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Building Instructor Capacity for Community-Based Renewable Energy Education through Solar Photovoltaic Training and PBL Module Development

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ABSTRACT

The transition toward renewable energy requires not only technological advancement but also human capacity to disseminate renewable energy knowledge in educational and community settings. This community service program aimed to prepare prospective trainers to facilitate renewable energy learning at the Community Learning Centre (PKBM) Banyutowo in Klaten Regency, Indonesia, while supporting SDG 7 on affordable and clean energy and SDG 4 on quality education. The program adopted a training-of-trainers community service approach and was implemented from January to April 2026. Its activities included preparation and partner-needs alignment, a workshop titled "Green Energy and Green Building for Sustainable STEM Education" held at Universitas Sebelas Maret on 9 February 2026, a partner-site visit to PKBM Banyutowo, and a follow-up teaching activity on 15 April 2026. A total of 54 students from engineering education programs participated as prospective trainers. The workshop consisted of solar photovoltaic (PV) concept presentation, solar PV trainer kit demonstration, PV system design and wiring practice, Problem-Based Learning (PBL) module development, and evaluation. Feedback data were obtained from 19 valid participant responses using a 13-item Likert-scale questionnaire, representing a 35.2% response rate. The responses were used descriptively to identify trends in participants' perceptions of the workshop. The results indicate active participant engagement, positive response trends regarding organization and instructional delivery, and the development of preliminary PBL module concepts. Seven workshop alumni later facilitated solar PV learning for PKBM learners using the same trainer kit. These findings suggest that integrating technical training, hands-on experimentation, and PBL-oriented pedagogy provides a relevant foundation for strengthening renewable energy literacy and prospective trainer capacity in community-based education.

Keywords: community-based education; project-based learning; renewable energy literacy; solar photovoltaic education; sustainable development goals

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INTRODUCTION

The global shift from fossil fuels to renewables is driven by climate targets, energy security, and long-term cost concerns. Fossil fuels still supply over 80% of global primary energy, with renewables around 13–17%, so the transition is significant but incomplete (Holechek et al., 2022; Ozkan et al., 2025). Modeling suggests fully replacing fossil fuels by 2050 would require roughly a 6–8-fold increase in renewable energy output, combined with faster energy-efficiency gains, strong carbon pricing, and lifestyle changes in high-consuming countries (Holechek et al., 2022; Kabeyi & Olanrewaju, 2022). Studies of OECD countries show that growing renewable capacity does progressively displace fossil fuels, with hydropower and biomass achieving close to one-for-one replacement, while solar and wind currently provide partial displacement that increases as grids are modernized (Karlilar Pata & Balcilar, 2024). Globally, policies such as feed-in tariffs, subsidy reform, and long-term climate commitments under the Paris Agreement are central, but progress is uneven and often too slow to meet 1.5–2 °C goals (Akinwale, 2024; Kabeyi & Olanrewaju, 2022; Odunayo Adewunmi et al., 2024; Ozkan et al., 2025).

In Indonesia and Malaysia, the transition is especially complex because economies and state revenues are deeply intertwined with fossil fuels. Indonesia's primary energy mix remains about 90% fossil fuels, despite enormous solar, geothermal, hydro, and other renewable potential exceeding 400 GW (Adrian et al., 2023; Komariah et al., 2023; Pambudi et al., 2023; Wong & Dewayanti, 2024). Policy analyses highlight heavy coal dependence, large fossil-fuel subsidies, and underwhelming renewable investment as key barriers, even as Indonesia has pledged net-zero by 2060 and set renewable-mix targets of 23% by 2025 and 31% by 2050 (Komariah et al., 2023; Pambudi et al., 2023; Resosudarmo et al., 2023; Wong & Dewayanti, 2024). Scenario and techno-economic studies show that a rapid coal-to-renewables shift, which centered on solar PV, grid expansion, storage, and early coal-plant retirement, could cut system costs and achieve carbon neutrality by 2050–2060 if backed by strong regulation and finance (Gulagi et al., 2025; Komariah et al., 2023). Work comparing Malaysia with other countries finds that Malaysia is diversifying its mix via supportive policies for solar, hydro, and biomass, but still faces grid, regulatory, and investment challenges (Pudjono et al., 2025). Overall, both Indonesia and Malaysia illustrate the broader global pattern with abundant renewable resources and clear climate incentives, but slow structural change due to policy, financial, and institutional constraints (Adrian et al., 2023; Pambudi et al., 2023; Pudjono et al., 2025; Wong & Dewayanti, 2024).

While the global expansion of renewable energy defines the technical trajectory of the energy transition, its success ultimately depends on how effectively it aligns with broader development objectives, particularly those articulated in the Sustainable Development Goals (SDGs). In this context, education plays a critical role in preparing future professionals to support sustainable energy systems. Embedding SDG 7 in engineering education also shapes graduates' values and competencies for a low carbon future. Integrating sustainability and SDG content across curricula through project- and problem-based learning helps students see how their skills apply to real issues like efficient buildings, decentralized renewables, and energy communities, raising awareness of resource use and long-term affordability (Álvarez et al., 2021; Ashraf & Alanezi, 2020; Biancardi et al., 2023; Calvo et al., 2024). Frameworks for "education for sustainable development" emphasize competencies in sustainable use of resources, systems thinking, and ethical judgment, so that engineers can weigh trade-offs between cost, equity, and environmental impact in energy decisions (Heldal et al., 2024; Kazadi Tshikolu et al., 2025; Sánchez-Carracedo et al., 2021). Innovative pedagogies such as interdisciplinary energy courses, low-carbon and renewable-energy projects, and even AI- and VR-enhanced learning further prepare students to lead just, affordable energy transitions in both industrialized and developing contexts (Al-Juboori et al., 2025; Friman, 2024; Kazadi Tshikolu et al., 2025; Torres-Rivera et al., 2025; Warastuti et al., 2025). Taken together, these developments highlight the need not only for supportive policies and technologies but also for educational initiatives that build human capacity to understand, implement, and disseminate renewable energy technologies.

Within this broader educational landscape, developing skilled instructors becomes crucial for effectively disseminating technical knowledge, particularly in non-formal educational settings where learning is often practice oriented and community based. Studies of non-formal technical and environmental education show that communities and children gain tangible skills, such as improved farming techniques, watershed management, or technological literacy, when facilitators are trained not only in technical content but also in adult learning principles, communication, and project- or inquiry-based approaches (Lemut Bajec, 2023; Márföldi & Nagy, 2025; Zikargae et al., 2022). Training-of-trainers models and capacity-building workshops enable a small cadre of competent instructors to multiply impact through community projects, experience-sharing, and supervised practical activities, even where most learners are initially illiterate or lack formal schooling (Zikargae et al., 2022). Research on technical and vocational education further indicates that instructors' professional skills, instructional delivery, and continuous development strongly influence the quality of learning and the alignment of teaching with societal and industrial needs (Shodipe & Ogbuanya, 2024). In non-formal technical clubs and community programs, insufficient instructor preparation is a major barrier: teachers report feeling incompetent to run technically oriented activities and highlight the lack of targeted training opportunities, underscoring that investing in instructor upskilling is foundational to sustaining high-quality, inclusive technical education beyond the formal school system (Lemut Bajec, 2023; Li et al., 2022; Shodipe & Ogbuanya, 2024). These findings highlight that strengthening instructor capacity is a key prerequisite for expanding community-based education in emerging technical domains, including renewable energy technologies such as solar photovoltaic systems.

This need for instructor capacity development is particularly relevant in community learning institutions that serve diverse learners and emphasize practical, community-oriented education. One such institution is the Community Learning Center (PKBM) Banyutowo located in Klaten Regency, Indonesia. As a community-based non-formal education institution, PKBM Banyutowo provides a range of programs including equivalency education (Packages A, B, and C), early childhood education, childcare services, and life-skills training for community members. The center currently serves learners across different age groups and socio-economic backgrounds and has implemented various community environmental programs, including waste management initiatives and environmentally oriented training activities. However, despite its active role in community education, learning activities at PKBM Banyutowo have not yet fully integrated renewable energy technologies and related technical skills. Strengthening instructor capacity and introducing practical renewable energy learning resources therefore present an opportunity to expand energy literacy and green skills among community learners.

In response to this need, a guest lecture and hands-on workshop on solar photovoltaic systems were organised as part of a community service initiative by Universitas Sebelas Maret, in collaboration with University Malaysia Pahang Al-Sultan Abdullah, to prepare prospective trainers who will later facilitate renewable energy education activities at PKBM Banyutowo. The program was designed as a practice-oriented learning experience combining conceptual lectures, discussion sessions, and direct demonstrations of solar energy systems. As part of the activity, a solar photovoltaic trainer kit was developed and demonstrated to support hands-on exploration of photovoltaic components and system operation. The trainer kit is intended to function as a practical learning medium for renewable energy education activities at PKBM Banyutowo and to support the dissemination of solar energy knowledge within community-based learning programs.

METHOD

This community service activity was conducted using a training-of-trainers community service approach through a workshop titled "*Green Energy and Green Building for Sustainable STEM Education*" and a follow-up community-based teaching activity at PKBM Banyutowo. The activity aimed to enhance participants' understanding of renewable energy concepts, particularly solar photovoltaic (PV) power generation systems, while supporting the objectives of SDG 7 (Affordable and Clean Energy) through renewable energy literacy and SDG 4 (Quality Education) through capacity development for community-based learning. The program also sought to prepare prospective trainers who will later facilitate renewable energy learning activities at the Community Learning Centre (PKBM) Banyutowo.

The overall program was implemented from January to April 2026. The implementation included preparation and partner-needs alignment, installation and preparation of supporting green-energy facilities, the trainer capacity-building workshop, a partner-site visit, and the follow-up teaching activity for PKBM learners. The preparation and infrastructure-related activities included the installation of a solar power system and a rainwater harvesting facility at PKBM Banyutowo site. These facilities were intended to provide contextual learning resources for renewable energy and green building education in the PKBM environment.

The workshop was organised on 9 February 2026 at Universitas Sebelas Maret and involved 54 university students from three study programs within the Faculty of Teacher Training and Education, Universitas Sebelas Maret, namely Informatics Engineering Education (PTIK), Mechanical Engineering Education (PTM), and Building Engineering Education (PTB). These students were selected as participants because they are prospective educators and technical instructors who are expected to contribute to community-based learning activities. In addition to the workshop stages shown in Figure 1, the program included a partner-site visit to PKBM Banyutowo on 9 February 2026 and a follow-up teaching implementation at PKBM Banyutowo on 15 April 2026.

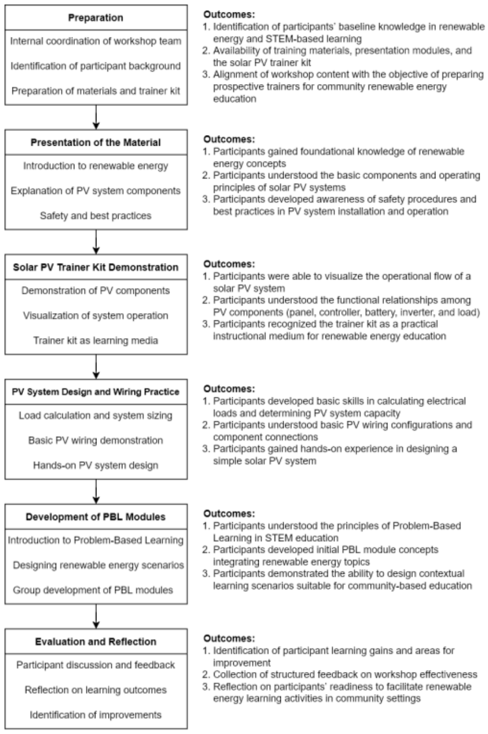

Figure 1 Steps of the Implementation Method

Preparation

The preparation phase was carried out from January to early February 2026 before the workshop to ensure the entire series of activities would run smoothly. During this stage, the community service team conducted internal coordination to design the training program and align the workshop content with the objectives of strengthening renewable energy literacy and preparing prospective trainers for community-based learning environments.

In addition, the team conducted a preliminary analysis of participants' background knowledge related to renewable energy and STEM-based learning. The team also coordinated with PKBM Banyutowo to identify partner needs related to renewable energy learning, green building awareness, and practical learning resources for community learners. The results of this analysis were used as the basis for designing the training materials and learning activities to be delivered during the workshop.

Figure 2 Solar PV Trainer Kit

The implementation team also prepared various supporting materials, including presentations, training modules, and practical equipment for demonstrations and hands-on activities. A solar photovoltaic trainer kit (see Figure 2) was also prepared as an instructional medium to support practical demonstrations of PV system components and their operation. This kit were later used in the follow-up teaching activity at PKBM Banyutowo.

Presentation of the Material

The second stage involved presenting fundamental concepts of solar photovoltaic power generation systems. In this session, participants were introduced to the concept of renewable energy and the role of solar energy in supporting sustainable development and environmentally friendly infrastructure, as shown in Figure 3.

Figure 3 Presentation of the Material

The materials presented included an introduction to the main components of a PV system, such as solar modules, charge controllers, batteries, and inverters. Participants were also introduced to different types of PV systems, including grid-connected and stand-alone systems, and their potential applications in small-scale educational or community-based facilities.

This session also emphasised safety considerations and best practices for installing and operating solar power systems. The purpose of this stage was to provide participants with a conceptual understanding of solar PV technology before proceeding to the practical activities.

Solar Photovoltaic Trainer Kit Demonstration

Following the presentation of the theoretical concepts, participants were introduced to a solar photovoltaic trainer kit designed as an interactive learning medium for renewable energy education. The trainer kit demonstrates the fundamental components of a PV system, including the solar module, charge controller, battery unit, inverter, and electrical loads. The demonstration of the trainer kit is shown in Figure 4.

Figure 4 Trainer Kit Demonstration

During this demonstration session, participants observed how electrical energy generated by the solar module flows through the system, is regulated by the charge controller, and is stored in the battery before being used to supply electrical loads. The trainer kit enabled participants to visualise the operational principles of a PV system in a simplified, controlled learning environment.

In addition to demonstrating the system's technical operation, this session highlighted the potential of the trainer kit as a practical learning medium in STEM education. The trainer kit is intended to support future renewable energy learning activities in community-based education environments, including PKBM Banyutowo.

PV System Design and Wiring Practice

After observing the trainer kit demonstration, the workshop continued with a hands-on session on solar power system design and basic wiring practice, as illustrated in Figures 5 and 6.

Figure 5 PV System Design

Figure 6 PV Wiring Practice

In this stage, participants were introduced to methods for calculating electrical load requirements and determining the appropriate capacity of PV system components. Participants were guided through several design steps, including calculating daily energy demand, estimating peak power requirements, determining PV array capacity, and selecting suitable battery storage and charge controller specifications. After designing the system, a basic PV system wiring practice was conducted to help participants understand the connections between system components. This activity was used as one of the indicators of participants’ developing technical readiness, particularly their ability to identify PV components, understand component functions, and follow basic wiring procedures using the trainer kit.

Development of PBL Modules

In the next stage, participants were introduced to Project-Based Learning (PBL) as an instructional approach that emphasises contextual problem solving and active student engagement. The process of group-based module development is shown in Figure 7.

Figure 7 Development of PBL Modules

Participants were asked to design renewable energy-based learning scenarios that could be implemented in educational contexts. Each group developed a preliminary concept for a project-based learning module that integrates solar energy concepts into practical learning activities. The preliminary PBL module concepts were treated as learning products that indicated participants' ability to translate technical renewable energy content into community-oriented instructional activities.

Partner-Site Visit and Follow-Up Teaching Implementation

On 9 February 2026, representatives from Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA) and the implementation team visited PKBM Banyutowo to observe the partner context and discuss the relevance of renewable energy learning for community learners. During this visit, the UMPSA partners also reviewed the previously installed renewable-energy-related facilities at PKBM Banyutowo, including the solar power system and rainwater harvesting system, as shown in Figures 8, 9, and 10.

Figure 8 Team Visit to PKBM Banyutowo

(a) (b)

Figure 9 PV Systems, (a) Control Box, (b) PV Panels

Figure 10 Rainwater Harvesting System

This visit helped align the workshop outputs with the partner's educational needs and clarified the pathway through which trained university students could later support renewable energy learning activities at PKBM Banyutowo. The site observation also provided contextual information on how the installed facilities could be used as learning resources for introducing green energy and green building concepts in a non-formal education setting.

The follow-up community teaching activity was conducted on 15 April 2026 at PKBM Banyutowo. In this activity, seven alumni of the 9 February 2026 workshop taught solar PV system concepts to PKBM learners using the same learning kit introduced during the workshop and the previously developed solar PV trainer kit, as can be seen in Figures 11 and 12. This activity functioned as the transfer stage of the training-of-trainers model, in which selected workshop alumni applied their technical and pedagogical preparation in a non-formal community education setting. Documentation of this activity, including photographs of the teaching process and the use of the trainer kit, was used as supporting evidence of program implementation and may be presented in the Result and Discussion section. The use of the same trainer kit in both the workshop and the PKBM teaching activity also helped maintain continuity between trainer preparation and community-level learning implementation.

Figure 11 Solar PV System Learning at PKBM Banyutowo

Figure 12 PKBM Learners Using Solar PV Trainer Kit

Evaluation and Reflection

The final stage consisted of an evaluation and reflection session to assess the effectiveness of the workshop and participants' understanding of the material presented. The evaluation process involved reflective discussions and the collection of feedback from participants regarding the content, learning activities, and overall workshop experience. The feedback instrument was a structured questionnaire consisting of 13 closed-ended statements using a five-point scale, where higher scores indicated more positive participant perceptions. The statements covered several aspects of the activity, including the clarity of the workshop schedule and activity sequence, timeline implementation, committee communication, technical implementation, facilities, committee responsiveness, session transitions, speaker clarity, speaker mastery, discussion facilitation, topic relevance, participant comfort, and overall satisfaction. The feedback data used in this manuscript consisted of 19 valid participant responses, as presented in Table 1.

The Likert-scale responses were not treated as inferential quantitative data, but were used descriptively to identify general trends in participants' perceptions and opinions regarding the workshop implementation. Therefore, the analysis focused on observing the tendency of responses across the 13 statements, particularly the dominance of positive responses and the presence of lower scores that indicated areas for improvement. In addition to the closed-ended feedback, reflective discussion during the final session was used to identify participants' perceived learning gains, challenges during the hands-on PV system activities, and suggestions for improving future training.The results of this evaluation were used to assess the effectiveness of the training program and identify areas for improvement in future implementations of similar community service activities. The success indicators were linked to the objectives of the program and included participants' positive perception of the workshop organisation, clarity of instructional delivery, perceived relevance of the green energy and sustainability topic, comfort during participation, overall satisfaction, and readiness to continue learning and applying solar PV concepts in community-based education settings. Although the program did not administer a formal pre-test and post-test, the evaluation provided formative evidence regarding participants' reception of the training and the aspects of implementation that supported prospective instructor capacity-building.

RESULT AND DISCUSSION

Workshop Implementation and Participant Engagement

The workshop titled *"Green Energy and Green Building for Sustainable STEM Education"* was successfully implemented on 9 February 2026 at Universitas Sebelas Maret as part of a community service program aimed at preparing prospective trainers who will later facilitate renewable energy learning activities at PKBM Banyutowo in Klaten Regency. This workshop formed one component of a broader January to April 2026 training-of-trainers community service program that also included preparation, partner-needs alignment, installation and preparation of green-energy facilities at the partner site, partner-site observation, and follow-up teaching implementation at PKBM Banyutowo.

The participants consisted of university students from engineering education programs who are expected to contribute to community-based educational initiatives. The activity proceeded through six systematic stages: preparation, presentation of basic solar PV material, demonstration of the solar photovoltaic trainer kit, PV system design and wiring practice, development of Problem-Based Learning (PBL) modules, and evaluation. In relation to the broader program design, these six workshop stages were followed by a partner-site visit and a community teaching activity that enabled workshop alumni to apply the learning outcomes in a non-formal education setting.

Throughout the workshop, participants demonstrated active engagement. This was evident from their enthusiasm during the lecture sessions, the number of questions raised during discussions, and the collaborative effort observed during hands-on activities and group-based learning design tasks. The workshop environment encouraged interactive learning, allowing participants to engage with both the theoretical aspects of renewable energy and practical problem-solving activities related to solar photovoltaic systems.

During the preparation phase, the community service team conducted a needs analysis to assess participants' prior understanding of renewable energy and STEM-based learning approaches. The results indicated that most participants had limited familiarity with solar photovoltaic systems and had not previously been exposed to structured PBL methodologies in the context of energy education. These findings confirmed the relevance of the workshop design and justified the decision to begin with foundational conceptual material before progressing to practical and pedagogical activities. The preparation phase also ensured that all training modules, presentation slides, and practical equipment, including the solar PV trainer kit, were prepared prior to the workshop. The preparation stage also included coordination with PKBM Banyutowo to ensure that the workshop content was relevant to community-based renewable energy learning needs. In addition, the program prepared supporting green-energy facilities at the partner site, including a solar power system and rainwater harvesting facility, which were intended to serve as contextual learning resources for future activities.

Participants' Understanding of Solar Photovoltaic Systems

The material presentation phase introduced participants to the fundamental concepts of solar photovoltaic (PV) energy systems, including the working principles of photovoltaic cells, the main system components (solar panels, charge controllers, batteries, and inverters), and the configuration of stand-alone PV systems suitable for small-scale applications and community-based educational settings. Participants responded positively to the material delivery, and the discussion session that followed the lecture revealed that many participants had developed an initial awareness of how solar PV systems can be utilised as alternative energy solutions for community facilities, including PKBM Banyutowo.

Following the conceptual explanation, participants were introduced to the solar photovoltaic trainer kit through a demonstration session. The trainer kit illustrated the functional relationships between PV system components and allowed participants to observe how electrical energy generated by the solar module flows through the charge controller, is stored in the battery system, and subsequently powers electrical loads. The demonstration helped participants visualise the operational principles of a solar PV system before engaging in more advanced hands-on activities.

The subsequent hands-on PV system design and wiring practice session further deepened participants' understanding of how individual components interact within a complete system. By working through load calculations, determining component sizing requirements, and observing the basic wiring demonstration using the solar PV trainer kit, participants were able to connect theoretical knowledge with tangible practical skills. The trainer kit, designed as a portable, modular learning medium, proved effective at making abstract concepts more accessible and engaging. Participants reported that direct interaction with the equipment helped improve their understanding of the operational logic of PV systems.

These outcomes are consistent with findings in renewable energy education literature, which highlight that hands-on, experiential learning approaches significantly enhance learners' comprehension of technical concepts and their confidence in applying them (Abdurrahman et al., 2023; Hoque et al., 2022). The integration of a physical trainer kit into the workshop also aligns with the broader argument that practical laboratory and demonstration tools are essential for building genuine technical competence, particularly in non-formal educational settings where learners may lack prior technical backgrounds (Lemut Bajec, 2023; Márföldi & Nagy, 2025). The solar PV trainer kit developed through this activity, therefore, functions not only as a demonstration tool during the workshop but also as a reusable learning resource that can support future renewable energy education activities at PKBM Banyutowo. This role was later reinforced in the follow-up teaching activity at PKBM Banyutowo, where the same learning kit and the previously developed solar PV trainer kit were used by workshop alumni to introduce solar PV concepts to community learners.

Development of PBL Modules

The PBL module development phase served as the pedagogical core of the workshop, requiring participants to transition from passive knowledge reception to active application of concepts within a structured learning design process. Participants were introduced to the fundamental principles of Problem-Based Learning, including how to frame real-world problems as learning drivers, scaffold student inquiry, and design contextually relevant projects that connect solar energy knowledge to local community conditions.

The introduction of PBL was well received by the participants. Many reported that this approach provided a more engaging and authentic learning experience than conventional lecture-based instruction. Through collaborative group activities, participants developed initial PBL module concepts that integrated solar energy topics into learning activities suitable for community-based education contexts.

Each group formulated a problem scenario related to energy use or environmental sustainability, identified learning objectives for renewable energy literacy, and proposed project activities that would enable learners to investigate the problem and develop practical solutions. Although the modules produced during the workshop were still preliminary drafts rather than finalised instructional materials, the design process played an important role in building participants' confidence as prospective facilitators of renewable energy learning. Thus, the PBL module development activity should be understood as an initial instructional design exercise rather than as a final module validation process.

The effectiveness of this approach is supported by research demonstrating that project- and problem-based learning methodologies promote critical thinking, collaborative skills, and deeper understanding of STEM content (Álvarez et al., 2021; Chioma Angela et al., 2024; Kazadi Tshikolu et al., 2025). For community learning centres, where learners often have diverse backgrounds and practical motivations related to livelihoods and community development, PBL is particularly appropriate because it contextualises learning within real-world problems that participants recognise as meaningful (Hayat et al., 2024; Zikargae et al., 2022).

Through this workshop, participants not only gained technical knowledge of solar photovoltaic systems but also acquired a pedagogical framework adaptable to renewable energy learning activities in community-based education environments. The integration of technical training, hands-on experimentation, and PBL-based instructional design, therefore, provides a comprehensive approach for preparing prospective trainers who can later facilitate renewable energy education initiatives at PKBM Banyutowo.

Partner-Site Observation and Knowledge Transfer to PKBM Banyutowo

Following the workshop on 9 February 2026, representatives from Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA) and the implementation team visited PKBM Banyutowo to observe the partner context and discuss the relevance of renewable energy learning for community learners. During this visit, the UMPSA partners also reviewed the renewable-energy-related facilities that had previously been installed at PKBM Banyutowo, including the solar power system and rainwater harvesting facility, as shown in Figures 8, 9, and 10. This observation provided contextual evidence that the program was not limited to classroom-based training, but was also connected to real learning resources available at the partner site.

The follow-up community teaching activity was conducted on 15 April 2026 at PKBM Banyutowo. In this activity, seven alumni of the 9 February 2026 workshop taught solar PV system concepts to PKBM learners using the same learning kit introduced during the workshop and the previously developed solar PV trainer kit, as can be seen in Figures 11 and 12. This activity functioned as the transfer stage of the training-of-trainers model, in which selected workshop alumni applied their technical and pedagogical preparation in a non-formal community education setting.

The April teaching activity strengthened the continuity between trainer preparation and community-level implementation. It also provided practical evidence that the workshop outputs could be transferred beyond the university setting. However, this follow-up activity should be interpreted as implementation evidence rather than as a formal measurement of learning outcomes among PKBM learners, because no structured assessment of PKBM learners was administered during this stage.

Participants' Feedback and Perceived Impact

The participants' perceptions of the workshop were identified through structured feedback collected at the end of the activity. The results of this evaluation are presented in Table 1, which summarises participant responses across several aspects of the workshop implementation, including organisational quality, learning experience, and overall satisfaction. The Likert-scale feedback was used to observe general trends in participants' perceptions and opinions, rather than to conduct inferential quantitative analysis or to claim measured learning gains.

Table 1 Feedback from Participants

Statement	**Respondent**																		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
The workshop's schedule and sequence of activities are clearly organized and easy to follow	4	5	5	5	5	5	4	5	5	5	4	5	4	5	4	4	4	5	4
The event proceeded according to the scheduled timeline	4	5	5	4	3	4	5	4	3	4	2	4	4	5	2	5	4	4	3
The information and instructions from the organizing committee were clearly communicated	3	5	5	5	4	5	5	4	4	5	5	5	4	5	4	4	4	5	4
The technical aspects of the event (venue/platform, audio, and visuals) went smoothly	4	5	5	4	4	5	4	5	4	5	5	5	4	5	4	4	4	5	4
The facilities provided during the event ensure the comfort of the participants	4	5	4	4	4	5	5	5	3	5	5	5	5	5	4	4	3	4	5
The committee was responsive and assisted the participants throughout the event	4	5	5	4	4	5	5	5	2	5	4	4	5	4	3	5	3	4	4
The transitions between sessions (opening, presentation of material, discussion, closing) went smoothly	4	5	5	4	4	5	5	5	4	5	5	5	5	5	4	4	3	4	4
The speaker's presentation was clear and easy to understand	4	5	5	4	4	5	5	5	4	5	5	4	4	5	4	5	4	4	4
The speaker demonstrated a good command of the subject matter	4	5	5	5	4	5	5	5	4	5	5	4	5	5	4	5	4	4	5
The discussion and Q&A session were well-facilitated	4	5	5	4	4	5	5	5	5	5	4	5	5	5	4	5	4	5	4
The workshop topic is relevant to the issues of green energy and sustainability	4	5	5	4	4	5	5	5	4	5	3	4	5	5	4	5	4	5	5
Overall, I felt comfortable participating in the activity from start to finish	4	5	5	4	4	5	5	5	5	5	5	4	5	5	4	4	4	4	4
My overall level of satisfaction with the conduct of this workshop/guest lecture	4	5	5	4	4	5	5	5	5	5	5	4	4	5	4	5	4	4	4

Most respondents provided scores of 4 and 5 for statements related to the organisation of the workshop, including the clarity of the schedule and the sequence of activities. This indicates that the workshop was generally perceived as well structured and easy to follow. Similarly, the event's implementation within the planned timeline received positive ratings from most participants. Although a small number of lower scores were recorded, these responses suggest that only minor improvements in time management may be required in future implementations.

Regarding communication and logistical support, participants largely agreed that the information and instructions provided by the organising committee were clear and effective. The technical aspects of the event, including the venue, audio support, and visual presentation materials, were also evaluated positively, reflecting the workshop's smooth operational management. These findings demonstrate that effective organisation and clear communication are essential for successful training activities (Md Sharif et al., 2025).

Participant comfort and support were also identified as strengths of the activity. Most respondents reported that the facilities provided during the workshop were adequate and that the organising team was responsive in assisting participants throughout the event. In addition, the transitions between sessions, including the opening, presentation of materials, discussion, and closing, were perceived as smooth. Such continuity contributes to creating a cohesive learning environment and helps maintain participant engagement during training activities.

From the instructional perspective, the speaker’s performance received particularly positive evaluations. Participants reported that the presentation was clear, easy to understand, and demonstrated a strong command of the subject matter. The discussion and question-and-answer sessions were also well facilitated, enabling participants to actively interact with the material and clarify technical concepts related to renewable energy systems.

Furthermore, participants strongly acknowledged the relevance of the workshop topic to current issues in green energy and sustainability. This indicates that the content successfully addressed real-world challenges and aligned with participants’ professional and educational interests. Many participants recognised that knowledge of renewable energy technologies, particularly solar photovoltaic systems, is increasingly important for supporting sustainable development and promoting environmentally responsible practices.Finally, most participants reported feeling comfortable throughout the activity and expressed high overall satisfaction with the workshop. These findings suggest that the training activity provided a positive and meaningful learning experience for participants.

Moreover, the combination of conceptual explanation, hands-on practice, and interactive discussion supported the development of both technical understanding and pedagogical awareness. Such competencies are essential for preparing participants as prospective trainers who may later facilitate renewable energy learning activities in community-based education environments such as PKBM Banyutowo. The subsequent involvement of seven workshop alumni in the 15 April 2026 teaching activity at PKBM Banyutowo further illustrates how this prospective trainer role began to be operationalised in the partner setting.

Evaluation, Reflection, and Implications for Instructor Capacity

The final evaluation stage was conducted through reflective discussions and the collection of structured feedback from participants. During this stage, participants reflected on the extent to which the workshop had expanded their understanding of solar photovoltaic (PV) systems, clarified the role of renewable energy in sustainable development, and enhanced their readiness to facilitate renewable energy learning activities in community-based education settings. The feedback gathered indicated a generally positive reception of the workshop components, with participants highlighting the practical system design session and the solar PV trainer kit demonstration as particularly impactful elements of the training.

Participants also identified several areas for further development. In particular, they noted the need for additional training sessions to strengthen their mastery of PV system sizing calculations and to further refine the PBL modules initiated during the workshop. These responses suggest that while the workshop provided a valuable foundation for renewable energy education, continued professional development is necessary to consolidate participants' technical and pedagogical competencies. This observation aligns with previous studies indicating that a single training intervention is rarely sufficient to fully address instructor capacity gaps in non-formal technical education settings (Shodipe & Ogbuanya, 2024).

Therefore, the workshop can be interpreted as an initial capacity-building intervention that establishes the foundation for a longer-term training trajectory. Future capacity-building efforts may include follow-up workshops, peer mentoring, and continued access to instructional resources, such as the solar PV trainer kit. Such sustained support is important to ensure prospective trainers gradually develop the confidence and expertise needed to deliver renewable energy education effectively. The April 2026 PKBM teaching activity represented an initial follow-up step in this trajectory, because selected workshop alumni were able to use the training resources in a real community learning environment.

The implications of this activity extend beyond the immediate learning outcomes for participants. By preparing a cohort of prospective trainers with foundational knowledge of solar PV systems and familiarity with PBL-based instructional design, the workshop strengthens PKBM Banyutowo's institutional capacity to implement renewable energy education programs. This potential multiplier effect is consistent with the training-of-trainers model described in non-formal education literature, in which a relatively small group of trained facilitators can expand the reach of educational initiatives through community-level dissemination and collaborative learning activities (Zikargae et al., 2022). In this program, the multiplier effect was reflected in the transition from 54 workshop participants to seven workshop alumni who later facilitated solar PV learning for PKBM learners.

From a broader perspective, the activity also demonstrates the potential role of community learning centres as strategic platforms for promoting renewable energy literacy and green skills. In regions such as Klaten Regency, where access to formal technical training opportunities may be limited, community-based learning initiatives can play an important role in expanding public awareness of sustainable energy technologies and supporting local capacity for environmentally responsible practices (Almeida & Morais, 2024; Covaciu, 2025). The presence of installed green-energy facilities at PKBM Banyutowo, including the solar power system and rainwater harvesting facility, further supports the role of the centre as a contextual learning environment where renewable energy and green building concepts can be introduced through direct observation and practice.

Taken together, the results of this community service activity indicate that integrating hands-on solar PV training with PBL-oriented pedagogical preparation is an effective and contextually appropriate model for developing renewable energy education capacity. By combining technical instruction, experiential learning, and instructional design practice, the workshop provides participants with both the knowledge and the pedagogical tools required to facilitate renewable energy learning activities in community education environments such as PKBM Banyutowo. Nevertheless, the results should be interpreted within the scope of the program evaluation. The feedback data represent participants' perceptions and response trends, while the follow-up teaching activity provides implementation evidence rather than formal evidence of measured learning gains.

Future initiatives should consider extending the duration of technical training, incorporating pre- and post-assessment instruments to more systematically measure participant learning gains, and establishing mentoring networks to support the continued professional development of trained facilitators beyond the initial workshop. Future programs should also consider developing a more structured observation rubric for wiring practice, a quality review rubric for PBL module drafts, and a simple learning assessment for PKBM learners so that the effect of the training-of-trainers model can be examined more systematically.

CONCLUSION

This community service activity demonstrates that integrating hands-on solar photovoltaic training with project-based learning (PBL) oriented pedagogical preparation is a relevant and contextually appropriate approach for developing renewable energy education capacity. The workshop supported participants' initial understanding of solar photovoltaic systems while also providing practical experience in system design, wiring practice, and instructional planning.

The use of a solar PV trainer kit played an important role in supporting experiential learning by enabling participants to visualise system operation and connect theoretical knowledge with practical application. In addition, the development of PBL module concepts allowed participants to translate technical knowledge into educational activities that can be implemented in community-based learning contexts. These outcomes indicate that the combination of technical demonstration, hands-on practice, and instructional design activities can provide a useful foundation for preparing prospective trainers in renewable energy education.

The results of the participant feedback further indicate that the workshop was well organised and well received, with generally positive response trends with the quality of instruction, learning activities, and the overall workshop experience. These outcomes suggest that the training model provided created a meaningful learning environment that combined technical competence development with pedagogical preparation. However, since the evaluation relied on event feedback and reflective discussion, the findings should be interpreted as formative evidence of participant reception rather than as a direct measurement of learning gains.

More broadly, the activity contributes to strengthening PKBM Banyutowo's institutional capacity to introduce renewable energy education into its community programs. This contribution was reinforced through the broader January to April 2026 implementation process, including the preparation of green-energy facilities, the UMPSA partner visit to review the installed solar power system and rainwater harvesting facility, and the follow-up teaching activity conducted on 15 April 2026 by seven workshop alumni at PKBM Banyutowo. By strengthening instructor capacity and renewable energy literacy in community education environments, the program contributes to advancing SDG 4 (Quality Education) and SDG 7 (Affordable and Clean Energy) through community-based renewable energy learning initiatives.

Future programs should consider extending the duration of technical training, implementing pre- and post-assessment instruments to more systematically measure learning outcomes, developing observation rubrics for PV wiring practice, reviewing the quality of PBL module products, assessing community learners' understanding, and establishing follow-up mentoring mechanisms to support the continued development of trained instructors.

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