



SOPHIA

Sustainable Off-grid solutions for
Pharmacies and Hospitals In Africa

UPSCALING AND ROADMAP FOR GREEN ENERGY TRANSITION IN AFRICA USING SOPHIA TECHNOLOGY

DELIVERABLE D7.6

VERSION 1.0

PROJECT ACRONYM	SOPHIA
PROJECT TITLE	SUSTAINABLE OFF-GRID SOLUTIONS FOR HOSPITALS AND PHARMACIES IN AFRICA
FUNDED UNDER	H2020-EU.3.3
PROJECT URL	http://www.sophia4africa.eu/
COORDINATOR	UNIVERSITY OF APPLIED SCIENCES KARLSRUHE
PROJECT DURATION	01/10/2021 – 30/09/2025 (48 MONTHS)



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036836.

SOPHIA CONSORTIUM

NO.	BENEFICIARY	ADDRESS	MAIN CONTACT
1.	 HKA	HOCHSCHULE KARLSRUHE (HKA) Moltkestr. 30, DE-76133 Karlsruhe, Germany	Coordinator: Prof. Dr.-Ing. habil. Michael Kauffeld
2.	 OST INSTITUT FÜR SOLARTECHNIK	OST - OSTSCHWEIZER FACHHOCHSCHULE (SPF-OST) Oberseestrasse 10, CH-8640 Rapperswil, Switzerland	Dr. Mihaela Dudita
3.	 MAKERERE UNIVERSITY	MAKERERE UNIVERSITY (MAK) Main Campus, PO Box 7072, 256 Kampala, Uganda	Prof. Dr. Nicholas Kiggundu
4.		FONDATION 2iE ASSOCIATION (2iE) Rue de la Science, PO Box 01BP594, 01 Ouagadougou, Burkina Faso	Dr.-Ing. habil. Kokouvi Edem N'Tsoukpoe
5.	 Steinbeis Europa Zentrum	STEINBEIS INNOVATION GMBH (SEZ) Steinhäuserstr. 12, DE-76135 Karlsruhe, Germany	Dr. Anthony Salingre
6.	 MINSANTE Ministère de la Santé Publique	MINISTERE DE LA SANTE PUBLIQUE (MPHC) Boulevard Rudolph Manga Bell Yaounde, Cameroon	Ms. Jeanne Aurélie Abomo Ayinda
7.	 IIR INSTITUT INTERNATIONAL DU FROID INTERNATIONAL INSTITUTE OF REFRIGERATION	INSTITUT INTERNATIONAL DU FROID (IIR) Boulevard Malesherbes 177, FR-75017 Paris, France	Ms. Ina Colombo
8.	 Operieren in Afrika e.V.	OPERIEREN IN AFRIKA EV (Oia) Wirthstrasse 11, DE-79110 Freiburg, Germany	Prof. Bernhard Rumstadt
9.		EVERFLO(PTY)LTD (EVERFLO) 10 McLaren Way Racing Park, 7441 Milnerton, South Africa	Mr. Evert Potgieter
10.		KOVCO PTY LTD (KOVCO) Century City, PO Box 134, 7446 Century City, South Africa	Mr. Brendan Prestage
11.	 MARTIN MEMBRANE SYSTEMS A WILLO COMPANY	MARTIN SYSTEMS GMBH (MS) Address: Friedrichstrasse 95, DE-10117 Berlin, Germany	Ms. Carola Dannen
12.	 Simply Solar	SIMPLY SOLAR SCHEFFLER TECHNOLOGIES AND CONSULTING (SISO) Graf von Werdenbergstrasse 6, DE- 89344 Aislingen, Germany	Ms. Heike Hoedt
13.	 RAACH SOLAR DESIGNING PHOTOVOLTAIC POWER	RAACH SOLAR GMBH (RS) Stellwinkel 1, DE-88451 Dettlingen an der Iller, Germany	Mr. Jürgen Raach

DOCUMENT INFORMATION

RESPONSIBLE PARTNER	Steinbeis Innovation gGmbH (SEZ)
AUTHOR (S)	Lucia Hörner (SEZ)
REVIEW	Frederick von Netzer (SEZ)
APPROVAL	Mihaela Dudita-Kauffeld (SPF-OST)
KEYWORDS	Exploitation, Learnings, Policy recommendations, Roadmap, Green Energy Transition
DISSEMINATION LEVEL ¹	PU
DUE DATE OF DELIVERABLE	30.09.2025
ACTUAL SUBMISSION DATE	30.09.2025

¹PU = Public

PP = Restricted to other program participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services)*

DOCUMENT HISTORY

DATE	VERSION	CHANGE HISTORY	AUTHOR
23.04.2025	0.1	Table of Contents	Lucia Hörner (SEZ)
27.05.2025	0.2	First draft	Lucia Hörner (SEZ)
05.08.2025	0.3	Version including partner comments	Kirsten Laaks (Everflo), Heike Hoedt (SISO), Frederick von Netzer (SEZ), Mihaela Dudita-Kauffeld (SPF-OST)
29.08.2025	0.4	Revised version based on partner comments	Lucia Hörner (SEZ)
23.09.2025	0.5	Update based on comments during Final Meeting	Lucia Hörner (SEZ)
29.09.2025	0.6	Review	Frederick von Netzer (SEZ), Sophie von Stralendorff (SEZ)
30.09.2025	1.0	Final version	Lucia Hörner (SEZ)

TABLE OF CONTENTS

SOPHIA CONSORTIUM	2
DOCUMENT INFORMATION.....	3
DOCUMENT HISTORY	3
EXECUTIVE SUMMARY	6
1. Introduction	7
2. Relevant African actors	8
2.1 Continental actors	8
2.2 Regional actors	11
2.3 National actors in SophiA countries.....	12
2.3.1 Burkina Faso.....	12
2.3.2 Cameroon	13
2.3.3 Malawi.....	14
2.3.4 Uganda	15
2.4 Relevant academic and knowledge actors	16
2.5 Pan-African Business and Practitioners' Networks	17
2.6 Corporate actors, innovation hubs, startups and social enterprises	18
2.6.1 Off-Grid Solar PV & System Integration	18
2.6.2 Clean Cooking Technologies	18
2.6.3 <i>Renewable Energy-Based Refrigeration</i>	18
2.6.4 <i>Water Treatment & Access</i>	19
3. Existing roadmaps in the area	19
3.1 Continental strategies and roadmaps.....	19
3.2 National strategies and roadmaps in SophiA countries	21
3.2.1 Burkina Faso – Rural Electrification Strategy 2024–2028.....	21
3.2.2 Cameroon – Updated Rural Electrification Master Plan.....	21
3.2.3 Uganda – Renewable Energy Strategy 2024–2027 & Solar Productive Use Roadmap	22
3.2.4 South Africa – Just Transition Framework & IPP Modernization.....	22
4. Technological and market drivers and future application	22
4.1 Technological drivers	22
4.2 Market drivers	24
5. Practical realities from SophiA and similar research projects.....	26



5.1	Technological barriers identified.....	26
5.2	Market barriers identified.....	28
5.3	Related projects and lessons learned through exchanges in GDSO and KEN	31
6.	Upscaling strategies and policy recommendations	34
6.1	Target audience: European Commission (EC).....	34
6.2	Target audience: African Governments	34
6.3	Target audience: African Public Organisations.....	35
6.4	Published SophiA policy recommendations.....	37
7.	Conclusion	37
8.	References.....	40
9.	Annex.....	45

LIST OF FIGURES

Figure 1: Overview of selected global, Africa wide and regional Actors involved in Green Energy Transition. Originating from KFW, GIZ, & IRENA (2021).	8
Figure 2: SophiA "sister projects", funded under the same call.....	31



EXECUTIVE SUMMARY

The SophiA project addresses one of Sub-Saharan Africa's most pressing challenges: the lack of reliable, sustainable energy, cooling, and clean water for rural hospitals, pharmacies, and communities. With over 600 million people in the region still lacking access to electricity and hundreds of millions without safe drinking water, the need for integrated, climate-resilient infrastructure is urgent. SophiA, funded by the European Union's Horizon 2020 programme, brings together a consortium of European and African partners to develop, pilot, and scale modular containerized systems that combine solar power, energy storage, renewable refrigeration, clean cooking, and water treatment.

This report presents a comprehensive roadmap for upscaling green energy transition in Africa using SophiA technology. It maps the landscape of relevant actors—from continental bodies like the African Union and African Development Bank, to regional and national agencies, academic institutions, and practitioners' networks like U-3ARC. The report reviews existing strategies and roadmaps, highlighting alignment with continental initiatives such as the African Energy Transition Programme and national electrification plans in Burkina Faso, Cameroon, Uganda, and South Africa.

Technological innovation is at the heart of SophiA's approach. The project leverages advances in solar PV efficiency, thermal energy storage, clean cooking appliances, renewable energy-based refrigeration, and water treatment. Digital energy management and modular system architecture enable flexible, adaptive deployment, while the use of natural refrigerants supports climate-friendly solutions. Demonstration sites in four African countries have provided valuable insights into technical, operational, and social factors for successful deployment.

The report identifies key market and technological drivers—including expanding off-grid energy demand, the need for resilient healthcare infrastructure, climate finance opportunities, and the rise of telemedicine and digital health. It also addresses practical barriers such as system complexity, high upfront costs, fragmented procurement, regulatory gaps, and the need for local capacity building and maintenance ecosystems.

Drawing on lessons learned from SophiA and related EU-funded projects, the report offers actionable policy recommendations for the European Commission, African governments, and public organizations. These include supporting demonstration projects, harmonizing standards, facilitating technology transfer, integrating multi-service solutions into national strategies, revising fiscal frameworks, and launching results-based financing models. The importance of local partnerships, capacity building, and replicable case studies is emphasized as critical for long-term sustainability and impact.

In conclusion, SophiA demonstrates that integrated, modular solutions can play a transformative role in Africa's green energy transition. The project's scalable approach offers a blueprint for resilient health systems, economic empowerment, and climate adaptation. Continued collaboration among governments, industry, academia, and development partners will be essential to sustain and expand the gains achieved. The roadmap and strategies presented in this report invite all stakeholders to join in building a more sustainable, inclusive, and equitable energy future for Africa.



1. INTRODUCTION

Access to reliable energy, cooling, and clean water remains a critical challenge for millions across Sub-Saharan Africa. As of 2023, over 600 million people in the region still lack access to electricity (IRENA, 2022), and more than 300 million do not have safe drinking water at home (JMP, 2025). Rural clinics and pharmacies often operate without dependable power, making it difficult to store vaccines, medicines, and food safely, and to provide essential health services. The World Health Organization (WHO) estimates that up to 50% of vaccines are wasted globally each year, largely due to inadequate cold chain infrastructure—a problem especially acute in remote African communities (UNEP, 2020; AFRICALOGISTICS, 2024). Furthermore, the COVID-19 pandemic has highlighted the vulnerability of rural health systems, with many facilities unable to maintain cold chains or support digital health solutions due to unreliable energy supply. These gaps not only threaten public health and food security but also slow progress toward the UN Sustainable Development Goals (SDGs), particularly SDG 3, SDG 6, and SDG 7 (UN, 2015).

The SophiA project —“Sustainable Off-grid Solutions for Hospitals and Pharmacies in Africa”—was launched to respond to these challenges by developing, piloting, and scaling modular containerized systems that combine solar photovoltaic power, energy storage, renewable energy-based refrigeration, clean cooking, and water treatment. Supported by the European Union’s Horizon 2020 programme, SophiA brings together a diverse consortium of European and African partners, leveraging expertise from academia, industry, government, and civil society to co-create solutions tailored to local contexts.

This deliverable, D7.7, presents the upscaling roadmap for the green energy transition in Africa using SophiA technology. It synthesizes the project’s learnings, stakeholder engagement, and strategic recommendations, drawing on extensive collaboration with continental, regional, and national actors. The report situates SophiA within the broader landscape of African energy transition initiatives, including the African Energy Transition Programme, national electrification strategies, and a network of “sister projects” funded under the same Horizon 2020 call. By mapping relevant actors, existing roadmaps, and technological and market drivers, the report provides a comprehensive foundation for future decision-making by policymakers, public organizations, and industry stakeholders.

A central focus of SophiA is the integration of multiple services—energy, cooling, water, and digital connectivity—into a single, adaptable platform. This approach reflects the realities of rural African communities, where infrastructure gaps are multidimensional and solutions must be robust, flexible, and easy to maintain. The project’s demonstration sites in Burkina Faso, Cameroon, Uganda, and Malawi have provided valuable insights into the technical, operational, and social factors that shape successful deployment. Lessons learned from these pilots, as well as exchanges with related EU-funded projects, inform the upscaling strategies and policy recommendations presented in this report.

The document also addresses the practical barriers encountered during implementation, including technical complexity, financing challenges, regulatory gaps, and the need for local capacity building. By highlighting both achievements and obstacles, the report aims to foster a realistic understanding of what is required to scale integrated off-grid solutions across diverse African contexts.



Ultimately, this public report is intended as a guide for decision-makers, practitioners, and development partners seeking to advance the green energy transition in Africa. It offers actionable strategies, policy recommendations, and a vision for how modular, sustainable technologies like SophiA can contribute to resilient health systems, economic empowerment, and climate adaptation. The insights and roadmap presented here invite all stakeholders to join in building a more sustainable, inclusive, and equitable energy future for Africa.

2. RELEVANT AFRICAN ACTORS



Figure 34 – Overview of selected global, Africa-wide and regional electricity-sector institutions and initiatives supported by development partners

Figure 1: Overview of selected global, Africa wide and regional Actors involved in Green Energy Transition. Originating from KfW, GIZ, & IRENA (2021).

2.1 Continental actors

Core continental-level actors of Africa's green energy transition are the following:

a. African Energy Commission (AFREC)

The African Energy Commission (AFREC) is the technical energy agency of the African Union (AU) mandated to coordinate, harmonize, and develop energy policies and programs across the continent. One of its cornerstone contributions is the African Energy Information System (AEIS), which collects, analyses, and disseminates energy data from African Union Member States — a vital input for evidence-based policymaking and investment planning. While its core mandate includes all energy forms, AFREC has significantly expanded its data and knowledge products to support off-grid electrification, decentralized energy systems, and clean cooking access. It works closely with national ministries and regional actors like ECREEE and SACREEE to harmonize data collection methodologies. By informing AU policies and continental initiatives such as Africa Single Electricity Market (AfSEM) and Programme for Infrastructure Development in Africa (PIDA), AFREC ensures that off-grid energy solutions are not sidelined in favour of large-scale infrastructure alone. AFREC also supports the implementation of the African Union Energy Transition Programme and contributes technical expertise to integrated energy planning and forecasting. Unlike development finance institutions or political bodies, AFREC acts as a technical and knowledge-driven body, offering



policy tools, analytics, and technical guidelines that underpin energy system planning at regional and national levels.

b. African Union Commission (AUC) – Energy Department

The AUC's Energy Department is the political and strategic driver behind Africa's continental energy agenda, and it increasingly integrates off-grid energy solutions into its priorities to meet SDG 7 and Agenda 2063. It leads the implementation of frameworks such as the AfSEM and the African Energy Transition Programme, both of which explicitly recognize the importance of off-grid and mini-grid systems and sustainable cooling in achieving universal energy access. The AUC works with Regional Economic Communities (RECs), national governments, donors and continental agencies like AFREC and AfDB to create enabling policy environments for decentralized renewables, including frameworks for quality standards, regulatory streamlining, and investment incentives. Its coordination role also involves aligning off-grid solutions with climate goals, gender equality, and resilience strategies. In this context, the AUC ensures that continental policies treat off-grid energy not as a stopgap but as a long-term infrastructure and development pathway. Its role is not technical or financial, but rather political and strategic, ensuring that energy policy agendas align with broader African Union goals such as Agenda 2063. The department also engages with global partners (e.g., the EU, IRENA, UN bodies) to mobilize support for Africa's energy transition and represents Africa's energy priorities in international forums.

c. African Development Bank (AfDB)

The AfDB is a major financial and technical enabler of off-grid energy projects across Africa. The bank's involvement goes beyond traditional lending by actively engaging in project development, risk mitigation, and private sector mobilization, particularly in renewable energy, energy efficiency, and climate adaptation. Through its Sustainable Energy Fund for Africa (SEFA) and initiatives like the Desert to Power programme, the AfDB provides blended finance, technical assistance, and capacity building to accelerate off-grid solar, clean cooking solutions, and energy storage systems, especially in underserved regions. Through its flagship Feed Africa strategy and the Sustainable Energy Fund for Africa (SEFA), AfDB invests in off-grid refrigeration, cold storage pilot programs, and technology scale-up projects—most notably targeting smallholder agriculture and rural clinics. Its support covers the entire value chain — from market assessments and feasibility studies to results-based financing for private developers. The Bank actively works with RECs, national governments, and continental entities like AUC and AUDA-NEPAD to ensure off-grid energy is mainstreamed into national energy investment plans and regional development strategies. AfDB's comparative advantage lies in resource mobilization, infrastructure financing, and scaling up investment-ready green energy projects in partnership with governments and developers.

d. Africa Renewable Energy Initiative (AREI)

The Africa Renewable Energy Initiative (AREI) is a high-level, African-owned and African-led initiative that seeks to accelerate the deployment of renewable energy on the continent, with a central emphasis on off-grid, decentralized energy systems. Launched in 2015 during COP21, AREI aims to add at least 300 GW of renewable energy capacity by 2030. AREI is unique in that it emphasizes transformational, decentralized, and people-centred energy access, especially for underserved communities. AREI uniquely promotes projects that deliver development co-benefits, such as health, education, and economic empowerment in off-grid



areas. AREI works closely with the AUC, AfDB (its implementing agency), and IRENA, and serves as a strategic platform for coordinating the African ownership over the energy transition, emphasizing small-scale solar, wind, biogas, and energy for productive use in agriculture and water services and bringing together African institutions, civil society, and international partners under the political guidance of the African Union. Compared to other continental actors, AREI is most directly focused on community-scale and household-level energy solutions and champions a rights-based approach to energy access. AREI differentiates itself by placing strong emphasis on governance, inclusivity, and ownership, ensuring that renewable energy projects are not only technically viable and climate-resilient, but also socially just. While AfDB may finance renewable projects and AFREC offers data systems, AREI focuses on ensuring that renewables are scaled inclusively and equitably, with African priorities at the centre.

e. African Union Development Agency – NEPAD (AUDA-NEPAD)

AUDA-NEPAD serves as the technical implementation arm of the African Union, translating continental political priorities into actionable development programs. It plays a key role in integrating off-grid energy solutions into broader development infrastructure. While much of AUDA-NEPAD's portfolio includes large-scale energy corridors, it increasingly supports off-grid energy through the Programme for Infrastructure Development in Africa (PIDA) and Smart Villages models, which combine solar PV, clean cooking, refrigeration, and water access for rural communities. AUDA-NEPAD also promotes public-private partnerships and cross-sectoral coordination between energy, agriculture, health, and ICT to enable energy access where grid expansion is uneconomical. It acts as a bridge between regional actors, financial institutions, and community-level implementation, and supports policy harmonization across RECs to reduce market fragmentation for off-grid developers. AUDA-NEPAD's comparative advantage lies in ensuring that off-grid energy is integrated into rural development and resilience planning, not treated as an isolated sector. Unlike AFREC or AUC, AUDA-NEPAD is operationally oriented and works more closely with project developers, national governments, and regional economic communities (RECs) to move strategic concepts into bankable projects.

f. Africa-EU Energy Partnership (AEEP)

The Africa-EU Energy Partnership (AEEP) is a long-standing strategic dialogue platform jointly led by the African Union and the European Union and serves as a key enabler of Africa's off-grid energy transition through dialogue, technical support, and funding mobilization. AEEP facilitates strategic alignment between African priorities and EU external energy policies, with a focus on decentralized renewables, energy efficiency, clean cooking, and climate-smart infrastructure. The partnership has supported regional initiatives like ROGEP (World Bank Group 2025) (through ECREEE) and renewable energy enterprise development via programs such as ElectriFI (European Commission 2025 a) and the Africa-EU Green Energy Initiative (European Commission 2025 b). The partnership encourages local manufacturing, digital innovation, and skills development, all crucial for scaling off-grid technologies sustainably. Through its monitoring and tracking mechanisms, AEEP provides transparent data on progress and challenges, helping donors and governments fine-tune interventions. Unlike purely African actors, AEEP is instrumental in linking external funding (such as Global Gateway or NDICI) and expertise to African off-grid priorities. It differs from AfDB in that it does not fund projects



directly but rather facilitates the policy and partnership architecture that enables project financing and implementation.

2.2 Regional actors

Besides the actors engaged across the continent, there is regional economic communities (RECs) that play an important role in Africa's green energy transition. They are formally recognized by the African Union as pillars of regional integration and development. They each implement energy strategies tailored to their geographic and socioeconomic contexts, while contributing to and aligning with continental frameworks like the African Union Energy Transition Programme, Programme for Infrastructure Development in Africa (PIDA), and Africa Single Electricity Market (AfSEM).

a. ECOWAS – Economic Community of West African States

ECOWAS is widely recognized as a continental leader in off-grid energy transition efforts. Through its specialized institution, the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), it has developed robust regional policies and implementation frameworks targeting rural electrification, decentralized renewables, and clean cooking technologies. ECREEE's programs — such as the Regional Off-Grid Electrification Project (ROGEP) and the ECOWAS Policy for Gender Mainstreaming in Energy Access — aim to expand access through stand-alone solar home systems, mini-grids, and productive use technologies. These efforts are particularly significant in countries like Mali, Niger, and Burkina Faso, where grid extension is not feasible in the near term. ECOWAS aligns closely with continental actors like AFREC (for data and monitoring), AUC (for policy coordination), and IRENA (for technical support). It also works with the African Development Bank (AfDB) on blended finance mechanisms for off-grid entrepreneurs. What sets ECOWAS apart is its well-developed regulatory frameworks and regional cooperation mechanisms specifically targeting the off-grid sector, making it a model for other RECs.

b. SADC – Southern African Development Community

Within SADC, the focus on off-grid energy has historically been less prominent than grid-based solutions, but efforts are accelerating, particularly through the Southern African Development Community Centre for Renewable Energy and Energy Efficiency (SACREEE). SADC's off-grid activities are centred around energy access in remote rural areas, with emphasis on solar PV, clean cooking, and solar refrigeration — technologies relevant to health clinics, schools, and agricultural productivity. Countries such as Zambia, Malawi, and Mozambique have developed national off-grid strategies that SACREEE helps align regionally. Though SAPP focuses primarily on grid interconnection, SADC is increasingly incorporating off-grid electrification into its Regional Energy Access Strategy and Action Plan, with support from AUDA-NEPAD, AfDB, and donor-financed regional programs. Compared to ECOWAS, SADC is still building institutional strength around off-grid coordination, but it has a large potential market and growing activity in results-based financing and productive use innovation — particularly in agriculture and cold chains.

c. EAC – East African Community



The East African Community (EAC) has a dynamic and fast-evolving off-grid energy landscape. Many of its member countries — including Kenya, Uganda, Tanzania, and Rwanda — are global leaders in solar home systems, mini-grid innovation, and PAYGo business models. The EAC has been working to harmonize quality standards, licensing frameworks, and tariff models for off-grid systems, helping reduce regulatory fragmentation that can stifle cross-border trade and investment. Its off-grid strategy emphasizes private sector participation, affordability, and productive use, and includes specific efforts to address clean cooking solutions through regionally aligned strategies. The East African Centre of Excellence for Renewable Energy and Efficiency (EACREEE) serves as a technical body, coordinating donor-supported projects and connecting national off-grid initiatives to continental frameworks such as the AfSEM and AREI. Unlike SADC, which is more grid-focused, or COMESA, which leans toward economic integration, the EAC is at the forefront of off-grid technology deployment, thanks to a strong entrepreneurial ecosystem and innovation hubs in Nairobi and Kampala.

d. COMESA – Common Market for Eastern and Southern Africa

COMESA approaches off-grid energy primarily through a market integration and regulatory reform lens. Its work emphasizes the removal of trade and investment barriers for clean energy technologies, including off-grid solar PV kits, cookstoves, and mini-grid components. COMESA has partnered with agencies like the Regional Centre for Renewable Energy and Energy Efficiency (RCREEE) and SEforALL to develop guidelines for cross-border equipment standards, investment incentives, and private sector facilitation. While not as operational as ECOWAS or EAC in direct project implementation, COMESA plays a critical role in enabling a harmonized off-grid market across eastern and southern Africa, spanning from Sudan to Zimbabwe. It also supports gender mainstreaming, climate resilience, and agricultural-energy nexus projects that use decentralized energy to boost food security. COMESA works closely with AUDA-NEPAD and AUC to align off-grid market facilitation with PIDA and the Africa Green Stimulus Programme. Its strength lies in leveraging economic integration tools to scale up decentralized energy solutions.

2.3 National actors in SophiA countries

2.3.1 Burkina Faso

a. Ministry of Energy, Mines and Quarries (Ministère de l'Énergie, des Mines et des Carrières)

- Lead national policymaker on energy transition.
- Oversees national strategies such as the National Electrification Strategy (SNE) and Energy Transition Roadmap, which include strong off-grid and mini-grid components.

b. Agence Burkinabè de l'Électrification Rurale (ABER)

- Key implementing agency for rural electrification.
- Coordinates deployment of solar mini-grids, SHS, and public facility electrification (schools, clinics).



- Directly relevant for scaling SophiA's rural health infrastructure solutions.

c. FDE – Fonds de Développement de l'Électrification

- Provides funding for off-grid solutions, often in partnership with international donors.
- Supports PPPs and results-based financing schemes for solar projects.

d. ONEA – Office National de l'Eau et de l'Assainissement

- National utility for water and sanitation services (state water supply company of Burkina Faso).
- Participates in projects with external funding bodies (such as GIZ, EC, AfDB etc.).

e. MARAH – Ministère de l'Agriculture, des Ressources Animales et Halieutiques

- Develop and implement policies for sustainable agricultural practices, strengthen animal husbandry and manage fisheries resources.
- Aimed at improving food security, building resilience to climate change and agricultural productivity.
- DGRE – Direction Générale des Ressources en Eau within MARAH is responsible for water resources management.
- DGAEP – Direction Générale de l'Approvisionnement en Eau Potable within MARAH oversees drinking water supply.

f. Ministère de la Santé et de l'Hygiène Publique

- Central authority responsible for public health infrastructure and service delivery in Burkina Faso.
- It oversees the deployment and operation of health facilities, including rural clinics and hospitals.
- Also, it aligns health sector investments with Burkina Faso's national energy transition and rural electrification strategies.

2.3.2 Cameroon

a. Ministère de la santé publique (MINSANTE)

- Oversees the modernization and electrification of hospitals, clinics, and rural health posts.
- Aligns health sector investments and procurement processes with Cameroon's updated Rural Electrification Master Plan.

b. Ministère de l'Agriculture et du Développement rural (MINADER)

- Oversees programs that support rural electrification, agro-processing, and water management.
- Aligns agricultural modernization and rural development strategies with Cameroon's energy transition goals.



- Works with other ministries (such as Health and Energy) to ensure that rural infrastructure upgrades—especially those involving cold chains for food and vaccines, water access, and productive use of energy—are coordinated and sustainable.

c. Ministry of Water Resources and Energy (MINEE)

- Oversees national electrification goals, including off-grid and clean cooking policies.
- Leads on the Rural Electrification Master Plan and coordinates with REEEP and IRENA on renewable programs.

d. Agence d'Électrification Rurale (AER)

- Main implementing body for off-grid electrification.
- Supports deployment of decentralized solar PV and solar cooling systems, often through community-based approaches.

e. ARSEL – Electricity Sector Regulatory Agency

- Sets tariffs and licensing rules for mini-grid operators.
- Vital for enabling or constraining the off-grid energy business environment.

f. CREPD (Centre for Research and Innovation on Renewable Energy and Sustainable Development)

- Academic and R&D actor contributing to solar PV innovation, cooling technologies, and community energy systems.

2.3.3 Malawi

a. Ministry of Energy

- Lead policymaker, driving national plans like the Malawi Renewable Energy Strategy and Integrated Energy Plan (IEP).
- Supports large-scale rollout of solar mini-grids and decentralized systems in partnership with donors.

b. Malawi Energy Regulatory Authority (MERA)

- Develops off-grid licensing frameworks and technical standards for solar and clean cooking.

c. Rural Electrification Fund (REF)

- Administers grants and incentives to mini-grid developers.
- Relevant to SophiA scale-up strategies in rural clinics and schools.

d. Community Energy Malawi (CEM)

- Influential NGO and technical advisor focusing on community-driven energy access, including productive uses like cooling and water treatment.

e. Ministry of Water and Sanitation



- Coordinate and provide policy direction on water, sanitation and hygiene matters.
- A corporate office is responsible for policy, planning, general management and administration.

f. Ministry of Agriculture

- It oversees programs that promote rural electrification, agro-processing, and water management.
- Aligns agricultural modernization and rural development strategies with Malawi's energy transition goals.
- Works with other ministries (such as Health and Energy) to ensure that rural infrastructure upgrades—especially those involving cold chains for food and vaccines, water access, and productive use of energy—are coordinated and sustainable.

g. Ministry of Health

- Oversees the electrification and upgrading of hospitals, clinics, and rural health posts.
- Aligns health sector investments and procurement processes with Malawi's national energy transition and rural electrification strategies.

2.3.4 Uganda

a. Ministry of Health

- Driving force behind the country's efforts to modernize health infrastructure and expand access to essential services in rural areas.
- It is instrumental in pushing the adoption of solar-powered systems, reliable cold chains for vaccines and medicines, and clean water solutions in clinics and hospitals.

b. Ministry of Agriculture, Animal Industry and Fisheries

- It is a central player in shaping rural development and agricultural modernization.
- In the context of green energy transition, the ministry is actively involved in promoting sustainable practices, supporting rural electrification, and improving water management for farming communities.

c. Ministry of Energy and Mineral Development (MEMD)

- National lead on energy transition, implementing the Energy Policy for Uganda (2023) and Electricity Connections Policy, both with strong off-grid components.

d. REA – Rural Electrification Agency (being integrated into the Electricity Regulatory Authority as of recent reforms)

- Formerly the lead implementing body for off-grid electrification and mini-grid programs.
- Oversaw large-scale solar PV deployments and energy-for-health projects.

e. Uganda Energy Credit Capitalisation Company (UECCC)



D7.6: Upscaling and roadmap for green energy transition in Africa using SophiA technology

- Provides financial instruments (loans, guarantees) to off-grid solar and clean cooking enterprises.
- Key to supporting private sector uptake of technologies like SophiA's.

f. GIZ/EnDev Uganda & Power Africa Uganda Accelerator

- Donor-supported programs with strong links to solar cooling, clean water tech, and market building for energy access solutions.

g. Ministry of Water and Environment

- Directorate of Water Development and Directorate of Water Resource Management under the ministry operates via agencies such as National Water and Sewerage Corporation (NWSC) and National Environment Management Authority (NEMA) to regulate and promote water resource management.

2.4 Relevant academic and knowledge actors

2iE (Institut International d'Ingénierie de l'Eau et de l'Environnement) is a leading academic and research institution in Burkina Faso focused on water, energy, and environmental engineering. In Africa's green energy transition, 2iE plays a pivotal role by advancing research, training local technicians and engineers, and developing innovative solutions tailored to African contexts. For SophiA, 2iE has contributed technical expertise, capacity building, and field validation—helping to adapt, test, and optimize modular energy, cooling, and water systems for rural clinics and communities. Their involvement has ensured that SophiA technologies are locally relevant, scalable, and supported by a skilled workforce, making 2iE a key driver for successful deployment and long-term sustainability in West Africa.

Makerere University is a leading academic institution in Uganda, recognized for its research and innovation in energy, agriculture, and health. In the continent's green energy transition, Makerere University contributes by developing and testing sustainable technologies, training local experts, and supporting evidence-based policy. For SophiA, Makerere's role included piloting and validating modular energy, cooling, and water systems in Ugandan contexts, sharing technical expertise, and building local capacity. Their involvement helped to ensure that SophiA solutions are adapted to real-world needs, scalable across rural communities, and supported by a skilled workforce—making Makerere a valuable partner for successful deployment and long-term impact in Uganda.

The African Centre of Excellence for Sustainable Cooling and Cold-chain (ACES), headquartered in Rwanda and supported by the University of Rwanda in collaboration with the UK government and UNEP, has emerged as a cornerstone initiative. ACES functions as a knowledge and demonstration hub, developing and testing decentralized, solar-powered cooling systems for agricultural produce and vaccines. Its role is pivotal in bridging technological innovation with practical application, training local technicians, and scaling affordable solutions across East Africa and beyond.

Situated in Malawi, Mzuzu University is a public institution that offers programs in renewable energy technologies through its Faculty of Science, Technology, and Innovation. The university operates the Test and Training Centre for Renewable Energy Technologies (TCRET), which



serves as a hub for research and training in renewable energy. By providing education and practical skills in this field, Mzuni plays a vital role in promoting sustainable energy solutions in Malawi.

2.5 Pan-African Business and Practitioners' Networks

Pan-African business and practitioners' networks have emerged as critical enablers of Africa's off-grid green energy transition, serving as platforms for collaboration, advocacy, innovation, and investment among private sector actors operating across the continent.

U-3ARC (Union of Associations of African Actors in Refrigeration and Air Conditioning (U-3ARC, 2025) is a pan-African practitioner network that connects professionals, technicians, and organizations working in cooling and refrigeration. In Africa's green energy transition, U-3ARC plays a vital role in several ways: It promotes sustainable refrigeration practices by advocating for the adoption of natural refrigerants and energy-efficient cooling technologies, facilitates knowledge exchange and capacity building across the continent, and supports local training and technician certification, thus addressing the critical shortage of skilled professionals needed to install, operate, and maintain advanced cooling and refrigeration systems in Africa.

One of the most influential is the Alliance for Rural Electrification (ARE) (Alliance for Rural Electrification 2025), which, although global, has a strong African footprint and actively engages African mini-grid developers, solar home system providers, and clean cooking entrepreneurs. ARE supports its members through market intelligence, policy dialogue, capacity building, and matchmaking with financiers, particularly in emerging markets.

Similarly, the Africa Mini-Grid Developers Association (AMDA) (AMDA 2025) is a dedicated pan-African network that represents mini-grid operators and developers, advocating for improved regulatory frameworks, financing models, and operational standards tailored to Africa's rural energy realities. AMDA's national chapters — in Kenya, Nigeria, Tanzania, and beyond — facilitate local engagement while feeding into continental and global policy processes. Currently, AMDA represents over 56 member companies across 24 countries in five regions on the continent.

The African Solar Industry Association (AFSIA) (AFSIA 2024) is another rapidly growing business network that fosters knowledge exchange and investment for solar PV across multiple applications, from rooftop to utility-scale, and increasingly in off-grid health, water, and agricultural services. AFSIA publishes market reports and offers networking events that bring together suppliers, installers, financiers, and policymakers. The association also recognizes excellence in the solar industry through initiatives like the AFSIA Solar Awards.

Additionally, the Renewable Energy Solutions for Africa Foundation (RES4Africa) (RES4AFRICA 2023), while technically a foundation, functions as a hybrid business-policy platform that includes African and international companies working in energy access. It plays a convening role to align private sector strategies with national energy policies and donor programs, especially through its capacity-building initiatives such as Micro-Grid Academy.



Together, these networks fill a vital gap by supporting private sector leadership, facilitating cross-border knowledge transfer, and shaping a more cohesive African market for off-grid renewables, energy storage, clean cooking, and solar-powered productive use technologies. Their influence ensures that the business environment evolves in tandem with policy goals, particularly in underserved rural and peri-urban markets.

2.6 Corporate actors, innovation hubs, startups and social enterprises

2.6.1 Off-Grid Solar PV & System Integration

- **d.light** (d.light 2025): A global leader in solar home systems, d.light has provided clean power to over 30 million households across 72 countries, including Kenya, Nigeria, Uganda, and Tanzania. Their pay-as-you-go model makes solar energy accessible to low-income communities, and their efforts have helped avoid 38 million metric tons of CO₂ emissions since 2007.
- **Husk Power Systems** (HUSK 2025): Operating in Nigeria and other regions, Husk Power Systems develops solar hybrid mini-grids that serve entire rural economies. Their systems power households, businesses, and productive uses like grain milling and water purification, offering a 30% cost saving over diesel alternatives.
- **ARED (African Renewable Energy Distributor)** (ARED 2024): Based in Rwanda, ARED deploys solar-powered "Shiriki Hubs"—kiosks that provide phone charging, Wi-Fi, and digital services in rural and refugee communities. These hubs enhance digital inclusivity and are expanding into Uganda, Ivory Coast, and Nigeria.

2.6.2 Clean Cooking Technologies

- **KOKO Networks** (KOKO 2025): Headquartered in Nairobi, KOKO Networks offers bioethanol cooking solutions to replace charcoal. With over 1 million households served in Kenya and Rwanda, their system includes smart fuel dispensers and affordable cookstoves, supported by carbon credit financing.
- **Burn Manufacturing** (BURN 2025): Based in Kenya, Burn Manufacturing has sold over 4.5 million clean cookstoves across Africa. Their products reduce deforestation and health risks associated with traditional cooking methods. In 2023, they launched Africa's first carbon credit futures based on emissions reductions from efficient cookstoves.

2.6.3 Renewable Energy-Based Refrigeration

ColdHubs in Nigeria exemplifies a scalable model—offering pay-per-use, solar-powered walk-in cold rooms for perishable produce in open-air markets. This innovation directly reduces post-harvest losses for smallholder farmers, who otherwise lack refrigeration access. In Kenya, Solar Freeze—now part of SokoFresh—has developed mobile solar-powered cold storage units that operate as service hubs for rural farming cooperatives. These systems are vital in extending shelf life and stabilizing incomes in the face of unreliable grids.



International startups like Ecozen and Inficold (originally from India) have expanded their pilot operations to Ghana, Kenya, and other African countries, bringing solar-powered cold rooms and thermal energy storage innovations into agribusiness value chains. South Africa's Bokamoso Impact takes an integrated approach, coupling renewable energy and cold chain solutions with skills development and agro-processing for rural women and youth. SureChill, active in southern Africa, provides off-grid, solar-compatible refrigeration for medical and vaccine storage using water-based thermal energy storage—well suited for health clinics lacking consistent electricity. These enterprises represent a new generation of African innovators that are linking energy access with broader development objectives.

2.6.4 Water Treatment & Access

- Innovation: Africa (innovation: africa 2021): This non-profit organization installs solar-powered water pumping systems in rural African villages, delivering clean water to schools and medical centers. Their approach includes training local technicians and using remote monitoring to ensure sustainability. Their projects also include solar refrigeration for vaccine storage, benefiting over 5.4 million people across 10 countries.
- Majik Water (MAJIK WATER 2024): Co-founded by Kenyan entrepreneur Beth Koigi, Majik Water develops atmospheric water generators that extract clean drinking water from air humidity. This technology provides a sustainable water source for off-grid communities lacking reliable access to clean water.

3. EXISTING ROADMAPS IN THE AREA

3.1 Continental strategies and roadmaps

a. African Energy Transition Programme (African Union Commission – Energy Department) (AFREC 2025)

The African Energy Transition Programme—spearheaded by the African Union Commission's Energy Department—offers a continental framework to guide countries towards inclusive, just, and climate-resilient energy systems. A core pillar of this program is its prioritization of decentralized renewable energy for underserved communities, recognizing the importance of off-grid solar PV, clean cooking technologies, and renewable energy-based refrigeration. It calls for harmonization of national policies with AU-wide energy goals and provides technical assistance to member states to integrate clean energy into development planning. Moreover, it supports the coupling of energy with agriculture, healthcare, and water, enabling uptake of technologies like solar water pumping and filtration systems. It acts as a connective policy tissue for aligning development aid, national plans, and regional implementation under one strategic umbrella.

b. Continental Power Systems Master Plan (CMP) – AUDA-NEPAD (AUDA-NEPAD 2022)

The Continental Master Plan (CMP), under the guidance of AUDA-NEPAD, serves as a long-term infrastructure and investment roadmap for Africa's power system integration. Although initially centered around regional electricity trade, the CMP recognizes that universal access cannot be achieved without a significant role for off-grid and mini-grid systems powered by



solar PV and supported by energy storage. The CMP outlines the need for hybrid planning that supports both transmission infrastructure and distributed, community-scale interventions. This includes provisions for off-grid cold storage, clean cooking systems, and the integration of solar-based water treatment technologies in rural areas. The plan also calls for closer collaboration with regional economic communities to localize its impact and identify viable investment corridors for off-grid innovation.

c. Africa Renewable Energy Initiative (AREI)

The Africa Renewable Energy Initiative (AREI) is a politically endorsed continental initiative with a unique focus on accelerating renewable energy deployment, especially in off-grid and underserved regions. Its roadmap targets the installation of 300 GW of renewable capacity by 2030, prioritizing community-level projects over utility-scale developments. The initiative supports projects involving solar mini-grids, standalone PV, battery storage, and clean cooking—especially those that deliver gender equity and poverty alleviation. AREI's technical body works with countries to assess project bankability, and it has actively supported innovations such as solar refrigeration for agriculture and health clinics as well as integrated energy-water systems for rural use. AREI promotes decentralized development as an energy justice issue and helps attract international finance aligned with African-led priorities.

d. Africa 2030 Renewable Energy Roadmap (IRENA) (IRENA 2015)

Although not an African-led roadmap, the IRENA Africa 2030 Renewable Energy Roadmap has shaped many continental and national strategies by demonstrating how Africa can meet its energy needs using predominantly renewables. The roadmap features deployment scenarios with substantial shares of off-grid solar PV, distributed energy storage, and productive-use applications such as solar-powered cooling and clean cooking. It emphasizes cross-sector linkages, with scenarios modelling the energy needed for sustainable water access, including pumping, treatment, and purification. While proposing a renewable energy share of up to 50% in total energy generation by 2030, it also integrates renewable energy with other development goals such as health, education and food security. A notable recommendation is the shift from traditional biomass combustion to modern renewable energy cooking solutions, which could reduce the use of traditional cook stoves by over 60%, leading to substantial health benefits and economic savings. It has helped influence subsequent planning efforts, including the CMP, and encourages the development of enabling regulatory and investment environments tailored to local market realities. Recent updates of the roadmap include the *Renewable Energy Transition in Africa* (2021) and *Towards a Prosperous and Sustainable Africa* (2022).

e. Sustainable Scaling: Meeting the Clean Cooking Challenge in Africa (2024) (AFREC 2024)

This publication, led by the African Energy Commission (AFREC), presents a continent-wide call to action for integrating clean cooking solutions into national energy and socio-economic development frameworks. It moves away from one-size-fits-all models, emphasizing the need for locally adapted technologies that reflect the cooking habits, fuel availability, and cultural preferences of diverse African communities. The strategy focuses on three key enablers: policy mainstreaming, capacity development, and market-based incentives for clean cooking innovation. Importantly, it advocates for the inclusion of clean cooking in national electrification and off-grid strategies, calling for close alignment with renewable energy policies and



decentralized infrastructure planning. SophiA's pilot deployments in remote health facilities and community hubs demonstrate exactly the kind of integrated, context-specific innovation promoted in the report. By aligning with this strategy, SophiA can frame its systems as blueprints for scalable clean cooking infrastructure in energy-poor regions.

f. Clean Cooking Declaration (2024) (IEA (2025) - IEA

In what was described as a landmark gathering, the International Energy Agency (IEA) convened more than 1,000 public and private stakeholders to issue a joint declaration making 2024 a “pivotal year” for universal clean cooking access in Africa. The declaration included significant financial commitments from development banks, energy ministries, and philanthropic foundations, aiming to unlock both public and blended financing mechanisms. It outlines a framework for co-investment in innovation, focusing on off-grid and decentralized cooking technologies, particularly those that use electricity or renewable biofuels.

Relevance for SophiA: The IEA's push for co-investment and innovation aligns directly with SophiA's ambition to scale solar-powered and integrated energy solutions in remote areas. As part of a project already field-testing advanced energy systems in healthcare and community infrastructure, SophiA stands to benefit from the financial and policy support endorsed by this declaration. The prioritization of off-grid electrified cooking systems validates SophiA's technical approach and may serve as a gateway for future public-private partnerships.

3.2 National strategies and roadmaps in SophiA countries

3.2.1 Burkina Faso – Rural Electrification Strategy 2024–2028

Burkina Faso's updated strategy explicitly centres on leveraging solar energy for rural electrification, aiming for 50% rural coverage by 2028. Its alignment with the Desert-to-Power initiative makes it particularly relevant for the SophiA technologies, especially in regions where grid extension is economically unfeasible. The strategy supports standalone solar systems, mini-grids, and importantly, the deployment of solar-powered refrigeration systems and water pumping. These align directly with SophiA's integrated container approach, which bundles solar PV, storage, refrigeration (using natural refrigerants), and water purification. Given Burkina Faso's focus on strengthening agricultural value chains and rural healthcare, SophiA's system has strong use cases—such as vaccine storage and clean water for clinics. The roadmap also emphasizes partnerships with international donors and private actors, creating an enabling environment for the scaling of pilot projects like SophiA into national programs.

3.2.2 Cameroon – Updated Rural Electrification Master Plan

Cameroon's revised Master Plan reflects a decentralized electrification approach, increasingly relying on off-grid systems to reach remote regions. Although traditionally dominated by grid extension policies, the update shows a shift toward hybrid models combining grid, mini-grid, and standalone solar. The inclusion of productive use components, such as solar-powered agro-processing and cooling, presents a pathway for technologies like SophiA. The recent MoU between EDF Cameroon and the Rural Electrification Agency illustrates growing openness to technology demonstration and private sector involvement. Cameroon's rural zones, often characterized by poor access to refrigeration and water treatment, stand to benefit



from SophiA's modular, containerized solution. However, water treatment is not yet as prominently addressed, suggesting that integrating SophiA's capabilities into ongoing health and WASH (Water, Sanitation, and Hygiene) programs could enhance policy traction and scalability.

3.2.3 Uganda – Renewable Energy Strategy 2024–2027 & Solar Productive Use Roadmap

Uganda's 2024–2027 Renewable Energy Strategy and its complementary Productive Use of Renewable Energy (PURE) Roadmap are highly aligned with SophiA's objectives. The country has a mature off-grid solar market, bolstered by proactive policies that incentivize solar entrepreneurship and target refugee-hosting and underserved regions. The PURE roadmap, in particular, highlights the integration of solar PV with cold storage, water pumping, and purification technologies—a near-perfect match for SophiA's integrated system. Uganda's policy also supports local manufacturing and after-sales service, key components for long-term sustainability and technology adoption. With clear policy backing and donor coordination mechanisms in place, Uganda presents a fertile ground for SophiA upscaling, especially through public-private partnerships in rural electrification and agro-health nexus programs.

3.2.4 South Africa – Just Transition Framework & IPP Modernization

South Africa's Just Energy Transition Implementation Plan (JET IP), approved in 2023, outlines the country's roadmap for transitioning to a low-carbon economy over five years. The JET IP serves as a central framework for coordinating efforts and mobilizing resources to achieve South Africa's climate and energy goals. It is the most macroeconomic and politically structured of the four, positioning the green energy transition within a just development framework. While it traditionally focuses on utility-scale transitions (coal-to-renewables), it also incorporates off-grid and municipal support to reach informal and peri-urban areas. The inclusion of green industries and skills development provides opportunities for scaling technologies like SophiA through local assembly, technician training, and integration with public service delivery. South Africa's advanced cooling and water treatment sectors—including a robust R&D environment—could enable technological refinement and commercialization of SophiA's components. However, adoption in ultra-remote regions is less emphasized than in other countries. The project could gain traction by aligning with JET IP's municipal service and health infrastructure components, especially under initiatives linked to energy access for clinics and schools.

4. TECHNOLOGICAL AND MARKET DRIVERS AND FUTURE APPLICATION

4.1 Technological drivers

a. Clean Cooking: Solar Electric Pressure Cookers & Low-Wattage Induction

In clean cooking, electrification of cooking appliances—particularly through induction and resistive cookers adapted for low-wattage use—is a central technological driver. Advances in insulated cookstove design and smart metering have made it possible to reduce energy



demand without compromising performance. Field trials under the Modern Energy Cooking Services (MECS) programme in Malawi demonstrated that an off-grid solar-PV-powered electric pressure cooker (EPC) system can be delivered for US \$200–300 per unit, with life-cycle cost parity to charcoal within five years. (IEA 2025) Laboratory and pilot studies further show that low-wattage induction stoves integrated into mini-grids reduce cooking energy demand by 40–60 % compared to resistive hotplates, while maintaining cooking performance (MECS 2023). These findings, complemented by the experience in the SophiA demo sites, indicate the relevance of integrating solar cooking in the overall SophiA concept. Its implementation of solar powered steam cookers in hospital kitchens including a thermal energy storage unit showcases the diverse opportunities for off-grid clean cooking.

b. Renewable energy-based refrigeration

Technological breakthroughs in renewable energy-based refrigeration are a foundational driver for applications such as vaccine storage and food preservation in remote settings. A major advancement is the use of Phase Change Materials (PCMs) -such as paraffin and salt-hydrate composites-, which can store thermal energy for extended periods, allowing refrigeration units to maintain cold temperatures overnight or during cloudy days without continuous electricity input. Recent research demonstrates that embedding PCMs in solar vaccine refrigerators can maintain 2 – 8 °C for up to 72 hours without power making them highly compatible with solar-powered electric batteries. Another key innovation is the use of natural refrigerants like R290 (propane), which offer high thermodynamic efficiency and near-zero global warming potential (GWP), outperforming HydroFluroCarbons (HFCs) in off-grid DC compressor systems. The evolution of DC-powered, solar-direct refrigerators with brushless DC compressors and intelligent controllers has also significantly increased system reliability and reduced energy consumption. SophiA technologies align with these trends by integrating solar PV with PCM-enhanced refrigeration units that utilize natural refrigerants, ensuring not only energy efficiency and environmental safety but also improved operational resilience in areas with limited grid access.

c. System Integration: Digital Energy Management and Modular Architecture

The ability to integrate diverse energy services—solar PV, storage, cooking, cooling, and water treatment—into a unified, smartly managed system is one of the most transformative technological drivers in off-grid electrification. Recent developments in digital energy management systems (EMS), microgrid controllers, and open-source interoperability platforms have enabled real-time optimization of energy generation, storage, and end-use loads. These tools allow for predictive maintenance, remote monitoring, and adaptive load balancing, ensuring that limited energy resources are deployed most efficiently. Modular system architecture, which facilitates plug-and-play expansion of different services, is also enabling the deployment of tailored systems to meet diverse community needs. In the SophiA context, system integration technologies are critical to ensure that each energy-consuming component—refrigerators, SteamCube, water treatment systems—operates within an optimized and adaptive environment that enhances performance, prolongs component life, and minimizes downtime. However, in early stages of deployment, it might be preferred to work with independent systems that offer a more robust approach, facilitate the identification and solving of mistakes and thereby reduce system downtime.

d. Water Treatment: Solar-Powered Filtration and Membrane Innovation



Technological drivers in water treatment for off-grid environments have been significantly accelerated by advances in low-energy, solar-compatible filtration systems. Ultrafiltration (UF) membranes enable the removal of pathogens and suspended particles using minimal energy input, often requiring only gravity flow or small DC-powered pumps. The integration of solar PV with water treatment technologies, such as solar-powered UV disinfection or membrane filtration, has opened up new opportunities for decentralized clean water access. Another emerging trend is the use of membrane capacitive deionisation (MCDI) to remove the ions from water to produce deionized water. All these technologies can be combined in multi-stage approach to build a compact, field-deployable system. For SophiA, these innovations are essential: the project's units must deliver clean water in remote clinics, often with unreliable or no grid connection. The deployment of robust, low-maintenance, solar-powered water treatment systems aligns well with current technological trajectories and enhances the self-sufficiency of SophiA's decentralized energy-water-health nexus.

4.2 Market drivers

a. Expanding Off-Grid Energy Demand

Sub-Saharan Africa continues to face a massive energy access gap, with over 600 million people lacking electricity, particularly in remote and peri-urban areas. Many national electrification strategies now prioritize off-grid and mini-grid solutions where grid extension is economically or logistically unfeasible. Governments—including in Burkina Faso, Uganda, and Malawi (SophiA demo countries)—are increasingly funding decentralized solutions under their National Electrification Plans or Rural Energy Agencies. The SophiA containerized energy units, integrating solar PV, battery storage, and thermal cooling, directly respond to this demand by offering ready-to-deploy, self-sufficient infrastructure. By delivering energy access plus critical services—such as cooling, clean water, and digital connectivity—SophiA-type platforms can leapfrog traditional infrastructure models. This aligns with donor programs like the World Bank's Scaling Solar and Power Africa's Off-Grid Challenge, which are fostering local deployment partnerships (UNEP-CCC 2024).

b. Strengthening Healthcare Infrastructure Post-COVID

COVID-19 revealed how fragile and under-resourced rural healthcare systems are, especially in their ability to maintain vaccine cold chains, support basic diagnostics, and provide safe water. This has led to a surge in investments from actors like UNICEF, Gavi, and WHO into off-grid healthcare infrastructure. The African CDC's regional strategies now emphasize resilient, decentralized health facilities, which aligns with the core use case of SophiA: equipping rural clinics with solar-powered cooling, medical-grade refrigeration (using natural refrigerants), and water treatment. SophiA's capacity to power digital medical tools (like point-of-care diagnostics) also positions it as a healthtech enabler, directly supporting national health infrastructure strengthening efforts in target countries. Several procurement rounds under UNICEF's Cold Chain Equipment Optimization Platform (CCEOP) are now specifying solar direct-drive refrigeration and climate-resilient infrastructure - criteria SophiA technologies meet (IEA 2022).

c. Climate Finance and Low-Carbon Development Goals

SophiA's modular technologies are low-carbon by design—powered by solar, utilizing natural refrigerants like propane (R290) and R744 (CO₂), and offering energy-efficient water



purification and cooling. This aligns strongly with eligibility requirements for climate finance, a rapidly expanding funding stream. The Green Climate Fund (GCF) (Greenclimate Fund 2024), Africa Climate Foundation, and AfDB's Sustainable Energy Fund for Africa (SEFA) (African Development Bank Group 2024) are increasingly investing in cross-sectoral projects that reduce emissions while improving service delivery. SophiA's role as an enabler of both climate mitigation (through decarbonized infrastructure) and climate adaptation (via resilient health, energy, and water services) makes it an ideal candidate for climate-aligned funding. These instruments are also increasingly geared towards results-based financing models, which suit SophiA's quantifiable impacts in energy savings, emissions reductions, and service delivery.

d. Bundled Demand for Energy, Water, Cooling, and ICT

Across Africa, especially in rural areas, service delivery models are shifting toward multi-sectoral integration. Communities and clinics don't just need electricity—they require clean water, reliable cooling, and increasingly, connectivity for diagnostics and education. SophiA technologies combine all these into a single modular package. This bundled approach reduces deployment complexity, offers economies of scale, and supports multiple development goals (health, water, education, energy) with one investment. Initiatives such as UNDP's Solar for Health (UNDP 2025 a), GIZ's Energising Development (EnDev) (endev 2025), and the Africa Minigrids Programme (AMP) (UNDP 2025 b) favour such integrated platforms that go beyond lighting or power-only solutions. SophiA's modularity also makes it easy to tailor to local needs, a significant value proposition in funding rounds targeting “nexus” solutions (UNDP Solar for Health).

e. Telemedicine and Digital Health Infrastructure Expansion

The rise of telemedicine, mobile health platforms, and electronic medical records in Africa is rapidly increasing the need for reliable power and connectivity in rural clinics. Ministries of Health in Uganda (ICTworks 2023) and Senegal (Senenews 2025), for example, have launched digital health strategies that explicitly require electrified rural health centres. More broadly, a recent study has assessed the current state of national eHealth strategies in Africa (Oxford Open Digital Health 2024). The WHO Regional Office for Africa has also prioritized digital infrastructure in its health system strengthening agenda (WHO, African Region 2025). SophiA's ability to act as a “digital health node”—powering servers, routers, charging stations, and diagnostic tools—makes it highly relevant to these trends. The modular infrastructure can serve as the backbone for rural teleconsultation networks or vaccine registration systems, making it not just an energy solution, but a digital enabler of health transformation.

f. Local Manufacturing and Assembly Ecosystems

There is growing political and economic pressure to localize the production and assembly of clean energy technologies. Countries like Kenya, South Africa, Nigeria, and Rwanda have emerging ecosystems for assembling solar modules, clean cookstoves, water filters, and cold chain equipment. African industrial policy frameworks, including the African Continental Free Trade Area (AfCFTA) (AU-AFCFTA 2025), are making local assembly increasingly viable by reducing cross-border tariffs and incentivizing local sourcing. For SophiA, this creates an opportunity to reduce costs, improve maintainability, and create jobs by partnering with regional firms to produce components or assemble units closer to end-users. Initiatives like GEAPP's distributed energy manufacturing partnerships (GEAPP 2025) and GIZ's support for



local energy SMEs (ICTworks 2023) highlight the importance of regional innovation and fabrication hubs.

g. Evolving Procurement Standards and Donor Norms

International procurement frameworks are adapting to climate and health challenges, opening new space for integrated, modular, and performance-based infrastructure. Agencies like UNICEF, UNDP, WHO, and The Global Fund are moving away from large, centralized procurement in favour of decentralized, flexible platforms that support resilient service delivery. SophiA-type solutions can benefit from these reforms, especially where procurement criteria now include life-cycle costs, emissions profiles, and service integration potential. For example, the Global Fund latest New Funding Model 4 (ASWA Alliance 2025) allows health infrastructure spending on energy and water systems that improve outcomes. These new norms make it easier for innovative systems like SophiA to qualify for tenders and donor pipelines.

5. PRACTICAL REALITIES FROM SOPHIA AND SIMILAR RESEARCH PROJECTS

5.1 Technological barriers identified

a. Technical Complexity and System Integration

The SophiA technologies represent a convergence of multiple advanced systems—solar photovoltaic power, battery storage, water purification, medical refrigeration, HVAC, and ICT-enabled remote monitoring. While this integration is a technical strength, it also presents a major barrier: the complexity exceeds what many local service technicians or healthcare workers in remote settings are trained to manage. For example, ensuring that a solar-powered refrigeration unit harmoniously operates with a water purification system and digital sensors requires sophisticated system design and installation know-how. The lack of such local expertise can lead to higher upfront engineering costs, longer deployment timelines, and a dependency on external technical support. In field settings such as rural clinics, where even basic infrastructure may be lacking, this challenge can delay adoption or undermine sustainability.

b. Energy Storage and Power Management

Reliable energy storage is a linchpin for off-grid energy systems, particularly in healthcare settings where uninterrupted power is critical for services like vaccine refrigeration or emergency lighting. However, the lithium-ion batteries often used for energy storage remain expensive, degrade in hot climates, and require replacement every few years. This is a significant concern for sun-exposed, containerized units like those used in SophiA systems. Despite being covered by their own PV array for shading and AC systems added to cool batteries, these limitations threaten both the financial sustainability and technical reliability of the solution. Technologies like thermal storage (e.g., SureChill's cooling technology) or hybrid energy systems are emerging alternatives, but they too come with trade-offs in terms of cost, size, or complexity. Without innovation in affordable, long-lasting storage suited for African



climates, power reliability remains a weak link. The PVSteamCube is an approach for battery-less storage of electricity for thermal applications as it is also hybrid (i.e., can be powered by grid, generator or solar PV).

c. **Water Purification Technologies**

Access to clean water is critical for healthcare, and SophiA technologies incorporate advanced purification methods such as UF and MCDI technologies. These technologies, while effective, pose operational challenges in rural settings. They require stable power inputs, pre-filter (cartridge filter) replacements, and regular checks, all of which are difficult to ensure in remote areas with limited technical capacity or workforce. In many cases, if the filtration system malfunctions, the entire benefit of deploying such units is compromised—especially in environments where waterborne diseases are prevalent. Ensuring long-term water safety thus demands a robust yet simple technology design, committed maintenance workforce and routine checks as part of maintenance.

d. **Natural refrigerants**

While the adoption of natural refrigerants such as CO₂ (R744) and propane (R290) is essential for sustainable refrigeration and minimizing climate impact, their use introduces notable technical challenges in the context of SophiA deployments. CO₂ operates at very high pressures, which can be particularly problematic in warm climates commonly found in Sub-Saharan Africa; elevated ambient temperatures further increase system pressure, demanding robust engineering and specialized components to ensure safety and reliability. This not only raises costs but also complicates maintenance and repair in remote settings. Propane, on the other hand, is highly flammable, requiring stringent safety protocols, careful system design, and thorough technician training to mitigate fire risks. These safety requirements can be difficult to uphold in rural environments with limited technical capacity. As a result, while natural refrigerants offer clear environmental benefits, their technical drawbacks—high operating pressures for CO₂ and flammability for propane—pose significant barriers to widespread, sustainable adoption in off-grid health and energy infrastructure.

e. **Maintenance and Spare Parts Availability**

A core challenge for any off-grid infrastructure in remote areas is the availability of maintenance services and spare parts. Technologies like SophiA's rely on specialized components—such as inverters, pumps, and programmable logic controllers—that are not commonly stocked in rural African markets. If one part fails, the whole system may become inoperable, reducing community trust and leading to underutilization or abandonment. Furthermore, long lead times to ship parts or deploy technicians further compound downtime. Overcoming this barrier requires building local maintenance ecosystems, training technicians, and developing regional supply chains—actions that often fall outside the immediate project scope but are crucial for long-term sustainability. Also, technical staff may fluctuate and based on experience, there is little emphasis on know-how transfer to new staff, causing severe issues for project sustainability.

f. **Monitoring and Remote Diagnostics**

To ensure system functionality and troubleshoot issues before they escalate, remote monitoring via the Global System for Mobile Communications (GSM), satellite, or IoT-enabled systems is indispensable. However, many of the target deployment regions for SophiA



technologies suffer from unreliable cellular coverage or prohibitively high satellite data costs. This makes real-time diagnostics difficult, leading to undetected system failures that persist until a technician can physically visit the site. Some promising innovations include low-bandwidth IoT platforms with offline syncing and LoRaWAN-based communication systems. However, these remain at pilot stages and require broader deployment to become effective. Based on local experience in rural Malawi, Starlink could possibly offer a solution for remote hospitals. In any case, a scalable solution must balance cost, reliability, and connectivity constraints.

g. Environmental and Contextual Adaptability

Although SophiA technologies are developed with robustness in mind, they are originally engineered in European settings, which may not mirror the environmental conditions faced in Sub-Saharan Africa. High ambient temperatures, dust infiltration, humidity, and heavy rains can stress components and accelerate wear. For instance, electronics in coastal zones may suffer from corrosion, while systems in semi-arid zones may overheat without proper passive cooling. This mismatch between design assumptions and field realities can reduce the lifespan and efficiency of equipment. Therefore, climate-resilient redesigns—such as better ventilation, waterproofing, and dust shielding—are necessary to make these systems fully compatible with their deployment environments.

h. Interoperability with National Health and Infrastructure Systems

One often overlooked barrier is the difficulty of integrating new technologies like SophiA's into existing national systems for health, water, and energy. For instance, the data protocols used by the SophiA digital monitoring tools may not be compatible with national health information systems. Similarly, standalone water purification units might not align with municipal or regional water safety standards. In fragmented infrastructure environments, each new system often requires bespoke adaptations, training programs, and cross-sectoral coordination. This increases the administrative burden and slows scale-up. Establishing open standards and ensuring compatibility with national and regional frameworks early in the design process is therefore essential.

5.2 Market barriers identified

a. High Upfront Costs

Despite offering long-term benefits such as self-sufficient renewable energy use, energy savings and improved health service delivery, SophiA technologies are burdened by high upfront capital costs. These costs arise from the combination of solar PV and battery systems, medical-grade refrigeration, advanced water purification, IoT-enabled diagnostics, and the containerized structure itself. For rural clinics, local governments, and NGOs operating under tight or unpredictable budgets, such investments are often unattainable without external support. Furthermore, institutional funding processes—such as government procurement or donor programs—are slow and frequently prioritize cheaper, short-term solutions over capital-intensive, long-term infrastructure, and often neglect relevant maintenance efforts. Also, high import taxes on e.g. refrigeration equipment pose a large barrier to large scale deployment. As a result, promising solutions like SophiA often remain sidelined despite their transformative potential.



b. Lack of Sustainable Financing Mechanisms

There is a notable absence of financing models tailored to integrated off-grid healthcare and utility solutions in Africa. Technologies like SophiA require not only capital expenditure (CAPEX) financing but also long-term support for operational costs (OPEX), including maintenance, system updates, and personnel training. Yet few mechanisms exist that bundle these costs into flexible packages, such as lease-to-own agreements, revolving health infrastructure funds, or performance-based subsidies. Furthermore, public health budgets and donor cycles rarely align with the multi-year investment horizons these solutions need. This financing gap results in many projects stagnating in pilot stages, rather than progressing to full national or regional implementation.

c. Fragmented Health Sector Procurement

Procurement processes in the African health sector are often centralized, bureaucratic, and heavily influenced by external funding agencies such as Gavi, the Global Fund, or WHO. These systems are typically project-based and siloed, treating water, energy, and health as separate verticals rather than recognizing their interdependence. Containerized, multi-utility systems like SophiA's challenge this structure, as they integrate across sectors and require coordinated procurement that is rare in practice. Without institutional frameworks that allow integrated tendering and budgeting, such systems face systemic obstacles to being evaluated, approved, and adopted at scale.

d. Limited Market Awareness

A significant barrier to wider adoption of containerized off-grid solutions is the limited awareness and understanding of their capabilities among decision-makers, health administrators, and civil society organizations. These technologies are often viewed as niche, experimental, or overly sophisticated for local conditions—despite being designed specifically for rural and under-resourced contexts. Misconceptions about their usability, maintenance requirements, or cost can lead to unjustified risk aversion. As a result, even where such systems are demonstrated to be effective, local demand remains weak unless proactive awareness-raising and demonstration efforts are undertaken. As there is a wide range of potential fields of applications for SophiA technologies, an important aspect to be clarified early on is the clear formulation of the target market.

e. Policy and Regulatory Gaps

In many African countries, policies and regulations do not yet support the integration of decentralized, off-grid energy and infrastructure solutions into public service delivery frameworks. There are few or no standards for evaluating modular health facilities, and import duties on key components—such as solar panels, inverters, or medical-grade refrigeration—can be prohibitive. Moreover, energy regulations may prohibit standalone solar systems or create uncertainties around feeding into mini-grids. These gaps generate uncertainty for investors and implementers, who must navigate unclear or restrictive environments that delay deployments and increase costs. Advocacy for enabling policies and harmonized standards is therefore essential for market entry and growth.

f. Logistics and operational effectiveness



A significant market barrier encountered in the SophiA project relates to logistics, transport, and regulatory compliance across African countries. Shipping containerized systems to remote sites is often subject to long delays, with components at risk of damage due to poor road infrastructure and exposure during sea transport. Each country imposes its own set of regulations and requires specific transport documents, which complicates planning and can lead to unexpected setbacks. Furthermore, many countries mandate Certificates of Conformance (COCs) for the import of systems like SophiA containers, but the standards and certification processes differ widely. This diversity increases manufacturing complexity and costs, as multiple certifications and inspections must be managed in parallel, often prolonging production timelines. While project-based waivers were obtained in Cameroon and Uganda, such exemptions are unlikely for commercial roll-out, making regulatory navigation and compliance a persistent and costly challenge for scaling SophiA technologies. An interesting path to explore in the future may be an increased use of locally available components.

g. Limited Local Ecosystem

An enduring challenge for technologies like SophiA's is the underdevelopment of local technical ecosystems to support installation, maintenance, and repair. In many regions, there are few trained technicians familiar with containerized multi-utility systems, and after-sales services are weak or non-existent. U-3ARC aims to address the African-wide exchange and sharing of practical knowledge on refrigeration technologies, but training infrastructure remains scarce. As highlighted by Madi Sakandé, president of U-3ARC, during the final SophiA meeting, some African countries only have one training centre for refrigeration technologies. This creates a bottleneck in scaling efforts, as international suppliers must shoulder the burden of support and training—an approach that is neither scalable nor sustainable. Without local value chains, including regional hubs for spare parts and servicing, these systems risk obsolescence due to minor failures that cannot be quickly addressed.

h. Absence of Scaled Case Studies

Widespread adoption of technologies in the public health and energy sectors often hinges on clear, replicable success stories—especially in similar geographic and economic contexts. As of now, there are few highly visible, multi-country demonstrations of integrated containerized systems delivering quantifiable benefits in Africa. This absence of robust, independent impact evaluations on health outcomes (e.g., improved maternal care, vaccine preservation), energy savings, or operational cost-effectiveness undermines the confidence of institutional buyers. For SophiA and from related projects, publishing detailed case studies with transparent monitoring data and clear cost-benefit analyses is critical to overcoming this credibility barrier.

i. Market Fragmentation Across Countries

While discussions often frame “Africa” as a singular market, the continent comprises 54 countries with diverse regulatory environments, health system structures, infrastructure quality, and procurement mechanisms. For example, off-grid energy policy in Kenya differs vastly from that in Burkina Faso or Malawi. This fragmentation means that a solution proven in one country may face a completely different regulatory, logistical, or financial context in another. Therefore, scaling technologies like SophiA across the continent demands not only product adaptation but also extensive in-country engagement and administrative groundwork. This complexity slows down expansion and increases the cost of regional market entry.



5.3 Related projects and lessons learned through exchanges in GDSO and KEN

Since the beginning of the project, SophiA has actively engaged in meetings organized by the European Climate, Infrastructure and Environment Executive Agency (CINEA), the European Commission's Green Deal Support Office (GDSO), and the project's self-established Knowledge Exchange Network (KEN). These platforms facilitated dialogue among EU-funded initiatives and relevant stakeholders, fostering mutual learning and collaboration.

Several projects funded under the same Horizon 2020 call (H2020-LC-GD-2020-1) share thematic and geographic synergies with SophiA:

- **ENERGICA** (ID 101037428) – *Green transition and energy access in urban and rural Africa*
- **REEFFECT Africa** (ID 101036900) – *Renewable energies for Africa: Effective valorization of agri-food wastes*
- **SESA** (ID 101037141) – *Smart energy solutions for Africa*
- **STEAMBioAfrica** (ID 101036401) – *Clean, affordable, and secure energy for Africa*



Figure 2: SophiA "sister projects", funded under the same call



In addition, the SophiA consortium consulted further projects and networks with complementary objectives:

- **AEDIB|NET (ID 101017105)** – *African European Digital Innovation Bridge Network*
- **ENRICHinAfrica (ID 101004709)** – *Connecting EU and Africa Innovation Ecosystems*
- **LEAP- RE (ID 963530)**– *Long-term joint EU-AU Research and Innovation Partnership on Renewable Energy*
 - **PURAMS (LEAP-RE project, ID 963530)** – *Productive use in rural African markets using standalone solar*
- **PrAEctiCe (ID 101084248)** – *Potentials of Agroecological practices in east Africa with a focus on Circular water-energy-nutrient systems*
- **SEADE (ID 101135194)** – *Strengthening the Europe-Africa Digital Ecosystem through increased R&I cooperation*

These exchanges have yielded valuable insights into shared challenges and potential joint solutions. A summary of major challenges and lessons learned thanks to these exchanges can be found below:

- **Ensuring long-term sustainability beyond funding cycles:**
A recurring challenge among EU-funded projects is the continuity of systems post-project. Technologies often have lifespans exceeding 10 years, yet maintenance responsibilities remain unclear. Discussions highlighted the importance of revenue-generating models that empower local stakeholders. For SophiA, this includes developing business models for hospitals and universities (e.g., training services, paid cooling solutions) to ensure operational sustainability.
- **Managing transport and logistics complexities:**
Moving equipment and resources across African countries has proven significantly more challenging than anticipated. Many countries have complex import and customs regulations, often resulting in costly delays and unforeseen expenses. Transport infrastructure varies widely, and the distances between project sites and key facilities, coupled with limited transport options, have created logistical hurdles that slow down implementation. Flexible timelines, contingency budgets, early permit acquisition, and thorough pre-shipment checks are essential. In SophiA, routing shipments via major cities before final delivery to rural sites helped mitigate risks.
- **Building trust through capacity building:**
Trust among stakeholders – ranging from local communities to government bodies – is vital. Summer schools and so called “Train the Trainers” capacity building programs have proven effective in fostering technical skills and cross-cultural collaboration between young professionals, industry experts, and local leaders. These educational



and collaborative initiatives not only build technical capacity but also encourage long-term, cross-cultural partnerships, enhancing the sustainability of project impacts.

- **Leveraging local partnerships for legitimacy and problem-solving:**
In African countries, especially where power structures and influence vary significantly by region, collaboration with highly respected local actors has been essential. Influential community leaders, local government officials, and reputable academic figures bring legitimacy to projects, helping to secure broader community buy-in and smoother execution. Local partners often have the nuanced understanding necessary to navigate challenges, such as aligning projects with community values, addressing logistical issues, or ensuring local customs and practices are respected. This local expertise should be used as early as possible already during planning and commissioning to address context-specific challenges.
- **Mitigating supply delays:**
Global market shortages and lengthy procurement processes have delayed component delivery. Close coordination with suppliers and flexible planning are key to minimize disruptions.
- **Adapting solar cooling solutions to context:**
While there is strong demand for affordable cold storage in rural areas, viable business models remain elusive. SophiA applied a “cooling as a service” model in hospitals, where ice produced for medical purposes can also be sold to local communities, offering a promising approach. Similar models from other projects (e.g., fish cooling in Indonesia (Hannovermesse 2021)) suggest replicability if tailored to local needs and affordability. Clear communication and translating technical topics into easy-to-understand language, as well as training and advocacy are essential to promote sustainable refrigeration practices.
- **Establishing viable business models:**
A major barrier is not unwillingness, but inability of end-users to pay for sustainable energy services. Without external support, scaling remains difficult. Early engagement with manufacturers, partnerships with international organizations (e.g., UNICEF, Red Cross, World Bank), and awareness campaigns are critical to ensure continuity beyond project funding.

On 18 November 2025 a final closure webinar between the five projects funded under the same Green Deal call (ENERGICA, SESA, SophiA, REFLECT Africa and SteamBioAfrica) will be organized by the Green Deal Support Office. This webinar will be open to public by registration, including EC representatives and represent another opportunity to share final project insights and lessons learned.



6. UPSCALING STRATEGIES AND POLICY RECOMMENDATIONS

6.1 Target audience: European Commission (EC)

a. Policy Recommendations:

To support scalable off-grid innovations like SophiA, the European Commission (EC) can embed integrated technology solutions in its broader foreign policy instruments. A key entry point is the EU Global Gateway strategy, which aims to boost sustainable infrastructure in partner countries, particularly in Africa. SophiA's holistic approach—connecting solar PV with health-relevant refrigeration, water purification, and clean cooking—aligns strongly with the EC's goals in climate-resilient healthcare, digital connectivity, and green energy transitions. The EC, particularly DG INTPA, DG ENER and DG CLIMA, should earmark dedicated financing windows within programs like NDICI–Global Europe and Horizon Europe to support such technologies, especially in rural health and educational facilities. Furthermore, the EC can encourage adoption through pre-commercial procurement pilots, facilitating market uptake by bridging the innovation-to-market gap.

The EC can also lead efforts to mainstream climate-health alignment in its cooperation with African countries. This would involve prioritizing solar-based cold chains and clean cooking in EU–Africa health resilience initiatives and ensuring SophiA-like technologies are eligible for funding under the Team Europe initiatives for health and energy. Policy guidance can help promote the use of natural refrigerants and water filtration systems, supporting the European Green Deal's external dimension and the AU-EU Innovation Agenda.

b. Scaling Strategies:

To accelerate deployment, the EC can establish a SophiA Innovation Deployment Window, supporting demonstration projects and local co-financing mechanisms through the EU–Africa Global Gateway Investment Package. Such a window could pool resources from EIB, national development banks, and African institutions to de-risk investment in bundled technologies. Additionally, the EC should promote industrial co-development partnerships, connecting European SMEs and innovators with African manufacturers and assemblers. For example, facilitating technology transfer and joint ventures around solar fridges, clean cooking and water filters could create green jobs while ensuring affordable, locally adapted solutions.

In parallel, the EC should fund efforts to harmonize regulatory standards for decentralized solar cooling and water systems, including safety standards for natural refrigerants (R290/R600a), smart energy integration, and modular clean cooking solutions. This can be done through regulatory cooperation with African regional economic communities and bodies such as ARSO (African Organisation for Standardisation).

6.2 Target audience: African Governments

a. Policy Recommendations:

African governments play a pivotal role in enabling a supportive environment for off-grid energy innovation and uptake. A priority is to integrate decentralized multi-service solutions—like SophiA's combination of solar PV, cold chain, clean cooking, and water—into National Electrification Plans and climate strategies, such as Nationally Determined Contributions



(NDCs). These plans often focus on grid extension or standalone solar kits, overlooking integrated units for community health and resilience. By formally recognizing bundled systems in energy access policies, governments can help anchor SophiA-type deployments in long-term rural infrastructure plans.

Governments should also revise and expand clean energy taxation and import frameworks, offering fiscal incentives for components like natural refrigerant compressors, solar inverters, and advanced water filtration membranes. Further, by embedding clean cooking and safe drinking water goals in national health and climate adaptation policies, countries can ensure that off-grid areas are prioritized for integrated service delivery. Meanwhile, ministries of energy, health, and environment should also collaborate on developing national performance standards for SophiA components, particularly where no standards currently exist for multi-service rural systems.

b. Scaling Strategies:

On the implementation side, governments can launch public-private deployment partnerships targeting last-mile service delivery. For example, Ministries of Health can jointly procure SophiA units for remote clinics, while Ministries of Education could fund solar-cooling-water solutions in rural schools. Governments can leverage results-based financing (RBF) models, attracting private companies to deliver and maintain systems under performance-based contracts, with incentives tied to uptime, service quality, or health outcomes.

Additionally, governments can establish community-driven energy committees to shape service needs and system design, ensuring social acceptance and long-term use. Countries such as Uganda and Burkina Faso—which have off-grid solar roadmaps—can serve as early adopters, using donor-aligned funding and development partner support to test scalable models for SophiA integration into existing rural infrastructure programs.

6.3 Target audience: African Public Organisations

a) Policy Recommendations:

At the operational level, African public organizations such as Rural Electrification Agencies (REAs) are central to rolling out SophiA-type systems and should mainstream energy-health-water integration into their planning and budgeting. For example, REAs could issue technology-specific calls for proposals and classify SophiA as an approved technical solution for electrifying health posts and small water treatment hubs. To ensure sustainability, these agencies must invest in training local technicians and planners. Public procurement officers, facility managers, and field technicians require practical knowledge of solar PV system sizing, refrigeration using R600a/R290, modular filtration units, and hybrid battery-inverter systems. Capacity-building can be embedded in national electrification or health infrastructure programs. Moreover, public organisations should support local manufacturing ecosystems, developing incentive programs for local assembly or fabrication of solar cabinets, cold boxes, and filtration components.

Through energy arms like ECREEE (for ECOWAS) and SACREEE (for SADC), Regional Economic Communities (RECs) should develop regional roadmaps for health- and education-linked electrification, integrating clean cooking and water purification into off-grid energy frameworks. RECs can also assist in developing regional training and certification schemes



for technicians working with refrigerants like R290/R600a or membrane-based water purification units.

African Development Bank (AfDB) should expand its results-based financing and blended finance portfolios to support deployment of integrated systems in underserved regions. Moreover, it can support sovereign lending packages and project preparation support to enable governments to roll out SophiA-type technologies in public service infrastructure.

AUDA-NEPAD should support its member states in incorporating integrated clean energy systems into national infrastructure pipelines, especially under its Programme for Infrastructure Development in Africa (PIDA) and Skills Initiative for Africa (SIFA). It could also foster partnerships between African manufacturers, R&D centers, and the SophiA consortium to boost local production and adaptation of core technology components.

UNDP can embed SophiA-type solutions in climate resilience, rural development, and healthcare programs, while WHO can support integration into national health facility resilience strategies—especially around cold chain and water safety. UNEP, with its Kigali Cooling Efficiency Program and clean cooking portfolio, can promote adoption of natural refrigerants and clean biomass alternatives aligned with SophiA's design principles. These agencies should also assist in developing guidelines and policy briefs, based on SophiA demonstrations, for broader replication.

b) Scaling Strategies:

A pragmatic way to scale SophiA solutions is through pilot procurement programs, allowing REAs and local governments to test integrated units at representative sites (e.g., one rural clinic, one off-grid school, and one community water point per region). These pilots should be openly evaluated and publicized to build confidence among funders and communities. Governments can use such results to expand the program under national budgets or development partner co-financing.

REAs and RECs can jointly develop regional deployment frameworks, identifying clusters of off-grid health facilities, schools, and water points suitable for SophiA-type systems. These frameworks should be supported by standardized procurement toolkits, allowing for streamlined tendering and quality assurance.

The AfDB, in collaboration with AUDA-NEPAD, can create a dedicated regional financing facility or guarantee fund for integrated solar-health-water-cooking infrastructure, designed to crowd in private capital and support local enterprises in installation and servicing. Meanwhile, RECs and UN agencies should co-host regional knowledge exchanges and policy dialogues based on SophiA demo site lessons, engaging ministries, regulators, researchers, and civil society.

Furthermore, public bodies should collaborate with academic institutions to develop curricula and research on system integration and rural system performance. Institutions can also develop data platforms and dashboards to monitor the performance of decentralized SophiA units, providing critical evidence for scaling decisions and maintenance support. This would enable informed, long-term investments in energy-health-water integration and create replicable models for other regions.



Finally, all public actors should work towards embedding local value chains and capacity-building into the scale-up process. This includes support for vocational training, local R&D hubs, and public-private innovation clusters, ensuring that the scaling of technologies like SophiA not only meets sustainability goals but also fosters inclusive economic development.

6.4 Published SophiA policy recommendations

In the frame of SophiA, a policy brief on sustainable refrigeration has been published by IIF-IRR in September 2025 (Appendix) (IIF IIR 2025). This policy brief advocates for the transition to natural refrigerants in Africa's refrigeration and air-conditioning (RAC) sector, highlighting their environmental, economic, and safety benefits compared to synthetic refrigerants (CFCs, HCFCs, HFCs, HFOs). The document outlines the environmental risks of synthetic refrigerants—including ozone depletion, global warming, and persistent pollutants like PFAS—and emphasizes Africa's vulnerability to climate change.

The policy brief addresses African government policymakers and regulatory authorities, as well as industry stakeholders (manufacturers, technicians, and associations), and development partners involved in the refrigeration and air-conditioning sector.

Key policy recommendations include:

- Establishing and upgrading training programs for all stakeholders,
- Raising awareness and providing tailored guidance,
- Demonstrating and piloting natural refrigerant technologies,
- Developing the market and local manufacturing,
- Unlocking access to financing (e.g., incentives, innovative business models),
- Creating and enforcing regulatory infrastructure and safety standards.

The brief provides case studies of successful training and technology demonstrations, and calls for coordinated action among governments, industry, and development partners to enable a safe, sustainable, and climate-friendly RAC transition in Africa.

7. CONCLUSION

The SophiA project has demonstrated that integrated, modular solutions for off-grid energy, cooling, clean water, and digital connectivity can play a transformative role in advancing the green energy transition across Sub-Saharan Africa. By bringing together a diverse consortium of European and African partners, SophiA has developed, piloted, and refined containerized systems tailored to the unique needs of rural hospitals, pharmacies, and communities. These efforts have been grounded in a deep understanding of the continental, regional, and national actors shaping Africa's energy landscape, as well as the evolving policy frameworks and market realities that influence technology adoption.

A key achievement of SophiA has been its ability to bridge the gap between research and real-world deployment. The project's roadmap aligns with continental strategies such as the African Energy Transition Programme and national electrification plans in countries like Burkina Faso,



Cameroon, Uganda, and South Africa. By leveraging partnerships with local governments, academic institutions, and business networks, SophiA has ensured that its solutions are not only technically robust but also contextually relevant and scalable. The project's engagement with "sister projects" and knowledge exchange platforms has further enriched its approach, fostering mutual learning and the development of joint policy recommendations.

Technologically, SophiA has capitalized on advances in solar PV efficiency, energy storage, clean cooking, renewable energy-based refrigeration, and water treatment. The integration of digital energy management systems and modular architecture has enabled flexible, adaptive deployment, while the use of natural refrigerants underscores the project's commitment to climate-friendly innovation. However, the journey has not been without challenges. Technical barriers such as system complexity, battery reliability, and the safe use of natural refrigerants have required ongoing adaptation and capacity building. Market barriers—including high upfront costs, fragmented procurement processes, limited local technical ecosystems, and regulatory gaps—have highlighted the need for sustained advocacy, financing innovation, and policy reform.

The lessons learned from SophiA and related projects point to several critical success factors for upscaling integrated energy-health-water solutions in Africa. First, long-term sustainability depends on building local capacity—not only through technician training and vocational education, but also by fostering local manufacturing, maintenance, and supply chains. Second, effective deployment requires navigating complex logistics, regulatory environments, and market fragmentation, which can only be overcome through early engagement with local partners and flexible, context-sensitive planning. Third, the creation of replicable case studies and transparent impact evaluations is essential to build trust among institutional buyers and funders, paving the way for broader adoption.

Policy recommendations developed in the frame of SophiA emphasize the importance of coordinated action among European and African stakeholders. The European Commission is called upon to support demonstration projects, harmonize standards, and facilitate technology transfer, while African governments are encouraged to integrate multi-service solutions into national strategies, revise fiscal frameworks, and launch results-based financing models. Public organizations, including Rural Electrification Agencies and Regional Economic Communities, play a pivotal role in mainstreaming energy-health-water integration, supporting local manufacturing, and embedding capacity building into infrastructure programs.

Looking ahead, the SophiA project offers a blueprint for sustainable, inclusive development in Africa's energy and health sectors. Its modular, scalable approach can be adapted to diverse contexts, supporting not only rural clinics and schools but also broader community resilience and economic empowerment. Continued collaboration among governments, industry, academia, and development partners will be vital to ensure that the gains achieved by SophiA are sustained and expanded beyond the project's funding cycle. By prioritizing local ownership, capacity building, and policy alignment, stakeholders can unlock the full potential of integrated off-grid solutions—delivering tangible benefits for health, climate, and livelihoods across the continent.

In summary, SophiA's experience underscores that the green energy transition in Africa is not only a technical challenge but also a social, economic, and institutional one. Success will



D7.6: Upscaling and roadmap for green energy transition in Africa using SophiA technology

depend on the ability to combine innovation with inclusivity, flexibility with rigor, and ambition with pragmatism. The insights and strategies presented in this deliverable provide a solid foundation for future action, inviting all stakeholders to join in the effort to build a more sustainable and equitable energy future for Africa.



8. REFERENCES

- AFREC (2024) *Sustainable Scaling : Meeting the Clean Cooking Challenge in Africa*. URL: https://au-afrec.org/sites/default/files/2024-11/English%20Ver. Main%20Publication Sustainable%20Scaling Meeting%20the%20Clean%20Cooking%20Challenge%20in%20Africa_0.pdf?utm_source=chatgpt.com [Last accessed on Sep 30th 2025]
- AFREC (2025) *AFREC. African Energy Transition Programme*. URL: <https://au-afrec.org/energy-transition-programme> [Last accessed on Sep 30th 2025]
- AFRICALOGISTICS (2024) *theAFRICALOGISTICS 2024. Reducing wastage: Improving vaccine cold chain management in Africa*. 26.10.2024. URL: <https://theafricalogistics.com/reducing-wastage-improving-vaccine-cold-chain-management-in-africa/> [Last accessed on Sep 30th 2025]
- African Development Bank Group (2024) *Sustainable Energy for Africa (SEFA) – Annual Report 2023*. URL: <https://www.afdb.org/en/documents/sustainable-energy-fund-africa-sefa-annual-report-2023> [Last accessed on Sep 30th 2025]
- AFSIA (2024) *AFSIA. Africa Solar Industry Association*. URL: <https://www.afsiasolar.com/> [Last accessed on Sep 30th 2025]
- Alliance for Rural Electrification (2025) *Alliance for Rural Electrification*. URL: <https://www.ruralelec.org/> [Last accessed on Sep 30th 2025]
- AMDA (2025) *AMDA*. URL: https://www.africamda.org/?utm_source=chatgpt.com [Last accessed on Sep 30th 2025]
- ARED (2024) *ARED. Look inward*. URL: <https://aredgroup.com/> [Last accessed on Sep 30th 2025]
- ASWA Alliance (2025) *ASWA Alliance*. URL: <https://home.aswaalliance.org/> [Last accessed on Sep 30th 2025]
- AU-AFCFTA (2025) *AFCFTA*. URL: <https://au-afcfta.org/>



[Last accessed on Sep 30th 2025]

AUDA-NEPAD (2022)

The African Continental Master Plan. URL: <https://www.nepad.org/continental-master-plan>
[Last accessed on Sep 30th 2025]

BURN (2025)

BURN. URL: <https://www.burnstoves.com/>
[Last accessed on Sep 30th 2025]

d.light (2025)

d.light. URL: <https://www.dlight.com/>
[Last accessed on Sep 30th 2025]

endev (2025)

Portfolio. URL: <https://endev.info/portfolio/>
[Last accessed on Sep 30th 2025]

European Commission (2025) a

ElectriFi – The Electrification Financing Initiative. URL: https://international-partnerships.ec.europa.eu/policies/programming/projects/electrifi-electrification-financing-initiative_en
[Last accessed on Sep 30th 2025]

European Commission (2025) b

Africa-Europe Green Energy. URL: https://international-partnerships.ec.europa.eu/policies/global-gateway/africa-europe-green-energy_en
[Last accessed on Sep 30th 2025]

GEAPP (2025)

Global Energy Alliance for People and Planet. URL: <https://energyalliance.org/>
[Last accessed on Sep 30th 2025]

Greenclimate Fund (2024)

Annual Report 2023. URL: <https://www.greenclimate.fund/document/annual-report-2023>
[Last accessed on Sep 30th 2025]

Hannover Messe (2021)

Solar ice-making machine for Indonesian small-scale fishermen. URL: <https://www.hannovermesse.de/en/news/news-articles/solar-ice-making-machine-for-indonesian-small-scale-fishermen>
[Last accessed on Sep 30th 2025]

HUSK (2025)

HUSK. URL: <https://huskpowersystems.com/>
[Last accessed on Sep 30th 2025]

ICTworks (2023)

Moving from e-chaos to Uganda's new digital health strategy. URL: <https://www.ictworks.org/moving-from-e-chaos-to-ugandas-new-digital-health-strategy/>
[Last accessed on Sep 30th 2025]



IEA (2022)	<i>Africa Energy Outlook 2022</i> . URL: https://www.iea.org/reports/africa-energy-outlook-2022 [Last accessed on Sep 30 th 2025]
IEA (2025)	<i>The Clean Cooking Declaration: Making 2024 the Pivotal Year for Clean Cooking</i> . URL: https://www.iea.org/news/the-clean-cooking-declaration-making-2024-the-pivotal-year-for-clean-cooking [Last accessed on Sep 30 th 2025]
IIF IIR (2025)	<i>Natural refrigerants in Africa</i> . URL: https://iifiir.org/en/fridoc/natural-refrigerants-in-africa-150971 [Last accessed on Sep 30 th 2025]
innovation: africa (2021)	<i>innovation: Africa</i> . URL: https://innoafrica.org/ [Last accessed on Sep 30 th 2025]
IRENA (2015)	<i>AFRICA 2023: Roadmap for a renewable energy future</i> . URL: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_Africa_2030_REmap_2015_low-res.pdf?utm_source=chatgpt.com
IRENA (2022)	IEA (2022), <i>Africa Energy Outlook 2022</i> , IEA, Paris https://www.iea.org/reports/africa-energy-outlook-2022 , Licence: CC BY 4.0. [Last accessed on Sep 30 th 2025]
JMP (2025)	WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply, Sanitation and Hygiene. URL: https://washdata.org/ . [Last accessed on Sep 30 th 2025]
KFW, GIZ, & IRENA (2021)	KFW, GIZ, & IRENA (2021): <i>The Renewable Energy Transition in Africa</i> (2021). p.58. URL: irena.org/-/media/Files/IRENA/Agency/Publication/2021/March/Renewable Energy Transition Africa 2021.pdf?utm_source=chatgpt.com . [Last accessed on Sep 30 th 2025]
KOKO (2025)	KOKO. URL: https://kokonetworks.com/koko-fuel/ [Last accessed on Sep 30 th 2025]
MAJIK WATER (2024)	<i>MAJIK WATER. Transforming Water Access</i> . URL: https://majikwater.africa/ [Last accessed on Sep 30 th 2025]



MECS (2023)	<i>Empowering Efficiency: Distributing off-grid solar electric cooking systems using women-lead organizing in rural Malawi.</i> URL: https://mecs.org.uk/wp-content/uploads/2023/03/EfficientEmpowermentReport_20230314.pdf?utm [Last accessed on Sep 30 th 2025]
Oxford Open Digital Health (2024)	<i>National eHealth strategy frameworks in Africa: a comprehensive assessment using the WHO-ITU eHealth strategy toolkit and FAIR guidelines.</i> URL: https://academic.oup.com/oodh/article/doi/10.1093/oodh/oqae047/7905772 [Last accessed on Sep 30 th 2025]
RES4AFRICA (2023)	<i>RES4AFRICA Foundation.</i> URL: https://res4africa.org/ [Last accessed on Sep 30 th 2025]
Senenews (2025)	<i>Senegal: Authorities give the green light to a digital health strategy.</i> URL: https://www.senenews.com/en/senegal/senegal-authorities-give-the-green-light-to-a-digital-health-strategy-7624.html [Last accessed on Sep 30 th 2025]
U-3ARC (2025)	Union of Associations of African Actors in Refrigeration and Air Conditioning (U-3ARC). URL: https://www.u-3arc.org/ . [Last accessed on Sep 30 th 2025]
UN (2015)	United Nations. Department of Economic and Social Affairs. Sustainable Development. The 17 Goals. URL: https://sdgs.un.org/goal . [Last accessed on Sep 30 th 2025]
UNDP (2025 a)	<i>Solar for Health.</i> URL: https://www.undp.org/energy/solar-health [Last accessed on Sep 30 th 2025]
UNDP (2025 b)	<i>The Africa Minigrids Program.</i> URL: https://www.undp.org/energy/africa-minigrids-program [Last accessed on Sep 30 th 2025]
UNEP (2020)	UN Environment Programme. News, Stories & Speeches. Story. Climate Action. <i>Why optimized cold-chains could save a billion COVID vaccines.</i> 26.06.2020. URL: https://www.unep.org/news-and-stories/story/why-optimized-cold-chains-



	<u>could-save-billion-covid-vaccines</u> . [Last accessed on Sep 30 th 2025]
UNEP-CCC (2024)	<i>Powering progress: market creation strategies for solar e-cooking technologies in off-grid and displaced communities</i> . URL: https://unepccc.org/wp-content/uploads/2024/05/powering-progress-market-creation-strategies-for-solar-e-cooking-in-off-grid-and-displaced-communities.pdf?utm [Last accessed on Sep 30 th 2025]
UNICEF (2018)	<i>Cold Chain Equipment – Solar Direct Drive and Mains Powered Refrigerator Systems: Product Profiles, Availability, and Guidance</i> . URL: https://www.unicef.org/supply/sites/unicef.org/supply/files/2019-06/cold-chain-equipment-sdd-drive-and-mains-powered-refrigerators.pdf [Last accessed on Sep 30 th 2025]
WHO, African Region (2025)	<i>Digital Health</i> . URL: https://www.afro.who.int/health-topics/digital-health [Last accessed on Sep 30 th 2025]
World Bank Group (2025)	<i>Regional Off-Grid Electricity Access Project</i> . URL: https://projects.worldbank.org/en/projects-operations/project-detail/P160708 [Last accessed on Sep 30 th 2025]



9. ANNEX

Policy Brief | Natural Refrigerants in Africa





sophia4africa.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N. 101036836.

Disclaimer: The sole responsibility for the content of this paper lies with the authors.

It does not necessarily reflect the opinion of the European Commission (EC).

The EC is not responsible for any use that may be made of the information it contains.

© SOPHIA. All rights reserved.

Any duplication or use of objects such as diagrams in other electronic or printed publications is not permitted without the author's agreement.





SOPHIA

Sustainable Off-grid solutions for
Pharmacies and Hospitals In Africa



POLICY
BRIEF

Natural Refrigerants in Africa



Acknowledgements

About the SophiA project

The “Sustainable Off-grid solutions for Pharmacies and Hospitals in Africa” project (SophiA) will enable more African people to access carbon-neutral energy for electricity, heating and cooling of medicine and food, as well as safe and clean drinking water, thereby improving the quality of life in a sustainable way.

The SophiA project was made possible by EU Commission. It received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 101036836.

About the policy brief

This Policy Brief was prepared by Michael Kauffeld (Karlsruhe University of Applied Sciences, SophiA coordinator), Daniel Colbourne (Re-Phridge Ltd), Monique Baha (IIR), Yosr Allouche (IIR Director General), Abdoulaye Gaye (ROCA Senegal), Marco Duran (IIR), Hubert Nsoh Zan (Energy Commission, Ghana), Alain Tchoua (U-3ARC), Lassine Katilé (U-3ARC).

The following experts contributed with valuable inputs: Marco Buoni (REAL Alternatives, Centro Studi Galileo, Italy), Nils Hansen (GIZ), Nnaemeka Ikegwuonu (ColdHubs, Nigeria).

The brief was reviewed by Daniel Colbourne (Re-Phridge Ltd), Bassam Elassaad (UN RTOC), Xinfang Wang (University of Birmingham, UK), Marco Duran (IIR), Yosr Allouche (IIR Director General), Alex Pachai (IIR) and Madi Sakandé (U-3ARC).

The brief was edited by Monique Baha (Scientific Writer, IIR), translated by Maud Grasmenil (Translator, IIR) and designed by Marie-Christelle Attila (Graphic Designer, IIR).

This publication was reviewed and edited with the support of IIR



INSTITUT INTERNATIONAL DU FROID
INTERNATIONAL INSTITUTE OF REFRIGERATION

Copyright © September 2025 SophiA – All rights reserved

TABLE OF CONTENTS

Acknowledgements	2
Acronyms	3
1.HISTORICAL PERSPECTIVE	4
2.ENVIRONMENTAL IMPACT OF SYNTHETIC REFRIGERANTS	6
- Box 1: Avoiding environmental dumping in Africa	8
3.PROPERTIES OF NATURAL REFRIGERANTS AND APPLICATIONS IN REFRIGERATION SYSTEMS	9
4.BARRIERS TO THE ADOPTION OF NATURAL REFRIGERANTS	12
4.1. Absence of an appropriate regulatory framework	13
4.2. Limited access to adequate training	14
4.3. Limited availability of components	14
4.4. Limited availability of natural refrigerants	15
5.POLICY RECOMMENDATIONS	16
5.1. Setting up or overhauling training programmes	17
- Box 2: Case studies of training initiatives in Africa	18
5.2. Raising awareness and providing guidance	19
5.3. Demonstrating technology development	19
- Box 3: Natural refrigerant-based systems in operation in Africa	20
5.4. Developing the natural refrigerants market in Africa	23
5.5. Unlocking access to financing	23
5.6. Developing regulatory infrastructure for natural refrigerants in Africa	24
6.REFERENCES	25

ACRONYMS

CFCs	Chlorofluorocarbons
GHGs	Greenhouse Gas
GWP	Global Warming Potential
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
HFOs	Hydrofluoroolefins
ODS	Ozone Depleting Substances
TFA	Trifluoroacetic Acid
RAC	Refrigeration and Air Conditioning
PFAS	per- and polyfluoroalkyl substances

01 Historical Perspective

Since the 19th century, the choice of refrigerant has evolved from natural refrigerants to synthetic ones due to environmental, climatic, safety and economic factors. In Ghana, for example, ammonia systems at the Tema fishing harbour were replaced by synthetic refrigerants in the 1990s, but ammonia is being reintroduced for its lower operating costs.

Advocacy for natural refrigerants is crucial in Africa to address environmental concerns and support the implementation of international agreements such as the Kigali Amendment to the Montreal Protocol.

01. Historical perspective

Since mechanical refrigeration was invented in the 19th century, the choice of refrigerant has evolved due to environmental, climatic, safety and economic factors ^[1,2]. As there was no chemical industry at the time, early refrigeration systems relied on natural refrigerants such as ammonia, carbon dioxide, dimethyl ether, sulphur dioxide, and water ^[3,4].

In the 1930s and 1940s, the invention of halogenated refrigerants contributed to the widespread adoption of refrigeration systems as these substances were then promoted as safe alternatives. In many applications – except for industrial refrigeration and refrigeration systems in the petrochemical industry, which continued to use ammonia and hydrocarbons respectively – natural refrigerants were replaced by synthetic ones based on chlorinated and/or fluorinated hydrocarbons, sometimes with added bromine atoms.

In Ghana, for instance, prior to the 1990s, central water-cooled ammonia plants dominated the cold storage facilities at the Tema fishing harbour. In the 1990s, the centralised ammonia plant from the cold store market was replaced by a condensing unit using synthetic refrigerants, which had the advantage of a

lower initial cost ^[5]. In the 2010s, ammonia systems were gradually reintroduced at the Tema fishing harbour due to their lower operating costs in energy use and maintenance ^[6].

At the time, studies led by UNEP and UNIDO examined strategies and opportunities to overcome barriers to the uptake of low global warming potential (GWP) refrigerants – including natural refrigerants – in Article 5 countries ^[7,8]. They highlighted the importance of access to information and stakeholder engagement as instrumental in the uptake of natural refrigerants among industry and policy representatives in developing countries and emerging economies.

This policy brief aims to guide the technological adoption of natural refrigerants based on environmental, climatic, safety, and economic considerations. Advocacy for natural refrigerants in Africa is based on scientific evidence of the detrimental effects of synthetic refrigerants on the ozone layer, global warming, and other environmental impacts, and is considered as a key driver for the successful implementation of international agreements such as the Kigali Amendment to the Montreal Protocol.



A bird's eye view of the Tema port in Ghana © Shutterstock

02

Environmental impact of synthetic refrigerants

Africa is especially vulnerable to the effects of climate change, bearing high costs for adaptation measures. While global efforts under the Montreal Protocol have nearly eliminated ozone-depleting substances, HCFC-based systems still account for half of the African air conditioning market, highlighting the need for climate-friendly alternatives.

02. Environmental impact of synthetic refrigerants

Africa is one of the most vulnerable continents to the effects of climate change, bearing disproportionately high costs for essential climate adaptation measures ^[9]. African economies are heavily dependent on climate-sensitive sectors. In this context, the refrigeration and air-conditioning (RAC) sector is becoming a major, vital pillar for achieving sustainable development.

Unfortunately, synthetic gases used in refrigeration systems are a significant source of greenhouse gas (GHG) emissions. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are chlorine-containing refrigerants that damage the ozone layer. This threat to Earth's biosphere led to the signature of the Montreal Protocol on Substances that Deplete the Ozone Layer in 1987. Through its various amendments and universal ratification, CFCs and HCFCs have now been virtually eliminated from new refrigeration and air-conditioning systems – although the molecules will persist in the atmosphere for several decades.

According to UNEP, as of 2024, the Parties to the Montreal Protocol have phased out nearly 99% of ozone-depleting substances (ODS) globally compared to 1990 levels ^[10]. The ozone layer is currently on a path to recovery and is expected to heal back to pre-CFC and HCFC levels by 2100 ^[11]. However, in Africa, air conditioners containing the HCFC refrigerant R22 still account for nearly half of the market ^[12]. See Box 1 on the issue of environmental dumping of equipment containing obsolete refrigerants in Africa.

Hydrofluorocarbon refrigerants (HFCs) were introduced to the market in the late 1980s and early 1990s as ozone-safe replacements for CFCs and HCFCs. However, most HFCs and HFC blends have relatively high GWPs. Consequently, HFCs are being phased down and even phased out in some regions, according to the Kigali Amendment to the Montreal Protocol, adopted in 2016. As of 2024, 45 out of 54 African countries have ratified the Kigali Amendment, thereby pledging to reduce the production and consumption of HFCs by 80% by 2045 ^[13]. According to the HFC phase-down schedule, African countries – along with most developing countries, or Article 5 parties – are required to freeze HFC consumption in 2024 and begin a stepwise reduction starting in 2029, continuing through to 2045. Some regions of the world have implemented even stricter policies, such as the EU F-gas regulation, revised in 2024, which limits the amount of HFCs to be placed on the market to 2% of 2015 levels by 2048 ^[14].

As a consequence of the HFC phase-down, refrigerant manufacturers are commercialising hydrofluoroolefins (HFOs) – another class of fluorinated substances with very low GWPs. Recent studies have shown that during degradation in the atmosphere some HFO refrigerants can break down into R23, a potent and long-lived HFC greenhouse gas ^[15], or produce trifluoroacetic acid (TFA) ^[16]. TFA is the most widespread of the per- and polyfluoroalkyl substances (PFASs), also known as “forever chemicals”. Due to the short atmospheric lifetimes of HFOs, it is reported that TFA formed during their degradation tends to accumulate in soil and surface water not far from the site of the refrigerant leak. TFA is a highly persistent pollutant and is suspected to negatively affect biological organisms at higher concentrations, including potential toxicity to reproductive systems ^[17]. Residues of TFA have been observed in water, air and soil samples worldwide, including in Africa (e.g. Malawi and South Africa) ^[16,17].

Several research studies have documented that the degradation of R1234yf – an HFO used to replace R134a (an HFC) in car air-conditioning systems – leads almost exclusively (~100 %) to TFA within days, given its short chemical atmospheric lifetime ^[18]. Holland et al. claim that if all R134a emissions worldwide were replaced by R1234yf emissions, simulations predict a 33-fold increase in global TFA deposition (up to 250-fold increase over Central Europe) ^[19].

Ongoing studies are investigating the formation of TFA as a degradation product of HFOs. In contrast, it is well established that natural refrigerants do not form TFA in the atmosphere and are therefore less likely to be subject to future regulatory restrictions.

Old refrigerators freezers © Shutterstock



Box 1: Avoiding environmental dumping in Africa

Most new room air conditioners marketed in Africa are inefficient and operating with HCFC and HFC refrigerants scheduled under the Montreal Protocol for phase out and phase down, respectively ^[12]. The commercialisation of new and used sub-optimal appliances, which fail to meet efficiency and environmental standards in more developed and regulated markets, into regions where regulations are less stringent or not enforced has been described as environmental dumping. Environmental dumping not only impoverishes buyers unable to afford electricity, it also complicates compliance with the Montreal Protocol due to the introduction of refrigerants scheduled for phase-out or phase-down. Furthermore, it increases GHGs emissions ^[20] and creates air, water, and land pollution from toxic substances released when processing the waste and refrigerants from obsolete appliances ^[22].

Conference Room Papers (CRPs) were submitted by Ghana on behalf of the African States Parties to stop the harmful dumping of new and used inefficient refrigeration and air conditioning appliances in all Article 5 Parties ^[21]. These CRPs led to the Unanimous 2023 Decision XXXV(13) of the Montreal Protocol recognising shared responsibility of Parties to prohibit the export of cooling equipment that does not satisfy their national regulations or is inconsistent with their standards ^[22]. Shared responsibility of exporting and importing authorities also opens developing countries' markets to best available technology with climate-friendly refrigerants.

In December 2023, the United States Environmental Protection Agency (US EPA) finalised its HFC phasedown rule, including prohibitions on exporting factory-completed products not qualified for domestic sales ^[23]. In February 2024, the European Union (EU) adopted Regulation 2024/573 on fluorinated GHGs, EU F-gas Regulation, prohibiting the export of certain used and new equipment containing climate-damaging fluorinated GHGs ^[14]. Shortly thereafter, United Nations (UN) Secretary-General António Guterres in his Call to Action on Extreme Heat, spotlighted the importance of stopping the dumping in developing countries of new inefficient cooling appliances with obsolete refrigerants ^[24].

The next step is for responsible global manufacturers of energy efficient air conditioners using climate-friendly refrigerants to capture African and other developing country markets, through innovative financial mechanisms and through strategic partnerships that could include financing support from the Montreal Protocol Multilateral Fund for the Implementation of the Montreal Protocol (MLF).

03

Properties of natural refrigerants and applications in refrigeration systems

When properly selected for the appropriate application, integrated into well-designed systems and managed under strict safety protocols, natural refrigerants are safe, energy-efficient, and cost effective for use in state-of-the-art refrigeration, air-conditioning, and heat pump systems.

03. Properties of natural refrigerants and applications in refrigeration systems

Natural refrigerants, including ammonia, carbon dioxide, hydrocarbons, water, and air, are substances that exist in nature and are part of the biosphere. Moderate use and emissions of these substances do not cause unknown changes in the environment, such as those generated by CFCs, HCFCs, HFCs and HFOs. Although natural refrigerants are produced industrially, their CO₂-equivalent emissions during manufacturing are only a fraction of those of fluorinated substances ^[25] and they can also be derived from plant-based processes ^[26].

When properly selected for the appropriate application, integrated into well-designed systems and managed under strict safety protocols, natural refrigerants are safe, energy-efficient, and cost effective for use in state-of-the-art refrigeration, air-conditioning, and heat pump systems. Thanks to their favourable thermodynamic properties, natural refrigerants often allow systems to achieve higher energy efficiency than those using fluorinated refrigerants, thereby reducing indirect emissions

associated with electricity generation. Table 1 summarises key characteristics of natural refrigerants compared to HFCs and HFOs (see IIR, 2016, for a full overview ^[27]).

As with CFCs, HCFCs, HFCs or HFOs, there is no one size fits all natural refrigerant. Each option must be evaluated based on factors such as availability, safety for the local and global environment, energy efficiency, cost, and other relevant criteria. Table 2 lists selected natural refrigerants along with their typical and potential future applications. Other hydrocarbons, not included in Table 2, are appropriate for specific applications such as pentane (R601) and isopentane (R601a) for high-temperature heat pumps, and ethane (R170) for ultra-low temperature systems.

Regarding future wider applications of hydrocarbons, for example in air-conditioning systems, extensive mitigation measures have been developed to address safety issues associated with flammability.

Table 1

Main characteristics of selected natural refrigerants, HFCs and HFOs

Refrigerant	GWP	PFAS	Flammable	Toxic	Comparative costs ⁽²⁾	
					Refrigerant	Installation
HFCs	High	Some are and a few form TFA	No GWP < 750 Moderate	Low, but toxic fumes when burning	Moderate	Low
HFOs	Low ⁽¹⁾	Some are and several form TFA	Moderate	No acute, but toxic fumes when burning	High	Moderate
Hydrocarbons	Low	No	Yes	Low	Low	Moderate
Carbon dioxide	Low	No	No	Above 10%	Low	Moderate
Ammonia	None	No	Moderate	High	Low	Moderate
Water	None	No	No	No	Low	Moderate

Table 2

Selected natural refrigerants and their typical current applications as well as future applications

		Hydrocarbons			Ammonia	Water	CO ₂
		HC-290	HC-600a	HC-1270	R717	R718	R744
Sealed refrigeration appliances	Domestic refrigerators		✓				
	Commercial plug-in appliances	✓					✓ ⁽²⁾
	Heat pump tumble dryers	✓					
Food retail	Stand-alone equipment	✓					✓ ⁽²⁾
	Condensing units	✓	✓	✓			✓ ⁽²⁾
	Centralised systems	✓ ⁽¹⁾		✓ ⁽¹⁾	✓ ⁽¹⁾		✓
	Distributed systems	✓		✓			✓
Transport refrigeration	Truck, trailer, vans	✓		✓			✓ ⁽²⁾
	Rail refrigerated transport	✓		✓			✓ ⁽²⁾
	Rail air conditioning	✓					
	Marine containers	✓		✓			✓ ⁽²⁾
	Ships	✓		✓	✓		✓ ⁽²⁾
Air-to air air conditioners and heat pumps	Small self-contained ACs	✓					
	Single-split ACs	✓					
	Multi-split ACs	(✓)		(✓)			
Applied building cooling systems	Ducted AC systems	✓ ⁽¹⁾		✓ ⁽¹⁾			
	Air conditioning chillers	✓		✓	✓	✓	
	VRF Air Conditioning ⁽³⁾	(✓)		(✓)			
Mobile air conditioning and heat pumps	Internal combustion engine	(✓)					✓
	Electric vehicle	✓					✓
Industrial refrigeration and heat pumps	Food processing	✓		✓	✓		✓
	Cold storage	✓		✓	✓		✓
	Leisure applications	✓		✓	✓	✓	✓
	Process refrigeration	✓		✓	✓	✓	✓
	Industrial heat pumps and heat recovery	✓	✓ ⁽⁴⁾	✓	✓	✓	✓ ⁽⁵⁾
Heating only heat pumps	Heat pump water heaters	✓		✓			✓
	Space heating heat pumps	✓		✓			✓

1. Only in combination with heat transfer fluid, not in direct evaporation in public areas
2. Efficiency in hot ambient not as good as with other refrigerants due to transcritical operation; centralised R744 systems include technical features which make them efficient even in warmer climate
3. Direct expansion/evaporation in heat exchangers in the individual rooms/zones of a building
4. High temperature heat pumps for steam production
5. For water, fluid or product heating with large temperature changes (gliding temperature) of heated substance

(✓) Once obstructive charge limits in safety standards have been resolved

1. Some HFOs form HFC-23 as one of their atmospheric breakdown products. HFC-23 has a GWP100 years of 14 700

2. For information purpose only, costs strongly depend on the degree of market maturity.

04

Barriers to the adoption of natural refrigerants

The absence of an appropriate regulatory framework represents the greatest barrier to a wide uptake of natural refrigerants in Africa, leading to inadequate training and limited awareness among technicians. Limited access to natural refrigerants, along with associated components and equipment, further hinders the adoption of natural refrigerants.

04. Barriers to the adoption of natural refrigerants

Arguably, the absence of an appropriate regulatory framework represents the greatest barrier to a wide uptake of natural refrigerants in Africa, leading to inadequate training and limited awareness among technicians. Figure 1 presents challenges and barriers associated with the introduction and uptake of natural refrigerants across the region.

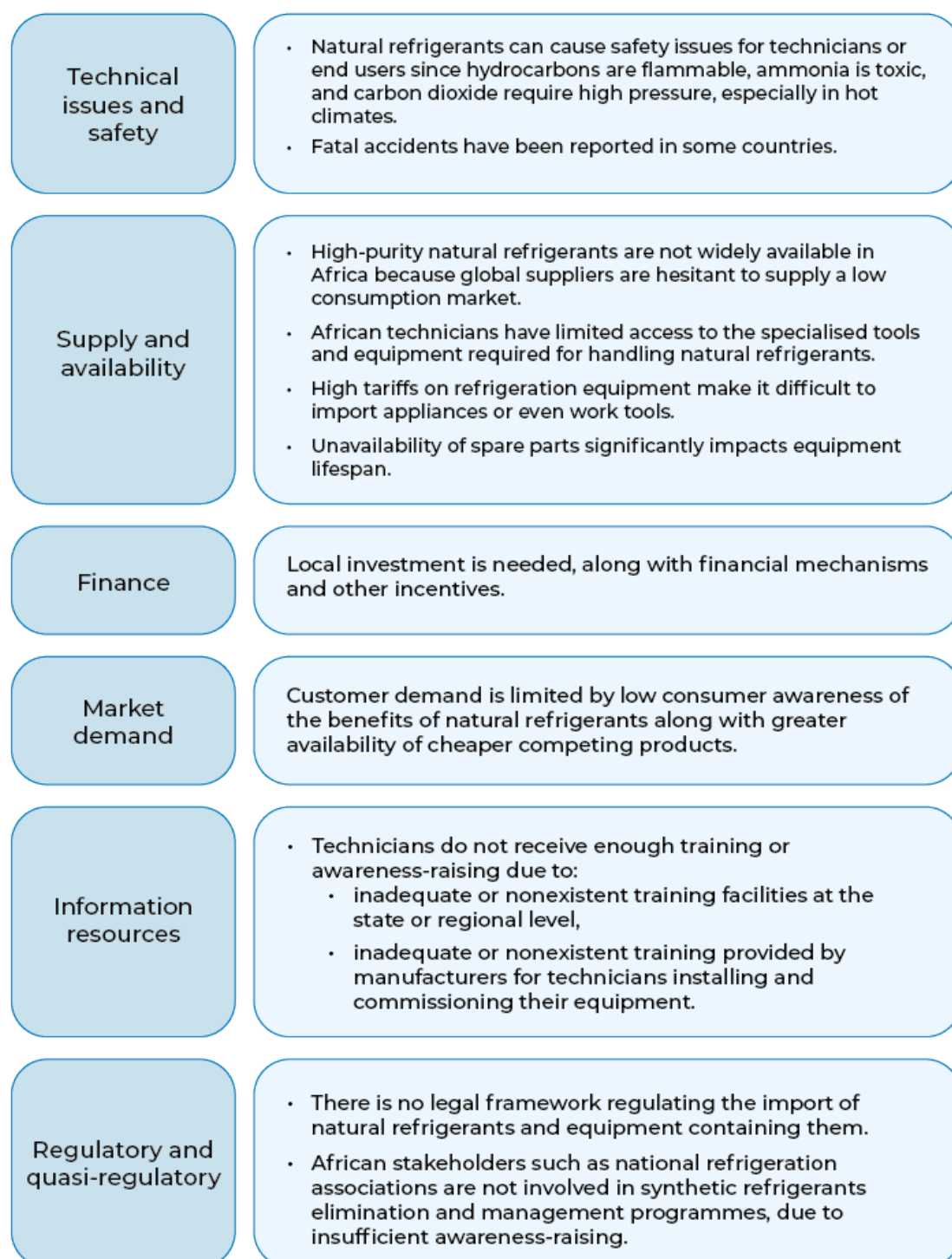


Figure 1

Challenges and barriers associated with the introduction and uptake of natural refrigerants in Africa

4.1. Absence of an appropriate regulatory framework

Most African countries have signed and ratified the Montreal Protocol and its Kigali Amendment. African countries have also adhered to the provisions of the United Nations Framework Convention on Climate Change by signing and ratifying its various international climate agreements, and many have included HFCs in their GHGs inventories. However, the related regulatory frameworks, restrictions, and instructions required to meet these targets are often not yet implemented or are slow to enforce due to limited understanding of the refrigeration sector, constrained technical and resource capacity, and/or insufficient political will.

Some countries, such as Senegal ^[28,29] and Kenya ^[30], have established regulatory frameworks to fulfil their international commitments to protect the ozone layer and combat global warming, specifically by phasing out HCFCs and regulating HFC imports. However, a legal gap remains in the regulation of natural refrigerants.

4.2. Limited access to adequate training

Although some African countries have technician programmes in place, such as the South African Qualification & Certification Committee ^[31], the refrigeration sector across Africa is overwhelmingly informal. Despite efforts by public authorities to establish formal training programmes, most workers still rely on “traditional apprenticeship” methods to obtain their professional qualification ^[32,33]. However, these apprenticeships lack clear curricula and formal organisation structures, operating largely outside the oversight of responsible training authorities. They are insufficiently and inadequately structured to meet the current qualification demands required for a rapid and safe transition to natural refrigerants ^[34].

Training gaps related to natural refrigerants are not only limited to the informal sector. While many public and private institutions do offer training in refrigeration and air conditioning, these programmes are generally not tailored to address environmental issues and refrigeration technologies that use natural refrigerants. The overall training offer in the field need to be reviewed, taking into account the specificity of the country.

4.3. Limited availability of components

Most African countries have no access to RAC manufacturing facilities and depend on imports. Unfortunately, high tariffs on refrigeration equipment – ranging from 40% to 111% in several countries – make it difficult to import appliances or even work tools. There are a few exceptions, countries where import tariffs on refrigeration equipment are lower than the regional average, such as Kenya (22%), Algeria (23%), and Morocco (23%) ^[35].



In the air conditioner market using HFCs and HCFCs, Egypt, Tunisia, and Nigeria are able to assemble and export air conditioners to the rest of the African market through partnerships and joint ventures with non-African RAC manufacturers ^[12]. However, such partnerships rarely extend to equipment that uses natural refrigerants, hindering initiatives to phase out HCFCs ^[36,37]. Consequently, African RAC technicians have limited access to the specialised tools and equipment required for handling flammable refrigerants.

4.4. Limited availability of natural refrigerants

In the absence of significant demand, high-purity natural refrigerants are not widely available in Africa at competitive prices. Global refrigerant suppliers are often reluctant to supply these refrigerants to African countries where consumption remains low or limited to pilot testing phases.

As an alternative, local production of natural refrigerants has been explored through pilot initiatives. In 2015, Nigeria commissioned its first plant producing high-purity hydrocarbon refrigerants using locally sourced liquefied petroleum gas as feedstock ^[38]. The Pamaque Nigeria Ltd plant has an annual production capacity of 200 tonnes each for R600a and R290, totalling 400 tonnes per year. The estimated investment cost for a plant producing 200 tonnes annually is approximately US\$460,000, including expenses for testing and plant certification ^[39]. Ultimately, the cost of natural refrigerants is expected to be substantially lower than that of fluorinated refrigerants, as demonstrated in established markets such as Europe.



Pamaque Nigeria Ltd hydrocarbon production plant in Nigeria ^[39] © Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), United Nations Development Programme (UNDP)

05 **Policy recommendations**

In the African context, the successful transition to natural refrigerants will require proactive interventions from government and industry stakeholders, end-users, and development partners.

- Setting up or overhauling training programmes
- Raising awareness and providing guidance
- Demonstrating technology development
- Developing the natural refrigerants market in Africa
- Unlocking access to financing
- Developing regulatory infrastructure for natural refrigerants in Africa

05. Policy recommendations

Under the Kigali Amendment to the Montreal Protocol, the use of HFCs is being phased down across all ratifying countries, following different timelines. This global commitment has amplified, leading to widespread discussions on the adoption of alternative refrigerants. In the African context, the successful transition to natural refrigerants will require proactive interventions from government and industry stakeholders, end-users, and development partners.

reviewed to incorporate the latest technological advances, environmental standards and safety requirements, as well as energy efficiency considerations.

Develop continuing education programmes. Tailored training opportunities should be made available for technicians already active in the sector, enabling them to acquire the necessary skills and competencies to safely and effectively work with natural refrigerants.

Raise awareness among all refrigeration stakeholders about environmental issues. It is important to integrate an environmental dimension into all training courses to raise awareness among future professionals of the issues related to climate change.

5.7. Setting up or overhauling training programmes

The successful adoption of natural refrigerants requires proper training of all stakeholders – not only service and maintenance technicians, but also design engineers, production line and factory workers who build refrigeration systems, as well as sales and marketing staff. While this is true for any refrigerant type, it is particularly critical for substances that are flammable, higher toxicity, or operate under high-pressure conditions.

To address current training challenges, the following actions are recommended:

Strengthen the technical capacity of the training centres by equipping them with the necessary tools and technologies. Very few institutions have the necessary equipment to train future technicians in the use of natural refrigerants.

Support national refrigeration and air-conditioning associations to expand training capacity by leveraging international funding mechanisms such as the Multilateral Fund for the Implementation of the Montreal Protocol.

Provide training for trainers and technicians. It is essential to upgrade the knowledge of training professionals and technicians on emerging technologies and safety standards related to natural refrigerants.

Adapt curricula. Training programs should be

Technician reading pressure levels on manifold gauges. © Shutterstock



Box 2: Case studies of training initiatives in Africa

Close to 300 African technicians trained through “REAL Alternatives for LIFE”

Launched in 2017, “REAL Alternatives for LIFE” is an EU-funded project which provides “train the trainer” sessions on low GWP refrigerants (hydrocarbons, CO₂, ammonia, HFOs) in order to ensure safe, efficient, reliable and cost-effective implementation. In partnership with IIR and U-3ARC, REAL Alternatives has issued over 1,800 certificates as of 2024, including training sessions for a little under 300 RAC technicians from Africa (Benin, Burkina, Cabo Verde, Egypt, Madagascar, Nigeria, Sudan, Togo, Tunisia).

REAL Alternatives training sessions cover the following main topics:

- Background on existing or upcoming regulations on HFCs and long-term alternative refrigerants, in order to anchor the importance of natural refrigerants.
- Key thermophysical properties of refrigerants
- Flammability and other safety hazards
- Working safely with natural refrigerants and reducing leak potential.
- System design. In the case of CO₂, this includes an explanation of transcritical operation, as well as cascade and booster systems.
- Installation and commissioning, as well as service and repair procedures.

Technicians from Burkina Faso, Cameroon, Mali and Senegal trained through GIZ ROCA

Between 2021 and 2024, GIZ Proklima ran the ROCA (“Refroidissement respectueux de l’Ozone et du Climat en Afrique de l’Ouest et Centrale”) project, co-funded by the European Union and the German Federal Ministry for Economic Cooperation and Development (BMZ). The ROCA project aimed to promote natural refrigerants and expedite compliance with the Kigali Amendment in four francophone African countries: Burkina Faso, Cameroon, Mali and Senegal. Regional workshops were organised to train technicians in the safe handling of natural refrigerants in room air conditioners. For instance, 100 technicians were introduced to the use of natural refrigerants such as propane (R290) during a training course held from 29 January to 01 March 2024 at the Lycée Technique et Professionnel François Xavier Ndione in Thiès, Senegal ^[40].

Technical and engineering training in SophiA technologies

Within the framework of the EU-funded project SophiA – Sustainable Off-grid solutions for Pharmacies and Hospitals in Africa, the 2iE Institute organised a capacity-building session for local technicians and engineers in Burkina Faso in June 2024 and in Cameroon in January 2025. The training provided participants with an in-depth understanding of sizing techniques for solar cooling systems based on natural refrigerants, as well as skills in servicing and maintaining filter-based water treatment systems and solar heat processes. Future training sessions are planned in Malawi and Uganda.

5.2. Raising awareness and providing guidance

As with all other regions, the introduction of flammable refrigerants remains a subject of ongoing debate in Africa, where technicians express concerns due to inadequate training and tools. Where there is insufficient knowledge, training and suitable tools and equipment, technicians will not be suitably competent to address the hazards of handling of refrigerants.

Awareness-raising efforts should highlight the environmental, energy, technical, and economic including life-cycle cost benefits of natural refrigerants, encouraging decision-makers and stakeholders to adopt these solutions as part of broader climate action strategies. Such efforts can take the form of workshops or communication campaigns targeting various stakeholders through tailored messaging. Additionally, site visits can be organised to showcase equipment using natural refrigerants that is being developed or marketed in Africa or in other regions. This will help to build familiarity and confidence in these technologies.

High quality industry guidance should be developed to support awareness-raising and training activities. These guides should address key topics, including national legislation, safe handling procedures, conversion guidelines for manufacturers, etc. Similar to awareness-raising and training initiatives, the guidance materials must be tailored to the specific needs of the different stakeholder groups.

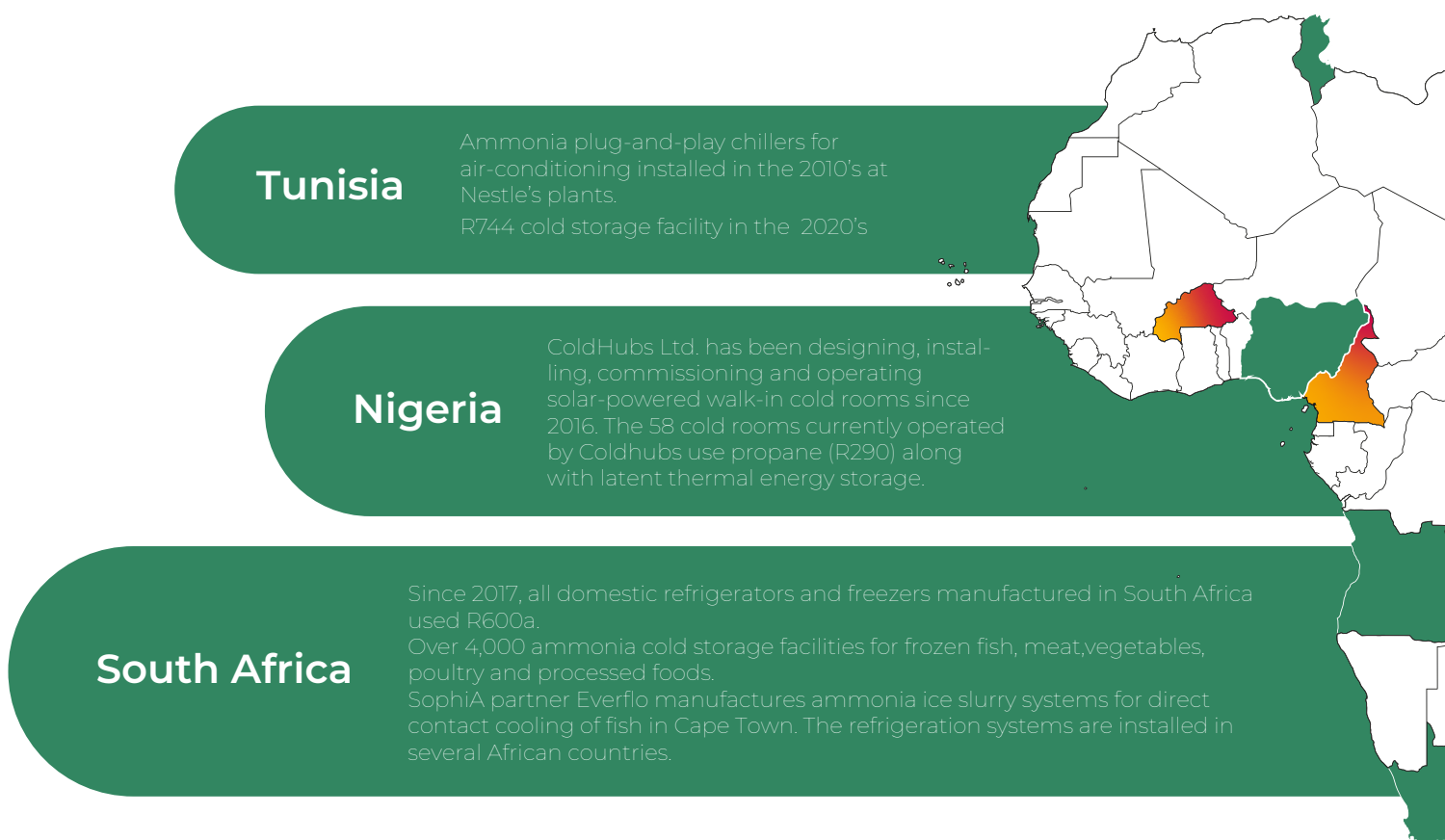
5.3. Demonstrating technology development

Since the early 2010s, with the first production lines for hydrocarbon-based domestic refrigerators in South Africa ^[41] and Eswatini (formerly Swaziland) ^[41,42], the adoption of natural refrigerants has steadily progressed in the region, particularly in commercial refrigeration. Over 4,000 large industrial cold storage facilities using ammonia (R717) are currently in operation in South Africa, commonly used for frozen fish, meat, vegetables, poultry, and processed foods ^[43]. Over 220 transcritical CO₂ (R744) units were in service in the country as of 2020, twice as many as in 2018 ^[44].

Figure 2 presents examples of natural refrigerant-based systems currently operating in Africa.



Box 3: Natural refrigerant-based systems in operation in Africa



SophiA containerised solar powered refrigeration systems

Cameroon

Solar-powered stand-alone refrigeration systems using propane .

Burkina Faso

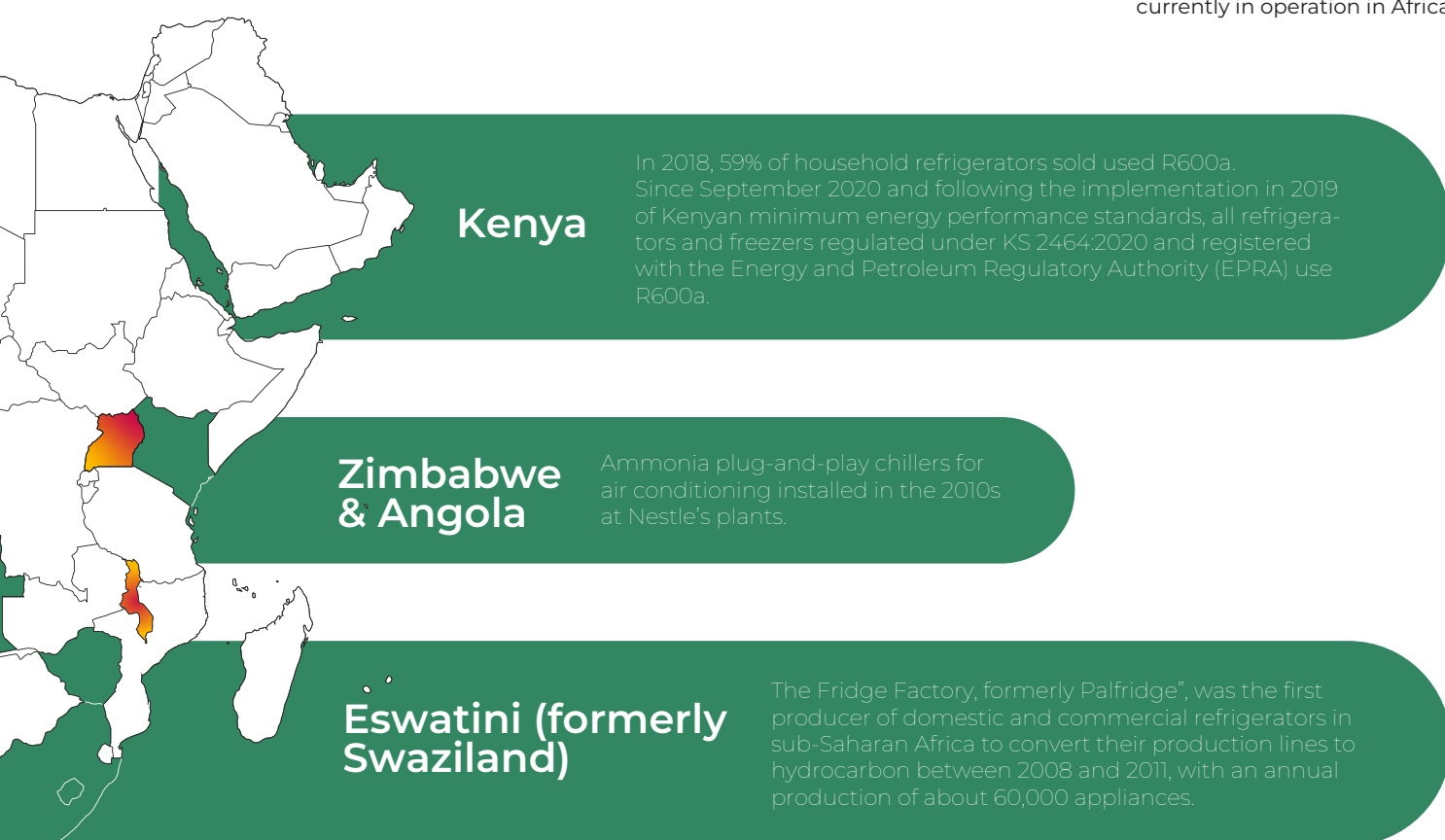
Containerised solar-powered refrigeration system.

Uganda & Malawi

Solar powered containers combining cooling and water treatment systems.

Figure 2

Examples of systems with natural refrigerants currently in operation in Africa



Further research and development activities are needed required to facilitate the uptake of natural refrigerants. Trials or pilot studies must be carried out to demonstrate the feasibility of these technologies under the specific African context and to identify opportunities for enhancing system performance, safety, and operability.

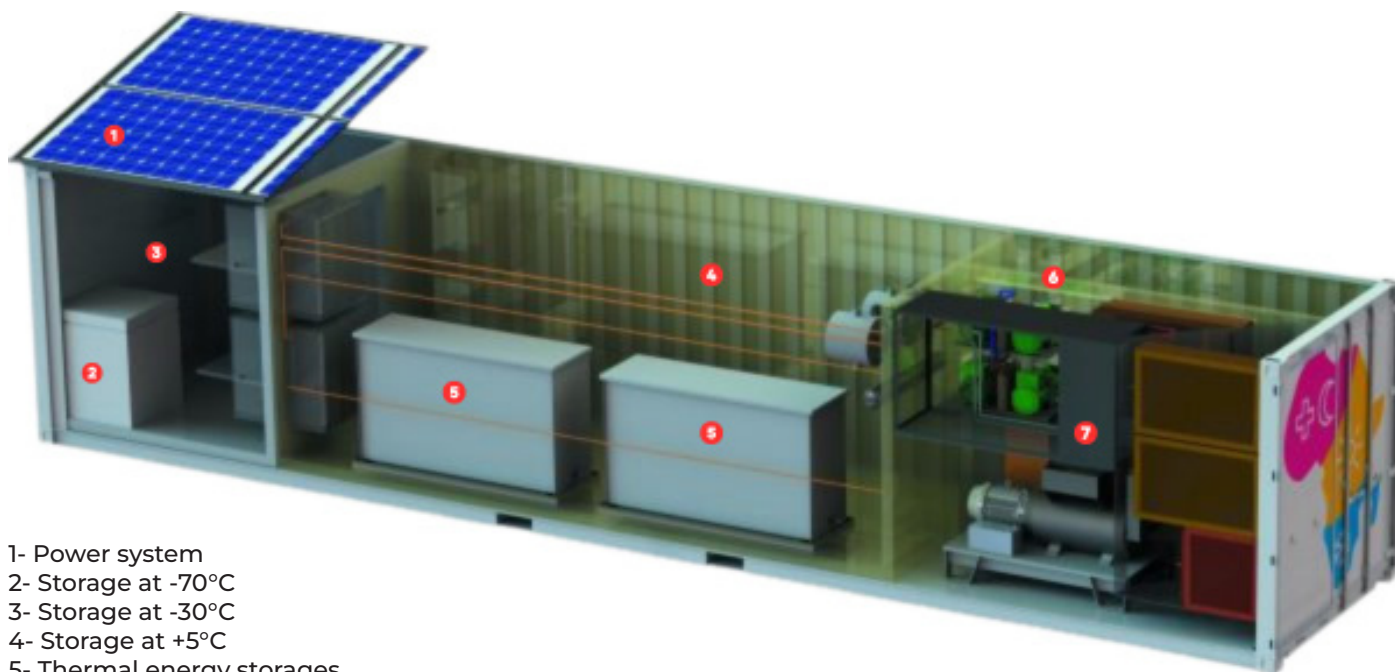
Forexample, as part of the EU-funded project SophiA ("Sustainable Off-grid solutions for Pharmacies and Hospitals in Africa"), a containerised solar-powered refrigeration system was installed in the Dr. Sedogo hospital in Léo, Burkina Faso. The container provides the hospital with cold storage facilities at +5 °C and –30 °C for ointments and blood plasma, respectively. A separate vaccine freezer operating at –70 °C was also installed, using ethane as the refrigerant.

The SophiA containerised refrigeration system consists of a propane-based upper stage in a cascade configuration, paired with R744 (CO₂) as the lower stage (see Figure 3). To minimise the size of the batteries for storing electrical energy, the SophiA system applies an ice bank storage system in the +5 °C cold room which at the same time is the cold surface cooling the +5 °C room, thus making a conventional fin-and-tube evaporator obsolete.

Following the SophiA demonstrator in Burkina Faso, second-generation solar-powered containers combining cooling and water treatment systems were installed in Uganda and Malawi. In Cameroon, solar-powered stand-alone refrigeration systems using propane were installed at the Ad Lucem hospital in Edéa in 2025.

Figure 3

SophiA containerised solar- powered refrigeration system as installed in Burkina Faso



- 1- Power system
- 2- Storage at -70°C
- 3- Storage at -30°C
- 4- Storage at +5°C
- 5- Thermal energy storages
- 6- Machinery room
- 7- Emergency lithium batteries



Inauguration of SophiA containers
at Dr. Sedego Hospital in Léo,
Burkina Faso.

5.4. Developing the natural refrigerants market in Africa

Increasing market demand for and access to natural refrigerants, along with associated components and equipment, require advocacy directed at political authorities to implement customs policies that facilitate the import of energy-efficient and climate-friendly refrigeration systems. At the same time, these policies should restrict the import of conventional systems based on high-GWP refrigerants. Furthermore, bilateral agreements between importing and exporting countries could play a vital role in regulating refrigerant types and setting minimum energy efficiency standards in line with international commitments.

To bridge the gap between international suppliers and buyers of natural refrigerants and related technologies, stakeholders should engage in networking through regional and international databases or directories [7]. Forming buyers' alliances to aggregate demand can enhance the attractiveness of the African market by enabling larger order quantities and stronger purchasing power [38].

Local development and manufacturing of systems and equipment using natural refrigerants must be promoted. Building on the example of the pilot hydrocarbon plant in Nigeria, African countries should explore local sourcing of hydrocarbons, CO₂, or ammonia as byproducts from agricultural processes, petrochemical plants, or methane gas extraction in order to produce high-purity refrigerants domestically [38].

5.5. Unlocking access to financing

Financial incentives are essential to overcoming a variety of barriers to the adoption of natural refrigerants. For instance, the Cooling-as-a-Service (CaaS) financial mechanism, driven by the Swiss-based Basel Agency for Sustainable Energy (BASE), has enabled financing for natural refrigerant projects in countries such as Nigeria and South Africa without the barrier of upfront investment [45]. In Nigeria, ColdHubs Ltd. has been designing, installing, commissioning, and operating solar-powered walk-in cold rooms using propane since 2016 through a CaaS mechanism [46].

At the national level, financial incentives may include subsidies or tax adjustments. Governments could offer financial subsidies for the purchase of natural refrigerants and related technologies. They can also introduce tax adjustments either on the refrigerant itself or on refrigeration systems. Such adjustments may apply to import duties, sales taxes, rebates, or elsewhere within the system.



ColdHubs, Cooling as a Service in Nigeria: a walk-in, modular, solar-powered R290 cold room for storing fresh produce in Nigeria © ColdHubs

5.6. Developing regulatory infrastructure for natural refrigerants in Africa

“Regulatory infrastructure” refers to various types of rules applied to safety and quality concepts and covers both legislation and standards (which are not necessarily mandatory).

The refrigeration industry relies heavily on safety standards to ensure compliance with good practices [47,48]. Beyond regulatory texts such as decrees or orders, which target market uptake, the development, manufacturing and operation as well as servicing of systems using natural refrigerants, requires the application of safety standards.

The lack of specific standards and regulations for natural refrigerants in Africa constitutes a significant obstacle to their widespread adoption and exposes users to considerable risks. Establishing an appropriate regulatory framework would facilitate the controlled expansion of natural refrigerants and support the formal organisation of the sector's related professions. Such a framework would also

enable the implementation of rigorous certification and registration schemes for technicians, thus enhancing the expertise of RAC professionals and increasing the end-user confidence.

African countries must develop regulations and standards governing the storage, distribution, and handling of natural refrigerants, taking into account the specific African context. When adopting international or other national standards, tailoring them to local conditions may be necessary. It is essential to actively engage authorities and industry sub-sectors affected by these standards and guidelines to ensure diverse interests and expertise are well represented, and that the resulting regulations effectively support the safe and practical application of natural refrigerants.



A person working on a laptop with legal icons in holographic style. © Shutterstock

06. References

- [1]. Colbourne, D. (13 June 2022). Hydrocarbon refrigerants through the ages. 15th IIR-Gustav Lorentzen Conference on Natural Refrigerants (GL2022). Proceedings. Trondheim, Norway, 13-15 June 2022. <http://dx.doi.org/10.18462/iir.gl2022.0250>
- [2]. Hafner, A. (7, December 7). Development of CO₂ refrigeration technology between 1995 and 2020. 14th IIR-Gustav Lorentzen Conference on Natural Refrigerants (GL2020). Proceedings. Kyoto, Japan, 7-9 December 2020. <http://dx.doi.org/10.18462/iir.gl.2020.1133>
- [3]. Palm, B. (18 June 2018). Past and future of natural refrigerants. <https://iifiir.org/en/fridoc/past-and-future-of-natural-refrigerants-33836>
- [4]. Reif-Acherman, S. (2012). The early ice making systems in the nineteenth century. *International Journal of Refrigeration*, 35(5), 1224–1252. <https://doi.org/10.1016/j.ijrefrig.2012.03.003>
- [5]. Ghana National Cooling Plan. (2021). <https://www.undp.org/ghana/publications/ghana-national-cooling-plan-report>
- [6]. United Nations Development Programme (UNDP), & Climate and Clean Air Coalition (CCAC). (2015). Ghana HFC Inventory. <https://www.ccacoalition.org/resources/ghana-hfc-inventory>
- [7]. Colbourne, D. (21 August 2011, August 21). Barriers to the uptake of low-GWP alternatives to HCFC refrigerants in developing countries. Proceedings of the 23rd IIR International Congress of Refrigeration: Prague, Czech Republic, 21-26 August, 2011. Overarching Theme: Refrigeration for Sustainable Development. <https://iifiir.org/en/fridoc/barriers-to-the-uptake-of-low-gwp-alternatives-to-hcfc-refrigerants-in-28092>
- [8]. UNIDO, & Shecco. (2013). Natural solutions for developing countries. UNIDO (United Nations Industrial Development Organization). <https://iifiir.org/en/fridoc/natural-solutions-for-developing-countries-4541>
- [9]. World Meteorological Organization (WMO). (22 August 2024). State of the Climate in Africa 2023. World Meteorological Organization. <https://wmo.int/publication-series/state-of-climate-africa-2023>
- [10]. UNEP. (1 September 2023). Ozone layer recovery is on track, helping avoid global warming by 0.5 °C. <https://www.unep.org/news-and-stories/press-release/ozone-layer-recovery-track-helping-avoid-global-warming-05degc>
- [11]. World Meteorological Organization (WMO). (2022). Scientific Assessment of Ozone Depletion: 2022 (Report No. 278). WMO. <https://csl.noaa.gov/assessments/ozone/2022/>
- [12]. CLASP. (2020). Environmentally Harmful Dumping of Inefficient and Obsolete Air Conditioners in Africa. <https://www.clasp.ngo/research/all/environmentally-harmful-dumping-of-inefficient-and-obsolete-air-conditioners-in-africa/>
- [13]. United Nations Treaty Collection. (3, October 2024). Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer. https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-2-f&chapter=27&clang=en
- [14]. European Commission. (n.d.). Guidance on the EU's F-gas Regulation and its legal framework. Retrieved 28 October 2024, from https://climate.ec.europa.eu/eu-action/fluorinated-greenhouse-gases/eu-rules_en
- [15]. McGillen, M. R., Fried, Z. T. P., Khan, M. A. H., Kuwata, K. T., Martin, C. M., O'Doherty, S., Pecere, F., Shallcross, D. E., Stanley, K. M., & Zhang, K. (2023). Ozonolysis can produce long-lived greenhouse gases from commercial refrigerants. *Proceedings of the National Academy of Sciences*, 120(51), e2312714120. <https://doi.org/10.1073/pnas.2312714120>
- [16]. Garavagno, M. de los A., Holland, R., Khan, M. A. H., Orr-Ewing, A. J., & Shallcross, D. E. (2024). Trifluoroacetic Acid: Toxicity, Sources, Sinks and Future Prospects. *Sustainability*, 16(6), Article 6. <https://doi.org/10.3390/su16062382>
- [17]. Fleet, D., Hanlon, J., Osborne, K., La Vedrine, M., & Ashford, A. (2018). Study on environmental and health effects of HFO refrigerants. 1st IIR International Conference on the Application of HFO Refrigerants, Birmingham, 2-5 September 2018. <https://doi.org/10.18462/iir.hfo.2018.1187>
- [18]. David, L. M., Barth, M., Höglund-Isaksson, L., Purohit, P., Velders, G. J. M., Glaser, S., & Ravishankara, A. R. (2021). Trifluoroacetic acid deposition from emissions of HFO-1234yf in India, China, and the Middle East. *Atmospheric Chemistry and Physics*, 21(19), 14833–14849. <https://doi.org/10.5194/acp-21-14833-2021>

- [19]. Holland, R., Khan, M. A. H., Driscoll, I., Chhantyal-Pun, R., Derwent, R. G., Taatjes, C. A., Orr-Ewing, A. J., Percival, C. J., & Shallcross, D. E. (2021). Investigation of the Production of Trifluoroacetic Acid from Two Halocarbons, HFC-134a and HFO-1234yf and Its Fates Using a Global Three-Dimensional Chemical Transport Model. *ACS Earth and Space Chemistry*, 5(4), 849–857. <https://doi.org/10.1021/acsearthspacechem.0c00355>
- [20]. Durand, A., Nwala, G. I., Rúa, C. de la, & Agyarko, K. A. (2024). Environmental assessment of used refrigerating appliances: Why does an import ban make sense and what could other countries learn from Ghana? *Journal of Cleaner Production*, 463, 142596. <https://doi.org/10.1016/j.jclepro.2024.142596>
- [21]. UNEP. (2022). Conference room papers (CRPs). Stopping the harmful dumping of new and used inefficient refrigeration and air conditioning appliances using obsolete ozone-depleting substances and hydrofluorocarbon refrigerants: Submission by Ghana on behalf of the African States parties to the Montreal Protocol (including updated background information). <https://ozone.unep.org/meetings/thirty-fourth-meeting-parties/session-documents#meeting-section-13151>
- [22]. Decision XXXV/13: The import and export of prohibited cooling equipment. (n.d.). Retrieved 30 October 2024, from <https://ozone.unep.org/treaties/montreal-protocol/meetings/thirty-fifth-meeting-parties/decisions/decision-xxxv13-import-and-export-prohibited-cooling-equipment>
- [23]. US EPA. (2024). Protecting Our Climate by Reducing Use of HFCs [Other Policies and Guidance]. <https://www.epa.gov/climate-hfcs-reduction>
- [24]. United Nations Secretary-General's Call to Action on Extreme Heat. (2024). United Nations. <https://www.un.org/en/climatechange/extreme-heat>
- [25]. Kauffeld, M., & Dudita, M. (11, June 2021). Environmental impact of HFO refrigerants & alternatives for the future. Open Access Government. <https://www.openaccessgovernment.org/hfo-refrigerants/112698/>
- [26]. ZeroSottoZero. (13, June 2022). Refrigeranti idrocarburi, uno sguardo dalla culla alla tomba—Un'intervista. <https://www.zerosottozero.it/2022/06/13/refrigeranti-idrocarburi-uno-sguardo-dalla-culla-alla-tomba-unintervista/>
- [27]. IIF-IIR, & Kauffeld, M. (2016). Current long-term alternative refrigerants and their possible applications, 31st Informatory Note on refrigeration technologies. International Institute of Refrigeration. <https://iifiir.org/en/fridoc/current-long-term-alternative-refrigerants-and-their-possible-139189>
- [28]. Arrêté Interministériel Réglementant La Consommation Des Substances Appauvrissant La Couche d'ozone. (2000). <https://www.fao.org/faolex/results/details/fr/c/LEX-FAOC060663/>
- [29]. Arrêté interministériel n°031160 du 23 septembre 2021 Réglementant l'importation, la distribution et la consommation des substances appauvrissant l'ozone et les hydrofluorocarbures (2021).
- [30]. Ministry of Environment Climate Change and Forestry (Kenya), Papst, I., Carreno, A. M., & Schloemann, R. (2023). National Cooling Action Plan for Kenya. <https://iifiir.org/fr/fridoc/plan-d-action-national-pour-le-refroidissement-au-kenya-147208>
- [31]. UNEP. (2023). Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC) 2022 Assessment Report (Montreal Protocol on Substances That Deplete the Ozone Layer.). <https://ozone.unep.org/system/files/documents/RTOC-assessment%20-report-2022.pdf>
- [32]. Gaye, A. (2019). Entre éducation non formelle et informelle, l'apprentissage professionnel « traditionnel » au Sénégal : Analyse des pratiques des maîtres d'apprentissage et de leurs impacts sur les apprentis [Phd thesis, Université de Lille]. <https://theses.hal.science/tel-02533715>
- [33]. Walther, R. (2006). La formation en secteur informel—Note de problématique. Agence Française de Développement. <https://www.afd.fr/fr/ressources/la-formation-en-secteur-informel-note-de-problematique>
- [34]. Green Cooling Initiative. (16, October 2023). Training refrigeration technicians in the informal sector to promote Green Cooling. <https://www.green-cooling-initiative.org/news-media/news/news-detail/2023/10/16/training-refrigeration-technicians-in-the-informal-sector-to-promote-green-cooling>
- [35]. U-3ARC. (2025). Importation Equipements. Aberrants taux de taxation de droit de douane. U-3ARC. <https://www.u-3arc.org/fr/actualites-et-publications/importation-equipements-aberrants-taux-de-taxation-de-droit-de-douane>
- [36]. Egypt. HCFC phase-out management plan (stage II, fourth tranche). (n.d.). UNDP. Retrieved 24 March 2025, from <https://downloads.unido.org/ot/34/80/34804054/4.%20Egypt%20-%20HPMP%20Stage%20II,%20fourth%20tranche%20-%20project%20document.pdf>

- [37]. UNEP. (10, May 2024). Technical and Financial Report for the Group Project for Transformation of Commercial Air Conditioning Companies (HCFC Phase-out Management Plan (HPMP) Egypt (Stage II)), UNIDO ID:140400. https://downloads.unido.org/ot/32/26/32264856/Project%20IEC_Final%20Report_27March2023-P1-combined-compressed.pdf
- [38]. UNIDO. (2017). Africa and the Kigali Amendment. <https://www.ccacoalition.org/resources/africa-and-kigali-amendment>
- [39]. Carvajal, A. R. (2020). Reporte Final de la Consultoría para evaluación del mercado actual y potencial de los refrigerantes hidrocarburos (HC) en Costa Rica. Green Cooling Initiative. <https://www.green-cooling-initiative.org/es/sobre-nosotros/nuestros-proyectos/sustainable-and-climate-friendly-phase-out-of-ozone-depleting-substances-spods/costa-rica>
- [40]. Green Cooling Initiative. (30 April 2024). Senegal: Trainings in Green Cooling. <https://www.green-cooling-initiative.org/news-media/news/news-detail/2024/04/30/senegal-trainings-in-green-cooling>
- [41]. GIZ Proklima. (2010). Converting the Production of Refrigeration Equipment to Natural Refrigerants. <https://www.ctc-n.org/resources/converting-production-refrigeration-equipment-natural-refrigerants>
- [42]. Green Cooling Initiative. (n.d.). Success story: The Fridge Factory conversion project. Retrieved 28 January 2025, from <https://www.green-cooling-initiative.org/fr/reseau-refroidissement-vert/best-practices-detail/success-story-the-fridge-factory-conversion-project>
- [43]. United Nations Industrial Development Organization (UNIDO). (2018). South Africa HFC Inventory. <https://www.ccacoalition.org/en/resources/south-africa-hfc-inventory>
- [44]. ATMOsphere. (2022). Heat Pumps Report 2022. ATMOsphere. <https://atmosphere.cool/heat-pumps-report-2022/>
- [45]. ATMOsphere. (2023). Natural Refrigerants: State of the Industry. <https://atmosphere.cool/product/natural-refrigerants-state-of-the-industry-free/>
- [46]. ColdHubs. (31, January 2025). Our 2024 Social Impact. Solar-Powered Cold Storage for Developing Countries. <https://www.coldhubs.com/coldhubnews/2025/1/31/our-2024-social-impact>
- [47]. GIZ. (2023). International Safety Standards in Air Conditioning, Refrigeration and Heat Pump. <https://www.green-cooling-initiative.org/news-media/publications/publication-detail/2023/06/21/international-safety-standards-in-air-conditioning-refrigeration-amp-heat-pump>
- [48]. IIF-IIR, Coulomb, D., Colombo, I., & Sagna, B. (2015). Qualification and certification of refrigeration technicians, 28th Informatory Note on refrigeration technologies. International Institute of Refrigeration. <https://iifiir.org/en/fridoc/qualification-and-certification-of-refrigeration-technicians-138666>



SOPHIA