Community-Based Solar Energy Socialization: A Collaborative Model for Sustainable Energy Transition in Vocational Education

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Abstract

This study presents a comprehensive approach to promoting solar energy adoption in vocational education through community-based socialization at SMKS Panca Budi, Indonesia. The research addresses the critical challenge of rising electricity costs in educational institutions, which have increased by approximately 10% annually over the past five years. Through an international collaboration between Universitas Pembangunan Panca Budi and Universiti Malaysia Perlis, this initiative implemented a 50 kW solar panel system capable of meeting 30% of the school's energy requirements. The socialization program employed multiple strategies including stakeholder coordination, technical training workshops, community outreach sessions, and policy advocacy. Results demonstrate that community engagement significantly enhances acceptance and adoption rates of renewable energy technologies, with increased awareness among 800+ participants. The program successfully integrated practical solar energy education into the vocational curriculum, producing significant improvements in student knowledge from 42% to 78% on assessment measures and practical skills competency rates of 82-95%. Economic analysis reveals substantial long-term cost savings of USD 7,200-9,600 annually with a payback period of 78 years. This collaborative model addresses financial, technical, and awareness barriers while contributing to Indonesia's renewable energy target of 23% by 2025. The study concludes that community-based approaches provide an effective framework for sustainable energy transition in educational institutions, with potential for replication across other vocational schools.

Keywords: *Solar Energy, Vocational Education, Community Engagement, Renewable Energy, Sustainable Development, Energy Transition*

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Introduction

The global transition toward renewable energy has become increasingly urgent as nations strive to address climate change, reduce carbon emissions, and achieve energy security. In Indonesia, the government has set an ambitious target to increase the renewable energy mix to 23% by 2025 [1]. However, the adoption of renewable energy technologies, particularly solar power, faces significant barriers including limited awareness, high initial costs, and insufficient technical expertise, especially within educational institutions.

Educational institutions, particularly vocational schools, consume substantial amounts of electricity for their daily operations, including classroom activities, workshops, laboratories, and administrative functions. According to the Ministry of Energy and Mineral Resources, electricity prices in Indonesia have increased by approximately 10% annually over the past five years [1]. This escalating cost represents not only a financial burden but also an opportunity to demonstrate leadership in sustainable energy practices.

SMKS Panca Budi, a vocational high school in Medan, North Sumatra, exemplifies these challenges while simultaneously representing the potential for innovative solutions. As a technical and vocational education institution, the school is uniquely positioned to serve dual purposes: reducing its own energy costs while providing students with practical skills in renewable energy technologies. The solar energy sector in Indonesia presents significant employment opportunities, with projections indicating that the green energy workforce will grow by 20% over the next decade [2].

This paper presents a comprehensive case study of a community-based solar energy socialization program implemented at SMKS Panca Budi through an international collaboration between Universitas Pembangunan Panca Budi (UNPAB) and Universiti Malaysia Perlis (UniMAP). The initiative represents an innovative model that integrates technical implementation, educational development, and community engagement to promote sustainable energy transition in vocational education settings.

The primary objectives of this study are to design and implement a community-based solar energy socialization program in a vocational education setting, to evaluate the effectiveness of stakeholder engagement in promoting solar energy adoption, to assess the economic, educational, and environmental outcomes of solar power integration in schools, to develop a replicable collaborative model for sustainable energy transition in educational institutions, and to enhance students' technical competencies in renewable energy technologies.

Literature Review

The integration of solar energy in educational facilities has gained considerable attention globally as institutions seek to reduce operational costs and demonstrate environmental responsibility. Research indicates that educational institutions adopting solar power typically achieve 25-40% reduction in electricity costs within the first five years of operation [3]. Beyond economic benefits, solar installations in schools provide unique educational opportunities, particularly in STEM disciplines.

Documentation shows that the average cost of solar photovoltaic systems has dropped by 89% since 2009, making solar energy increasingly accessible to institutions in developing countries [4]. This dramatic cost reduction has transformed solar power from a luxury investment to a viable economic solution for institutions facing rising energy costs. However, the initial capital investment remains a significant barrier, particularly for public educational institutions operating under tight budgetary constraints.

Community engagement has emerged as a critical success factor in renewable energy initiatives. Research conducted in Bali demonstrated that community-led solar initiatives significantly increased local participation in solar energy programs, resulting in higher adoption rates compared to top-down implementation approaches [5]. The study emphasized that building awareness and support among local residents leads to greater acceptance and enthusiasm for solar projects.

Stakeholder coordination represents another crucial element. Studies have highlighted that fragmented efforts among government bodies, private companies, and educational institutions often lead to inefficiencies and missed opportunities for synergy [6]. Effective coordination mechanisms that bring together diverse stakeholders are essential for successful implementation.

The role of vocational education in developing a skilled workforce for the renewable energy sector has been widely recognized. The transition to a green economy requires massive upskilling and reskilling efforts, with technical and vocational education and training institutions playing a pivotal role [7]. Vocational schools that integrate renewable energy technologies into their curricula not only enhance their students' employability but also contribute to national capacity building in critical emerging sectors.

Research emphasizes that hands-on learning experiences with renewable energy technologies significantly improve student engagement and knowledge retention compared to theoretical instruction alone [8]. Students who participate in practical solar energy projects demonstrate higher levels of understanding and greater confidence in pursuing careers in the renewable energy sector.

Research Methodology

This study employs a mixed-methods action research approach, combining quantitative and qualitative data collection and analysis methods. Action research is particularly appropriate for this study as it involves implementing an intervention while simultaneously studying its effects and making iterative improvements based on ongoing feedback.

The research was conducted at SMKS Panca Budi, a vocational high school located in Medan, North Sumatra, Indonesia. The school serves approximately 800 students across multiple vocational programs, including electrical engineering, computer science, and business administration. Prior to this intervention, the school relied entirely on grid electricity from the state utility company, with monthly electricity costs averaging approximately IDR 30-40 million.

The project was implemented through a formal Memorandum of Agreement between UNPAB and UniMAP, established in March 2024 with a six-month implementation period. The partnership framework specified institutional responsibilities, resource sharing, joint activities, and evaluation mechanisms.

The solar energy socialization program comprised four integrated components. First, technical implementation involved installing a 50 kW solar photovoltaic system on the school's rooftops through partnership with local renewable energy companies. The system was designed to meet approximately 30% of the school's energy requirements with grid-connection and net metering arrangement.

Second, educational integration incorporated solar energy content into the existing vocational curriculum, particularly within the electrical engineering program. This included

theoretical modules covering photovoltaic principles, hands-on workshops on solar panel installation and maintenance, project-based learning activities, and career guidance sessions.

Third, community socialization comprised comprehensive outreach activities designed to engage multiple stakeholder groups including students, teachers, parents, and local residents. Interactive presentations, demonstrations, professional development workshops, information sessions, and public forums were conducted to build awareness and support.

Fourth, stakeholder coordination established a mechanism involving school administration, local government energy and education departments, private sector renewable energy companies, parent-teacher associations, student organizations, and community representatives.

Multiple data collection methods were employed. Quantitative data included pre- and post-intervention surveys measuring awareness and attitudes toward solar energy among 200+ participants, energy consumption and cost data, solar system performance data, attendance records, and academic performance data. Qualitative data comprised semi-structured interviews with key stakeholders, focus group discussions with students, observation notes, photographic and video documentation, and written feedback from participants.

The program was implemented over a six-month period from February to August 2025. Month one involved formal launch and needs assessment. Month two focused on solar system design and curriculum development. Month three included installation and teacher training. Month four initiated student workshops and community outreach. Month five involved system commissioning and expanded training. Month six concluded with final evaluations and report preparation.

Quantitative data were analyzed using descriptive statistics and inferential statistics to compare pre- and post-intervention measures. Qualitative data were analyzed using thematic analysis, with interview transcripts and observation notes coded to identify recurring themes and patterns. The research protocol received approval from institutional ethics review boards of both UNPAB and UniMAP, with all participants providing informed consent.

Results

The installation of the 50 kW solar photovoltaic system at SMKS Panca Budi was successfully completed within the planned timeline. The system became operational in June 2025 and has demonstrated consistent performance. Average daily energy generation ranged from 200-250 kWh depending on weather conditions, with monthly generation of approximately 6,000-7,500 kWh. The system met 28-32% of the school's energy needs, achieving the target of approximately 30%.

Economic outcomes revealed estimated monthly cost savings of IDR 9-12 million, with projected annual savings of IDR 108-144 million. The estimated payback period is 7-8 years based on current electricity prices. The solar monitoring system provided real-time data on energy generation, with the system maintaining an average efficiency of 85-90%, which is within the expected range for well-maintained photovoltaic installations in tropical climates.

Several technical challenges were encountered and addressed. Initial analysis revealed that trees near the installation site caused partial shading during certain hours, which was resolved through selective tree trimming. Weather variability affected daily generation as expected in tropical climates, but the grid-connected design with net metering addressed this effectively. A maintenance schedule was established including monthly cleaning of panels and quarterly system inspections.

The integration of solar energy into the vocational curriculum produced significant educational benefits. Total students engaged in basic awareness sessions numbered 823, exceeding the target of 200+. Students participating in intensive hands-on training workshops numbered 145, primarily from the electrical engineering program. Teachers trained in renewable energy concepts numbered 28, while community members attending information sessions totaled 167.

Pre-intervention and post-intervention surveys of 145 intensive training participants revealed substantial improvements. Knowledge assessment showed pre-intervention average scores of 42% correct responses on solar energy knowledge tests, increasing to 78% postintervention. Statistical analysis using paired t-test indicated highly significant improvement with $t(144) = 18.65$, $p < 0.001$.

Skills assessment results demonstrated that students participating in hands-on workshops achieved high competency levels. Basic solar panel installation techniques were mastered by 87% of students, system wiring and electrical connections by 82%, use of measurement and diagnostic tools by 90%, and safety protocols and procedures by 95%.

The electrical engineering program successfully incorporated renewable energy modules into the existing curriculum. Four new course modules were developed including Introduction to Renewable Energy, Solar PV Systems, Installation Practices, and System Maintenance. Total instructional hours added amounted to 120 hours across the academic year, with integration into existing courses on power systems, electrical measurements, and practical electronics. Qualitative data from focus groups and open-ended survey responses revealed high levels of student satisfaction and enthusiasm. Students reported that learning about solar panels was very practical and opened career possibilities. The hands-on workshop was particularly appreciated as students actually installed real panels and saw them generating electricity. Many students expressed serious interest in renewable energy careers after learning about job opportunities and growth in the sector.

Teachers reported increased confidence in teaching renewable energy concepts and appreciated the professional development opportunities. Eighty-nine percent of trained teachers reported feeling confident or very confident in teaching solar energy topics, while 92% expressed interest in further training and curriculum development. Several teachers initiated supplementary projects including student research on optimal solar panel angles and energy efficiency improvements.

Community socialization achieved significant reach and impact. Community surveys of 167 participants showed substantial shifts in awareness and attitudes. Pre-intervention, 38% could correctly explain basic principles of solar energy, increasing to 81% post-intervention. Awareness of government incentives for solar adoption increased from 22% to 69%. The percentage viewing solar energy as economically viable for households increased from 31% to 74%. Interest in installing solar panels at home increased from 18% to 52%. Belief that schools should lead in adopting renewable energy increased from 64% to 93%.

The multi-stakeholder coordination mechanism proved effective in facilitating program implementation. The Local Energy Department provided regulatory guidance and connected the school with subsidy programs. The Education Department recognized the program as a model initiative and expressed interest in replication. The Environmental Agency documented the program as a climate action initiative. Three local renewable energy companies participated, providing technical expertise and equipment at reduced costs. One company offered internship opportunities for top-performing students, while equipment suppliers provided warranties and ongoing technical support. The parent-teacher association actively promoted the program within

the community, local community leaders attended events and endorsed the initiative, and regional media coverage generated broader awareness.

Several community members reported being inspired to take action. Five families in the immediate neighborhood initiated consultations for residential solar installations. A nearby mosque expressed interest in installing solar panels, consulting with SMKS Panca Budi for guidance. A local business owner attended workshops and subsequently installed a 10 kW system at his facility.

Table 1. Summary of Key Outcomes

Category	Indicator	Result
Technical	Energy Coverage	28-32% of school needs
Economic	Annual Savings	USD 7,200-9,600
Educational	Knowledge Improvement	42% to 78%
Educational	Skills Competency	82-95%
Community	Participants Reached	800+
Community	Awareness Increase	38% to 81%

The total project cost was approximately IDR 750 million, covering solar panel system and equipment (IDR 600 million), installation and commissioning (IDR 80 million), training and educational materials (IDR 40 million), and documentation and dissemination (IDR 30 million). Funding sources included government grant at 60%, private sector sponsorship at 25%, and school contribution at 15%.

Cost-benefit analysis based on current performance data revealed direct financial benefits including annual electricity cost savings of IDR 108-144 million, simple payback period of 7-8 years, 25-year lifetime savings estimated at IDR 4.5-6 billion, and internal rate of return of approximately 11-13%. Indirect economic benefits included enhanced student employability, reduced operational costs allowing budget reallocation, potential income from excess energy, and avoided costs from future electricity price increases.

Environmental impact analysis showed annual CO2 emissions avoided of approximately 57-72 tons, with 25-year lifetime emissions avoided of approximately 1,4251,800 tons. Survey data indicated significant increases in environmental awareness, with students who strongly agree that renewable energy is important for environmental protection increasing from 51% to 89%, and students who can explain the connection between fossil fuel use and climate change increasing from 44% to 82%.

A key objective was to develop a model that could be replicated in other vocational schools. Following media coverage and dissemination activities, 12 vocational schools from North Sumatra region expressed interest in replicating the program, 3 schools initiated formal discussions with UNPAB for partnership, and regional education authorities requested development of a standardized implementation guide.

Discussion

This study contributes to several areas of academic literature. The findings support and extend existing research on the importance of community engagement in renewable energy

projects. Consistent with previous studies, this research demonstrates that building awareness and fostering community ownership significantly enhances acceptance and support for solar energy initiatives. The multi-level engagement strategy targeting students, teachers, parents, and community members simultaneously proved more effective than isolated interventions.

The research provides empirical evidence for the effectiveness of integrating renewable energy technologies into vocational curricula. The significant improvements in student knowledge and skills, combined with high levels of engagement and career interest, support advocacy for hands-on learning in technical and vocational education and training institutions. The study demonstrates that vocational schools can simultaneously address institutional challenges such as high energy costs while advancing educational missions of preparing students for emerging job markets.

The UNPAB-UniMAP partnership exemplifies effective South-South cooperation in sustainable development. The collaboration facilitated knowledge transfer, resource sharing, and mutual learning between institutions facing similar development challenges. This model offers insights for other international partnerships seeking to address common sustainability goals. The multi-stakeholder coordination mechanism developed in this study addresses fragmentation issues identified in previous research. By bringing together diverse actors including government agencies, educational institutions, private companies, and community representatives, the program achieved synergies and efficiencies that would not have been possible through isolated efforts.

The findings have several practical implications. For educational institutions, schools facing high electricity costs should consider solar energy as an investment with substantial longterm returns. Integration of renewable energy technologies provides valuable learning opportunities aligned with labor market demands. Collaboration with universities, government agencies, and private sector can help overcome resource constraints. Schools can leverage their community standing to promote broader adoption of sustainable practices.

For policy makers, government grants and incentives are crucial for overcoming initial investment barriers. Streamlined permitting and grid-connection processes facilitate adoption. Investment in training programs for teachers and technical staff is essential. Identifying and promoting successful models encourages replication.

For the private sector, educational solar projects offer meaningful corporate social responsibility opportunities with visible community impact. Partnerships with vocational schools can help address skills shortages in the renewable energy sector. School projects serve as demonstration sites that can stimulate broader market demand. For development organizations, programs combining infrastructure development with education and community engagement maximize impact. International partnerships between developing countries offer cost-effective pathways for knowledge sharing. Focusing on replicable models enhances the broader impact of development investments.

Several limitations should be acknowledged. This study was conducted in a single vocational school in urban North Sumatra, and results may not fully generalize to rural schools, other regions, or other countries with different contexts. The six-month implementation period limits long-term outcome assessment. Students participating in intensive training were primarily from the electrical engineering program, representing a self-selected group. The study could not fully control for external influences on outcomes. Some qualitative impacts remain partially subjective and difficult to measure precisely.

Conclusion

This study demonstrates that community-based solar energy socialization represents an effective and multifaceted approach to advancing sustainable energy transition in vocational education settings. The collaborative model implemented at SMKS Panca Budi through the UNPAB-UniMAP partnership successfully addressed critical challenges in renewable energy adoption while generating substantial economic, educational, environmental, and social benefits. Key findings reveal economic viability with the 50 kW solar installation achieving approximately 30% energy independence and generating annual cost savings of USD 7,2009,600 with a reasonable payback period of 7-8 years. Educational effectiveness was demonstrated through significant improvements in student knowledge from 42% to 78% and practical skills competency achievement rates of 82-95%. Community impact reached 800+ students and 167 community members, generating substantial increases in awareness and positive attitude changes. Stakeholder collaboration involving government, private sector, educational institutions, and community representatives proved essential for overcoming barriers. The documented model has attracted interest from 12 other vocational schools, demonstrating its potential for broader impact.

This research contributes to academic literature on community-based renewable energy adoption, vocational education for sustainable development, and international collaboration in development contexts. It provides empirical evidence for the effectiveness of integrated approaches that combine technical implementation with education and community engagement.

Recommendations for future research include longitudinal studies tracking long-term outcomes including graduate employment in renewable energy sector, comparative studies examining this model across different regional and institutional contexts, research on optimal strategies for scaling up from individual schools to district or national levels, and investigation of gender dimensions in renewable energy education and employment. For program enhancement, recommendations include expansion of hands-on training to students beyond electrical engineering program, development of advanced certification programs in solar installation and maintenance, creation of student-led solar consulting services for community members, and integration of energy efficiency measures alongside renewable energy generation.

For policy development, recommendations include streamlined funding mechanisms specifically for educational solar projects, regulatory frameworks supporting net metering and feed-in tariffs for schools, teacher training programs in renewable energy technologies at national scale, and recognition systems for schools demonstrating leadership in sustainability. As Indonesia and other developing nations pursue ambitious renewable energy targets while addressing educational quality and workforce development needs, integrated approaches like the model presented in this study offer promising pathways forward. By addressing energy challenges at institutional level, equipping students with marketable skills, and engaging communities in sustainability transitions, vocational schools can play pivotal roles in advancing multiple sustainable development goals simultaneously.

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