Case Study: BESS Capacity Building for Malawi

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National Laboratory of the Rockies

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List of Acronyms

BESS	battery energy storage system
DER	distributed energy resource
EMT	electromagnetic transient
ESCOM	Electricity Supply Corporation of Malawi
GFM	grid-forming
IBR	inverter-based resource
IEEE	Institute of Electrical and Electronics Engineers
MERA	Malawi Energy Regulatory Authority
MUBAS	Malawi University of Business and Applied Science
NLR	National Laboratory of the Rockies

Executive Summary

To strengthen Malawi's national electricity grid and to enhance reliability, the government of Malawi and the Electricity Supply Corporation of Malawi are partnering with the Global Alliance for People and Planet to develop a 20-megawatt/30-megawatt-hour battery energy storage system at Kanengo, Malawi, expected to come online in 2026. In parallel, the Global Energy Alliance for People and Planet and the National Laboratory of the Rockies implemented a comprehensive technical capacity-building program to equip the Electricity Supply Corporation of Malawi, the Malawi Energy Regulatory Authority, and the Malawi University of Business and Applied Sciences with the expertise needed to plan, regulate, and operate advanced storage systems.

Between May 2024 and May 2025, more than 44 participants from the Electricity Supply Corporation of Malawi, the Malawi Energy Regulatory Authority, and the Malawi University of Business and Applied Sciences engaged in a blended training program consisting of in-person workshops and virtual sessions. The curriculum covered foundational battery energy storage system topics—such as technology, safety, operations, and degradation—as well as advanced subjects, including tariff design, regulatory frameworks, frequency control, system modeling, and decommissioning. Training also emphasized monitoring, evaluation, and learning to ensure long-term knowledge transfer and impact assessment.

The capacity-building program demonstrated measurable improvements in awareness and confidence across key technical and regulatory domains, particularly frequency control, inverter technologies, end-of-life considerations, and system modeling. However, participants also identified areas requiring continued support, notably grid codes, tariffs, and compliance mechanisms.

Several cross-cutting lessons emerged that are applicable to other geographies advancing battery energy storage system adoption:

- **Stakeholder engagement** is critical to ensure coordinated planning and knowledge sharing across utilities, regulators, government agencies, and academic institutions.
- **High-quality, context-specific data** underpin effective training, project design, and performance evaluation.
- **Iterative and responsive training design** allows alignment with evolving needs, ensuring tailored, and practical learning.
- **Varied learning formats and active engagement methods** enhance retention and application of knowledge.

Through this effort, Malawi has taken important steps toward building institutional confidence in energy storage technologies, strengthening regulatory frameworks, and developing the technical skills required for integration of distributed energy resources. The Kanengo battery energy and storage system pilot project offers a replicable model for advancing energy storage implementation across emerging markets in Southern Africa and beyond.

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1 Background

The national electricity grid in Malawi faces reliability challenges in maintaining stable operations. To manage frequency within acceptable tolerances and to ensure continuity of supply, generation at power plants is sometimes reduced —particularly at Salima, which is the largest plant and therefore most frequently curtailed and also at Golomoti and Nkhotakota. These challenges are limiting both existing electricity services as well as the ability for the national transmission system operator, the Electricity Supply Corporation of Malawi (ESCOM), and the Malawian government to expand energy access in the country. This further causes ESCOM to curtail variable distributed energy resources (DERs) and rely on costly diesel standby generators to help balance the grid and meet peak demand. The government of Malawi and ESCOM are developing a suite of solutions to more reliably address these challenges.

The Global Energy Alliance for People and Planet (the Alliance) is supporting the government of Malawi and ESCOM in developing a 20-megawatt/30-megawatt-hour battery energy storage system (BESS) project in Kanengo, Malawi, to stabilize Malawi's national grid, better integrate energy from DERs, and build institutional confidence in BESS and other advanced energy technologies in Malawi as well as the broader Southern African region. The plant is planned to come online in April 2026.

In addition, the Alliance is supporting technical capacity building focused on technical implementation and integration of energy storage, regulatory needs for energy storage, as well as monitoring, evaluation, and learning. This case study is part of a series of case studies to document key lessons from the Kanengo BESS pilot project. This case study provides an overview of the technical capacity-building trainings for ESCOM as part of the Alliance project and highlights key lessons learned that can be adapted to other contexts. Other case studies are focused on monitoring, evaluation, and learning; procurement; development of requests for proposals; and bid review (led by the Alliance).

1.1 About the Global Energy Alliance for People and Planet

The Alliance builds transformative public, private, and philanthropic partnerships to end energy poverty and accelerate economic opportunity. Founded in 2021 by The Rockefeller Foundation, IKEA Foundation, and Bezos Earth Fund, the Alliance works in more than 30 countries to unlock financial support, strengthen institutions, and transform markets, delivering progress that goes beyond individual projects to drive lasting systems change. Through their two interconnected global pillars—Grids of the Future, focused on innovation and infrastructure, and Energy and Opportunity, with a focus on jobs and livelihoods—they work toward their vision: a world where everyone has access to affordable, reliable electricity and the means to use it to improve their lives.

2 Approach

The Alliance partnered with the National Laboratory of the Rockies (NLR) to support technical capacity building for ESCOM as well as other key stakeholders, including the Malawi Energy Regulatory Authority (MERA) and Malawi University of Business and Applied Sciences (MUBAS). The multiparty training program focused on a range of topics related to a BESS-enabling environment, operations, and broader power sector planning and combined both in-person and virtual workshops over the course of 10 months from July 2024 through May 2025.

Training topics were identified through a combination of direct questionnaires to ESCOM, MERA, and MUBAS staff, recommendations from the Alliance, as well as from past NLR experience in global BESS projects.

Based on participant answers, as well as discussions and questions flagged during initial training sessions, areas of focus for BESS training included:

- BESS basics, including technology models, electrochemistry, state of charge management, degradation curves, and safety based on real systems
- Utilization of BESS for frequency and voltage control and system stability
- Training on tools used to evaluate financial viability, necessity, and cost-benefit analysis of energy storage projects and to set appropriate tariffs for real-world projects
- Tariff design and evaluation for different BESS contracts and charging/discharging as well as how to value "deferred investment" BESS business models (behind-the-meter, transmission owned, independent power producer)
- Dynamics of BESS operations and interactions with changing operational environment (e.g., interconnected operations with Southern African Power Pool)
- Grid integration issues, particularly BESS behavior during system shutdown
- Benchmarks for costing components as well as operations and maintenance in emerging economies
- Decommissioning and end-of-life of BESS assets
- Mechanisms for tracking and ensuring compliance with BESS regulations, including audit protocols and frequency.

Trainings were conducted in a combination of in-person workshops in Malawi (May 2024, January 2025, May 2025) and a virtual workshop series in the fall of 2024 and spring of 2025.

3 Trainings

From 2024 to 2025, NLR designed and delivered a series of technical trainings to support stakeholders from ESCOM, MERA, and MUBAS in building confidence and capacity for integrating and operating BESS in Malawi. Table 1 provides an overview of the topics covered in the training sessions. A total of 44 individuals participated in the program, which organized participants into two thematic working groups—(1) Regulatory and (2) Implementation and Integration—to ensure targeted learning and foster peer collaboration. The goal of this effort was to increase the capacity of these organizations to deliver distributed energy resources and related solutions to Malawi.

Table 1. Summary of training topics covered in the Malawi BESS pilot project.

Topic	Description	Key Learnings / Takeaways	Action Item(s)
Grid Code Provisions for BESS [Link to materials] 1/14/25, 4/28/25 ESCOM, MERA, MUBAS; 1 in-person session	Integration of BESS into grid codes, including authority/obligation roles for ESCOM and MERA, enforcement, and stakeholder engagement.	• **Consider grid-forming characteristics** for future procurement of BESS if targets are met for increased inverter-based resources (IBRs) and the number of hours with reduced online synchronous generation capacity is limited. • Two sessions **reviewing grid code in Malawi compared to industry standards for integrating BESS** (including the Institute of Electrical and Electronics Engineers [IEEE] 1547, IEEE 2800, International Electric Code, and Chile Grid Code Review compared to IEEE 2800). Specific discussion areas of interest included droop settings (currently 4%−10%, but could be faster for BESS), definition of "h constant" for frequency control and response, how to balance protection and grid requirements, and grid-forming requirements.	• The grid code technical committee might consider **reviewing and proposing updates to the grid code to address BESS and IBR integration**. Compare with EPC specs to identify alignment gaps. • MERA will need to do **testing and inspection not only before commercial operation but also on an annual basis**. Further, penalties can be assessed and enforced if out of compliance (for all generator units as well as storage).

Topic	Description	Key Learnings / Takeaways	Action Item(s)
 **BESS Licensing and Standards** [Link to materials] 1/13/25 ESCOM, MERA, MUBAS; 1 in-person session	Licensing and permitting requirements for BESS, including licensing authority and responsibilities, types of generator licenses, transmission assets, safety standards, and licensing structure.	• Licensing and permitting for BESS require **clarity on application processes** (including siting and interconnection), **approval processe**s (including authority, type of asset, ownership models), and **inspection processes** (particularly for safety and environmental issues). • There are a few **sets of standards** and best practices for BESS that can be leveraged to refine licensing requirements in Malawi, **notably IEEE 1547 and IEEE 2800-2022**. Similar codes exist in the International Electric Code. • Integrating distributed energy resources into the grid requires an **evolution in power system planning and operation to manage variability and uncertainty**, including the regular use of models for optimizing the system subject to security and other constraints.	• **MERA plans to develop a formal BESS licensing and permitting framework**—to clarify application, approval, and inspection processes specific to BESS technologies. • **MERA intends to establish BESS-specific safety standards and inspection protocols**—drawing on international codes (e.g., NFPA, UL) to ensure safe design and operation. • **MERA aims to coordinate with Environmental Affairs Department to require environmental licensing for BESS projects—** including decommissioning and recycling plans as part of project approvals.
 **Modeling for BESS** [Link to Materials] 2/18/25, 2/25/25, 3/4/25 ESCOM, MERA, MUBAS; 3 virtual sessions	NLR System Advisor Model™ (SAM), both an overview and hands-on demonstrations.	• SAM is an **open-source software for performance and financial analysis of DER projects**. SAM calculates a power system's energy output (kilowatts), and a power project's annual cash flow ($) based on power system, cost, and financing inputs from the user. • Users can **simulate projects at hourly or subhourly resolution**, assess cash flows, and conduct sensitivity, uncertainty, and parametric analyses.	• **MERA and ESCOM expect to use SAM outputs to strengthen regulatory filings and funding proposals**—by incorporating evidence-based performance and cost projections into documentation.

Topic	Description	Key Learnings / Takeaways	Action Item(s)
		• **The tool is highly customizable**, with scripting capabilities, a Python package (PySAM), and an open-source codebase. • **Inputs and assumptions can be refined iteratively** as the user understands how changes affect outputs. Net present value, power purchase agreement revenue, net rate of return, and efficiency are key output parameters to review when refining inputs.	
 **Planning Tools for BESS** **[Link to materials]()** 1/13/25 ESCOM, MERA, MUBAS: 1 in-person session	Operational planning tools for BESS, including software and simulation tools for BESS design, performance analysis, and optimization.	• In addition to traditional long-term power system planning components, there are additional planning considerations for integrating DERs, including **load forecasting, resource expansion, capacity expansion, transmission upgrades, flexibility, operational changes, reserves optimization**, etc. • **The Alliance-funded integrated resource plan and BESS grid study** are excellent planning resources that provide information such as future electricity supply and demand. These resources can be utilized in future planning. • **Grid integration studies (capacity expansion modeling, production cost modeling, power flow)** are an ongoing process, as resource and situational changes occur. The analytical framework setup allows users to continue to hone expertise for look-ahead scenarios at all time scales. Pricing yielded by production cost (locational marginal prices) can be the basis for tariff payments (if using value instead of cost basis) and provide investment signals for storage and DERs.	• **ESCOM and MERA plan to improve the collection, sharing, and transparency of load, generation, and storage performance data** to support robust modeling, regulatory filings, and investment decisions.

Topic	Description	Key Learnings / Takeaways	Action Item(s)
System Dynamics and Frequency Control for BESS **Link to materials #1** **Link to materials #2** 3/13/25, 3/18/25, 3/25/25, 4/29/25 ESCOM and MUBAS; 4 sessions—3 virtual, 1 in-person	**Session 1** focused on frequency principles, frequency stability, interconnected operations, and tiered frequency control response with detail on control strategies (primary, secondary, and tertiary frequency control). **Session 2** covered frequency control with BESS, integration of IBRs, grid-following vs. grid-forming, and an example of BESS optimization (sizing and siting for frequency stability). **Session 3** trained users on how to use PowerWorld and provided an opportunity to work on example case studies in the software. **Session 4** focused on reviewing primary, secondary, and fast frequency control and specifically how BESS assets can help to provide these services and the risk of not providing these services	• **Maintaining grid stability requires a balance between power supply and demand**, with frequency control ensuring that deviations are quickly corrected to avoid system failures. • **Frequency regulation consists of primary, secondary, and tertiary control**, each requiring coordinated responses from BESS and other grid assets to maintain system reliability. • Primary frequency response allows BESS to automatically **inject or absorb power within seconds of a frequency deviation**, helping to stabilize the system quicker than other resources can respond. • Secondary frequency control, often managed through automatic generation control, helps **restore frequency to nominal levels over a longer time horizon** by coordinating BESS with other generation assets. • Tertiary frequency control can help to replace primary and secondary frequency control following disturbances to **improve long-term system stability and economic efficiency,** ensuring grid operators can manage sustained imbalances effectively. • **IBRs can provide various system services,** including primary frequency response, secondary frequency response, and voltage control. • For BESS, primary frequency response and fast frequency response are **limited by state of charge**. Other IBRs are potentially constrained by the prime mover.	• **ESCOM aims to sufficiently train a broad team of engineers** with expert-level understanding of classical power system frequency control. • **ESCOM proposes to design and define appropriate network modeling tools** (capable of dispatch, steady-state, dynamics) and **invest in ensuring ongoing validation of network models to "as built" standards,** including potential field testing/validation during commissioning or during periodic testing of equipment (annual/bi-annual, etc.). • **ESCOM intends to invest in sufficiently high-resolution phasor measurement unit or disturbance recorders** on the bulk power system to leverage large system events as sources for model validation. • **ESCOM expects to create and ensure continuous improvement of processes** that interconnect new resources to the bulk power system.

Topic	Description	Key Learnings / Takeaways	Action Item(s)
	well especially in n-1 contingencies.	• Commercial and open-source simulation tools can model and visualize grid operations and system responses to disturbances (e.g., power flow, contingency, and stability). For BESS projects, they also **enable time-domain simulations, modeling batteries as controllable resources** that charge or discharge to support frequency control.	
 **Tariffs and Remuneration Considerations for BESS** [**Link to materials #1**] [**Link to materials #2**] 12/12/25, 1/14/25, and 4/29/25 ESCOM, MERA, MUBAS; 3 sessions—1 virtual, 2 in-person	Tariffs, remuneration, and value streams for BESS, including various structures for ownership and operation, types of payment and costing structures for recovery, and valuation methodologies for BESS.	• **A tariff structure defines the pricing mechanism for electricity**, specifying rates for both end-user consumption (e.g., per kilowatt-hour or per kilowatt-month) and procurement from suppliers—both of which are necessary for energy storage. • **Tariffs for energy storage usually take the form of capacity payments, energy payments, cost-of-service payments, or some combination**. The current tariff methodology governed by MERA allows for only a cost-of-service ("cost-plus") approach, not a value-based approach. As a result, ESCOM is limited to structuring BESS tariffs around cost recovery rather than remuneration based on capacity or energy value. Future tariff structures could evolve if ESCOM adopts resource adequacy assessments and production cost modeling. • **A clear system need should drive storage procurement**, with transparent roles for ESCOM (valuation and cost analysis) and MERA (auditing and ratepayer protection). • **Competitive, transparent procurement processes**—such as auctions with	• **ESCOM intends to conduct production cost modeling** to enable future transition from cost-of-service to value-based energy storage tariffs. • **MERA proposes to review and update regulatory framework** to address BESS integration.

Topic	Description	Key Learnings / Takeaways	Action Item(s)
		benchmarking and stakeholder review—help reduce risk, discourage unsolicited proposals, and align projects with market expectations.	
Battery Performance and Degradation [Link to materials] 4/1/25 ESCOM, MERA, MUBAS; 1 virtual session	Key factors that influence battery lifetime—temperature, state of charge, depth of discharge, and charging rate—and how proper management of these variables can extend the operational life of a BESS.	• **Battery lifetime is influenced by multiple factors**, including temperature, state of charge, depth of discharge, and charging rate, all of which must be carefully managed to extend operational life. • **Temperature management is critical** because excessive heat accelerates degradation, whereas extreme cold can reduce battery efficiency and capacity. The ideal temperature can vary across different battery types but is usually between 20°C and 40°C. • Depth of discharge impacts cycle life, with **deeper discharges leading to faster degradation**, making it important to balance usable energy with battery longevity. • **Charging speed affects battery health**, with high charging speeds generating heat and stress that can shorten life span if not properly controlled.	• **ESCOM expects to set operating guidelines for climate suitability** for Kanengo BESS. • **ESCOM plans to optimize depth-of-discharge and charging profiles** for Kanengo BESS. • **ESCOM plans to enforce routine system monitoring and balancing** of the Kanengo BESS to avoid system imbalances in state of charge, temperature, and capacity.
Decommissioning and Environmental Considerations for BESS [Link to materials]	Best practices for decommissioning batteries at end of life, including regulatory considerations and language that can be included in national guidelines. The session also addressed the safe transport of hazardous materials and drew on	• **BESS life span and contract terms:** Modern lithium-ion systems typically last 15–20 years, with performance contracts aligned to this range and backed by warranties of 10–15 years or 5,000–10,000 cycles. • **Midlife planning:** Around year 10, projects may consider augmentation (adding capacity) or repowering (equipment upgrades), which can extend operational life	• **Policy alignment in Malawi:** The Electricity Act provides a foundation for decommissioning, but there's an opportunity to strengthen requirements by incorporating detailed planning, cost, and waste management provisions

Topic	Description	Key Learnings / Takeaways	Action Item(s)
4/15/25 ESCOM, MERA, MUBAS; 1 virtual session	global and U.S. examples to illustrate effective regulatory approaches.	but may trigger new regulatory approvals if the footprint or battery chemistry changes. • **End-of-life options:** By year 15, owners evaluate whether to repower, extend contracts, or decommission; any extension usually requires updates to contracts, land use agreements, and permits. • **Decommissioning requirements:** Best practice includes a detailed decommissioning plan with cost estimates, financial assurance, and performance criteria—often required before construction and updated regularly.	from Malawi's environmental laws.
 **Grid-Forming vs. Grid- Following** [Link to materials] 4/28/25 ESCOM, MERA, MUBAS; 1 in-person session	Key differences between grid-forming (GFM) and grid-following IBRs, including control strategies, cost considerations, appropriate use cases, and implications for grid codes. It also covered how to specify GFM capabilities in contracts and request for proposals, black start potential, and deployment examples from the United States and Europe.	• GFM inverters **enhance stability by generating their own voltage waveform**—critical for high-IBR grids. • GFM battery inverters are commercially available and **cost little more (often 1%–2%)** than grid-following ones. • Real-world case studies (e.g., Kaua'i, Maui) show **GFM improves performance** even in zero-inertia systems. • **Electromagnetic Transient (EMT) simulations are essential** to validate GFM capabilities and predict system behavior. • **Ride-through and control settings** (e.g., droop, phase-locked loop) significantly impact stability and must be tuned.	• **ESCOM intends to consider GFM capabilities** in future utility-scale BESS projects. • **ESCOM could include GFM verification through EMT** simulation in contracts and requests for proposals.
 **Safety Planning and Hazard Mitigation for BESS**	Comprehensive introduction to the design, applications, safety considerations, and operational features of BESS, with a focus on lithium-ion technology	• Lithium-ion batteries are favored for their maturity, efficiency, and scalability, but come with **unique safety and hazard considerations**. • AES's layered **safety architecture includes both passive and active**	• **ESCOM plans to integrate BESS hazard mitigation strategies**—including thermal management, gas detection, and emergency

Topic	Description	Key Learnings / Takeaways	Action Item(s)
Link to materials 5/5/25 ESCOM, MERA, MUBAS; 1 in-person	and The AES Corporation's approach to hazard mitigation and emergency response.	**systems**, ranging from battery management systems to direct fire suppressant injection. • Industry standards like **UL 9540A and NFPA 855** guide the safe design, installation, and operation of BESS systems.	shutdowns—into project planning. • **ESCOM aims to engage early with local first responders** to align on emergency response plans. • **ESCOM expects to ensure BESS deployments comply with UL, NFPA, and other relevant standards** and certifications.

All the training resources are also available at the Southern Africa BESS Center of Excellence: https://sabess.mzuni.ac.mw/reports-and-resources/.

4 Impact

During the January 2025 Malawi workshop, participants from across MERA, MUBAS, and ESCOM were asked about their baseline awareness of and confidence regarding certain BESS topics. The results highlighted low confidence and awareness across key issues such as BESS for frequency and voltage control, enabling policy and grid codes, remuneration and tariffs, end-of-life considerations, models and tools for energy storage, and so on.

Similar questions were asked of participants in the learning tour in May 2025, although there were some differences in participants and questions. Most learning tour participants attended the January workshop, but the January workshop included a larger number of stakeholders. Some questions for the learning tour were adjusted based on the focus of the capacity-building sessions. In spite of these variations, some conclusions can be drawn: there was positive awareness-building for key BESS topics, particularly frequency control; grid-forming versus grid-following inverters; end-of-life considerations; and BESS chemistries. Although the data also suggest improvement in other categories such as grid codes, tariffs, standards, among others, the questionnaire primarily highlights a need for continued engagement on topics as most participants are still responding “neutral” for their awareness and confidence levels (Figure 1).

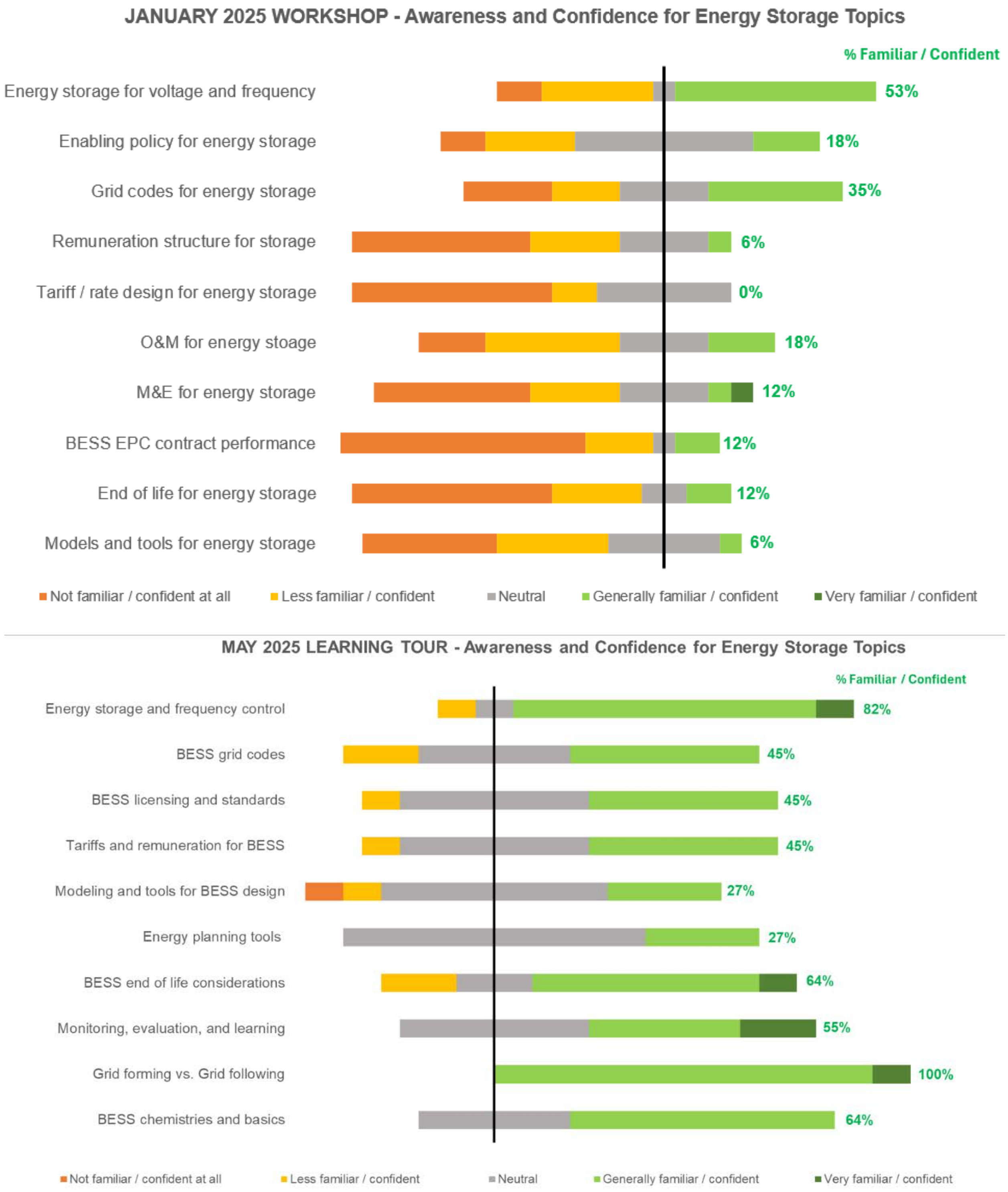

Figure 1. Awareness and confidence for energy storage topics for the January 2025 workshop (top) and the May 2025 learning tour (bottom)

5 Key Learnings

The training process has highlighted several key learnings that are relevant for other geographies and contexts for developing technical capacity for managing BESS projects:

1 **Ensure the right stakeholders are in the room for capacity building.** Effective BESS planning, deployment, and operations require effective coordination across a variety of stakeholders, including, but not limited to, utilities and system operators (ESCOM in the case of Malawi), regulators (e.g., MERA), and energy ministries and other government offices (e.g., Ministry of Energy). Other stakeholders such as researchers, universities, industry associations, regional collaborations also have a role to play in developing and disseminating key learnings as well as establishing research agendas and evaluating battery performance.

2 **Use high-quality, high-resolution data, which are the cornerstone for BESS projects and capacity building.** Key early steps in BESS capacity building include identifying and/or establishing data streams needed for assessing energy system context, energy baselines, and agreements necessary for sharing those data streams. Data will, of course, be necessary for managing operations and assessing the impact of BESS systems, and it will also be important to use system specific data in the design of trainings wherever possible, especially for workstreams such as modeling and planning.

3 **Create training plans that are iterative and responsive to stakeholders' needs.** With the wide range of stakeholders involved, different stakeholders may need different training and support, so materials could be tailored effectively and appropriately. For certain trainings (e.g., on specialized topics such as modeling or financing), it may also be important to have organizations nominate specific people to attend rather than the full group. With the wide variety and potential "newness" of the BESS topic for many stakeholders in emerging markets, it will also be important to allow for flexibility in the training program as priorities shift and/or additional needs are identified. For Malawi, because the capacity building occurred over the course of a year, the training team had multiple touchpoints with participants to realign priorities for training and ensure planned content was meeting needs and expectations.

4 **Mix up mediums and format to help build retention, prioritizing in-person interaction where possible.** In-person learning sessions are significantly more effective for building understanding, participation, and long-term retention, particularly for hands-on topics and collaborative discussion. Virtual sessions can be used to complement in-person engagement when needed; when doing so, scheduling consistent 1-hour sessions at the same time each week well in advance helps stakeholders plan and participate. Across both formats, incorporating short homework assignments, hands-on demonstrations, case studies, opportunities for participants to share their screens (especially during model or tool walkthroughs), and interactive in-person elements such as quizzes or competitions can further strengthen engagement and knowledge retention.