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Promoting Energy Conservation and Solar Panel Training to Improve Renewable Energy Literacy Among High School Students

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ABSTRACT

Background: Improving renewable energy literacy among students is a strategic step in supporting sustainable energy transition in Indonesia. The high dependence on fossil fuels and low awareness of energy conservation, particularly among high school students, necessitates educational interventions that integrate practical experience with renewable energy technology.

Purpose of the Study: This community service activity aims to increase students' understanding of energy conservation and renewable energy, provide basic skills in utilizing solar panel technology, and encourage students to act as agents of change in supporting a sustainable lifestyle.

Methods: This activity was conducted at SMA Negeri 1 Cepu, involving 68 tenth-grade students through an experience-based and project-based learning approach. Implementation methods included needs analysis, training module development, dissemination of energy conservation materials, practical installation of a small-scale solar power plant (SPP) system, and evaluation using an online questionnaire.

Results: The activity demonstrated a significant improvement in participants' understanding and skills. The average pre-test score increased from 47.6% to 78.7% in the post-test, representing an increase of 31.1 percentage points. These results indicate improved understanding of energy conservation concepts, greater familiarity with the main components of solar panels, and enhanced ability to independently install simple solar power systems. The program also produced sustainable outputs, including solar panel modules and equipment, which were handed over to the school as educational learning materials.

Keywords
Renewable Energy; Solar Panels; Energy Literacy; Community Service; Experiential Learning

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Introduction

The increasing demand for electrical energy in line with population growth and economic activity represents an urgent global challenge that must be addressed, including in Indonesia. The high dependence on fossil fuels such as coal, petroleum, and natural gas not only causes supply limitations but also has a negative impact on the environment through increased greenhouse gas emissions and accelerated climate change (Armaroli & Balzani, 2007). This condition necessitates concrete efforts in the development and utilization of renewable energy as a sustainable and environmentally friendly alternative energy source. Efforts to optimize conventional energy systems, such as improving diesel generator efficiency through variable-speed operation (Muhtadi et al., 2022), further reinforce the urgency of transitioning toward cleaner energy alternatives, in line with the achievement of the Sustainable Development Goals (SDGs), particularly SDG 7 on access to affordable, reliable, and modern energy (Hoque et al., 2022; Sachs et al., 2019).

Indonesia has enormous solar energy potential due to its geographical location on the equator with relatively high solar radiation intensity throughout the year. Various studies show that solar energy has the potential to be one of the strategic solutions in supporting the national energy transition and achieving renewable energy mix targets (Islam et al., 2009; Muhtadi et al., 2019). However, the utilization of solar energy at the community level, especially in education and local communities, is still not optimal. This situation arises not only from infrastructure and investment limitations (Nasirov et al., 2015), but also the low level of public understanding and awareness regarding energy conservation and renewable energy technologies (Altuntaş & Turan, 2018; Zakaria et al., 2019).

Student groups, particularly high school students, constitute a strategic segment in efforts to improve energy literacy. Research indicates that students have great potential as agents of change who can disseminate knowledge and practices of sustainable energy in schools, families, and surrounding communities (Ballantyne et al., 1998; Denault et al., 2024). Renewable energy education at the secondary school level has proven effective in increasing environmental awareness, knowledge about sustainable energy, and student motivation to pursue careers in renewable energy (Kandpal & Broman, 2014; Queiruga-Dios et al., 2020). Nevertheless, initial observations at SMA Negeri 1 Cepu revealed that students' understanding of energy conservation and the use of solar panel technology is remains limited. Theoretical learning materials without direct practical support represent one of the factors hindering students' mastery of concepts and skills in the field of renewable energy (Ayata et al., 2024).

Energy literacy, which encompasses cognitive knowledge, affective attitudes, and energy-related behaviors, constitutes a fundamental competency that communities must possess to support energy sustainability (DeWaters & Powers, 2011; Lee et al., 2015). DeWaters and Powers' (2011) study of high school students in New York showed that although students had a high level of concern for energy issues (73% of the maximum score on the affective aspect), their cognitive (42% correct) and behavioral (65% of the maximum score) scores were still relatively low. Similar findings were also found in a comparative study in Japan (Akitsu & Ishihara, 2018), which emphasized the importance of awareness of consequences as the strongest predictor in the relationship between basic energy knowledge and energy-saving behavior. This condition indicates the necessity for a learning approach that not only emphasizes cognitive aspects but also integrates practical and contextual experiences to shape attitudes and behaviors that support energy conservation.

Various studies show that practice-based and project-based learning approaches (project-based learning and experiential learning) have been proven effective in improving students' energy literacy. Previous research have found that energy project-based learning significantly improves the knowledge, attitudes, behaviors, and beliefs of secondary school students regarding energy compared to conventional learning (Karpudewan et al., 2016). Similar findings have also been

reported that an integrative geospatial curriculum approach can improve the energy literacy of secondary school students in the United States (Bodzin et al., 2013). Furthermore, a systematic review confirms that active, collaborative, and experience-based learning has a positive impact on students' interest, awareness, and knowledge of renewable energy and sustainable development (Nair & Yunus, 2021; Rahmayanti, 2023).

Based on these issues, the situation analysis at SMA Negeri 1 Cepu identified several objective conditions requiring intervention. First, students' limited understanding of renewable energy concepts and their practical applications in daily life. Second, the absence of hands-on learning facilities for solar panel technology, which restricts students' opportunities to develop technical skills. Third, the lack of integration between theoretical curriculum content and practical experience in renewable energy education. These conditions collectively hinder the development of comprehensive energy literacy among students, encompassing cognitive understanding, positive attitudes, and energy-saving behaviors.

The selection of SMA Negeri 1 Cepu as the subject of community service was based on several strategic considerations. The school demonstrates strong commitment to environmental education and possesses adequate supporting infrastructure for implementing renewable energy training programs. Additionally, the school's location in Cepu sub-district represents a community with moderate awareness of renewable energy issues, making it an appropriate setting for intervention that can be replicated in similar contexts. The active participation of physics teachers in the needs analysis phase also indicated institutional readiness to support program sustainability.

This community service initiative addresses these challenges through an educational, applicable, and contextual approach. Energy conservation awareness activities combined with appropriate technology training based on solar panels are implemented as relevant solutions. This approach aligns with recommendations from various studies emphasizing the importance of integrating renewable energy content into school curricula using learning methods that involve direct experiments, real projects, and everyday contexts (Chao et al., 2017; Majid et al., 2025). Beyond providing conceptual knowledge, this approach offers students direct experience in understanding the working principles and application of solar power generation systems, which has been proven more effective in improving knowledge retention and practical skills (Ercan et al., 2017).

The expected social changes from this community service activity encompass multiple dimensions. At the individual level, students are expected to develop comprehensive energy literacy, including cognitive understanding of renewable energy concepts, positive attitudes toward sustainable energy practices, and behavioral changes manifested in energy conservation habits. At the institutional level, the provision of solar panel modules and training materials is anticipated to facilitate the integration of renewable energy content into the school's teaching and learning activities, creating a sustainable learning ecosystem. At the community level, students as agents of change are expected to disseminate knowledge and practices of energy conservation to their families and surrounding communities, contributing to broader awareness of sustainable energy utilization.

The main contribution of this community service activity lies in its efforts to improve renewable energy literacy among students through participatory learning methods and hands-on practice based on experiential learning and project-based learning theories. This approach has been proven in various studies to improve not only cognitive understanding but also technical skills, positive attitudes toward renewable energy, and energy-saving behavior (Ergül & Kargın, 2014; Hikmah et al., 2023). Additionally, this activity provides learning resources in the form of modules and solar panel equipment that can be used sustainably by schools, in line with the sustainability principles of renewable energy education programs (Pugu et al., 2024; Rahman, 2025). Thus, this activity is expected to have impacts not only on short-term knowledge improvement but also to

support the long-term learning process of renewable energy and contribute to human resource development that supports sustainable energy transition (Atstāja, 2025).

Based on this background, the objectives of this community service activity are: first, to increase students' understanding of the importance of energy conservation and renewable energy; second, to provide students with basic skills in utilizing solar panel technology as a source of electrical energy; and third, to encourage students to act as agents of change in supporting sustainable lifestyles and the utilization of environmentally friendly energy in the community. These objectives are formulated to address the identified problems and are expected to contribute to achieving the broader goal of sustainable energy transition through education and community empowerment.

Method

This community service activity was designed and implemented using an integrated approach that combines experiential learning and project-based learning methodologies. The research approach was qualitative-descriptive, focusing on the community service process and its outcomes in improving students' renewable energy literacy. The subjects of this study were 68 tenth-grade students of SMA Negeri 1 Cepu, Blora Regency, Central Java, selected through purposive sampling based on their availability and willingness to participate in the program.

The location of the community service was at SMA Negeri 1 Cepu, chosen based on several strategic considerations: the school's commitment to environmental education, adequate supporting infrastructure, and active participation of physics teachers in supporting renewable energy education. The involvement of the assisted community in the planning and organizing process was realized through focus group discussions with teachers and students to identify specific needs and design appropriate intervention strategies.

The methods and strategies used to achieve the expected goals combined theoretical socialization with hands-on practical training. The experiential learning approach emphasized direct student involvement in assembling and operating solar panel systems, while the project-based learning approach encouraged collaborative work and problem-solving through real projects. These strategies were chosen based on empirical evidence from previous studies indicating their effectiveness in improving students' energy literacy (Bodzin et al., 2013; Karpudewan et al., 2016).

The materials and instruments used in this activity included: (1) monocrystalline solar panel modules 30 Wp; (2) 10 A PWM solar charge controller; (3) 12 V 12 Ah battery; (4) 12 V to 220 V DC-AC inverter, 500 W; (5) electrical load consisting of 220 V 5 W LED light; (6) electrical cables and connectors; and (7) solar panel support frame made of hollow iron. The study also used supporting materials such as training modules, online evaluation forms (Google Forms), and presentation media.

The data collection process involved pre-activity observations, documentation during implementation, and post-activity evaluation using structured online questionnaires. The analysis techniques included descriptive statistics to measure improvements in understanding and thematic analysis to identify emerging patterns in students' responses and behaviors. The stages of community service activities are illustrated in the following flow diagram (Figure 1).

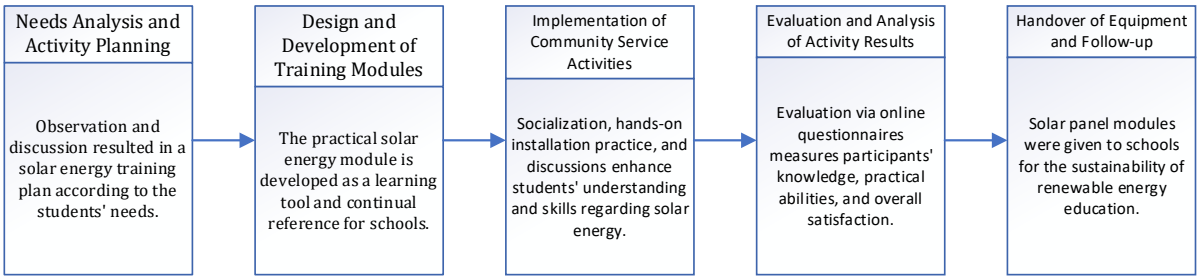


Figure 1. Flow Diagram of Community Service Implementation Method

The process of joint community action planning involved collaborative discussions between the implementation team, school management, physics teachers, and student representatives. The planning sessions identified key challenges in renewable energy education, determined appropriate intervention strategies, and established clear implementation timelines. This participatory approach ensured that the program design was contextually relevant and aligned with the school's educational objectives.

The subjects of community service were tenth-grade students selected based on their enrollment in physics courses and their expressed interest in renewable energy topics. The location of the service at SMA Negeri 1 Cepu provided an appropriate setting with adequate facilities for practical training activities. The involvement of the assisted community in the organizing process was manifested through active participation in needs assessment, module review, and feedback provision during pilot testing of training materials.

The implementation strategy emphasized a hands-on, experiential approach where students actively engaged in assembling solar power systems under guided supervision. This methodology was designed to bridge the gap between theoretical knowledge and practical application, fostering deeper understanding and skill development. The five stages of the community service method, as illustrated in Figure 1, were implemented sequentially to ensure systematic progression from initial needs identification to sustainable program outcomes.

The planning process began with needs analysis conducted through observations and discussions with physics teachers at SMA Negeri 1 Cepu. This phase identified the limited understanding of solar energy among students and the lack of practical learning facilities. Based on these findings, the team developed training modules that emphasized basic concepts of energy conservation, introduction to solar power system components, working principles of solar panels, and simple installation steps. The modules were designed to be reusable learning resources that support the sustainability of renewable energy education at the school.

The implementation phase combined three main activities: socialization and presentation of materials on energy conservation and solar energy potential; practical installation sessions where students worked in groups to assemble and operate complete solar panel systems including panels, charge controllers, batteries, inverters, and loads; and mentoring sessions that allowed students to ask questions and discuss technical challenges. This integrated approach ensured that students gained both theoretical understanding and practical skills in renewable energy technology.

The activity was conducted in three main sessions with a total duration of three hours: the first session (1 hour) covered needs analysis, pre-test administration, and a presentation on energy conservation; the second session (1.5 hours) included demonstrations and hands-on practical training on the installation of solar panel systems using a rotation model across four parallel activity zones — direct installation practice, manual wiring simulation, data analysis, and case study discussion — so that each group of 5–6 students had the opportunity to actively engage with the material under the facilitator's guidance; and the third session (30 minutes) included evaluation, post-tests, discussions, and the handover of equipment. Student attendance reached 100%, with

all 68 registered students present and participating in the entire series of activities from start to finish.

The program's success criteria included measurable improvements in students' cognitive understanding of renewable energy concepts, practical skills in solar panel installation and operation, and attitudinal changes toward energy conservation. All outcomes were assessed through structured evaluation instruments administered via Google Forms, which covered aspects of material understanding, practical skills acquisition, and participant satisfaction. The final stage of equipment handover ensured program sustainability by providing the school with functional solar panel systems that could be continuously used for ongoing renewable energy education.

Result

The community service activity in the form of socialization of renewable energy conservation and training in appropriate technology based on solar panels was successfully carried out at SMA Negeri 1 Cepu, involving 68 tenth-grade students as activity partners. This section presents the results obtained from the research, which are supported by sufficient data gathered through online questionnaires, direct observations during practical sessions, and documentation of student activities throughout the training program.

The outcomes of the community service process describe the dynamics of the assistance activities, including the variety of actions undertaken, the forms of technical interventions aimed at solving the problem of limited renewable energy literacy, and the emergence of expected social changes. These changes include the formation of new understanding and awareness regarding renewable energy, shifts in student behavior toward energy conservation, the development of practical skills in solar panel technology, and the emergence of new awareness toward sustainable energy transformation among the school community.

The research results address the research questions outlined in the introduction section regarding how to effectively improve students' renewable energy literacy and practical skills through experiential learning and project-based learning approaches. The findings demonstrate measurable improvements across cognitive, psychomotor, and affective domains of learning, validating the effectiveness of the implemented methodology.



Figure 2. Welding process to build a standing frame for PV panel modules

Preparation of Facilities and Infrastructure

The initial stage of the activity began with the preparation of supporting facilities in the form of making a support frame for the solar panel modules. The frame was constructed through welding processes to ensure the strength and stability of the modules during the installation practice. This preparation stage played an important role in supporting the smooth and safe

implementation of the field practice activities, as illustrated in Figure 2.

The construction of the solar panel support frame utilized hollow iron materials that were cut, assembled, and welded according to the designed specifications. The frame was engineered to provide stable mounting for the 30 Wp monocrystalline solar panel module at an optimal angle for capturing solar radiation. This infrastructure preparation demonstrates the technical intervention component of the community service program, where appropriate technology is adapted to local conditions and educational needs (Kurnianingsih et al., 2025).

Implementation of Socialization and Training on Solar Panel Installation

After the facility preparation stage, the activity continued with the dissemination of material and practical training on solar panel system installation. At this stage, students received explanations about the concept of renewable energy conservation, an introduction to the main components of a solar power system, and the working principles of solar panels. The socialization session was designed to provide students with foundational knowledge necessary for understanding the technical aspects of the subsequent hands-on training.

After the theoretical presentation, students directly practiced installing and configuring a small-scale solar power system, from panel installation to load testing, as shown in Figure 3. This practical activity encouraged active student participation and enhanced understanding through direct experience. Students worked in groups to assemble complete SPP systems, which included mounting solar panels on the support frame, connecting charge controllers, wiring battery systems, installing inverters, and testing electrical loads. The hands-on approach aligns with experiential learning principles that emphasize learning through doing and reflection on practical experiences (Muhid et al., 2018).



Figure 3. Training for Installing and Configuring Solar Panel systems

Student Participation and Understanding Levels

The success of this community service activity was evaluated based on the achievements of the students as service partners, with the main indicators including the level of participation, understanding of the material, and practical skills in installing a Solar Power Plant (SPP) system. During the activity, students showed a high level of participation. This was reflected in their active involvement in discussion sessions, question and answer sessions, and group work during the SPP system assembly practice. Their active participation demonstrated their interest and motivation to learn about the renewable energy material presented.

Table 1. Assessment Results of Students' Understanding of Renewable Energy and Solar Power Plant Systems

No	Question	Pre-test Correct (%)	Post-test Correct (%)	Key Notes
1	Energy source in solar power generation systems	73.5	98.5	The majority of participants recognized the sun as the primary source of energy.
2	Definition of a solar panel	77.9	92.6	The majority of participants recognized solar panels as converters of solar energy into electricity.
3	Function of the battery regulator (charge controller)	14.7	51.5	Misconceptions persist; certain participants regard regulators as energy storage devices.
4	Inverter function	41.2	80.9	The majority of participants comprehend inverters as apparatuses that transform direct current (DC) into alternating current (AC).
5	Battery/Accumulator Function	51.5	79.4	The majority of participants know that batteries function as electrical energy storage devices
6	Definition of renewable energy	55.9	85.3	Participants often recognize the notion of renewable energy.
7	Definition of on-grid power generation system	36.8	76.5	Most participants understand systems connected to the main electrical grid
8	Definition of an off-grid power generation system	29.4	64.7	Understanding is still limited; some participants do not yet understand the characteristics of independent systems
	Average	47.6	78.7	

The evaluation of students' level of understanding was conducted after the entire training series was completed through an online questionnaire using Google Forms. The evaluation instrument consisted of eight questions covering aspects of renewable energy literacy, including solar energy sources, the functions and working principles of solar panels, the main components of a SPP system (charge controller, inverter, and battery), the concept of renewable energy, and the differences between on-grid and off-grid SPP systems. A total of 68 students participated in filling out the questionnaire, so the data obtained was considered representative for quantitative analysis.

Evaluation results presented in Table 1 show that the distribution of students' correct answers for each question item. A total of 98.5% of students (67 out of 68 respondents) correctly answered the question regarding the primary energy source in a solar power system. A total of 92.6% of students correctly answered the definition of a solar panel. Meanwhile, the pre-test scores

for these first two questions were 73.5% (50 students) and 77.9% (53 students), compared to post-test scores of 98.5% (67 students) and 92.6% (63 students), representing increases of 25.0 and 14.7 percentage points, respectively.

Regarding solar power system components, 80.9% (55 students) correctly identified the function of the inverter (DC to AC), and 79.4% (54 students) understood the function of the battery as an energy storage medium. A total of 85.3% (58 students) could correctly define renewable energy. The pre-test scores for these three items were 41.2% (28 students), 51.5% (35 students), and 55.9% (38 students), which increased to 80.9% (55 students), 79.4% (54 students), and 85.3% (58 students) in the post-test, representing gains of 39.7, 27.9, and 29.4 percentage points, respectively.

The three items with the lowest post-test scores were the function of a battery charger/regulator (51.5% or 35 students), off-grid solar power systems (64.7% or 44 students), and on-grid solar power systems (76.5% or 52 students). The pre-test scores for these three items were 14.7% (10 students), 29.4% (20 students), and 36.8% (25 students), which increased to 51.5% (35 students), 64.7% (44 students), and 76.5% (52 students) in the post-test, with gains of 36.8, 35.3, and 39.7 percentage points, respectively. All three post-test scores remained below the overall post-test average of 78.7%.

Improvement of Students' Practical Skills

Besides theoretical knowledge, the training also boosted students' hands-on skills. Most students were able to successfully construct a basic solar panel system by following the prescribed procedures, including panel installation, wiring of the charge controller, battery, and inverter, as well as testing the lamp load. During the practical sessions, students showed competence in mounting solar panels on the support frame with proper orientation, safely connecting electrical cables and connectors, wiring the charge controller to the solar panel and battery, installing the inverter and integrating it with the battery system, and testing the complete system through the operation of LED lamp loads.

These competencies indicate the success of the activity in enhancing the practical skills of the service partners and confirm the effectiveness of the practice-based learning approach applied in this community service program. The hands-on experience increased students' confidence in handling renewable energy equipment and improved their understanding of practical considerations in solar power system installation

Program Sustainability and Handover of Learning Facilities

In addition to improving cognitive understanding and practical competencies, this community service initiative also generated sustainable learning facilities for the school. As a follow-up effort to ensure program sustainability, the solar panel module system used during the training was officially handed over to SMA Negeri 1 Cepu.

The equipment package consisted of a complete 30 Wp solar panel module with a support frame, a 10 A PWM solar charge controller, a 12 V 12 Ah battery, a 500 W DC–AC inverter, a complete wiring system equipped with connectors, an LED lamp load for demonstration, and training module documentation. This handover was intended to enable the continued use of the equipment as a learning medium for renewable energy topics and to support the integration of energy conservation materials into classroom instruction. The school administration expressed its commitment to incorporating the equipment into the physics curriculum and utilizing it for project-based learning activities in future academic years.

Overall, the results indicate that students not only experienced increased understanding and practical skills but also gained access to sustainable renewable energy learning facilities. These findings confirm that the community service activity produced a tangible impact on the service partners, with an average improvement in understanding of 78.7% across all evaluated aspects of renewable energy literacy.

Discussion

The implementation of socialization and training activities on renewable energy conservation and solar panel technology at SMA Negeri 1 Cepu demonstrates the strong potential of experiential and project-based learning approaches in enhancing students' renewable energy literacy. This discussion examines the findings in relation to relevant theoretical perspectives and previous studies, while also highlighting the contributions, limitations, and implications of the program.

Effectiveness of Experience-Based and Project-Based Learning Approaches

The outcomes of this activity show that experiential and project-based learning approaches are effective in improving students' understanding and skills related to renewable energy. Direct student involvement in solar panel installation provided concrete experiences that reinforced conceptual knowledge previously introduced during theoretical sessions. The average understanding score of 78.7% across all evaluation indicators suggests that the integration of theoretical explanations and hands-on practice yields measurable learning outcomes.

These results align with prior studies showing that practice-based learning significantly improves energy literacy and technical understanding. High achievement levels in identifying energy sources and understanding solar panel functions further support the effectiveness of combining cognitive instruction with psychomotor activities. Previous research also indicates that active participation in project-based tasks fosters the development of essential skills such as problem solving and teamwork, which were evident during the group-based installation activities in this program.

The experiential learning strategy employed aligns with Kolb's learning cycle (Wijnen-Meijer et al., 2022), in which students engage in concrete experience through hands-on installation, reflective observation during discussion sessions, abstract conceptualization by understanding system principles, and active experimentation through system testing. This cyclical learning process has been shown to strengthen both knowledge retention and skill acquisition in technical education settings.

Analysis of Student Understanding and Misconceptions

Although the overall results were positive, the evaluation identified specific areas of limited student understanding. Lower comprehension of charge controller functions and off-grid system characteristics indicates a need for more focused explanations and additional demonstrations. The misconception that charge controllers serve as energy storage devices rather than regulation components suggests that students may experience difficulty distinguishing system component functions when introduced within a limited training timeframe.

Similar challenges have been reported in the renewable energy education literature, where high student enthusiasm is often accompanied by weaker understanding of technical details. These findings suggest that continuous reinforcement of technical concepts within a sustainability framework is necessary to improve conceptual clarity and retention. Future implementations should therefore emphasize clearer explanations of component functions, supported by visual

representations and more individualized interaction with system components, as well as ongoing assessment throughout the training process.

Contribution to Renewable Energy Literacy and Community Empowerment

This activity contributes meaningfully to the enhancement of renewable energy literacy among high school students, who represent a key demographic for promoting sustainable practices within their communities. The observed improvements across multiple dimensions of renewable energy knowledge indicate that the program effectively addressed initial gaps in awareness and understanding related to energy conservation and solar technology.

From a broader community-empowerment perspective, the initiative shows the importance of combining technical capacity building with awareness-raising efforts to achieve sustainable behavioral change. The handover of equipment to the school constitutes a long-term investment in educational infrastructure that will benefit successive cohorts of students. Integrating renewable energy education into formal schooling also supports wider sustainable development objectives by strengthening human capital and encouraging future engagement with clean energy technologies.

Comparison with Similar Activities and Program Sustainability

Compared with community service programs that rely solely on counseling or lectures, this activity offers distinct advantages through its emphasis on hands-on practice and sustainability. The permanent provision of solar panel equipment allows continued use as learning media beyond the initial training period, ensuring lasting educational benefits. This approach addresses common limitations of short-term training initiatives by enabling ongoing experimentation and reinforcement of concepts.

The availability of training modules further supports knowledge transfer by allowing teachers to integrate renewable energy topics into future lessons independently. School administrators' active involvement in curriculum planning reflects strong institutional commitment, which is critical to ensuring long-term program impact and sustainability.

Theoretical Contributions and Practical Implications

The program contributes to the theoretical discourse on renewable energy education by demonstrating the effectiveness of integrating experiential and project-based learning within the Indonesian secondary education context. The observed improvements in knowledge, skills, and attitudes confirm that hands-on technical activities can effectively complement traditional classroom instruction.

Practically, this program offers a replicable model that can be adapted by other schools and communities. The use of affordable and accessible equipment makes the approach feasible for institutions with limited resources, while the flexible training design allows adaptation to varying timeframes. The positive student engagement observed suggests that incorporating similar hands-on renewable energy projects into physics and environmental science curricula could enhance STEM education outcomes more broadly.

Limitations and Recommendations for Future Implementation

Despite its success, several limitations should be acknowledged. The program involved students from a single grade level, limiting its reach across the wider school community. Additionally, the one-day training duration constrained the depth of technical content that could

be addressed, particularly for more advanced system design concepts. The absence of longitudinal evaluation also limits understanding of long-term behavioral change resulting from the activity.

Future programs should therefore expand participation across multiple grade levels, extend training duration through modular sessions, and include follow-up evaluations to assess sustained knowledge retention and energy-related behaviors. Broadening the scope to include other renewable energy technologies would further enrich students' understanding of sustainable energy systems.

Integration with Broader Sustainable Development Goals

The outcomes of this activity align with several Sustainable Development Goals, particularly those related to quality education, clean energy, climate action, and partnerships. By equipping students with practical renewable energy skills and environmental awareness, the program supports long-term human capital development essential for Indonesia's energy transition.

In conclusion, this community service program effectively demonstrates the value of experiential and project-based learning in enhancing renewable energy literacy among students at SMA Negeri 1 Cepu. The combination of measurable learning improvements and sustainable learning facilities provides a strong foundation for scaling and refining similar initiatives in other educational contexts, contributing to a more sustainable energy future in Indonesia.

Conclusion

Community service activities in the form of renewable energy conservation socialization and appropriate technology training based on solar panels at SMA Negeri 1 Cepu were carried out through stages of needs analysis, module design, implementation of socialization and practice of installing solar power systems, and evaluation using Google Forms-based online questionnaires. The results of the activity showed that the service recipients—10th- grade students—experienced a significant improvement in their understanding and skills, as evidenced by an average correct answer rate of 78.7%. This indicates that, in general, students were able to understand the concept of energy conservation, identify the main components of solar panels, and independently install a simple solar power system. The main contribution of this activity lies in improving students' renewable energy literacy and practical skills, as well as the availability of modules and solar panel equipment that can be used sustainably by schools as learning media. However, this activity has limitations in terms of participant coverage, which is still limited to one grade level, and the relatively short duration of the training, so that technical aspects have not been optimally explored. Based on these limitations, it is recommended that future community service activities be carried out on an ongoing basis with a wider range of participants, a longer duration, and the integration of renewable energy material into the school curriculum. In the future, the scope of activities can be expanded through the development of school-scale solar energy projects, collaboration with industry or local government, and measurement of the long-term impact on changes in student behavior in supporting energy conservation and sustainable lifestyles.

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Conflicts of Interest

The authors declare no conflicts of interest that could influence the objectivity or findings of this project. There is no financial support or personal relationship that could influence the reported results regarding the solar panel training program.

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