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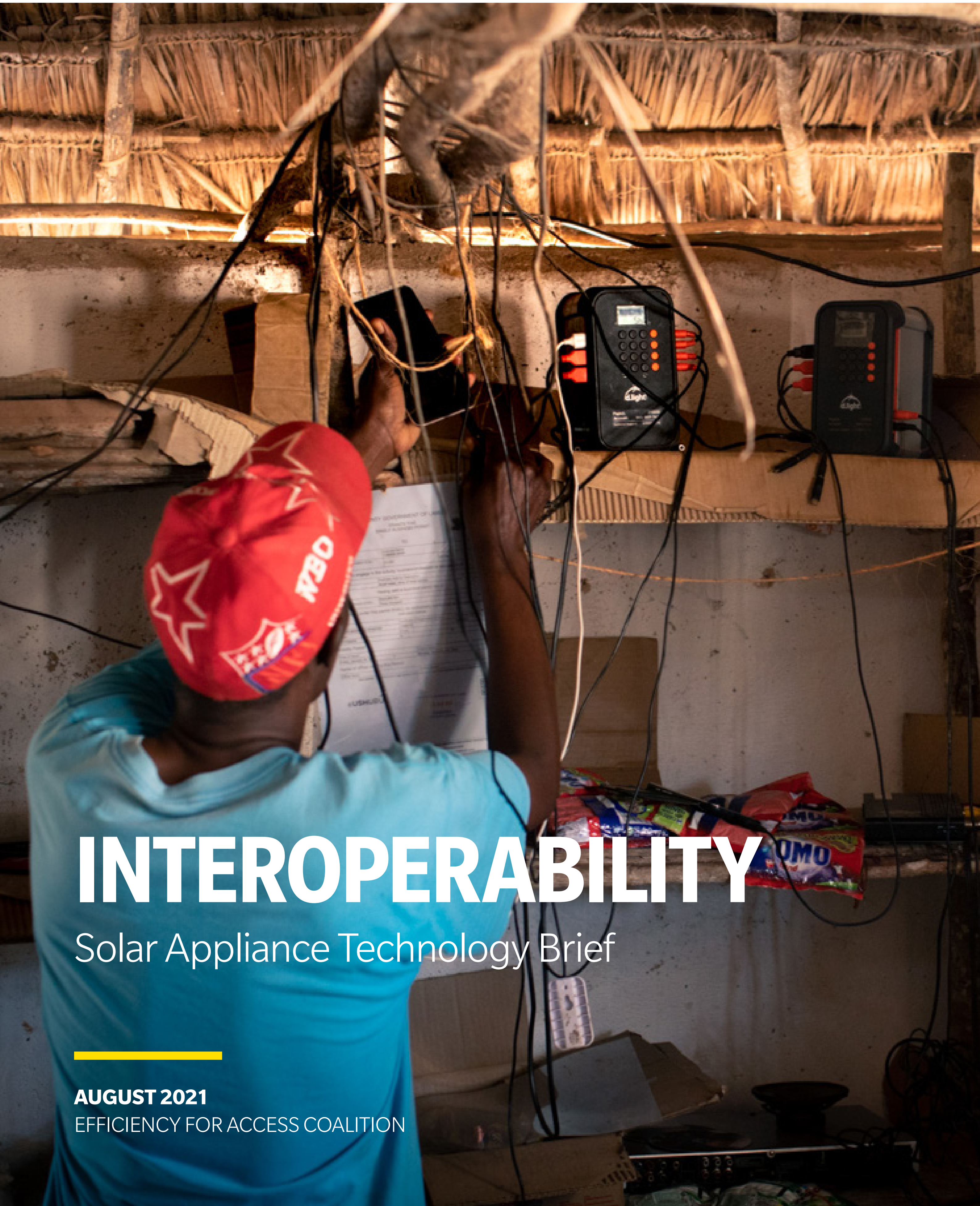

INTEROPERABILITY

Solar Appliance Technology Brief

AUGUST 2021

EFFICIENCY FOR ACCESS COALITION

This interoperability technology brief is one in a series of insight briefs developed to synthesize the latest market intelligence and chart the pathway to commercialization for some of the off- and weak-grid appropriate technologies most relevant to catalyzing energy access and achieving the Sustainable Development Goals.

The first iteration of the LEIA Technology Summaries was published in 2017 to help the newly established Efficiency for Access Coalition navigate a nascent market. At the time there was limited data and reliable research available on market trends and performance of appliances suitable for resource-constrained settings. This brief updates and expands on these summaries, bringing together the latest insights on market and technology trends, consumer impacts, and pathways to scale for solar water pumps intended for use by small holder farmers. You may access all of the briefs in the series here.

This brief was developed by CLASP and Energy Saving Trust as part of Low Energy Inclusive Appliances programme, a flagship program of the Efficiency for Access is a global coalition working to promote high performing appliances that enable access to clean energy for the world's poorest people. It is a catalyst for change, accelerating the growth of off-grid appliance markets to boost incomes, reduce carbon emissions, improve quality of life and support sustainable development.

This brief was authored by Makena Ireri and Monica Wambui of CLASP. We thank Graham Pugh (Clean Energy and Climate Change Solutions), Drew Corbyn (GOGLA), Jelena Popovic (University of Twente), Troy Barrie (Ariya Finergy) and Ari Reeves, Jenny Corry Smith and Yasemin Erboy Ruff (CLASP) and others for their review and input.

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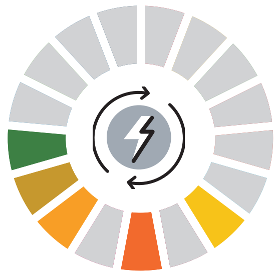
SDG INTERLINKAGES



INTEROPERABILITY

SDG 7: Clean Energy
SDG 9: Industry, Innovation & Infrastructure
SDG 11: Sustainable Cities & Communities
SDG 12: Responsible Consumption & Production
SDG 13: Climate Action

Interoperabilty can help advance universal energy access by merging the main grid, distributed energy systems and appliance/devices. Interoperabilty also encourages innovation by spurring new technologies and applications and reduces the amount of e-waste by minimizing obsolecence and increasing usable life through second life applications and repair.

Introduction

This brief presents a landscape assessment of interoperability, with a specific focus on interoperability between off-grid energy systems and devices. Interoperability allows for technology flexibility and adaptability, as well as consumer and distributor choice. Whilst off- and weak-grid markets are nascent, investments in appliance interoperability could yield large gains for the sector. Interoperability can help promote standardisation and economies of scale, especially at the component level. It can also lower the high-cost barrier for customers to access and move up the energy ladder, and enable a secondary market for appliances. By reducing the risk of technology obsolescence, interoperability also drives reduction in e-waste and appliance dumping.

The 2017 LEIA Appliance Technology Summaries predicted that the energy access market would be characterised by higher-powered systems and more complex grid environments. We forecasted the mini-grid market would compete with solar home system (SHS) market, the grid would expand to integrate with mini-grids and that some users would pool SHSs together in 'swarm solar' systems. Whilst some of these innovations remain in their infancy, the mini-grid sector is slowly maturing. There were nearly 500 solar mini-grids in Africa in 2018.[1] This number is predicted to grow to 16,000 sites by 2023.[2] Whilst the idea of grid integration with distributed energy systems (DES) is often discussed, few countries have adopted the policies and regulations needed to enable them and swarm grids are not yet a prevalent solution. Interoperability and interconnection remain nascent despite a maturing market. Standards will be key to creating the interoperable infrastructure needed to build the complex grids of the future and contribute to long-term sustainability and profitability, especially in distributed energy systems.[3]

DEFINITION

Interoperability refers to the concept of using technology and standardisation to enable systems, appliances and devices to operate in the same environment (i.e., on the same energy supply) and interact with no adverse effects. These interactions are on a continuum and range from compatibility[4] (e.g., a simple electrical connection), to more complex relationships, like exchanging information or permitted use of interchangeable[5] components (devices and appliances) within systems.[6] Interoperability is applicable in two domains:

- **Physical/electrical**,[7] the hardware and firmware requirements needed to enable different system/ device compatibility (including system architecture, voltage and power levels) and
- **Communication/data exchange**,[8] defined as the information exchange, collection, distribution, analysis and utilisation between systems.

1. Guest Contributor, "Solar Mini-Grids in Africa To Climb To 16,000 By 2023," ESI Africa, November 27, 2018, https://www.esi-africa.com/regional-news/africa/solar-mini-grids-in-africa-to-climb-to-16000-by-2023/, (accessed July 16, 2021).
2. Infergia Consulting, Minigrid for Village Electrification: Industry and Africa & Asian Markets. (2020), https://www.infinergia.com/en/mini-grid-market-report.
3. IRENA, Quality Infrastructure for Smart Mini Grids. (2020), https://www.irena.org/publications/2020/Dec/Quality-infrastructure-for-smart-mini-grids.
4. **Compatibility** is the ability of systems or components to perform their required functions while sharing the same hardware or software environment without necessarily communicating and not adversely affecting each other, e.g., appliances that are connected to a solar home system perform their respective functions independently in the same operating environment and are therefore compatible. Compatibility is typically guaranteed by formal or de-facto technical standards.
5. Two devices are **interchangeable** if they can be physically exchanged for each other and provide a defined level of identical operation in a system without additional configuration.
6. Advanced communications and load management aren't always needed to enable devices to be interchangeable. In the context of solar home systems and appliance interchangeable devices can be based on simple electrical and plug compatibility.
7. **Technical interoperability** falls under the Physical/ Electrical domain and enables both basic connectivity and network connectivity.
8. There are two levels in the Communication/Data Exchange domain, a. Syntactic interoperability: the ability to communicate and exchange meaningful information through standards that define the structure and format of the information. b. Semantic interoperability, which extends this capability to provide shared understanding/interpretation/meaning of the exchanged information despite different interfaces and programming languages.

State of Play

The Efficiency for Access Interoperability Working Group developed the first ever [2019 Compatibility and Interoperability Technology Roadmap] for the off-grid sector. It highlighted the opportunity for interoperability and outlined the barriers, such as R&D gaps, hindering an interoperable off-grid energy ecosystem. The roadmap recommended that the sector define uniform requirements for electrical connectivity and approaches to connectivity in support of load management in SHS systems. The sector is now pursuing multiple avenues toward interoperability in off-grid and weak-grid markets.

Interoperability in purely off-grid markets, dominated by direct current (DC) infrastructure, is applicable in two contexts:

- **Technical interoperability at the component level:** This refers to the ability of DES and various appliances to interoperate (e.g., between an SHS kit and lights, TVs or fans). This is mainly played out through physical/electrical compatibility. For example, voltage standards and connector alignment allowing appliances from one manufacturer to be powered by systems from a different manufacturer. Further, establishing common communication protocols ensures full interoperability; for example, interoperable pay-as-you-go (PAYGo) protocols between different original equipment manufacturers (OEMs). The Connect Initiative (Box 2) is a good example of sectoral effort at this level.

- **Systems-level interoperability:** This refers to the ability of multiple DES, for example, solar energy systems and/or mini-grids to connect with each other and share loads. This would require both physical and communication interoperability governed by technical standards. Establishing a 12V DC standard, for example, might open the way for swarming of small SHS kits.

Interoperability in both an off-grid and weak-grid context can be considered from supply side and consumer perspectives.[9]

Supply side (the combination of grid, solar and battery) considerations include:

- **Power converters** are needed to run appliances in non-native modes when the power supply and appliance are not directly compatible (e.g., running an alternating current (AC) appliance on a DC mini-grid). Whilst appliances perform best in their native modes, power conversion is a necessary step in some situations. It however always results in a 'sunk' power loss. Losses can vary according to the quality of the converter and how appropriately sized it is for the load.[10]

- **Hybrid solar inverter uninterrupted power supplies** (UPS) combine grid, battery and solar as an input. They provide power backup in weak-grid areas and may lower energy costs. An estimated 55 million households in India have already installed conventional UPS, which contain a battery and connect to the AC power grid. These households can be targeted to convert their conventional UPS systems to hybrid solar UPS systems.[11] The excess solar power cannot be exported to the grid.

- **Hybrid grid-tie inverters** combine grid and solar (battery is optional) as input power and allow for the export of power to the main grid. Some AC mini/micro-grid inverters can be replaced with hybrid grid-tied inverters with export capability (future compatibility).[12]

Consumer side (appliance usability on both AC and DC supplies) considerations include:

- **Dual input appliances** (hybrid appliances) can run on both AC and DC power. They are currently two to four times more expensive than conventional AC appliances, though prices will likely fall with wider adoption. Light bulbs and fans are expected to be cost-competitive first.[13]

- **Hybrid appliances with a single input (AC) and built-in battery storage** provide back-up power during a power cut. Whilst nascent, they could be an alternative to UPS systems and a major game-changer in weak grid contexts. However, their potential may be limited for households that are already using UPS solutions.

Standards, policy and regulatory structures play an important role in interoperability mainstreaming. Some governments are actively developing interoperability frameworks that will harness available DES to create robust smart grids. Few, if any, of these frameworks have been implemented, and fewer still consider interoperability at the component level, i.e., between DES and appliances (Box 1). Finally, private sector alliances may also be effective drivers of interoperability. They may be used to define common specifications, achieve industry consensus and set a starting point for standards development.

9. Id.
10. Efficiency for Access, Performance and Efficiency of Off-Grid Appliances with Power Converters: Phase 1. (2020), https://efficiencyforaccess.org/publications/performance-and-efficiency-of-off-grid-appliances-with-power-converters-phase-1.
11. GOGLA, Opportunities for Hybrid AC-DC Infrastructure in India. (2020), https://www.gogla.org/resources/opportunities-for-hybrid-ac-dc-infrastructure-in-india.
12. Id.
13. Id.

Policy

REGULATORY STRUCTURES FOR INTEROPERABILITY

Policy is an important vehicle for advancing interoperability. Where devices are interoperable, standards gradually improve overall performance over time. To date, specific interoperability-related standards for distributed energy systems are few but continue to be developed by industries and government. Examples include:

- **The Guidelines for 48V ELVDC (Extra-low voltage) distribution systems IS 16711: 2017.** Developed by the Bureau of Indian Standards, these guidelines cover the essential requirements for distribution of power from an extra-low-voltage 48V DC power source and are applicable to locations where electric utility services are not available and power is derived from single or multiple renewable energy sources.[14] Adopted in 2017, they include power sources defined under IEC 60364-4-41:2005 such as interconnected or standalone batteries, solar photovoltaic systems and other distributed renewable generation systems.

- **The Open DC Grid Standard.** This standard defines a micro-grid architecture that permits devices to exchange DC electric power.[15] It is well suited for distributing power in SHSs, which are often used when normal AC power is unavailable or unaffordable, thus enabling devices to communicate and optimise the use of limited available power.

14. Bureau of Indian Standards, National Conference on Low Voltage Direct Current (LVDC) Distribution Solutions and Applications, (2018), https://bis.gov.in/other/National_Conference_on_LVDC_held_in_Shillong_on_18_May_2018.pdf.
15. "Open DC Grid," Open DC Grid, accessed July 16, 2021, https://open-dc-grid.org/.

Market Insights

The global distributed energy and appliance market is growing. Interoperability is becoming a necessary way to cost-effectively integrate new development and technologies and create a competitive market without technology isolation. It is part of a suite of enabling technologies that have the potential to accelerate markets for off-grid compatible appliances (Figure 1). India, Kenya, Bangladesh and Myanmar have made the most progress towards universal electricity access since 2010.[16] These countries have made concerted efforts to electrify households and have created the conditions for interoperable technologies to take hold. The first indicator for accelerating interoperability is the widespread use of power converters. Power converter use in off- and weak-grid settings for AC and DC appliances in India is increasing.[17] Further, hybrid solar systems, which integrate solar, batteries and AC grid power, have become more popular. GOGLA estimates that 1.9 million households in India access energy this way.[18] Greater interoperability would be a game-changer, but no market projection of the value of interoperability in off- and weak-grid markets exists.[19]

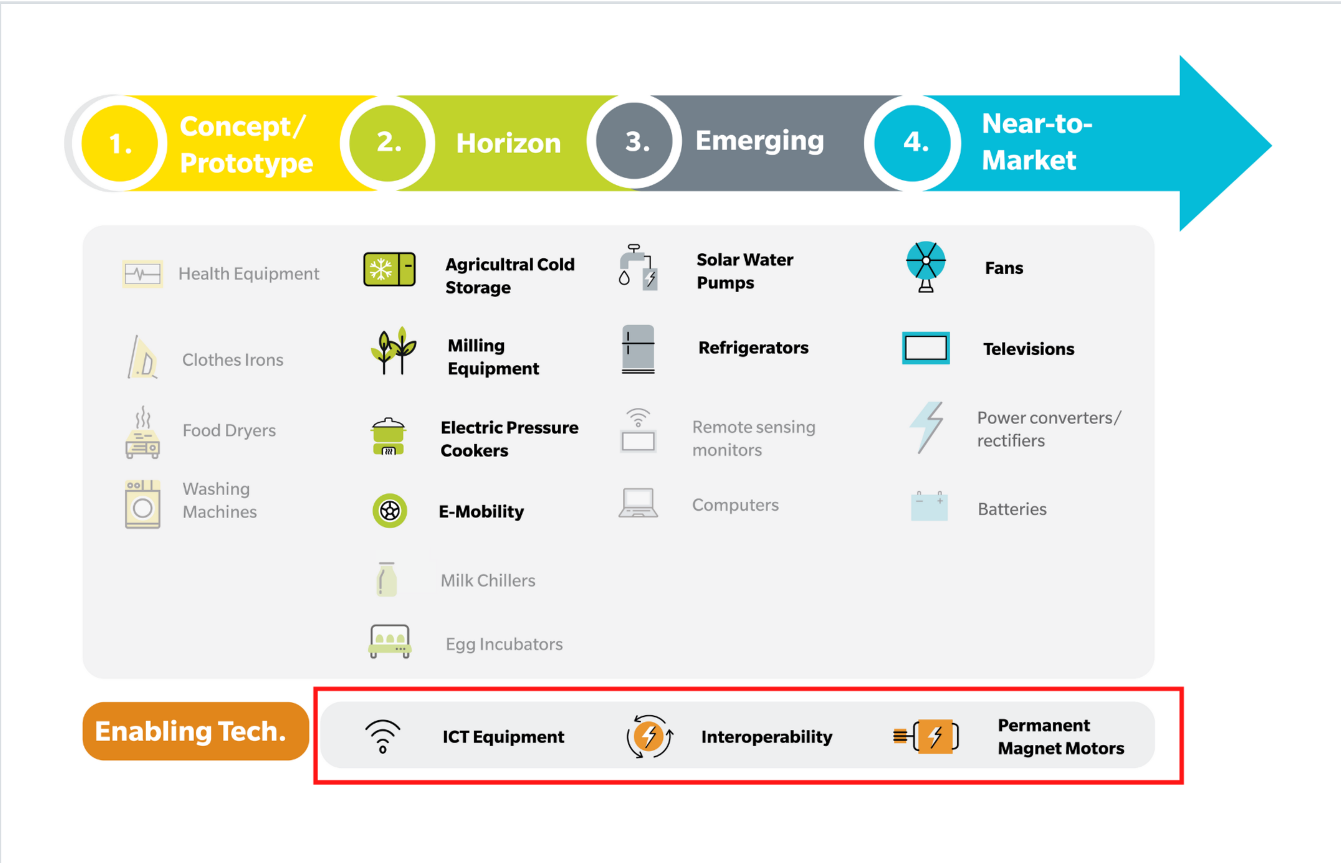
Impacts

Greater compatibility and interoperability in off- and weak-grid appliances would deliver a number of benefits to the market, environment and consumers.

Greater innovation and technology scale up: Vertical integration of systems incentivises incompatibility. Each innovator protects their own perceived uniqueness, stifling information sharing and collective technology and new applications. In contrast, allowing for open-source development of resource packages for diagnostics and load control is a common, interoperable communication protocol for SHS.[20]

Lower manufacturing and consumer costs: The high cost of developing bespoke components for different system providers adds to manufacturing costs, which are ultimately borne by consumers. Standardisation of components through interoperable systems allows providers to benefit from economies of scale and thereby reduce costs.

Figure 1: Relative Maturity of Select Appliances



16. GOGLA, Opportunities for Hybrid AC-DC infrastructure In India.
17. Id.
18. Id.
19. World Bank & GOGLA, Off-Grid Solar Market Trends Report. (Washington, DC: 2020), https://www.lightingglobal.org/resource/2020markettrendsreport/.
20. GOGLA, The Connect Initiative White Paper. (2021), https://www.gogla.org/resources/the-connect-white-paper.

Improved consumer flexibility and choice: In addition to lowering prices, additional market efficiencies could be achieved if consumers' ability to buy or sell appliances is not limited by system incompatibility. For example, consumers could easily monetise unused assets once they upgrade or swap failed components with those from a different brand. The constraints imposed by a lack of interoperability are already playing out in the East African SHS market and are expected to worsen as the prevalence of off-grid solutions increases. This issue could stifle the overall market and increase the cost for consumers to move up the energy ladder.[21]

Reduced e-waste: Interoperability will reduce component obsolescence and lower the rate at which these components enter electronic waste (e-waste) streams. Product incompatibility inhibits the resale/secondary market, forcing customers to "stack" custom solutions in the home[22] and leading to the dumping of abandoned assets in unprotected markets at the component level. Globally, nearly one million tonnes of power adapters are manufactured annually with little consideration for compatibility with other devices.[23]

Stronger consumer protection: Interoperability developed in tandem with robust quality assurance programs will protect consumers and foster markets that are based on value proposition and quality. A lack of compatibility and interoperability between systems tends to lock consumers into purchasing additional products from the same manufacturer. In this environment, competition is based on absolute retention of customers rather than on highest value proposition based on quality and price. Although proprietary non-interoperable systems can guarantee performance with all components and appliances matched and working well together, this can also be achieved in an interoperable ecosystem with communications technology such as "digital handshakes."[24]

Accelerated capacity building for repair and maintenance: Interoperability across systems can greatly increase the value of trained skills by making them more "portable" across a wide range of equipment and systems. Interoperable "plug-and-play" solutions that work across a broad range of operating conditions (e.g., 12V-48V) would reduce costs of having specialised technical force needed.

Current Success and Remaining Challenges

Current Success

Industry movement towards standardisation: Taking the next steps from the Efficiency for Access 2019 technology roadmap, the GOGLA Technology Working Group (TWG) is working to improve the interoperability of SHS components and appliances under the Connect Initiative. This initiative, funded by Efficiency for Access, will produce a set of standards for connectors and firmware for 12V SHS kits and appliances. The standards will enhance interoperability among these products, reduce barriers to pairing SHS kits with lights and appliances and increase flexibility and choice whilst reducing cost (Box 2).

Growing private sector R&D: With funding from Efficiency for Access, Angaza has developed a solution (Nexus Channel and Nexus Channel Core) that allows device-to-device communication secured by cloud services in a common language defined by open standards, even if those devices are from different manufacturers. Solaris has developed a free and secure Open Source Token System to make any product PAYGO compatible and the Open PAYGo Link. Through R&D grants, Efficiency for Access is also supporting Green-Empowerment to create an open source Solution for Smarter Load Management and Omnivoltaic to develop a dashboard and hardware for Device Data Discovery as a Service.

Remaining Challenges

Despite the potential positive impact of interoperability, the low price point needed for energy access solutions and the lag in adoption of standards and regulations do not provide manufacturers much leeway in terms of designing for overarching compatibility with each other. Integrating new technologies, redefining and redesigning working models of energy delivery, requiring new levels of collaboration and regulating the new interoperable future for fairness and consumer protection will not be without its challenges. Many of these challenges stem from the entrenched energy delivery modes prevalent in the market.

A lack of collaboration and consensus across the sector: There is no common vision for interoperability across the sector. Standardisation risks and operational constraints of energy systems providers and appliance manufactures create tension. Private sector actors dominate the off-grid energy sector in Sub-Saharan Africa and Asia. They may view interoperability as a risk to their existing consumers and business models. Whilst one grand unifying standard across the sector may not be possible, progressive action will require open discussions across a broad coalition of stakeholders in order to understand possible risks and specific needs over a range of energy access solutions.

Business risk: The growing energy access private sector is facing competitive pressure to maintain customised solutions. System providers try to keep their systems from being damaged and the consumers who use them safe. Interoperability could create a brand reputation risk due to product mismatch and reduced performance. There needs to be a concurrent focus on appropriate labels and consumer education so that consumers are aware when components are interoperable and when they are not. Other risks include payment default,

21. Efficiency for Access, Performance and Efficiency of Off-Grid Appliances with Power Converters, Phase 1. (2020), https://efficiencyforaccess.org/publications/performance-and-efficiency-of-off-grid-appliances-with-power-converters-phase-1.

22. Id.

23. Balde, C.P., Forti, V., Gray, V. Kuehr, R., Stegmann, P., Global E-waste Monitor 2017: Quantities, Flows, and Resources. (Bonn/Geneva/Vienna: United Nations University, International Telecommunication Union & International Solid Waste Association, 2017), https://www.itu.int/en/ITU-D/Climate-Change/Documents/GEM%202017/Global-E-waste%20Monitor%202017%20.pdf.

24. The identification and verification of appliances so that they only work on the SHS Kit they are connected to / have been sold with.

complex operational maintenance of products in the market and complicated backward compatibility requirements. For a cash-strapped market still reeling from the effects of the COVID-19 pandemic, these additional steps may not be welcome if they cut into profits.

Standardisation: As technology innovations progress, the sector must address quality needs around the use of digital technologies and interoperability of components.[25] It is important that standards and other regulatory structures not limit innovation but promote it. However, standardisation will inevitably be steered by market forces. New technologies will be insufficient to force change. The success of standards often depends upon other competitive pressures. For example, standards that fail to build sufficient consensus, recognition or approval in their target sector risk failure despite great technical promise.[26] Further, the fast technology cycles inherent in the off- and weak-grid sector may encourage technology obsolescence and create backward compatibility problems. Often, these fast-moving timelines do not match those of existing standards-making processes and policy or regulatory requirements, which take longer.

Risk of orphaned technology: A policy or standardisation push for interoperability via specific technologies may have unintended consequences. For example, pushing a specific interoperability standard or technology can hurt sector-wide interoperability efforts due to the risk of the technology being "orphaned."[27] The chosen technology, if not selected through market consensus, may lose industry support. Orphaned interoperability technologies can end up isolating users and hindering the effort toward interoperability overall.[28]

Lack of data: Manufacturers, distributors, policy makers and funders have a limited understanding of the technological benefits and cost efficiencies and gains achieved through interoperability. This is in part due to lack of quantifiable data, successful case studies, verified testing methodologies and effective mechanisms for collaboration.

Competing priorities and lack of expertise at the governmental level: Energy agencies are often occupied with complex challenges, including last mile connectivity, struggling utilities and demand stimulation, leaving them little capacity to address the challenges of the future. Whilst some governments recognise the need for interoperability (e.g., by inclusion of ideas around feed-in tariffs in energy policy documents), many have had little capacity to address the issues they see as tomorrow's challenge.[29]

25. IRENA, Off-Grid Renewable Energy Access Solutions to Expand Electricity Access: An Opportunity Not to be Missed. (2019), https://www.irena.org/publications/2019/Jan/Off-grid-renewable-energy-solutions-to-expand-electricity-to-access-An-opportunity-not-to-be-missed.

26. Bollinger, T., A Guide to Understanding Emerging Interoperability Technologies. (Washington, DC: Mitre Corporation, 2000), https://www.mitre.org/publications/technical-papers/a-guide-to-understanding-emerging-interoperability-technologies.

27. Orphaning refers to a sudden discontinuation or withdraw from market of a product, firmware or software, with an active user base, usually for business-related reasons.

28. Id.

29. Energy Act of Kenya, (2019), https://www.epra.go.ke/download/the-energy-act-2019/

BOX 2

In Focus

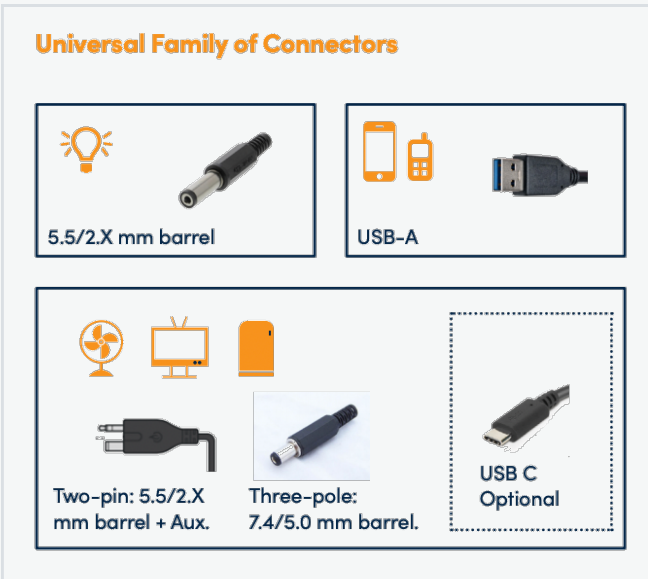
THE CONNECT INITIATIVE

The predominant model in the off-grid solar (OGS) sector is that of non-interoperable systems which use brand-specific connectors combined with proprietary digital protocols. For pay-as-you-go (PAYGo) consumers, this means they must purchase their solar home system kits (SHS Kits) and appliances from the same company. They are unable to use an appliance with another company's SHS, or vice versa. For cash sale customers, this means limited flexibility and choice of appliances and a high risk of buying an appliance that is not compatible with their SHS kit. With GOGLA members reporting sales of more than 3 million SHS kits and 2 million appliances (TVs, fans and fridges) since 2017, the status quo needs to change to give consumers greater choice and flexibly.

The Connect Initiative will develop and promote universal connector and firmware standards to enable interoperability between SHS kits and appliances. This will not only ease the process of upgrading for the customer but also catalyse market growth and present multiple benefits to all stakeholders. Adoption of the interoperability standards will be voluntary and driven by players who see value in the model.

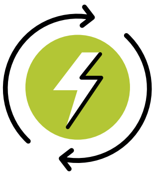
1. **Universal Connectors:** This family of connectors for 12V SHS kits will support power delivery and communication for lights, phone charging and other appliances.
2. **Firmware:** This will provide standardised digital services for appliances for both consumers and companies through two-way data flow.
    - **Consumers:** The firmware will support PAYGo activation, demand management and data & fault logging.
    - **Companies:** The firmware will support product telemetry, CRM & accounting, secure payments and other services to the companies.

Figure 2: Family of Connectors Under Connect Initiative (GOGLA)



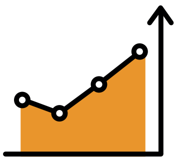
Pursue interoperability through industry convergence and consensus

There are three main pathways to achieving interoperability. First, the sector can coalesce around an agreed interoperability vision in a systematic and inclusive way. Second, a public entity can push a preferred approach through standardization and regulation. Finally, the sector can pursue a market-led approach that allows interoperability to progress naturally without external intervention. Efficiency for Access and GOGLA are working on an industry-led approach. They are convening and building support for interoperable solutions among a wide range of players (Box 2). Building on these early efforts in an inclusive way that considers all stakeholders will be key to setting a common and shared vision of future interoperability. Governments in particular could also play a key role in supporting such convenings to hasten the pace and accelerate the potential benefits for achieving universal energy access.



Start with low-hanging fruit

The interoperability challenge is complex; for continued progress, the sector should begin with the least complex and most easily attainable step. Physical/electrical connectivity and interoperability are easier to converge on due to a precedent for standardisation in other related sectors. For example, the adoption of USB for mobile phone and consumer electronics has revolutionised interoperability of these devices allowing them to dominate the market. Most SHS kits have already adopted a de-facto USB connection for mobile charging. Extending standardisation to the light and appliance connections should be a relatively easy next step.



Build a strong knowledge base with well-funded research

Actors need more data to demonstrate the benefits of interoperability so that they can elevate these considerations to "business as usual." Industry facilitators play a key role here. Consumer research is required to understand potential challenges to interoperability and routes to consumer awareness. Field testing for proposed interoperable solutions, like those implemented by the Connect Initiative, are required to validate proposed technical guidelines. The sector also needs more insight into the technical and economic aspects of SHS interoperability in higher voltage applications (48V). Research to develop the appropriate quality assurance framework for interoperability is crucial for converting any industry consensus into standards.

Standardisation will take time; funding should be sustained to ensure success

Coalescing the sector around agreed solutions, developing technologies and standards, and ensuring their adoption and widespread use will take time. Grant funding for practical demonstrations and applications of interoperability by companies has to be sustained in the longer term to ensure success.

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