

Optimizing Physics Learning Based on Solar Panel Projects on Renewable Energy Material to Grow Students' Environmental Awareness

Yani Khodijah, Rahayu Kariadinata, Yulia Sukmawardani

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Abstract

The phenomena of global warming and the energy problem have heightened interest in renewable energy sources, particularly solar energy. Vocational High Schools (SMK) play a vital role in equipping the youth to confront future environmental concerns. Consequently, implementing a solar panel project model in vocational schools will substantially enhance environmental consciousness and familiarize students with renewable energy technologies. This study aims to evaluate energy efficiency in the context of sustainability through a solar panel project model. This research methodology employs case studies, surveys, and quantitative data analysis. The study's results, processed using the t-test, reveal a significance value of 0.000, indicating that the average score for sustainable learning exceeds 75, hence demonstrating the effectiveness of student awareness of renewable energy technology.

Keywords: Renewable energy · Environmental Awareness · Solar Panels · Project Based Learning

INTRODUCTION

Renewable energy (RE) has garnered international focus as a remedy for the energy difficulties confronting humanity (Bhuiyan, 2022; Falcone, 2023). RE denotes naturally renewable energy sources, including solar, wind, biomass, hydro, and geothermal energy, together with new energy generated from advanced technologies such as hydrogen and waste-derived fuels (Hoque et al., 2022). A primary advantage of RE is its environmentally sustainable characteristics, as contrast to fossil fuels, which generate substantial carbon emissions and exacerbate climate change (Abbasi et al., 2022).

The advantages of renewable energy are vast and include multiple facets of existence. The exploitation of renewable energy promotes energy source diversification, diminishes reliance on imported fossil fuels, and creates new employment opportunities in the green energy sector (Abbasi et al., 2022; Bhuiyan, 2022). Renewable energy mitigates greenhouse gas emissions and air pollution, conserves ecosystems, and fosters sustainable development (Falcone, 2023). Renewable energy can provide community access to reliable and sustainable energy, especially in rural regions, hence enhancing quality of life. The numerous forms of renewable energy,

✉ Yani Khodijah
yanihodijah@gmail.com
Yulia Sukmawardani
yulia.sukmawardani@uinsgd.ac.id

Rahayu Kariadinata
rahayu.kariadinata@uinsgd.ac.id

Tadris Pendidikan IPA, Sekolah Pascasarjana, UIN Sunan Gunung Djati. Bandung, Indonesia.

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solar energy stands out as particularly promising. The sun is a plentiful energy source and is accessible nearly everywhere globally (El-Afifi, 2024; Franjić, 2023). Solar energy is produced by capturing solar radiation using technologies like photovoltaic (PV) panels, which convert sunlight into electrical energy, and thermal systems, which utilize the sun's heat for heating or power generation (Panagoda et al., 2023).

Indonesia, situated on the equator, possesses significant solar energy potential. Indonesia experiences an average solar irradiance of 4.8 kWh/m²/day, positioning it among the regions with the highest solar energy potential globally (Junaidi et al., 2024; Rufinaldo & Brent, 2025). Solar energy can be employed for several applications, including residential electricity requirements, energy provision in remote locations, and support for the industrial sector (Junaidi et al., 2024). Nonetheless, despite the significant potential of solar energy, its implementation in Indonesia remains very limited (Rufinaldo & Brent, 2025). Data from the Ministry of Energy and Mineral Resources (ESDM) indicates that solar energy's contribution to the national energy mix remains below 1%. This signifies that optimizing solar energy necessitates suitable solutions, particularly within the educational sector. Despite the numerous benefits of solar energy, its adoption encounters some obstacles in both community and educational contexts (Altassan, 2023; Obuseh et al., 2025; Ukoba et al., 2024). The primary hurdles within the community are the considerable initial expense of solar energy technology installation, insufficient comprehension of its advantages and operational mechanisms, and an absence of governmental incentives to promote solar energy adoption (Nuru et al., 2021; Obuseh et al., 2025; Ukoba et al., 2024).

In educational institutions, the study of renewable energy, especially solar energy, is frequently not a fundamental component of the curriculum. Most secondary school physics educational resources primarily emphasize fundamental topics without explicitly connecting them to practical applications like solar energy utilization (Husna, 2024; Nuru et al., 2021; Ramongalo, 2024). This leads to pupils having an unclear comprehension of the applicability of the physics they are studying to real-world societal concerns.

A further challenge is the restricted access to laboratory facilities and educational resources that facilitate project-based learning (Alarfaj et al., 2024; Meng et al., 2023). Project-based learning, shown by the solar panel initiative, possesses significant potential to actively involve students and offer practical experience in comprehending renewable energy principles (Elhassan, 2025; Wilson, 2021). This method not only improves students' comprehension of the subject but also cultivates 21st-century competencies, including critical thinking, problem-solving, and cooperation (Meng et al., 2023). Environmental consciousness is a crucial element in promoting the utilization of renewable energy sources, including solar energy. Environmental awareness includes personal comprehension, attitudes, and behaviors that demonstrate a commitment to environmental sustainability (Alarfaj et al., 2024). This awareness is reflected in energy-conserving practices, the utilization of sustainable energy sources, and advocacy for policies that facilitate the transition to green energy.

Project-based learning that incorporates solar energy with environmental concerns has significant potential to enhance students' environmental consciousness (Alarfaj et al., 2024). These initiatives enable students to comprehend renewable energy ideas, their effects on ecosystem sustainability, and their responsibilities as the younger generation in tackling environmental concerns (Ariza & Olatunde-Aiyedun, 2023). The solar panel project enables

students to utilize their physics knowledge to design, construct, and assess a basic solar energy system. This project educates students on the significance of renewable energy in mitigating carbon footprints, preserving natural resources, and promoting sustainable development. This practical experience aims to motivate students to embrace eco-friendly practices in their daily lives and become catalysts for societal change.

Promoting environmental awareness via solar panel project-based learning in educational institutions is a strategic initiative to foster the transition to renewable energy in Indonesia. Utilizing the extensive potential of solar energy, education may serve as a catalyst in cultivating a generation of youth equipped with both academic proficiency and a sense of environmental stewardship. This study seeks to analyze the optimization of solar panel project-based physics education to enhance students' environmental consciousness and promote renewable energy utilization in Indonesia. This research entails the monitoring and analysis of solar panel performance, encompassing energy output and resultant energy savings.

METHOD

Research Design

This study used a quantitative design with a field survey approach to analyze the implementation of solar panel project-based learning in improving students' sustainability values. This approach was chosen because it is suitable for measuring the effects of specific treatments on predetermined variables (Creswell & Poth, 2016).

Research Location and Subjects

The study was carried out at a Vocational High School (SMK) that provides a Renewable Energy Engineering (TET) program. The site was chosen for its appropriateness to the research emphasis on project-based learning in renewable energy. The participants comprised 70 tenth and eleventh grade TET students chosen through purposive sampling. The selection criteria included students with a theoretical foundation in renewable energy, specifically solar energy.

Research Instruments

This study utilized a student sustainability assessment and observational criteria for the execution of solar panel projects. The student sustainability assessment was constructed using indicators derived from the Education for Sustainable Development Framework (OECD, 2017), incorporating the aspects of knowledge, skills, and attitudes about sustainability. Instrument validation was performed with expert judgment from three specialists in renewable energy education.

Data Analysis

The sustainability test results of students were evaluated using a parametric statistical method, namely the paired sample t-test, to compare pre-test and post-test scores. The analysis was performed using SPSS software version 26. Before doing the t-test, the data underwent a normality assessment via the Kolmogorov-Smirnov test to confirm a normal distribution (Peers, 2006). Descriptive analysis of observational data was conducted utilizing a Likert scale to assess the degree of student participation during project implementation. The analysis results are displayed as diagrams and frequency tables.

RESULTS AND DISCUSSION

Raising Environmental Awareness Through Solar Panel Projects

The execution of a solar panel initiative at a vocational high school (SMK) has markedly enhanced pupils' environmental consciousness. The project, integral to a competency-based curriculum, enables students to gain direct experience about the significance of renewable energy and its advantages for environmental sustainability. By engaging in activities like solar panel design, installation, and maintenance, students gain practical experience that complements their theoretical knowledge and demonstrates the tangible effects of clean energy in their daily lives.

A primary measure of heightened environmental awareness among students is their altered behavior around energy consumption. Project observations indicated that numerous students commenced the adoption of new habits, including deactivating unused electronic gadgets and selecting energy-efficient appliances for their residences. This illustrates that project-based learning can effectively instill sustainability ideals. Dunnigan et al. (2020) assert that learning experiences incorporating direct application in real-world contexts are more effective in facilitating attitudinal change than conventional learning methods.

This project equips students with knowledge on the conversion of solar energy into clean electrical energy for many applications. Students also acquire knowledge on the detrimental effects of dependence on fossil fuels, including air pollution and greenhouse gas emissions. This awareness is essential for motivating students to embrace a more proactive approach to environmental protection, both at educational institutions and within their communities. Research by Ariza and Olatunde-Aiyedun (2023) indicates that project-based learning centered on renewable energy technologies markedly enhances students' knowledge and awareness of environmental issues.

The solar panel initiative also prompted students to engage in dialogues regarding sustainability solutions. During a group reflection session, students were had the opportunity to express their concepts regarding the use of renewable energy technologies in their residences or communities. Consequently, pupils exhibited an enhanced comprehension and were capable of linking renewable energy principles with tangible activities to mitigate adverse environmental effects. This corresponds with the conclusions of Ragustini et al. (2022), who asserted that project-based learning not only augments knowledge but also fosters the cultivation of essential abilities, including problem-solving and cooperation.

This project offered a transformative experience for kids. They not only understood the significance of sustainable energy but also acknowledged their position as catalysts for change. Observing firsthand the capacity of solar energy to supplant environmentally detrimental energy sources, students were increasingly inspired to engage in actions that promote environmental sustainability. According to Purwasih et al. (2025), education that fosters environmental consciousness in youth is essential for promoting sustainable development.

In summary, the sustainable solar panel initiative has served as a successful educational instrument for enhancing students' environmental consciousness. By integrating theoretical and practical education, students comprehend the significance of renewable energy and are motivated to embrace a more eco-friendly lifestyle. This project, with additional development,

could serve as a paradigm for sustainability teaching that can be broadly adopted across diverse educational institutions.

The Impact of Solar Panel Projects on Students' Sustainability Values

The gathered quantitative data were examined via a t-test to evaluate significant variations in the average sustainability learning scores prior to and following the project's implementation. The analytical results indicated a substantial rise, demonstrating the efficacy of the solar panel project in fostering sustainability knowledge and practices among students. The results are elaborated in Table 1.

Table 1. Results of the Student Ability T-Test

Parameter	t	df	Sig. (2-tailed)	Mean Difference
Class X	61.234	35	0	26.7
Class XI	39.882	35	0	25.63

The t-test results indicate a statistically significant disparity in the average sustainability ratings between students in grades 10 and 11. The significance (2-tailed) value of 0.000 for both groups is below the 0.05 threshold of significance. This signifies that the execution of the solar panel project substantially enhanced students' sustainability education. The disparity in average scores between the two groups exhibited a rise of 26.7 for grade 10 and 25.63 for grade 11, demonstrating sustained advancement over grades.

The significance value of 0.000, which is less than 0.05, indicates a statistically significant change in students' average sustainability scores before and after project implementation. The rise in average sustainability scores beyond 25 signifies a beneficial effect of this project-based learning. Figure 1 illustrates the distribution of student scores following project implementation.

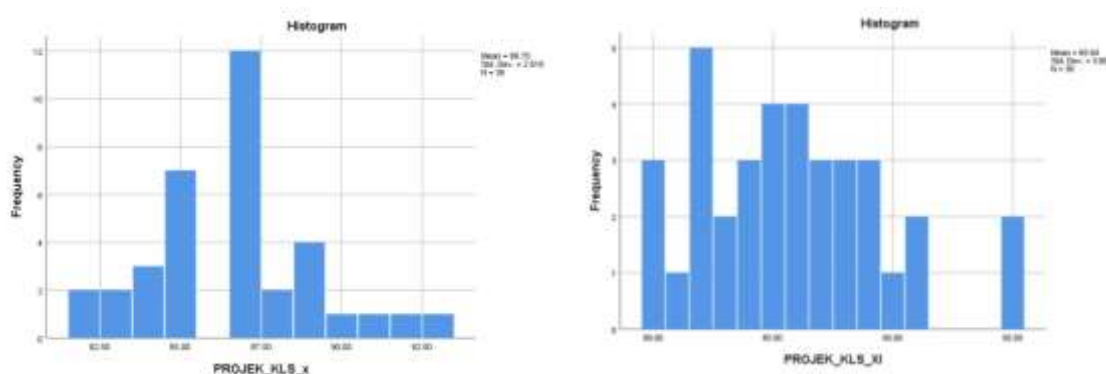


Figure 1. Histogram of Student Ability Results

Effectiveness of Solar Panel Project-Based Learning

A continuous learning score exceeding 75 signifies that the solar panel project serves as an effective learning model. This is substantiated by the hypothesis that project-based learning facilitates the integration of theoretical knowledge with practical applications, hence enhancing comprehension and engagement with the subject matter (Sulfiani et al., 2018). Moreover, this methodology also involves pupils emotionally and socially, which are crucial components in fostering environmental consciousness.

This efficacy was also manifested in heightened student participation in class discussions and the project assessment process. Educators observed heightened student excitement in devising innovative strategies to enhance solar panel efficiency. This corresponds with the research conducted by Sulfiani et al. (2018), which shown that project-based learning can improve students' problem-solving and collaborative abilities.

This project effectively enhanced students' environmental consciousness; yet, numerous hurdles persist for future implementation. A primary difficulty is the accessibility of resources, particularly solar panel components, which necessitate substantial upfront expenditures. Certain schools may encounter difficulties in securing funding for these projects. Moreover, pupils' preliminary comprehension of renewable energy technology differs. This necessitates the proactive involvement of educators in delivering comprehensive advice, particularly during the initial phases of project execution. Luo (2018) and Setiono (2021) observed that the efficacy of project-based learning is significantly affected by the facilitator's role in offering explicit guidance and fostering comprehensive student engagement.

The execution of the solar panel initiative not only enhanced students' environmental consciousness but also yielded real advantages for the school. Utilizing solar energy as a principal power source enables vocational schools to diminish their dependence on fossil fuels and decrease electricity operating expenses. These savings provide improved budget allocation for the advancement of more educational facilities. A research by the Hoque et al., (2022) indicates that investment in renewable energy within the education sector can yield substantial long-term benefits. Moreover, student participation in this project cultivates practical skills pertinent to the workplace. The renewable energy sector is expanding swiftly, hence proficiency in solar panel technology can enhance graduates' competitiveness in the employment market.

This study's findings underscore the significance of incorporating technology-driven initiatives into vocational education courses. By offering students practical experience, they not only grasp concepts but also perceive the tangible effects of applying ecologically sustainable technologies. This corresponds with sustainable development objectives, which underscore the necessity of educating youth to become catalysts for change. To advance, it is essential to tackle obstacles to the project's implementation, including enhancing access to renewable energy technology and offering training to educators. Collaboration with industry can serve as a means to furnish essential resources while familiarizing students with optimal workplace practices.

CONCLUSION

This study concludes that project-based learning involving solar panels at Vocational High Schools (SMK) substantially enhances students' awareness of renewable energy technology and promotes sustainable learning. Quantitative data analysis using a t-test yielded a significance value of 0.000, signifying an average sustainable learning score exceeding 75. This demonstrates that the learning approach is helpful in enhancing energy efficiency and elevating students' knowledge of the significance of renewable energy technology as a remedy for global environmental issues, including climate change and the energy crisis. This study validates the function of vocational high schools (SMK) in equipping youth to promote environmental sustainability using an innovative project-based educational methodology.

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