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Community Capacity Building Through Renewable Energy Operator Training: A Case Study on the Installation and Operation of Off-Grid Micro-Hydro Power Plants

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Abstract

Access to sustainable and decentralised energy remains a pressing challenge in many rural areas, particularly regions with limited grid infrastructure. Micro-Hydro Power Plants (MHPP) have emerged as a viable solution for using renewable resources to meet local energy demands. However, the long-term success of such systems is mainly dependent on the availability of skilled local operators capable of planning, implementing, and maintaining the infrastructure. This community-based research aimed to enhance local technical capacity through a structured training program focusing on designing, installing, and operating off-grid MHPP systems. The program was conducted in Banda Aceh and employed a combination of classroom instruction, expert presentations, interactive discussions, and hands-on fieldwork, including hydrological measurements for site feasibility. Participants were engaged in active learning sessions covering theoretical concepts, technical standards, and real-world practices. The results showed a significant increase in the participants' technical understanding, confidence, and readiness to contribute to local MHPP development. The novelty of this work lies in its integrative training model, which not only delivers technical knowledge but also empowers grassroots participants to become key agents in renewable energy deployment. Unlike conventional top-down approaches, this method emphasises local ownership, contextual adaptation, and participatory learning. In conclusion, the training program effectively bridges the gap between theory and practice, offering a replicable model for future community energy initiatives. Developing local expertise is essential to ensure the sustainability and scalability of MHPP systems, especially in off-grid regions seeking clean and independent energy access.

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1. Introduction

Access to clean, affordable, and sustainable energy remains a significant challenge in rural and remote areas, particularly in developing countries. Dependence on fossil fuels and limited national grid infrastructure have hindered local economic growth and reduced the quality of life in underserved communities. In this context, locally sourced renewable energy solutions such as Micro-Hydro Power Plants (MHPP) offer a practical and appropriate approach to closing the energy access gap, especially in regions with abundant hydrological potential [1–4]. MHPP is a renewable energy system that harnesses small rivers or streams' kinetic and potential energy to generate electricity [5–8]. It is environmentally friendly, efficient, and well-suited for community-scale implementation. However, the long-term success of MHPP systems relies heavily on the technical and managerial capacity of the local community, including site surveying, system installation, operation, and routine maintenance.

Unfortunately, many renewable energy projects at the village level fail to operate sustainably due to the lack of proper technical training for local operators [9–12]. Existing training models are often overly theoretical, rely on passive knowledge transfer, and lack field-based experience. A more practical, participatory, and community-oriented approach is needed in community engagement programs to ensure skill development and long-term system viability [13–16]. To address this issue, a renewable energy operator training program focused on off-grid MHPP systems was carried out in Banda Aceh in September 2023. The program was designed as a community service initiative with an integrated learning approach combining classroom theory, technical case studies, interactive discussions, and field practice, including hydrological measurement and system operation simulations [17–20]. Participants included engineering students, community representatives, and local energy practitioners.

The main objective of this training was to equip participants with practical skills and technical knowledge related to MHPP development [21–24]. This included identifying suitable sites, measuring stream flow, selecting key system components (e.g., turbine, penstock, generator), and understanding the basics of control systems and maintenance. The program encouraged active participation and empowered community members to become key stakeholders in managing renewable energy infrastructure. The implementation method followed four key phases: (1) delivery of core MHPP material through classroom lectures, (2) group discussion and case analysis, (3) field visit for stream flow measurement, and (4) assessment of participant outcomes through observation and documentation. This method promoted hands-on learning and strengthened participants' technical capacity through direct experience.

The training results indicate a substantial improvement in participants' understanding of MHPP principles, technical ability in site assessment and installation, and increased motivation to engage in community-based energy projects. Documentation of the activities shows strong participant enthusiasm and confirms the effectiveness of the practice-oriented training approach. Therefore, the main objective of this article is to describe the process, results, and impact of the off-grid MHPP operator training as a form of community-based research. It also highlights the novelty of the integrated training approach and its broader implications for community empowerment and the sustainability of decentralised renewable energy systems in rural areas.

2. Methodology

This community-based research was conducted through a structured and participatory training program to enhance local stakeholders' technical capacity in developing and operating off-grid Micro-Hydro

Power Plant (MHPP) systems. The training was held over five days, from 18 to 22 September 2023, in Banda Aceh, Indonesia, and involved multiple phases: planning, delivery, practical application, and evaluation.

Participants and Target Group

The training involved 25 participants from diverse backgrounds, including vocational and undergraduate students in engineering, community representatives from potential MHPP sites, and local technicians. The selection criteria emphasised willingness to apply the acquired skills in their communities. Facilitators included academic experts in renewable energy, MHPP practitioners, and engineers with field experience.

Training Design and Delivery

1) The program adopted an integrated instructional model combining four key components:
2) Classroom Sessions: Delivered fundamental concepts on MHPP systems, including hydrology, turbine types, energy estimation, and system components.
3) Technical Presentations: Provided real-world case studies, system design workflows, and troubleshooting strategies.
4) Interactive Discussions: Knowledge exchange, group problem-solving, and Q&A sessions based on community-specific challenges were facilitated.
5) Field Practice: Conducted at a local stream, focusing on hydrological measurements (stream width, depth, and flow rate estimation) using the float method and manual gauging.

Tools and Materials

Instructional media included projectors, printed manuals, flow measurement tools (e.g., measuring tape, stopwatch, floating object), and checklists for system evaluation. Participants also received worksheets and reference modules tailored to off-grid MHPP development.

Data Collection and Documentation

Qualitative data were collected through:

1) Observations of participant engagement and performance during classroom and field sessions.
2) Photo and video documentation of each activity phase (opening, instruction, fieldwork, group discussion, and closing).
3) Field notes and reflective feedback from facilitators and participants.

Evaluation and Outcome Analysis

The outcomes were assessed through:

1) Direct observation of the participant's ability to perform field measurements and interpret hydrological data.
2) Group presentations and discussions revealed their understanding of MHPP principles.
3) The final reflection session will evaluate perceived knowledge gain and potential for future application.

Ethical Considerations

Participants provided informed verbal consent to be involved in the training and documentation process. The activity addressed local customs, environmental awareness, and safety protocols during fieldwork.

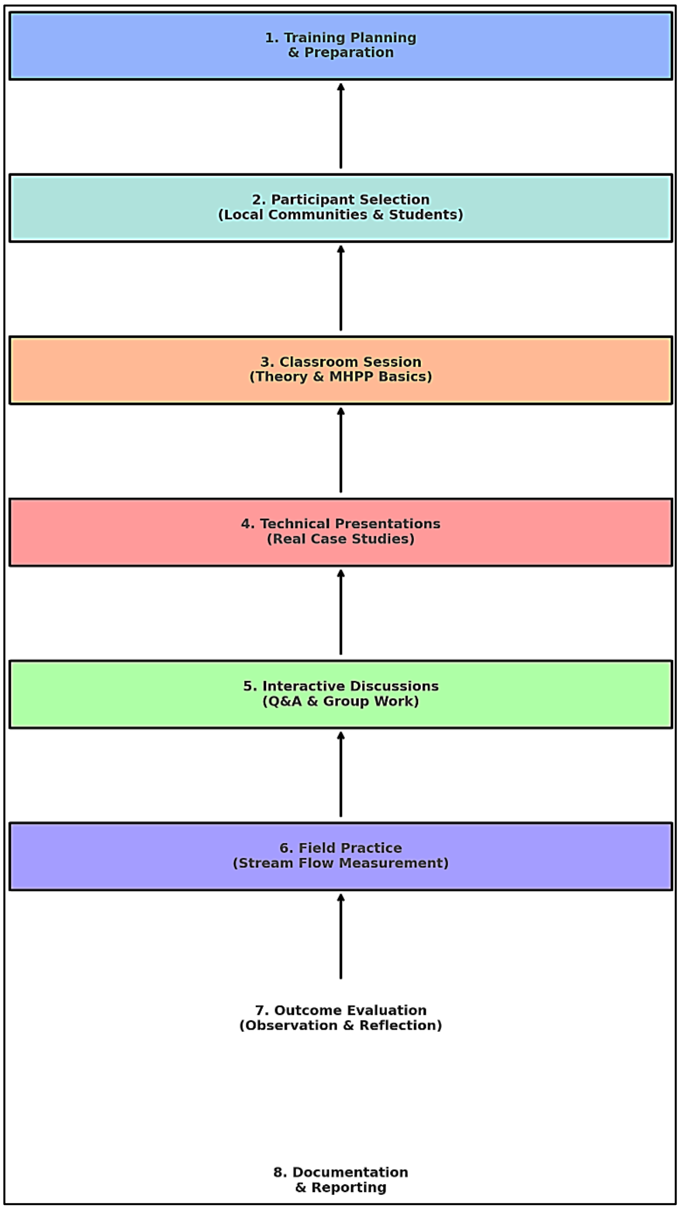

Figure 1: Flowchart of Community-Based Training Methodology for Off-Grid Micro-Hydro Power Plant (MHPP) Development

Figure 1 illustrates the methodological flowchart in the community-based training program for off-grid Micro-Hydro Power Plant (MHPP) development. The flowchart outlines eight sequential phases that structure the entire research and training process from initial planning to final reporting. The process begins with Training Planning and Preparation, which involves designing the curriculum, identifying local needs, and preparing instructional and field materials. This is followed by Participant Selection, focusing on recruiting individuals from local communities and students with the potential to be involved in future MHPP projects. The third and fourth stages, Classroom Sessions and Technical Presentations, were designed to build foundational knowledge and expose participants to real-world applications of MHPP systems. These phases covered hydrological theory, energy estimation, component identification, and case studies from previous installations.

The fifth phase, Interactive Discussions, allowed participants to engage in collaborative learning, ask context-specific questions, and develop problem-solving skills. This was a key transition toward the sixth phase, Field Practice, where participants conducted hands-on stream flow measurements to assess MHPP feasibility using basic hydrological tools. The last two steps focus on determining the effectiveness and impact of the program. In the Outcome Evaluation phase, facilitators observed participant performance and gathered feedback to evaluate learning outcomes. Finally, Documentation and Reporting ensured that the results, reflections, and lessons learned were systematically recorded for dissemination and future reference. In summary, **Figure 1** represents a holistic and participatory methodology that integrates theoretical knowledge, technical practice, and community engagement to empower local stakeholders in deploying sustainable energy systems.

3. Result & Discussion

The increasing demand for sustainable and decentralised energy solutions has highlighted the need for local capacity building, particularly in rural and off-grid areas. Micro-Hydro Power Plants (MHPP) represent a viable renewable energy alternative for such regions, offering clean, reliable, and community-managed electricity. However, the successful implementation of MHPP systems depends significantly on local operators' knowledge and technical competencies. In response to this need, a community service-based research initiative was conducted in Banda Aceh through a structured training program focused on planning, installing, and operating off-grid MHPP systems. This program aimed to transfer technical knowledge and empower local stakeholders to independently manage and sustain renewable energy infrastructure. Through a series of classroom lectures, interactive discussions, and hands-on field activities, participants were introduced to the essential components and operational procedures of MHPP systems. The training served as a practical platform for bridging theoretical knowledge with field application, supporting the long-term sustainability of renewable energy projects within the community. The following discussion presents a detailed review of the training process, outcomes, and potential impact on local energy resilience.

Figure 2 illustrates the opening session and initial presentation of the Training on Micro-Hydro Power Plant (MHPP) conducted in Banda Aceh on 18–22 September 2023. This moment captures the formal commencement of the capacity-building program to enhance local skills in renewable energy systems, particularly off-grid MHPP development. On the right side of the image, the lead speaker delivers an overview of the training objectives and their relevance to community-based energy development. The screen behind him displays the official banner and agenda of the event. The seated facilitator in the middle prepares the technical materials, while another trainer on the left engages with participants, signalling a collaborative and interactive learning environment. This session serves as a critical foundation for aligning participants' expectations, 143introducing the technical scope of MHPP systems, and setting the tone for the following hands-on and theoretical activities. The use of multimedia tools, formal documentation, and structured delivery reflects a professional and well-organised training approach under the framework of the ISED (Innovation and Investment for Sustainable and Inclusive Economic Development) project.

Figure 2: Opening Session and Presentation of Training on Micro-Hydro Power Plant (MHPP)

Figure 3 shows a classroom session conducted during the Micro-Hydro Power Plant (MHPP) training in Banda Aceh. This indoor session was crucial in delivering the theoretical foundation for understanding the components, design principles, and operational mechanisms of off-grid MHPP systems. The session was attended by diverse participants, including local technicians, students, and community members, highlighting the inclusive and participatory nature of the training. The instructor is seen presenting key concepts using a projector and printed materials, ensuring that complex technical information is communicated effectively. The participants, seated in groups, were encouraged to engage in discussions and question-and-answer sessions, which fostered active learning. This classroom-based component was essential in preparing the trainees for the subsequent hands-on fieldwork. It established a strong conceptual basis that would support their practical understanding of renewable energy implementation.

Figure 3: Classroom Session during the Training on Micro-Hydro Power Plant (MHPP)

The classroom arrangement, as depicted in **Figure 3**, was deliberately designed to support interactive and collaborative learning. Circular seating arrangements encouraged peer-to-peer discussion, while the presence of multiple facilitators allowed real-time clarification of technical queries. This setup significantly enhanced participant engagement, ensuring that the training was not limited to one-way instruction but fostered mutual knowledge exchange, which is particularly valuable in a community-based energy development context. Moreover, the session integrated multimedia tools and printed manuals to support diverse learning preferences among participants. The combination of visual presentations, live demonstrations, and written guidelines allowed trainees to absorb and retain complex information more effectively. This blended learning approach not only improved comprehension but also prepared participants to apply these concepts confidently during the hands-on fieldwork, reinforcing the practical applicability of the training content in real-world MHPP deployment scenarios.
Figure 4 presents a technical session where detailed materials related to Micro-Hydro Power Plant (MHPP) design and implementation were delivered to participants. The presenter elaborates on specific topics such as turbine selection, flow rate measurement, site feasibility analysis, and system components. This session aimed to bridge theoretical understanding with practical knowledge, equipping participants with essential competencies to independently evaluate and develop MHPP systems in their communities. The projected slides provided structured and visual support to explain complex engineering concepts. Each topic was broken down into manageable parts to ensure that the participants from various educational and technical backgrounds could follow and comprehend the material. Training handbooks, datasheets, and notebooks also allowed for note-taking and later reference, ensuring the information could be revisited after the session.
This technical segment was crucial in building the foundation for subsequent field activities. It allowed participants to familiarise themselves with the technical vocabulary and methodologies necessary for site assessment and installation. Discussions during this session were interactive, with participants encouraged to ask questions and share their experiences related to energy and infrastructure challenges

in their villages. Figure 3 highlights the knowledge transfer process central to the training's objective: empowering local actors with the technical capacity to plan, construct, and maintain MHPP systems. Integrating participatory methods and applied technical content created a conducive learning atmosphere, supporting the long-term sustainability of off-grid renewable energy projects.

Figure 4: Technical Material Presentation during the Training on Micro-Hydro Power Plant (MHPP)

Figure 5 captures the interactive discussion and Q&A session during the Micro-Hydro Power Plant (MHPP) training. This session reinforced participant understanding by encouraging two-way communication between facilitators and trainees. Participants could ask specific questions about the earlier technical content, clarify concepts, and apply the information to real-life scenarios in their communities. The interactive nature of the session fostered a more dynamic learning environment. One participant is seen standing and posing a question, signalling active engagement and a willingness to contribute to the collective learning process. This interaction is fundamental in capacity-building programs, as it enables knowledge to be contextualised and grounded in local experience, thus increasing its relevance and applicability.

Figure 5: Interactive Discussion and Q&A Session during the Micro-Hydro Power Plant (MHPP)

In addition to verbal discussion, participants were also encouraged to refer to training manuals and personal notes during the session. This approach allowed for deeper reflection and supported the retention of critical information related to hydrology, turbine mechanics, electrical load management, and community-based maintenance planning. The facilitators responded with elaborations, diagrams, and relatable examples to ensure comprehensive understanding. Ultimately, this session served as a platform for mutual learning. It helped identify common knowledge gaps, highlighted local challenges in implementing MHPP systems, and strengthened participants' confidence in applying their skills post-training. Figure 4 underscores the importance of integrating discussion and feedback mechanisms into technical training programs to ensure effectiveness and sustainability.

Figure 6: Expert Exchange during the Training on Off-Grid Micro-Hydro Power Systems

Figure 6 highlights an expert exchange session held during the training on Off-Grid Micro-Hydro Power Systems. This segment brought together experienced facilitators to share in-depth knowledge, field experiences, and technical strategies with participants. The exchange format enabled a deeper exploration of key issues such as system reliability, community ownership, environmental considerations, and long-term maintenance of MHPP installations. The two facilitators in the figure engage in a dialogic presentation, where one speaker outlines a concept while the other complements it with real-world insights or additional clarification. This collaborative method gave participants a holistic understanding of the topics covered, combining academic, technical, and practical dimensions. Such expert exchange is critical in demystifying complex engineering principles and making them accessible to non-specialist trainees.

This session also served as a platform to align technical solutions with local realities. For instance, the experts discussed the importance of tailoring MHPP designs to specific river conditions, community needs, and available materials. Participants were encouraged to raise questions about challenges they had faced in previous projects or anticipated in future ones, and the experts responded with practical, adaptable solutions based on their fieldwork and research. **Figure 6** illustrates how the training program fostered collaborative learning among participants and professionals. The expert exchange added significant value to the training by building trust, promoting dialogue, and ensuring the transfer of applied knowledge in an empowering and contextually relevant manner.

Figure 7 depicts the practical field session involving stream flow measurement, a crucial step in assessing the feasibility of a site for Micro-Hydro Power Plant (MHPP) installation. Accurate flow measurement is essential in determining the energy potential of the water source, and this hands-on activity allowed participants to directly apply theoretical knowledge gained during earlier classroom sessions. The participants are seen collaboratively measuring depth and flow rate using basic hydrological tools under the guidance of an experienced field supervisor. Depending on equipment availability, the method used in this activity likely follows standard hydrological practices, such as the float method or current meter measurements. These measurements are critical in estimating available water discharge, influencing turbine selection, system sizing, and energy output. The process also familiarised participants with field safety protocols and environmental awareness, reinforcing the importance of responsible site development.

Figure 7: Field Measurement of Stream Flow for Micro-Hydro Power Site Assessment

This field exercise was designed for technical skill development and fostering teamwork and confidence among participants. Working in small groups under real-world conditions enabled them to discuss measurement techniques, data recording methods, and how to adjust procedures to suit varying stream conditions. The informal yet focused environment promoted peer learning and encouraged critical thinking. **Figure 7** highlights the transition from theory to application, demonstrating how participatory and field-based learning can significantly enhance the effectiveness of renewable energy training programs. By involving trainees directly in data collection and analysis, the program ensured that participants could perform site evaluations independently for future MHPP projects in their regions.

Figure 8: Hydrological Survey Practice by Training Participants for MHPP Site Feasibility

Figure 8 illustrates a hands-on hydrological survey exercise conducted by training participants as part of the Micro-Hydro Power Plant (MHPP) site feasibility assessment. This activity was designed to deepen the participants' practical skills in identifying suitable river or stream conditions for off-grid

MHPP development. The group of trainees actively measures stream width, depth, and surface velocity, key parameters in estimating water discharge and potential energy output. The image showcases the participatory nature of the training, where each trainee is assigned a specific task within the survey process, such as using measuring tapes, depth gauges, or float markers. This division of functions fosters a collaborative learning environment and mirrors real-world conditions in which successful MHPP implementation relies on team-based fieldwork. The informal setting in a natural river environment adds realism to the training and builds confidence among participants for future independent site assessments.

The field exercise also emphasised data accuracy and consistency in hydrological logging. Trainers guided participants in recording measurements, calculating average flow, and noting environmental variables such as streambed composition and seasonal water variation. These insights are essential for designing sustainable and efficient MHPP systems tailored to local conditions. Overall, **Figure 8** underscores the effectiveness of experiential learning in renewable energy capacity-building. The training program reinforced technical competence by involving trainees directly in hydrological assessments and instilled a sense of ownership and responsibility for community-led energy initiatives. This approach ensures that knowledge gained during the training will have lasting practical value in deploying MHPPS in rural and remote areas.

Figure 9 captures a celebratory moment marking the completion of the Micro-Hydro Power Plant (MHPP) training program. The group photo, taken during the certificate awarding ceremony, symbolises the culmination of a multi-day capacity-building effort to equip participants with technical and practical knowledge in renewable energy, specifically in off-grid MHPP systems. The image includes both trainers and trainees, highlighting a spirit of collaboration and shared learning. The awarding of certificates serves not only as a formal recognition of participant achievement but also as a motivation to apply the acquired skills in real-world settings. These certificates can enhance community members' credibility when engaging with local stakeholders, NGOs, or government bodies on renewable energy projects. It also represents a milestone in their journey toward becoming competent local operators and advocates for sustainable energy development.

The expressions and body language of participants in the photo reflect pride and enthusiasm, indicating the training's success in fostering confidence and community ownership. Several participants proudly display their certificates, while others symbolise unity and accomplishment. Such moments reinforce the participants' commitment to implementing what they have learned, especially in challenging rural or remote environments. Ultimately, **Figure 9** reflects the broader impact of the training beyond technical instruction—it showcases empowerment, inspiration, and the creation of a community of practice. The closing ceremony marked the end of a training module and the beginning of a potentially transformative journey for each participant in contributing to the local development and sustainability of energy access.

Figure 9: Group Photo and Certificate Awarding at the Closing of MHPP Training

The novelty of this community-based research lies in its integrated and participatory training model that combines theoretical learning, hands-on technical exercises, and direct field application within a single framework focused on off-grid Micro-Hydro Power Plant (MHPP) systems. While previous studies and trainings often separate conceptual learning from practical implementation, this initiative bridges the two through a seamless and context-specific curriculum tailored to local needs and environmental conditions. This approach ensures that participants understand MHPP design in theory and can execute hydrological surveys, install components, and manage operations in real-world settings. Another key novelty is the empowerment of local actors as renewable energy operators and planners, which is often overlooked in conventional energy development programs. This training emphasises grassroots capacity building by enabling participants, many community members with minimal formal engineering backgrounds, to directly engage with and take ownership of sustainable energy infrastructure. The program promotes long-term sustainability, community resilience, and locally-driven innovation in renewable energy deployment by involving them in decision-making, measurement activities, and collaborative problem-solving. This positions the project as a replicable model for rural energy transformation aligned with inclusive development goals.

4. Conclusion

This community engagement research has successfully demonstrated the effectiveness of a comprehensive and participatory training program for developing and operating off-grid Micro-Hydro Power Plant (MHPP) systems. By integrating classroom-based theory, technical presentations, interactive discussions, and field-based hydrological assessments, the training equipped participants with conceptual understanding and practical skills necessary for planning, installing, and maintaining MHPP infrastructure in rural areas. The results indicate that participants gained substantial technical competence, especially in site assessment, flow measurement, and system component identification. More importantly, the program fostered a strong sense of ownership, collaboration, and confidence among local trainees, who had limited prior exposure to renewable energy systems. The approach enhanced individual capacities and contributed to community preparedness in initiating and sustaining local energy solutions. Therefore, the training model developed in this project presents a scalable and impactful strategy for advancing renewable energy access through grassroots empowerment.

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