new medical equipment to carry out various medical procedures. The practice sessions will enable them to use the equipment with ease in time of need.

Healthcare practices: This training should cover the regular theory and practical training of healthcare practices for various services to be offered by the staff. It should cover emergency care, mother and child care, specialist cares *etc.* As part of this training, the health care staff should be taught the basics of operating and maintaining different medical equipment.

RECOMMENDATIONS AND WAY FORWARD

5.1 SOLAR ENERGY SYSTEM DESIGN RECOMMENDATION

Modular designs for health facility levels

It is recommended that detailed modular designs are developed for each type of health facility. Also , to help authorities in implementing integrated packages of health services, human resources, appliances and solar energy, include in the guidelines the essential medical equipment as allocated for the services and human resources, as well as their specifications.

Customisation of solar energy system for improved optimisation

While a standardised modular system design has been detailed in Chapter 3 of this report, local factors could be considered to make it more robust and reliable. Assessing these factors would require in-depth training for the technical and assessment staff. Some of these factors are:

Operational hours of specific services and disease burden

Loads and their criticality are identified based on the health services to be offered. The total energy consumption, based on patients or population served – relating to 'ON' time of health appliances.

Critical and non-critical loads

Designs can be locally customised to cater to:

- Critical medical loads: loads that can have severe medical implications if not available at critical times (*e.g.* baby warmer, phototherapy, operation theatre light) and loads that need reliable energy to function continuously with no interruption, such as ice-lined refrigerators and deep freezers for vaccine storage, which need to maintain a specific temperature at all times or can result in vaccine spoilage.

- Basic loads: loads that include lights, televisions, printers, and so forth can be prioritised according to the needs of the specific health facility.

Terrain, geography and transportation infrastructure

Based on the terrain and road accessibility for the health facility, solar energy systems can be designed with a higher capacity battery, allowing for higher autonomy. This autonomy is also needed in areas with multiple rainy or cloudy days and limited sunshine hours.

Multiple systems at the local level

It is recommended that not all loads at a particular health facility are connected to one battery load. Splitting the battery bank into multiple systems will help increase the reliability of the overall system. Even if one part fails, the other parts would be functioning. Such designs are critical for remote areas, where it might take time for technical staff to reach the facility for repair.

In health facilities where there is an existing solar energy system, efforts should be made to integrate the current system with the new system, as per the system specifications mentioned in this document.

Criticality of energy-efficient appliances

Energy costs at a given health facility are often high because of the power consumption of most of the appliances, both critical and non-critical. The inefficiency of the appliances (such as old fluorescent lamps and fans) has not only driven the use of diesel up but also led to higher solar power needs than actually are required. Thus, it is strongly recommended that inefficient appliances be replaced with efficient ones, thus reducing the costs of solar energy systems. A study done by SELCO Foundation in 2018 showcases efficient improvements up to 40% to 60% resulting in savings.

Table 5.1 **Load critical equipment to be considered for energy efficiency**

Category	Equipment	Typical power consumption rates (W)	Expected power consumption in solar PV system (W)
Labour room	Radiant warmer	800	750
	Suction apparatus	200	180
	Spotlight		20
	Phototherapy	20	20
Laboratory	Centrifuge		230
	Microscope	30–100	60
	Semi auto analyser		100
Cold chain room	Ice-lined refrigerator	175	120
	Deep freezer		120
	Refrigerator	100–400	142

Recommendations for energy optimisation

Designing for the climate is extremely important for ensuring energy optimisation because approximately 40% of a building's energy consumption occurs due to active solutions for thermal comfort.

Air movement through cross ventilation: Window placement to improve spread of incoming air in the space (Figure 12).

Air movement through stack effect: Provision of openings at a higher level to promote hot air rising and being replaced by cool air (Figure 13).

Humidification: Wind towers or wind scoops with provision of water can improve the humidity of the space and make it more comfortable (Figure 14).

Daylighting and shading guidelines: Longer face of the building to face the north-south direction as the walls are easier to shade than east and west walls. Horizontal and vertical shading devices to be provided based on the orientation and size of the window.

Interior surfaces to be finished with light colours to improve light reflection within the space. Provision of light shelves and skylights to improve daylighting. Adding internal shading devices like curtains and blinds can further the control over heat and light entering the room.

Solar energy designs templates for medical staff housing

Table 5.2 **DRE design template for staff housing for health centres in São Tomé and Príncipe**

Rooms assumptions	· 1 common/resting room · 2–3 bedrooms · 1 bathroom · 1 storage room · 1 outside walk
Loads assumptions	· In the common/resting room: 1 light + 1 fan + 1 phone charging + 1 fridge · In each bedroom: 1 light + 1 fan + 1 phone charging plug-in · Outside: 2 lights
Energy requirements	**524 W, 3.7 kWh, 48 V**

5.2 TRAINING, CAPACITY-BUILDING AND AWARENESS

Installation and maintenance of the technologies related to DRE requires training in specialised skills. Such training also provides a potential employment opportunity in a burgeoning sector. Other important aspects of training are related to what entity is responsible for and deploys training, the financial allocation for the training, and choosing the resource person either among the health staff at the facility level or hired from outside. The focus needs to be largely on localisation of skills, as this would help encourage the growth and sustainability of the renewable energy sector in the country and enable for prompt and effective response to requests for service.

Step-by-step training modules for building relevant in-country capacity for health–energy programme deployments can be found in Annexure 3.

5.3 DEVELOP HEALTH–ENERGY INTER-MINISTERIAL PLAN

Delivery of health-care services across the country is inherently linked to the availability, reliability and quality of energy access. It would be detrimental to view the energy needs without considering health-care sector plans for establishing new facilities, upgrading existing ones, increasing services provided, and expanding and training human resources.

Given this, it is crucial that government departments, private sector stakeholders and NGOs across the health and energy sectors come together to co-ordinate long-term sustainable planning on health-care electrification through renewables. Within the larger goal of integrated planning, ministries would need to include certain aspects within each of their mandates. The recommendations shared below outline which aspects could be taken on by health ministries and departments and which ones could be led by energy sector government agencies.

Including DRE in health sector planning

Aligned with the Government of São Tomé and Príncipe's strategy to increase the share of renewables in the energy mix, personnel from both health and energy authorities should be aware of the intent to work towards this goal. Capacity-building and training programmes planned by the health department for health staffand government health officials need to take note of energy needs. Energy-related training can be planned in conjunction with existing skill- and capacity-building to include use of appliances and basic maintenance.

Better awareness would lead the budget planning and allocations of the Ministry of Health and related departments to include the costs of DRE systems and efficient appliances. It would also be important for this planning to include the costs of battery replacement over a five to eight year period for each of the facilities. Similarly, planning (budgets, human resources, technologies, *etc.*) for future expansion or upgradation of health services needs to include energy systems and appliances.

Strengthening DRE service networks in the country

It is essential to develop processes that encourage the adoption of DRE solutions for use in health-care facilities. Such processes could include a registry of energy enterprises that can conduct assessments, provide quality installation and have the capacity to service DRE systems. The registered list of enterprises can be used to develop after-sales networks by encouraging training of local technicians for repair and maintenance and building stronger supply chains for spare parts. This activity must be liaised with health departments to create a plan for servicing and maintenance in health facilities currently powered by solar and grid-based electricity. Furthermore, it is advised to include frameworks for annual maintenance contracts that can ensure after-sales support for solar-powered energy systems.

Strengthening quality product supply in the country

To ensure the use of quality products, it is essential to benchmark the energy-efficient technologies and solar components available in the country, as well as develop certification to recommend the use of the best technologies and products. Additionally, considering the specific market availability in São Tomé and Príncipe as a SIDS, policies should be developed to encourage the import of quality solar products and energy-efficient medical equipment. The tax regimes for components such as batteries and inverters and for medical and electrical appliances can thus be developed in a manner that incentivises greater efficiency and modernisation.

In addition to tax concessions and exemptions, the Government can engage with bilateral and multilateral agencies to create conditions conducive to supporting local entrepreneurship and manufacturing capabilities through incubation and business development services; low-cost credit lines, taking note of inflation and regional financial fluctuations; technology innovation links; human resource development; and other relevant factors (Moner-Girona *et al.*, 2021).

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ANNEXES

ANNEX 1 SURVEY FOR COSTS ESTIMATES OF THE PROPOSED SOLAR SYSTEMS IN SÃO TOMÉ AND PRÍNCIPE

SELCO proposed 10 solar systems ranging from 1.4 kWp to 26 kWp, with battery capacities ranging from 5.76 kWh to 102 kWh.

Thirteen local companies were contacted to provide cost estimates for the proposed solar systems. **Six of those companies sent detailed cost estimates**.

Table A1.1 **Comparison between the costs estimated by the companies**

Size of the system		Company 1: CISAN		Company 2: HET		Company 3: Electrofrio	
Installed capacity (kWp)	Storage capacity of the batteries (kWh)	Total cost (USD)	Cost per installed kWp (USD/kWp)	Total cost (USD)	Cost per installed kWp (USD/kWp)	Total cost (USD)	Cost per installed kWp (USD/kWp)
6.0	26.88	86 548	14 425	99 510	16 585	54 683	9 114
3.0	14.4	59 723	19 908	53 607	17 869	28 401	9 467
5.0	19.2	81 553	16 311	84 209	16 842	38 667	7 734
2.5	9.6	44 963	17 985	45 957	18 383	28 124	11 250
2.25	9.6	40 851	18 156	42 131	18 725	28 124	12 500
1.4	5.76	30 596	21 855	29 125	20 804	21 748	15 534
26.0	102.0	399 834	15 378	405 530	15 597	153 524	5 905
14.0	54.0	241 902	17 279	221 918	15 851	87 781	6 270
10.0	36.0	128 550	12 855	160 714	16 071	68 039	6 804
6.0	26.88	86 548	14 425	99 510	16 585	54 148	9 025
TOTAL		1 201 068		1 242 211		563 239	

Size of the system		Company 4: SES		Company 5: Pleno Ambiente		Company 6: Climac-tronica	
Installed capacity (kWp)	Storage capacity of the batteries (kWh)	Total cost (USD)	Cost per installed kWp (USD/kWp)	Total cost (USD)	Cost per installed kWp (USD/kWp)	Total cost (USD)	Cost per installed kWp (USD/kWp)
6.0	26.88	56 389	9 398	49 013	9 793	29 964	9 114
3.0	14.4	30 067	10 022	29 378	8 169	20 642	9 467
5.0	19.2	37 789	7 558	40 844	9 793	31 112	7 734
2.5	9.6	22 060	8 824	24 481	8 169	16 555	11 250
2.25	9.6	22 167	9 852	22 033	8 169	15 974	12 500
1.4	5.76	17 405	12 432	13 710	8 169	12 787	15 534
26.0	102.0	168 356	6 475	212 388	9 793	143 446	5 905
14.0	54.0	91 828	6 559	125 799	8 986	77 419	6 270
10.0	36.0	61 381	6 138	81 688	9 793	59 165	6 804
6.0	26.88	56 389	9 398	49 013	9 793	28 233	9 025
TOTAL		563 831		648 344		435 298	

System Cost Assumption:

- Cost estimates for smaller systems (up to 5 kWp) are higher than for larger ones (≥5 kWp).
- Average cost is 12 166 USD/kWp for a total installed power of up to 5 kWp.
- Average cost is 9 204 USD/kWp for a total installed power from 5 kWp to 26 kWp.
- The lowest cost budget is 7 373 USD/kWp for systems up to 5 kWp.
- The lowest cost budget is 5 457 USD/kWp for systems from 5 kWp to 26 kWp.
- Systems in Príncipe Island have an extra cost of 160 USD/kWp (on average) due to the transportation of material from São Tomé and the lodging of technicians in that island.
- Companies estimated higher costs for systems on the ground than for those installed on rooftops. On average, for each installed kWp, a ground system would cost 210 USD more than a rooftop one.
- Companies estimated that maintenance costs for 10 years represent between 2% to 30% of the total cost (average value = 14%).

ANNEX 2 EFFICIENT BUILT ENVIRONMENT GUIDELINES STRENGTHENING INFRASTRUCTURE AND IMPROVING BUILT ENVIRONMENT

Strengthening Infrastructure and Improving Built Environment

The need for energy-optimised built environments in healthcare

An indoor environment that experiences high temperature and humidity fluctuations and has poor ventilation systems can have negative effects on the health of the users. These kinds of spaces have to be avoided in hospitals or health care centres so as to promote better comfort for health workers and a faster recovery rate in patients.

Energy-optimised buildings are designed to utilise the energy supplied to them in the most optimised and economic way by taking steps to reduce energy loss. They are also used to be less expensive to operate during the life cycle of a building, to be more comfortable to reside in, as well as to be more environmentally friendly.

Case 1: A study conducted by SELCO Foundation showed that by providing energy optimised spaces for recovery in rural areas, health of the residents of the nearby villages has improved significantly. The cost for operationalising the health centre in terms of providing services of electricity and cooling are also reduced. This is clearly seen in the cases of the health centres in Keba, Arunachal Pradesh and YK Mole, Karnataka in India. The details of these cases are mentioned later in the document.

Case 2: A study conducted in four wards of a general hospital in Nigeria to test the relation between indoor environment quality and patient recovery showed that a good indoor environment in terms of thermal comfort, air quality, lighting and acoustics have a positive influence on the patients. This, in turn, improved the recovery rates as well.

Energy optimised built environments can be achieved by means of passive (without energy consumption) and active interventions. Inclusion of passive interventions can improve the indoor environment of the building hence reducing the amount of energy required to create a comfortable space. Active strategies are used to supply comfort conditions when passive strategies aren't sufficient. These majorly include lighting equipment such as bulbs and tube lights and cooling equipment such as fans and air-conditioners. In energy-optimised buildings, the amount of active equipment can be reduced, and low energy solutions can be used to reduce the building energy demand. Energy-optimised buildings balance these active and passive systems to provide an ample amount of comfort with lesser energy consumption.

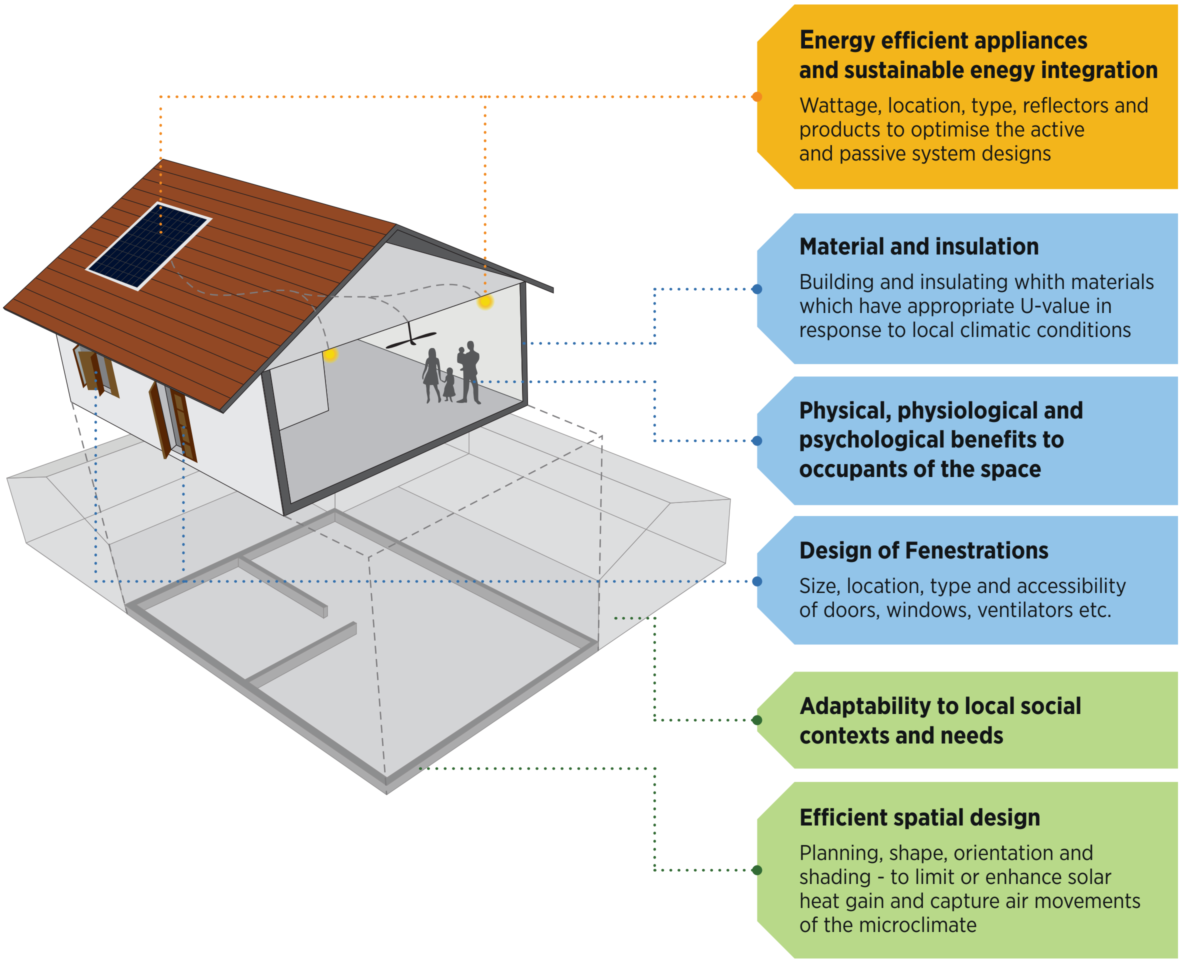
Passive interventions include:

Optimised spatial design to limit or enhance solar heat gain and capture air movements;

Design of fenestration to increase daylighting and natural ventilation in the space;

Material and insulation: building and insulating with materials which have appropriate U-value in response to local climatic conditions to ensure comfort in extreme heat and cold conditions.

Figure 5.1 **Efficient built environment design instructions**



Source: SELCO Foundation (2022).

Solutions

Optimisation benchmarks for various rooms

Indoor temperature, relative humidity and lux levels can differ based on the function of a space. Based on this, the design of the form of the building, the layout, window placement, circulation as well as various active technology integration can be defined. The following table lists down the different functions in a health centre and their indoor environment requirements.

Table A2.1 **Optimisation benchmarks for various rooms of health facilities**

Function		Dry bulb temperature (°C)	Relative humidity (%)	Minimum illumination (lux)
A	**Health centre**			
1.	Entrance, waiting areas, corridors, *etc.*	24 to 26 °C	45 to 55%	150
2.	Consultation and examination room	24 to 26 °C	45 to 55%	200
3.	Labour and delivery room	17 to 27 °C	45 to 55%	PHCs - 300 to 500 CHCs- 500
4.	Recovery/wards	24 to 26 °C	45 to 55%	150
5.	Operation theatres	17 to 27 °C	45 to 55%	500
6.	Auditorium	Summer - 23 to 26 °C Winter - 23 to 24 °C	Summer - 50 to 60 % Winter - 40% min.	250
7.	Washroom/passage	24 to 26 °C	45 to 55%	100
8.	Pharmacy/storage	17 to 27 °C	45 to 55%	100
B	**Accommodation**			
1.	Kitchen	24 to 26 °C	45 to 55%	200-300
2.	Living room	24 to 26 °C	45 to 55%	150-200
3.	Bedroom	24 to 26 °C	45 to 55%	100-150
4.	Bathroom	24 to 26 °C	45 to 55%	70-100

ANNEX 3 IDENTIFIED TRAINING NEEDS ACROSS IMPLEMENTATION PHASES IN SÃO TOMÉ AND PRÍNCIPE

Table A3.1 **São Tomé and Príncipe: Training needs**

Phase of implementation	Key stakeholder	Details
Programme conceptualisation	Health and energy department from national and district level	**Larger level awareness and perspective building exercise with district level energy and health stakeholders.** This is to be done by the ministry in order to have key buy-in from the nodal entities at district levels. This could include the introduction of DRE and its potential to improve the delivery of SDG3, how solar integration into public health facilities resolve critical problems associated with energy access challenges and health service delivery without compromising on climate change agenda; socioeconomic impact that the DRE integration would bring in terms of savings in electricity or fossil fuel cost for the local governments, economic impact due to improved health of communities, *etc.*
Assessments	Health delegation in district, and NGOs	One of the key components that has to be implemented in the initial stage of the DRE - Health programme is the detailed assessment of the healthcare facilities to develop system design and implementation pathways. The training components include basic understanding of importance of site assessment, step by step details of how to document the site specific nuances, and the key considerations in terms of not only the energy aspect, but also the gaps in healthcare services that could be addressed through the programme.
Procurement	Health and energy department from national and district level	Procurement of both medical equipment and services of clean energy enterprises in installing the systems are critical in the programme. The training programme to the programme implementing entity to include the best practices such as tendering (with adhering to national/ WHO guidelines for medical equipment), energy efficiency aspect during the procurement of technologies, selection of local enterprises on certain key criteria of ability to procure, install and provide the maintenance and service.
Installation of solutions	Local clean energy enterprises and EMAE	It's critical to train the local energy enterprises (installers of the solar systems for the health facilities) on **the Standard Operating Procedure for the installations of DRE in health facilities.** The two main components of the trainings include: On the detailed aspects of installation, key activities such as checklist and handover documents, providing initial training to the healthcare staff on the operation/ service/ maintenance aspects of solar to the **technicians, operation personnel of local enterprises.** On the general attitude towards the health sector, establishing partnerships with health sector stakeholders to develop contracts on service & maintenance, constant monitoring of the systems, for the **leads of local energy enterprises.**
Post-installation operation and maintenance	Health facilities staff, and electricians from O&M district cells	After the system installation, the health centre staff and community members must be trained on the **basic awareness, technicalities, operations & maintenance of the solar and medical equipment.** These training programmes with the community level and health facility level staff would have 2 main objectives: Improving the utilisation of new medical equipment powered by DRE by the facility level staff to provide better services to communities. Incorporating basic operations and maintenance practice for solar components among the health facility level personnel.

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