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Integrated Energy Access Planning

MEDICAL & AGRICULTURAL COLD CHAINS

JUNE 2024

IN PARTNERSHIP WITH:

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Other reports in this series

Madagascar – Clean Cooking Summary Report

This summary report provides an overview of clean cooking deployment pathways to 2030. By utilizing scenario-based approach, the report identifies potential mixes of modern and cleaner cooking technologies and fuels to achieve SDG7.1 targets by 2030 and the realization of Madagascar's SDG7 Energy Compact.

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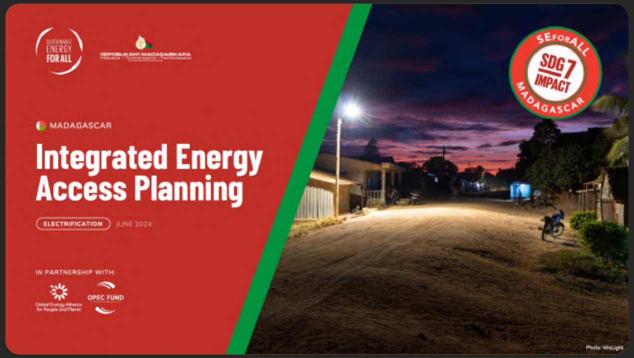

Madagascar – Electrification Summary Report

This summary report covers the least-cost electrification pathways for Madagascar to reach universal electrification. It provides actionable spatial intelligence on technological options and energy end-uses that can contribute to decision-making for the public sector, donors, and private and civil society organisations.

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ℹ The full-length technical reports for all components of the Madagascar IEP are available for download here

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CHAPTER ONE

Medical cold chains

Acronyms – Medical cold chains

ADER	Rural Electrification Agency / Agence de Développement de l'Electrification Rurale
BCG	Bacille Calmette-Guerin
CCE	Cold Chain Equipment
CHD	District hospital / Centre Hospitalier de District)
CHRD	Referral hospital at District Level / Centre Hospitalier de Référence District
CHRR	Referral hospital at the regional level / Centre Hospitalier de Référence de Région
CHU	University hospital / Centre Hospitalier Universitaire
CRNM	Medical and nutritional rehabilitation centre (Centre de Réadaptation Nutritionnelle et Médicale)
CSB1/ CSB2	Primary healthcare centre, levels 1 and 2 / Centre de Santé de Base –
DISP-MAT	Dispensary-Maternity /dispensaire-maternité
DPEV	Directorate of the Expanded Immunization Program / Direction du Programme Élargi de la Vaccination
DPT	Combined vaccine for Diphtheria-Pertussis-Tetanus
DRSP	Regional public health directorate / Direction Régionale de la Santé Publique
EPI	Expanded Programme on Immunization

GAVI	Global Vaccine Alliance
GoM	Government of Madagascar
GIS	Geographic Information System
IEP	Integrated Energy Access Plan
kWh/kWp	Kilo-Watt-hour and kilo-Watt-peak
LEAD	Least-Cost Electricity Access Development Project (World Bank)
LV	Low voltage
MSanP	Ministry of Public Health / Ministère de la Santé Publique
MV	Medium voltage
PCM	Phase Change Material
PQS	Performance, quality and safety
PV	Photovoltaic
SDD	Solar Direct Drive
SDSP	District- level Health Directorate / Service de district de la Santé Publique
SEforALL	Sustainable Energy for All

SSS	Standalone Solar PV System
UCC	Ultra cold chain
UN	United Nations
UNCEF	United Nations International Children's Emergency Fund
USAID	United States Agency for International Development
WHO	World Health Organization
WUENIC	WHO/UNICEF Estimates of National Immunization Coverage

Medical cold chain challenge in Madagascar

Medical cold chains are important to ensuring the availability of vaccines at health facilities and accessibility for all people, mainly children, who are eligible for vaccines.

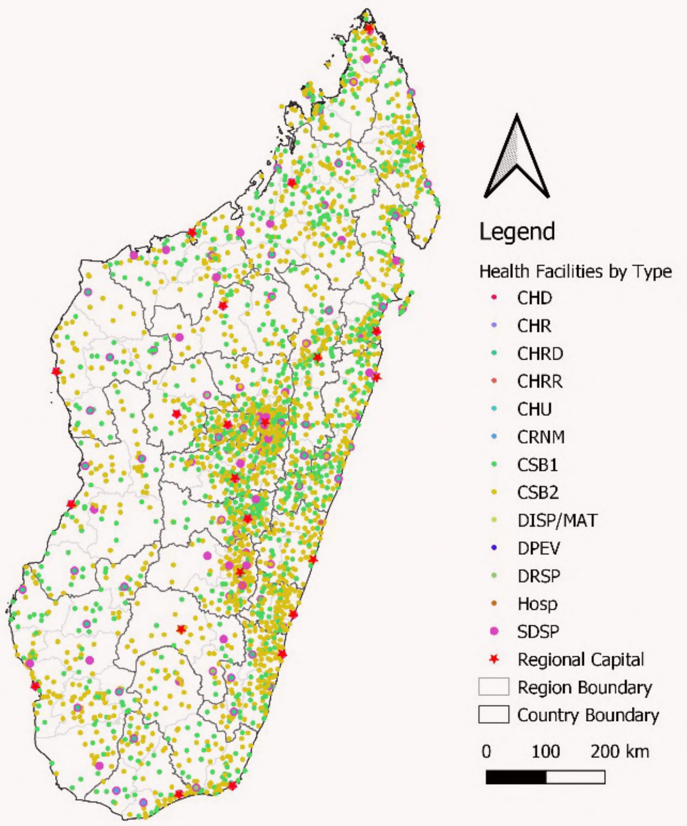
The coverage rate for routine vaccines has declined in the past several years due to COVID-19 disruptions in vaccine supply chains and healthcare access. Based on recent administrative data, the estimated coverage rate for all vaccines varies between 51% for BCG and 70% for the first dose of DPT. Regionally, low coverage numbers are more pronounced in more rural and harder-to-reach areas.

To address these challenges, the Ministry of Public Health (MSanP) immunization programme has prioritized the vaccination of “zero-dose” children, defined as those who have not received the first dose of the DPT vaccine.

Lack of access to electricity, as well as low accessibility of many sites, creates substantial challenges for ensuring the effective operation of medical cold chains in Madagascar.

In 2023, over 2,400 healthcare facilities lacked any access to electricity (out of 3,053 facilities in total). Of the facilities that had access, 35% had electricity less than 16 hours per day and many facilities faced issues of service reliability that impacted their operations.

Map 1: Healthcare Facilities in Madagascar by Level



Overview of vaccine supply chain levels and distribution practices in Madagascar

Table 1: Supply chain segments for vaccine distribution in Madagascar

SUPPLY CHAIN LEVEL	DISTRIBUTION METHOD: ROUTINE VACCINES AND COVID-19 VACCINES
National level	Vaccine storage, decisions on quantities to be distributed 5 trucks, 2 of which are refrigerated (note: only one truck was operating in September 2023) to distribute vaccines quarterly at district level. UNICEF provides additional transport if required. Vaccines are stored in refrigerated boxes during distribution if a refrigerated truck is not available.
Regional level	For administration only; not for storing vaccines.
District level	Receives quarterly vaccinations from the national level.
Healthcare-facility level	Monthly collection of vaccines at district level using various means of transport (government motorcycles, public transport, boats, zebu carts or walking).
Municipality	Health facility staff use bicycles or motorcycles with a small cooler for a day's service 5–10 km from the facility.

Note: The COVID-19 vaccine is integrated into the routine vaccine supply chain and cold chain, using the same cold chain equipment and means of transport. The country has 6 cold chain facilities specifically for the Pfizer vaccine, located at national and district levels.

CURRENT PROJECTS:

- LEAD Electrification: World Bank project to improve access to electricity services for households, businesses and health facilities in Madagascar. By August 2023, 47 health facilities had been electrified, and a further 453 will be electrified by 2024.
- Installation of a national cold room for vaccine storage, with support from Gavi.
- 107 new CCEs are currently in the country and awaiting installation (purchased by UNICEF, Gavi and the World Bank). They should be completed by mid-2024.
- The country is purchasing 373 CCEs through Gavi, which are due to arrive and be installed in 2024.

Methodology: Key data points and sources for analysis

Thanks to close collaboration with MSanP, DPEV, UNICEF, the World Bank and ADER, the study team was able to obtain multiple health-care facility and cold chain equipment (CCE) data sources, cross-check them, validate hypo-theses and clean and combine the datasets.

This process made it possible to establish a central « Master List » database of healthcare facilities by combining several sets of data.

The database contains all existing 3,100 healthcare facilities in Madagascar, along with information about their location, facilities, services provided and detailed inventory of each facility's medical equipment, including CCE. This database was shared back to MSanP to support its monitoring and planning processes.

Table 2: Principal datasets and sources used in the medical cold chain analysis

DATA	SOURCE	GRANULARITY	DATE UPDATED OR RECEIVED
Names and types of healthcare facilities	MSanP	Facility level (regional, district, facility)	MSanP/DPEV (updated November 2022) MSP/DSSB (updated June 2023)
GIS coordinates of the healthcare facility	ADER, LEAD	Facility level (regional, district, facility)	ADER (received April 2023) LEAD (received in July 2023)
Energy availability in healthcare facilities	MSanP, DPEV	Facility level (regional, district, facility)	MSanP/DPEV (updated November 2022)
Population/watershed data	MSanP.,Planning Department	Facility level (regional, district, facility)	MSanP/DPEV (updated November 2022)
Cold chain equipment, functional status, characteristics	DPEV inventory (updated November 2022), WHO PQS catalog	Facility level (regional, district, facility)	MSanP/DPEV (updated November 2022)
Vaccine article dimensions	MSanP, WHO prequalified list, warehouse measurement (Rotavirus)	By vaccine type, by SKU (Rotavirus)	MSanP/DPEV (updated November 2022) WHO (accessed July 2023) DPEV warehouse (measure taken in July 2023)
Routine vaccination schedule	DPEV	National level	MSanP/DPEV (updated November 2022)
COVID-19 vaccine deployment update	DPEV	District	MSanP/DPEV (updated July 2023)
Supply chain and distribution policy	DPEV	Facility level (regional, district, facility)	MSanP (discussions, 2023)
Fokontany coordinates and GIS features	ADER	Fokontany level	ADER (received April 2023)
List of facilities receiving LEAD support and those planning to do so	LEAD	Installation level	LEAD (received in July 2023)

Methodology: Cold chain analysis for vaccines and medical products

STEP 1: DATA COLLECTION

- Secondary data (PEV, MSanP, UNICEF, ADER, GAVI)
- Interviews (PEV, MSanP, UNICEF, LEAD)
- Study reports (PEV, Partners)

STEP 2: DATA CLEANING

- Clean data to ensure consistency consistent with data sources (CSB name, geographic code, identification number)
- Validated by the MSanP, PEV

STEP 3: SCENARIO BUILDING

- Build a baseline, validated with PEV
- Evaluate scenario options for growth in cold chain capacity requirements for 2030

STEP 4: GEOSPATIAL ANALYSIS*

- Vaccine cold chain capacity utilization

*relative to availability

STEP 5: RESULTS & VISUALIZATIONS

- Shortcomings in the current supply chain
- State of facilities and their electrification
- Electrification modality, type and location

STEP 6: RECOMMENDATIONS

- Investment needs in cold chain, transportation policy changes
- Supply chain best practices that require attention and investment

Assessment of cold chain equipment

The national cold chain inventory, completed in November 2022, lists 2,894 items of cold chain equipment (CCE) in good working order, plus 364 items in working order but in need of repair, spread across the different levels of the system.

The national cold chain inventory identifies some 39 different manufacturers for CCE appliances, the vast majority being made by B-Medical Systems / Dometic.

The average lifespan of a piece of CCE is estimated at around 10 years if properly maintained. Around 60% of functional performance, quality and safety (PQS)-compliant CCE is less than four years old, which means that the cold chain system is relatively young and promises to operate for another five to seven years with basic maintenance.

Around 12% of deployed CCE is between 15 and 20 years old, and less than 1% is over 20 years old; The MSanP should plan to replace these systems as soon as funds become available.

Table 3: Summary of cold chain equipment age and PQS status.

YEAR OF INSTALLATION	NON-PQS	PQS	TOTAL	% OF TOTAL
1980-1999	1	14	15	1%
2000-2009	14	385	399	14%
2010-2014	6	210	216	7%
2015-2019	30	1049	1079	37%
2020-2022	15	1168	1183	41%
Unknown	0	2	2	0%
Total	**66**	**2828**	**2894**	**100%**

Figure 1: Cold chain equipment operational status

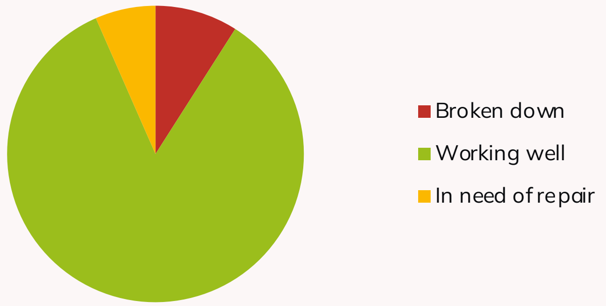
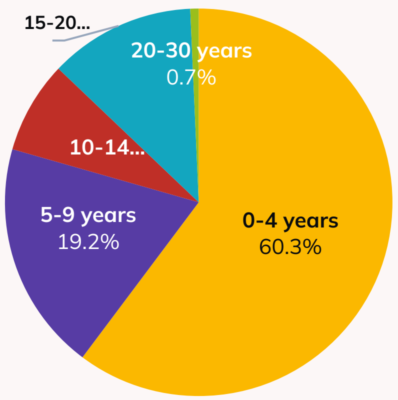


Figure 2: Age of functional PQS cold chain equipment

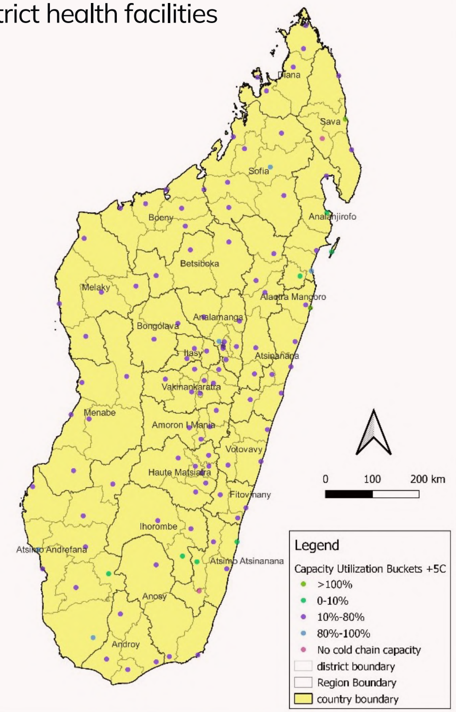


Assessment of vaccine storage capacity utilization

At facility level, the cold chain equipment available and in use is relatively young, works well, and, in the majority of facilities (71%), is underutilized at less than 10% of physical capacity.

However, 500 of the 2,506 structures (20%) at primary health care centres for which information on cold chain capacity is available, are listed as having no capacity, either because they have no refrigerator at all, or because the refrigerator they do have is not in working order.

Map 2: CCE capacity utilization +5C for district health facilities



Map 3: CCE capacity utilization -20C for district health facilities

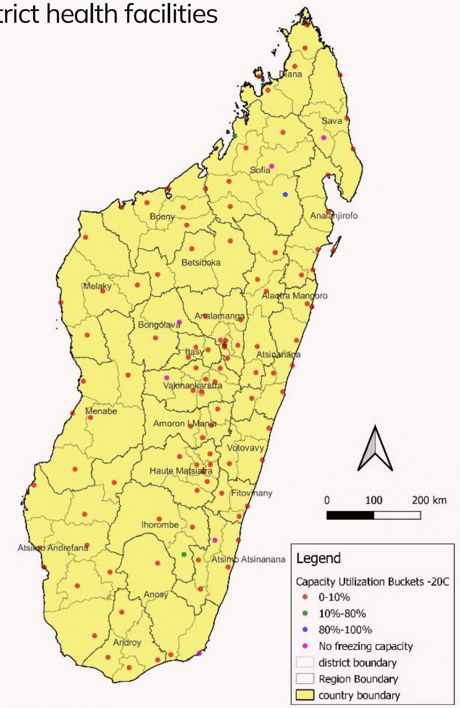
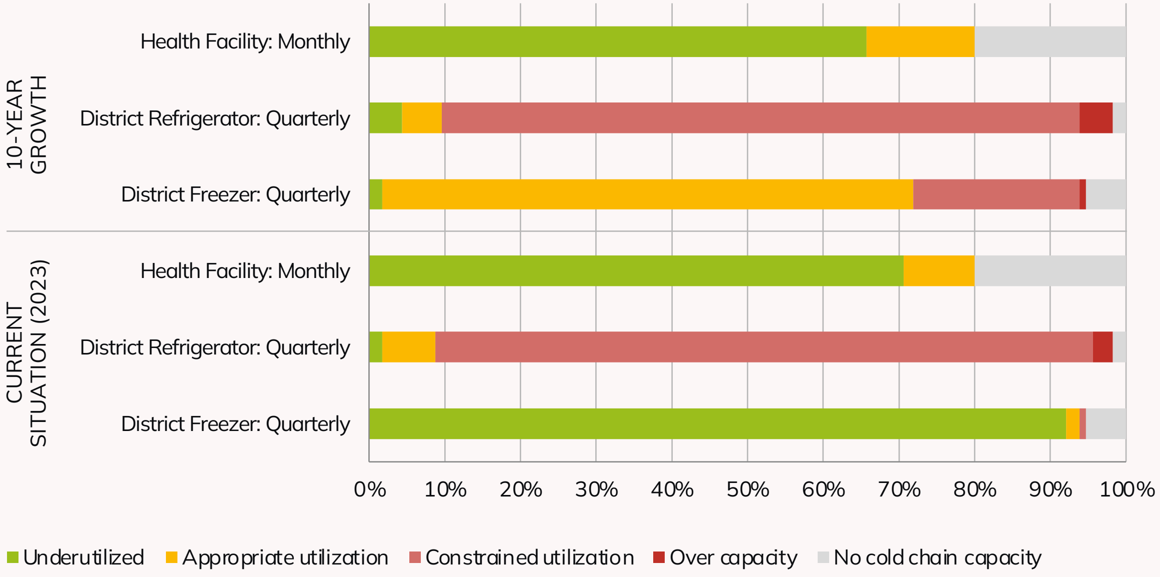


Figure 3: Cold chain equipment capacity utilization at district stores and distributing health facilities



Medical cold storage equipment options

The Madagascar IEP provides an estimate of medical cold chain equipment needed in the coming years, based on data on equipment age and operational status, as well as on projections for population growth and vaccine distribution. It is important to note, however, that these numbers and types of equipment are illustrative only and would need to be validated based on the reality of the equipment performance, true capacity needs and new cold chain technology that may become available in the coming years.

Currently, Madagascar's vaccine cold chain makes significant use of solar direct-drive (SDD) refrigerators and freezers. These units allow healthcare facilities without access to electricity, or those with limited or unreliable access, to ensure appropriate storage for vaccines and other medical necessities like blood.

While SDD cold storage is a critical resource in areas where access to energy is a challenge, conventional compression refrigerators have several advantages over SDD units. First, thermostatic control precision is generally higher. Another advantage is that the overall energy efficiency is greater, mainly because the cooling system operates at a lower temperature differential to ambient than is required to freeze phase change material (PCM). Finally initial investment is lower where reliable AC power is already available.

As access to electricity in Madagascar expands and becomes more reliable, less SDD equipment will likely be necessary. Additionally, investing in a strong maintenance system now would contribute to extending the lifespan of a piece of equipment. Finally, technological evolutions may also permit different procurement choices for facilities with intermittent or no access to grid electricity.

Figure 4: Cold chain equipment typically used in a health facility (Source JSI 2022)

Estimated cold chain equipment requirements to meet current and future needs

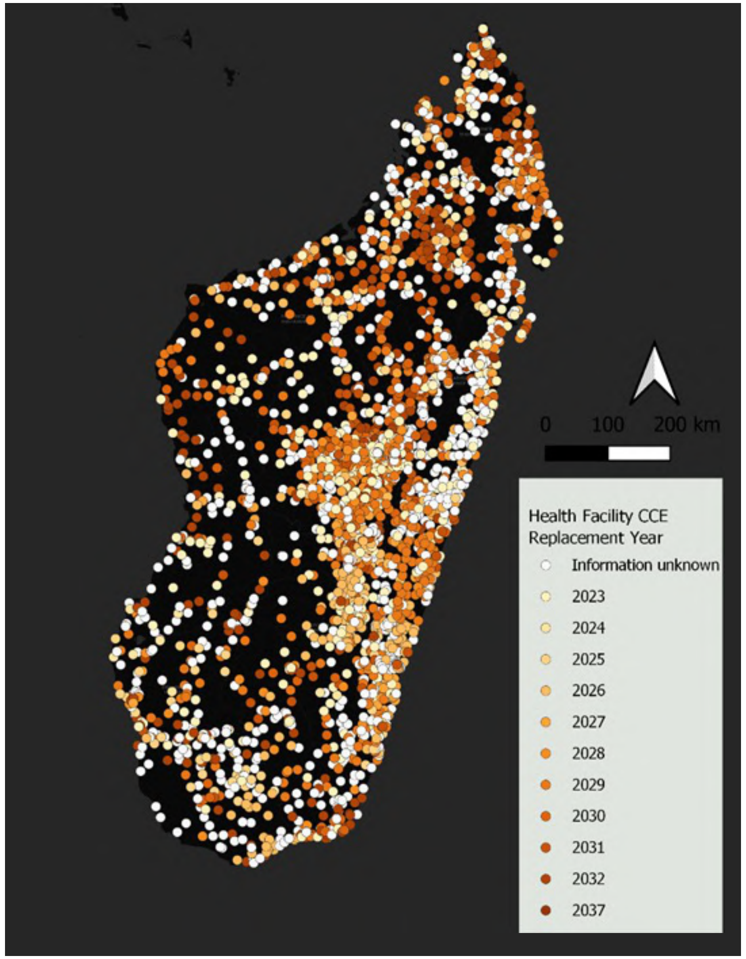
Table 4: Additional cold chain equipment required to meet current needs

CCE CAPACITY TO BE ACQUIRED (LITERS)	NUMBER OF REFRIGERATORS REQUIRED	NUMBER OF FREEZERS REQUIRED
30 liters CCE	500	7
60 liters CCE	3	0
90 liters CCE	1	0
120 liters CCE	1	0
120+ liters CCE	1	0

Table 5: Cold chain equipment required for future needs (expansion or replacement of aging equipment)

YEAR REQUIRED	COLD ROOM (POSITIVE STORAGE)	ELECTRIC FREEZER	ELECTRIC REFRIGERATOR	SOLAR FREEZER	SOLAR REFRIGERATOR
As soon as possible	2	99	191	18	1003
2024		1	2		23
2025	1	2	2		93
2026			1		254
2027		2	2		68
2028	2		13		107
2029		20	13	1	556
2030	1	6	10		209

Map 4: Health Facility CCE by future replacement year



Cold chain equipment annual deployment and indicative costs

The total estimated cost of the equipment to meet current and future medical cold storage needs to 2030 is USD 14.4 million. Costs are given as an indication, using a unit cost of EUR 2,500 (about USD 2,625) per electric compression freezer or refrigerator, and EUR 5,500 (about USD 5,775) per solar direct-drive freezer or refrigerator.

There is scope for some cost reduction for cold chain equipment by 2030 if it is possible to closely coordinate electrification (via sufficiently reliable and sustainable means) and cold chain equipment procurement, as this would reduce reliance on more expensive solar direct-drive refrigerators and allow for increased deployment of "standard" electric freezers and refrigerators. The analysis shows that shifting 40% of required procurement by 2030 for solar direct-drive refrigerators to electric compression equipment would generate an overall cost savings of USD 2.9 million.

Table 6: Estimated capital cost for new or replacement equipment

YEAR REQUIRED	ELECTRIC FREEZER (USD)	ELECTRIC REFRIGERATOR (USD)	SOLAR FREEZER (USD)	SOLAR REFRIGERATOR (USD)	TOTAL
As soon as possible	$259,875	$501,375	$103,950	$5,792,325	$6,657,525
2024	$2,625	$5,250	$0	$132,825	$140,700
2025	$5,250	$5,250	$0	$537,075	$547,575
2026	$0	$2,625	$0	$1,466,850	$1,469,475
2027	$5,250	$5,250	$0	$392,700	$403,200
2028	$0	$34,125	$0	$617,925	$652,050
2029	$52,500	$34,125	$5,775	$3,210,900	$3,303,300
2030	$15,750	$26,250	$0	$1,206,975	$1,248,975
Total	**$341,250**	**$614,250**	**$109,725**	**$13,357,575**	**$14,422,800**

Vaccine transportation and logistics

The central (national) storage level delivers vaccines to districts with good road access on a quarterly basis.

To ensure delivery, the MSanP in Madagascar has five trucks, two of which are refrigerated, to ensure vaccine distribution from the central level to the district level, yet only one cold truck is currently functioning. UNICEF provides the use of two additional trucks to fill in the current gap and to access the harder-to-reach areas.

Figure 5: Vaccines being loaded on a refrigerated cold truck for delivery

To ensure last-mile delivery, healthcare facilities then collect vaccines from district-level storage monthly, using a variety of transportation methods including government motorcycles when available, public transportation (tuk tuk or taxi), by boat, zebu carriage or on foot.

Health workers use cold boxes and vaccine carriers for distribution or community outreach when a cold truck is not available. While this is the standard approach, temperatures within cold boxes and vaccine carriers can be variable and difficult to monitor.

Figure 6: Vaccine carriers used for smaller distribution or outreach to communities

(Source: WHO 2022)

Health facility energy analysis

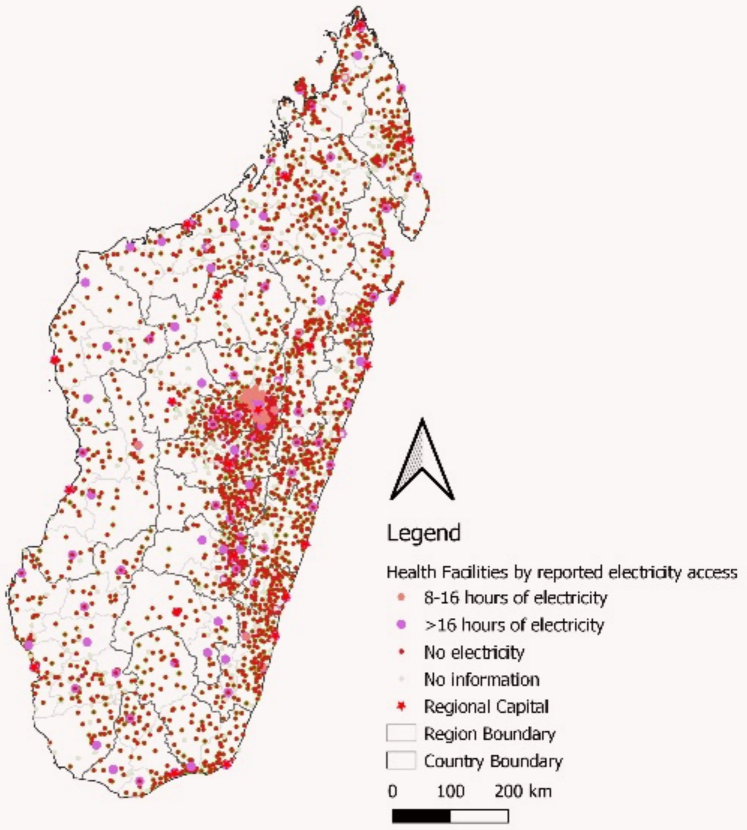
According to data from the MSanP, 2,421 of 3,053 facilities currently lack access to electricity. The majority of these facilities are basic health clinics (CSB1 and CSB2). The World Bank-funded LEAD project had electrified 47 CSB facilities with standalone solar systems by the end of 2023, and plans to electrify 452 more in a second phase of investments.

Reliability and availability of electricity is a challenge for about 35% of connected facilities (111), which report having access only between 8 and 16 hours per day.

Table 7: Healthcare facilities with declared access to electricity (MSanP, 2023)

HEALTH FACILITIES BY TYPE	>16 HOURS	8-16 HRS	NO ELECTRICITY	NO DATA	TOTAL
CHD	1	0	0	0	1
CHR	1	1	1	0	3
CHRD	9	10	40	0	59
CHRR	2	0	7	0	9
CHU	2	1	2	0	5
CRNM	1	0	2	0	3
CSB1	17	11	908	124	1060
CSB2	30	85	1458	199	1772
DISP/MAT	0	1	0	0	1
DPEV	1	0	0	0	1
DRSP	23	0	0	0	23
Hosp	0	2	0	0	2
SDSP	111	0	3	0	114
Total	**198**	**111**	**2421**	**323**	**3053**

Map 5: Healthcare facilities with declared access to electricity (MSanP, 2023)



Typical equipment and energy requirements by facility

Table 8: List of equipment by type of facility (Source: USAID Powering Health 2023)

EQUIPMENT	QUANTITY CSB /DIS/MAT SIZE 1	QUANTITY CHD /SDSP SIZE 2	QUANTITY CHR /DRSP/CRNM SIZE 3	QUANTITY CHU/DPEV SIZE 4	UNIT POWER (WATTS)
Lighting	5	40	120	120	10 W
Examination light	1	2	4	8	20 W
Microscope	1	3	5	5	10 W
Radio	1	1	1	1	30 W
Small refrigerator for vaccine storage	1	0	0	0	60 W
Large refrigerator for vaccine storage		1	3	3	500 W
Autoclave		1	1	2	630 W
Fan		8	20	20	80 W
Rotator/mixer		1	2	2	60 W
Water bath		1	2	2	400 W
Spectrophotometer		1	2	2	63 W
Dental chair		1	2	2	710 W
Compressor		1	2	2	370 W
Centrifuge		1	1	1	600 W
Jet Sonic Cleaner		1	1	1	45 W
Computer		2	4	4	120 W
Cell phone charger		5	10	20	5 W
Amalgam filling machine		1	1	1	80 W
X-ray machine			1	1	200 W
CD4 counters			1	2	200 W
Blood chemistry analyzer			1	1	45 W
Hematology mixer			1	1	230 W
Air-conditioning unit			3	3	1500 W
Resuscitator				1	165 W
Incubator				1	917 W
Scale of prenatal care				1	2 W
Nebulizer				1	85 W
Oxygen concentrator				1	285 W
Suction machine				1	145 W

The analysis identified critical facility equipment for various health facility levels using the USAID document Powering Health: Load Calculation Examples and information available about existing equipment on site at CSBs currently. This approach is applied to provide power for minimum critical health clinic equipment requirements for essential examinations, night birthing and vaccination functions.

Equipment and demand estimations exclude electrification of housing facilities for health workers and non-medical equipment to improve service quality. The SEforALL Powering Healthcare Market Assessment and Roadmap for Madagascar provides additional information and demand estimates including these ancillary uses for both CSB1-2 and CHRD facilities.

All facilities are assumed to be electrified with solar PV-battery systems ranging from 0.5 kWp to provide basic access to the smallest unconnected facilities, up to 42 kWp for backup solar systems for larger facilities that already benefit (or are expected to benefit) from a mains connection.

Table 9: Assumed energy requirements by healthcare facility type

	SIZE 1 CSB/DIS/ MAT	SIZE 2 CHD/SDSP	SIZE 3 CHR/DRSP /CRNM	SIZE 4 CHU/DPEV
Total Facility electricity consumption (kWh/day)	0.88	18.85	85.44	93.62
Share of electricity consumed by CCEs (%)	54.5%	21.2%	14.0%	12.8%
Electricity consumed by CCE only (kWh/day)	0.48	4.0	12.0	12.0

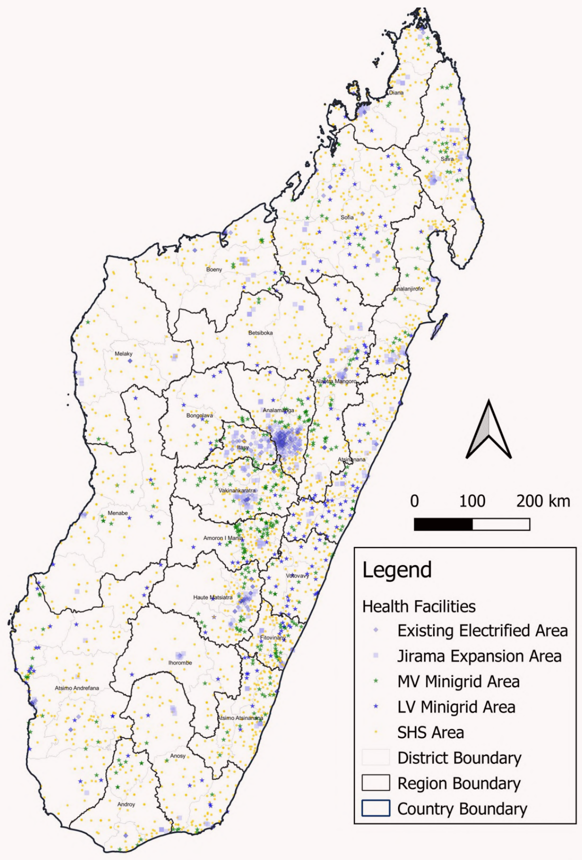
Health facility electrification analysis

The least-cost geospatial electrification planning conducted as a part of the Madagascar IEP allows for the identification of the least-cost electrification modality for each facility in the country. Most facilities, primarily rural and remote community health clinics, will require electrification via standalone solar systems. Facilities that are already or may be connected to the grid or a mini-grid may require a backup standalone solar solution that covers the energy requirements for critical functions to ensure reliable service during possible outages.

Table 10: Least-cost electrification modality for healthcare facilities in Madagascar

FACILITY LEVEL	GRID-CONNECTED AREAS	GRID EXPANSION	MV MINI-GRID	LV MINI-GRID	STANDALONE SOLAR SYSTEMS
CHD	56				1
CHR	182	1			
CHRD	1	16	5	1	22
CHRR	-	2			3
CHU	43				
CRNM	2	1			1
CSB1	15	75	132	74	723
CSB2	4	152	204	102	1132
DISP/MAT	1				
DPEV	15				
DRSP	5	4			4
Hosp	1				
SDSP	2	25	10	1	35
Total	**327**	**276**	**351**	**178**	**1924**

Map 6: Healthcare facilities classified by electrification modality by 2030 (IEP, 2023)



Investment requirements

Table 11: Investment requirements for equipment to ensure medical cold chain integrity and the electrification of basic healthcare facilities

YEAR	ELECTRIC FREEZER (USD)	ELECTRIC REFRIGERATOR (USD)	SOLAR FREEZER (USD)	SOLAR REFRIGERATOR (USD)	ELECTRIFICATION COSTS FOR BACKUP SYSTEMS FOR ALREADY CONNECTED FACILITIES (USD)	ELECTRIFICATION COSTS FOR OFF-GRID ELECTRIFICATION SYSTEMS (USD)	TOTAL
As soon as possible	$259,875	$501,375	$103,950	$5,792,325			
2030	$81,375	$112,875	$5,775	$7,565,250	$7,004,852	$7,075,270	
Total	**$341,250**	**$614,250**	**$109,725**	**$13,357,575**	**$7,004,852**	**$7,075,270**	**$ 28,502,922**

Table 11 estimates the overall investment requirements to:

- Adequately equip all relevant healthcare facilities with appropriate cold chain equipment from now until 2030 (assuming replacement of equipment over 10 years old)
- Provide standalone solar PV electrification to cover the critical functions of healthcare facilities in off-grid areas
- Provide solar PV-battery backup systems to cover the critical functions of healthcare facilities that are currently or are reasonably expected to be connected to a JIRAMA network or a mini-grid.

Meeting the full requirements of cold chain investments is expected to cost USD 14.4 million, while ensuring reliable basic electrification (excluding any costs related to grid extension and/or mini-grids and operations and maintenance expenditures) for all healthcare facilities in Madagascar is expected to require at minimum USD 14 million in investment through 2030.

The SEforALL Powering Healthcare Market Assessment and Roadmap for Madagascar provides additional information on investment requirements and rollout planning for the electrification of CSB and CHRD-level facilities. This analysis suggests that there may be significant benefits to providing additional standalone solar capacity to encompass needs for electrification of staff quarters and future equipment procurements to offer improved and expanded services, which would increase the cost of electrifying these facilities to USD 49 million. These costs exclude recurring expenditure on operations and maintenance (O&M) to keep the solar PV systems in working order, estimated at USD 31 million over ten years.

Note: Costs refer only to the provision of additional backup systems or suitably sized standalone solar systems for healthcare facilities. Costs related to grid extension and/or mini-grid connections development that would benefit healthcare facilities are included in the Madagascar IEP Geospatial Least-Cost Electrification Analysis

Conclusions

- The medical cold chain equipment (CCE) currently available and in use in Malagasy health facilities is working well. Cold chain capacity is sufficient where it is available, particularly at the facility level, and can easily accommodate population growth and new vaccines.
- However, more than 1,600 pieces of equipment are not functioning, and it will require a significant effort to decommission them and update the inventory. By 2030, more than 1,500 currently functioning pieces of equipment will be more than 10 years old and should be assessed for functionality and possibly decommissioned. MSanP has already developed a decommissioning plan that maps out the country's approach to remove non-functional equipment from the system. This plan should be reviewed regularly considering best environmental practices, technical and safety considerations and documentation in assets management systems and be adequately financed to ensure implementation.
- More than 500 facilities currently do not have functioning CCE, although some equipment is expected to be procured in 2024, with a focus on solar direct drive (SDD) equipment. It is important to note that expanding CCE to new health facilities must also consider the human resources required for expanding immunization services to a new facility, which includes demand creation and community mobilization.
- As access to reliable electricity expands in Madagascar, grid-powered CCE can be procured, which is generally less expensive than SDD and easier to maintain. The next procurement cycle could be an opportune moment to develop a CCE procurement strategy that is closely coordinated with healthcare facility electrification plans.
- Over 95% of healthcare facilities without any access to electricity are basic health centres (CSB1 and CSB2). Logically, these primary healthcare facilities are located across the entire country, including in remote areas, and would therefore require off-grid solar PV electrification solutions. District hospitals (CHRDs), also stand out with substantial investment needs both on- and off-grid to ensure access to electricity at existing and newly constructed facilities and improve the reliability of connections for those facilities that are already electrified.
- Although the majority of facilities will be electrified by off-grid systems, the total energy requirement for backup solar for facilities connected to a grid-based source of electricity is substantially higher than that for off-grid solutions and represents roughly the same volume of investment as off-grid health facility electrification does through 2030. This highlights the importance of investments in backup systems to ensure reliable supply to healthcare facilities including to those connected to the JIRAMA grid.
- The diverse range of facility types and needs in Madagascar's healthcare system highlights the need for a multifaceted approach to addressing energy needs that balances budget requirements and objectives of the electrification programme and takes into account basic services, potential future improvements including digitization and the need for sustainable solutions which will vary across and within facility types. However, within this needs-driven approach, standardization of system requirements for certain facility types such as CSBs could yield cost savings through economies of scale.

CHAPTER TWO

Agricultural cold chains

Acronyms – Agricultural cold chains

ADER	Rural Electrification Agency / Agence de Développement de l'Electrification Rurale
AVC	Agricultural Value Chain (Chaîne de Valeur Agricole)
CaaS	Cooling as a Service
CAPEX	Capital expenditure
CDPHM	Distribution Center of Fishery products of Mahajunga /Centre de Distribution des Produits Halieutiques de Mahajunga
CEFFEL	Consulting, Experimentation and Training on Fruits and Vegetables / Conseil Expérimentation Formation en Fruits Et Légumes
CIRAD	International Cooperation Center on Agronomy and Research / Centre de Coopération Internationale en Recherche Agronomique
FDA	Agricultural Development Fund / Fonds de Développement Agricole
IFAD	International Fund for Agricultural Development
GHI	Global Horizontal Irradiation – Irradiation Solaire Horizontale Globale
GIS	Geographic information system
GWh	Giga-Watt-hours
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit – Agence coopération International allemande pour le développement
GoM	Government of Madagascar
IEP	Integrated Energy Access Plan
INSTAT	National Statistics Institute (Institut National de la Statistique)
JIRAMA	JIro sy RAno MAlagasy – Electricity public utility
LEAD	Least-Cost Electricity Access Development Project / Projet de développement de l'accès à l'électricité au moindre coût de la Banque Mondiale
MEH	Ministry of Energy and Hydrocarbons / Ministère de l'Energie et des Hydrocarbures
MINAE	Ministry of Agriculture and Livestock / Ministère de l'Agriculture et l'Elevage
MPEB	Ministry of Fisheries and Blue Economy / Ministère de la Pêche de de l'Economie Bleue
ORE	Electricity Regulatory Office/ (Office de Régulation de l'Electricité)
OSM	Open Street Map
PrAda	Agriculture Value Chain Adaptation to Climate Change Project (Projet d'Adaptation des chaînes de valeurs agricoles au changement climatique)
PV	Photovoltaic
RH	Relative Humidity
ROI	Return on Investment
SDD	Solar Direct Drive
SDG	Sustainable Development Goal
SEforALL	Sustainable Energy for All

SSS	Standalone Solar PV system
SWIOFISH	Southwest Indian Ocean Fisheries project (Indian Ocean Commission and World Bank)
T	Tonnes
T-km	Tonne-kilometres
WFP	World Food Programme

Agricultural cold chain challenge in Madagascar

The agriculture and food industries contribute approximately 43% of GDP to the Malagasy economy and employ 80% of the active population, both formally and informally.

While Madagascar does have numerous export-oriented value chains, the majority of agricultural activities are focused on subsistence agriculture that produces rice, cassava, potatoes, beans and maize. Crops that are produced in surplus of subsistence needs are sold locally in the domestic market.

Agriculture is not yet mechanized (apart from maize where mechanization is effective but remains low), and women are primarily responsible for cultivation, seeding, pest management and harvesting activities.

Cold chain technology in agriculture is currently relatively limited in Madagascar. Expansion of crops and food preservation through access to cold chain technology could have a significant impact on food security for products that are produced for domestic consumption.

For those products that are produced specifically for export, improvement of agricultural cold chain technology could enhance export opportunities and bolster the economy.

Improved agricultural production and effective development of cold chains faces a number of challenges including:

ELECTRICITY ACCESS

Lack of access to reliable power is a major obstacle to cold chain performance in Madagascar.

INFRASTRUCTURE

Inadequate cold storage and transport facilities/infrastructure throughout the country.

TECHNOLOGY AND EQUIPMENT

Unavailable, unaffordable or inaccessible technologies and equipment further exacerbate cold chain shortcomings.

EDUCATION

Low levels of education among rural women is also an obstacle to the development and competitiveness of fresh vegetable value chains, and therefore to the development of the cold chain.

AWARENESS AND TRAINING

Lack of awareness and technical know-how in cold chain management.

FINANCING AND INVESTMENT

Insufficient access to financing and investment opportunities limits expansion and modernization of the agricultural cold chain.

Methodology and approach

Four value chains, dairy, fisheries, potatoes, and tomatoes were selected and validated for analysis in the Madagascar IEP. While more structured, export-oriented value chains may also have strong cold chain requirements, the IEP analysis prioritized production for local consumption based on: (1) the potential impact of improved cold storage; (2) sectoral priorities; and (3) their potential to contribute to improved income-generating activities or nutritional outcomes.

The milk sector is included because of its importance in food production and its value for domestic and export markets. According to the MDB (Malagasy Dairy Board), fresh milk production was estimated at 100,000,000 liters in 2022.

The fishing industry has major refrigeration and cold chain requirements, as well as significant export potential. The greatest concentration of fisheries (65% of potential) is in the north-western part of Madagascar, between Cap Saint Sébastien in the north and Pointe de l'Angadoka in the south, as well as Cap d'Amparafaka in the north and Nosy Voalavo in the south.

Potatoes are one of Madagascar's most important crops in terms of volume, accounting for some 500,000 tonnes/year. Potato production involves many players and is relatively well organized. The crop is currently in crisis due to the resurgence of diseases (mildew, bacterial blight, etc.). This situation is disrupting supplies to local and foreign markets (quality, regularity).

Tomato production is just as high (100,000 t/year), with well-organized production, particularly in the Itasy region. It's a profitable but fragile product, susceptible to disease and transport accidents. Production, harvesting and transport to market are not always mastered by farmers/producers, which can lead to high levels of losses and low sales revenues.

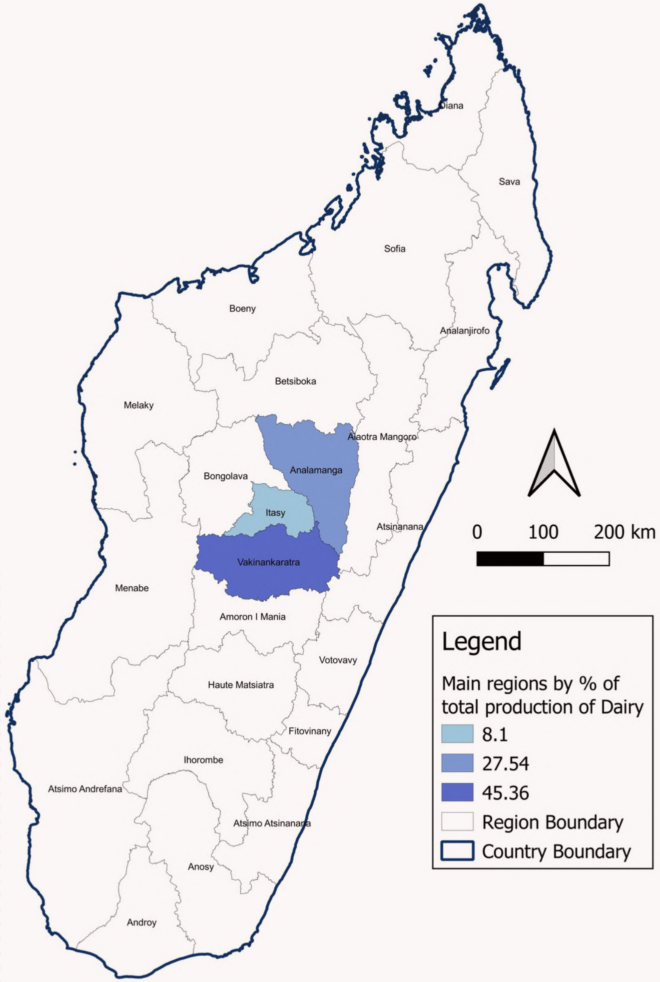
OBJECTIVES

- Assess agricultural value chains and evaluate post-harvest bottlenecks and losses
- Assess the status of cold chain technologies
- Assess the means and measures needed to facilitate access to cold chain technologies in the future
- Evaluate the benefits and costs of extending the post-harvest shelf life of products with cold chain technologies

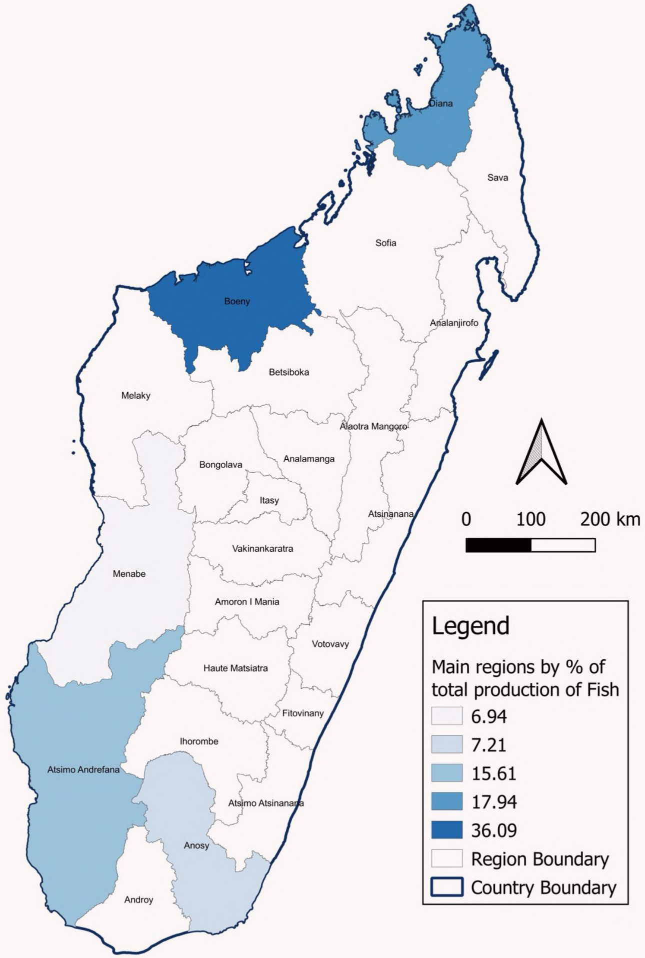
RESULTS

- Cold chain technologies are identified and located at the level of each value chain
- Energy, equipment and investment requirements are identified and spatialized for each level of each value chain
- Additional temperature control training, research and advocacy needs are identified along each value chain
- Estimated return on investment in cold chain investment is calculated

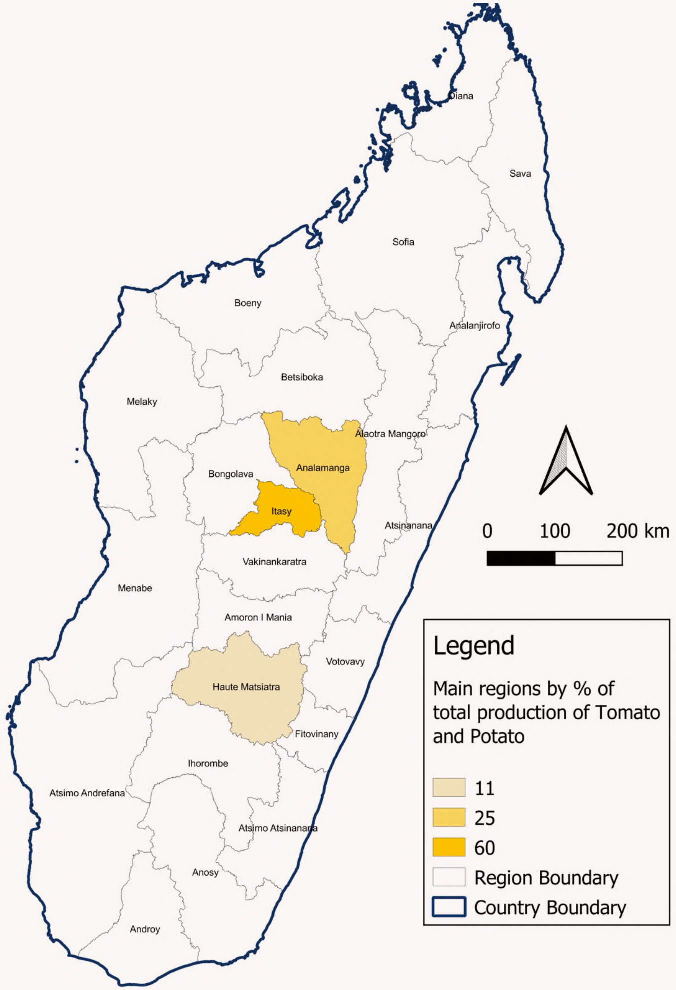
Map 1: Main dairy production zones



Map 2: Main fishing production areas



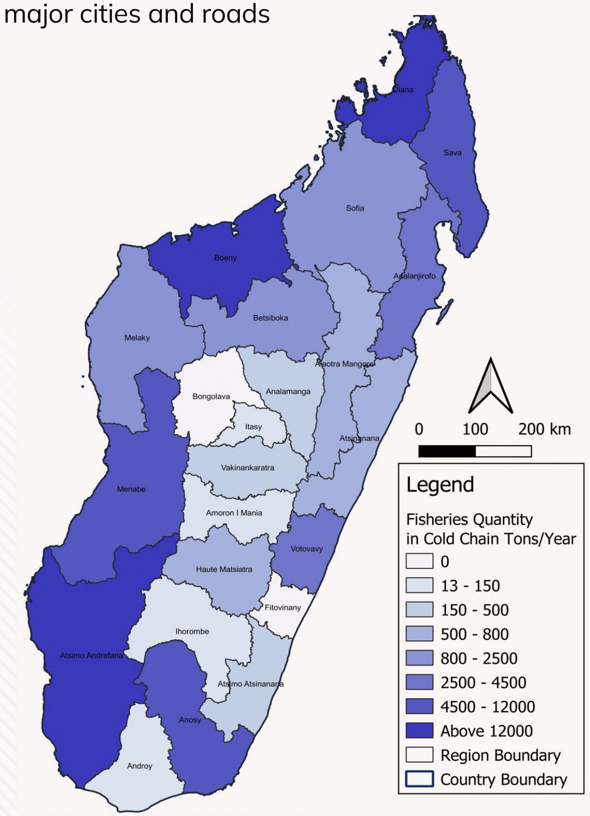
Map 3: Main potato and tomato production areas



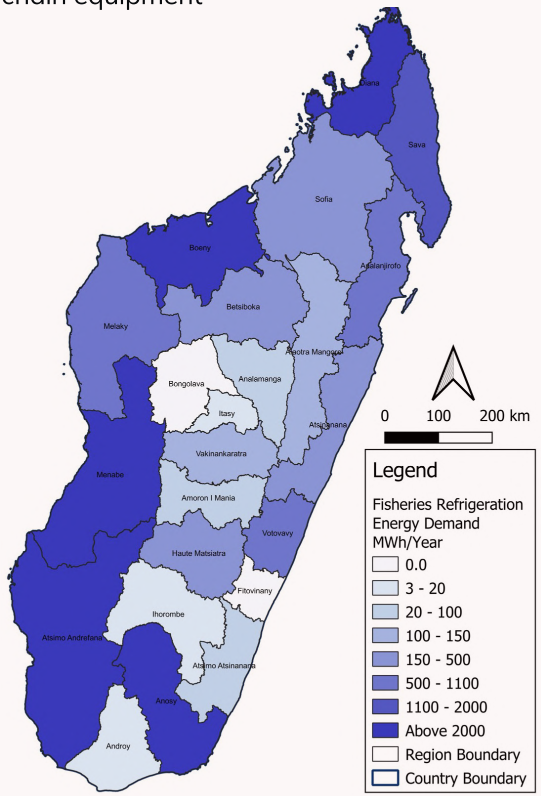
Results: Quantity in cold chain and cooling energy requirements

The Madagascar IEP assessed the quantities in the cold chain in various scenarios, as well as the associated energy demand and capital investment requirements for each value chain. Maps 4- 6 show an example for 100% cold chain penetration for the fisheries value chain.

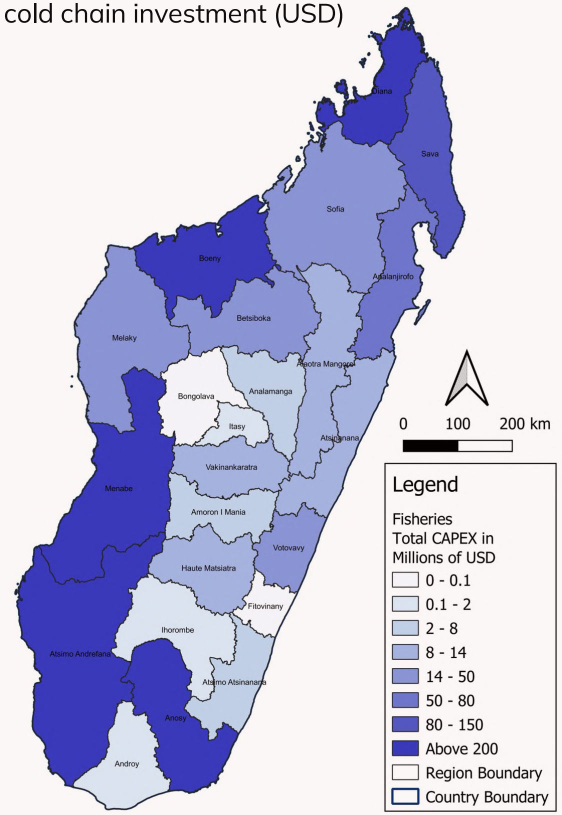
Map 4: Fisheries – Quantity in cold chain, with major cities and roads



Map 5: Fisheries – Energy requirement for cold chain equipment



Map 6: Fisheries – Estimated capital expenditure for cold chain investment (USD)



Results: Food spoilage analysis

Table 1: Food spoilage and return on cooling investment analysis

	POTATO	TOMATO	FISH	DAIRY
Attempted Production (t/year)	402,012	60,539	653,622	171,817
Successful Production (t/year)	251,258	40,864	130,724	103,090
Total Harvest Losses (t/year)	150,755	19,675	522,898	68,727
Remaining Production after Farm Consumption (t/year)	226,132	36,777	117,652	99,121
Estimated Portion of Total Harvest Losses at Farm Level	60%	60%	80%	80%
Estimated Portion of Total Harvest Losses at Wholesale or Commercial Processing Level	2%	10%		8%
Estimated Portion of Total Harvest Losses at Retail Level	2%	2%	8%	
Economic Value (US$/t)	$440.63	$440.63	$3,084.39	$384.68
Loss Economic Impact (US$/year)	$66,426,467	$8,669,373	$1,612,818,657	$26,437,598
Potential Cooling Loss Prevention	37.50%	32.50%	70.00%	50.00%
Cold Chain Preventable Loss Value (US$/year)	$24,909,925	$2,817,546	$1,128,973,060	$13,218,799
ROI for 100% CCE (years)	10	16	2	3

Results: Summary of cold chain requirements and costs

The Madagascar IEP assessed the impact and costs of various levels of penetration for cold chain technology. 100% penetration, as shown in table X, represents the investment requirements to develop a fully modernized cold chain for the representative value chains.

A more likely alternative would be an intermediary scenario, wherein a portion of all required investment is developed in the representative value chains, 20% penetration, as shown in table Y, is a reasonable target for a decade of cold chain function improvement. This level of improvement responds to needs and demonstrates the value of cold chain equipment adoption to other operators.

This approach would however require the creation of a multi-year plan that focuses first on the development of cooling at production sites, then on the introduction of refrigerated trucks to transport products to existing urban facilities, followed by a programme to build larger community facilities for small towns and large village markets.

Table 2: 100% cold chain penetration for all four value chains

SCENARIO 1	QTY IN THE COLD CHAIN IN TONS/YEAR	ENERGY DEMAND FOR REFRIGERATION IN GWH/YEAR	COLD CHAIN TRANSPORT IN T-KM/YEAR	COST OF COLD TRANSPORT IN USD	CAPEX COST IN USD	CAPEX PER CAPITA IN USD
Potatoes	226,132	53	19,528,802	$1,712,114	$250,457,668	$9
Tomato	36,777	12	3,070,227	$269,171	$46,415,023	$2
Fish	117,652	33	2,101,738	$184,262	$2,394,974,101	$83
Dairy products	99,121	115	1,024,541	$89,823	$37,092,598	$1
Total	**479,682**	**212**	**25,725,308**	**$2,255,369**	**$2,728,939,389**	**$95**

Table 3: 20% cold chain penetration in all four value chains

20% CROP SCENARIO	QTY IN THE COLD CHAIN IN TONS/YEAR	ENERGY DEMAND FOR REFRIGERATION IN GWH/YEAR	COLD CHAIN TRANSPORT IN T-KM/YEAR	COST OF COLD TRANSPORT IN USD	CAPEX COST IN USD	CAPEX PER CAPITA IN USD
Potatoes	45,226	11	3,905,760	$342,423	$50,091,534	$2
Tomato	7,355	2	614,045	$53,834	$9,283,005	$0
Fish	23,530	7	420,348	$36,852	$478,994,820	$17
Dairy products	19,824	23	204,908	$17,965	$7,418,520	$0
Total	**95,936**	**42**	**5,145,062**	**$451,074**	**$545,787,878**	**$19**

Conclusions

- Agriculture is vital to the Malagasy economy yet there remain significant challenges and obstacles to the sector reaching its full potential and improving livelihoods.
- The poor quality of roads is a major barrier for safe transport of fresh perishable products from rural areas to urban areas.
- ROI is fastest for fish, second fastest for dairy, and slowest for other horticultural products (tomatoes and potatoes).
- While the investments for tomatoes appear particularly unattractive, it should be noted that 70% of tomatoes can share equipment with potatoes, improving the economic feasibility of the investments for both products.
- Local fishing activities in areas without industrial fish processing and treatment appear to be the sector most adapted to targeted investment in the agricultural cold chain, as the spoilage rate, economic & nutrition value per tonne is highest for fish, which, coupled with the fastest ROI, shows strong potential for private sector involvement in the development of cold chain solutions.
- Going forward, pilot projects are critical to confirm the operation of the cold chain in different regions. In particular, it will be important for the sector to capitalize on the results of ongoing GIZ, WFP and SWIOFISH pilot projects to understand and scale effective delivery models and equipment choices.
- Training will also be necessary in the use and maintenance of refrigeration and other cold chain equipment needs to be implemented to ensure they are working properly, but training farmers in best harvesting practices will also help to avoid waste and harvesting losses, and should go hand in hand with providing access to cold chain equipment.

The costs of establishing an agricultural cold chain, while not negligible, nevertheless amount to only a few dollars per person on a national scale.

Combined with training in best harvesting practices, a strong cold chain has the potential to double domestic production of the crops we studied.

What's more, the same equipment can be used for several crops, including most of those not specifically investigated in this study.

Investing in a modern cold chain would mean both better nutrition and greater financial security for everyone involved in food and agriculture.

EXPLORE THE RESULTS FOR YOURSELF

madagascar-iep.sdg7energyplanning.org

ANY QUESTIONS:

uiep@seforall.org