How Perceptions and Innovations through Solar Panels in STEAM Projects?

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Abstract. This study investigates students' perceptions and innovations in developing solar panel technology through STEAM (Science, Technology, Engineering, Arts, Mathematics) project-based learning. Two prototypes were produced: a Solar-Powered NFT Hydroponic System for sustainable agriculture and a Motion Detection with Solar Energy (MDSE) device for home security. Using thematic analysis, this research examined design decisions, performance outcomes, and the functionality of solar panels in real-life conditions. The findings indicate that STEAM-based solar projects enhance electrical independence, reduce operational costs, and support environmental sustainability. The hydroponic system generated higher power output to maintain water circulation, while the MDSE model provided stable voltage for sensor activation. These innovations demonstrate the role of STEAM in advancing practical renewable energy solutions and contribute to SDG 2 (Zero Hunger), SDG 7 (Affordable and Clean Energy), and SDG 13 (Climate Action).

1 Introduction

Solar panels, also known as photovoltaic (PV) panels, are systems that convert solar energy directly into electricity using semiconductor materials such as silicon or cadmium telluride. When sunlight strikes these materials, it excites electrons, generating an electric current [1]. Solar panels are an efficient, inexpensive, and pollution-free renewable energy source, offering a promising future for large-scale renewable energy production [2]. Solar offers a promising future for clean energy production, with a comprehensive review of dust deposition, recycling, and integration with other clean energy sources [3]. Solar photovoltaic (PV) technologies offer sustainable development and can help alleviate the energy crisis by reducing CO2 and greenhouse gas emissions [4]. The rapid progress in solar technology indicates its increasing relevance in global energy transition efforts. With continuous

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technological development, solar panels are no longer just an renewable energy, but a key element in achieving clean power generation in the future.

Renewable energy capacity and investment have surged, with solar and wind leading the way. Since 2019, fossil fuel use for electricity has declined as renewables supply a growing share of global energy demand. This growth is propelled by falling costs, supportive policies, and international climate commitments. However, fossil fuels still dominate the global energy mix, and a six-fold acceleration in renewables is needed to meet climate targets by 2050 [5]. Renewable energy, including solar panels, makes an important contribution to supporting the achievement of the Sustainable Development Goals (SDGs), especially SDG 7 on Affordable and Clean Energy. Renewable energy has contributing to employment generation, sustainable production, energy access, and infrastructure development while addressing climate change mitigation and biodiversity conservation challenges [6], [7]. Renewable energy resources, particularly wind and solar, offer a sustainable and cost-effective solution to environmental challenges [8]. Solar PV systems can provide reliable, clean, and stable energy for the future, but more research is needed to align with the Sustainable Development Goals [9]. This context underlines the urgency of education and innovation to accelerate renewable energy adoption. Therefore, the development of learning models that engage students directly with renewable energy technology becomes increasingly important.

Implementing renewable energy as a STEAM project involves integrating science, technology, engineering, art, and mathematics through hands-on, collaborative, and real-world experiences. Projects are often based on local renewable energy resources, requiring analysing their environment and propose innovative solutions to connect theory to practice [10]. The STEAM Project require work in teams to design, build, and test renewable energy. This approach encourages critical thinking, creativity, and problem-solving by real-world challenges [11]. Implementing renewable energy as a STEAM project involves identifying energy challenges in their environment and then designing creative solutions based on solar panels or other renewable energy sources[12]. This activity provides an opportunity to test ideas, reflect on the process, and connect to community needs. Strategically, STEAM-based renewable energy projects bridge conceptual understanding with real implementation, aligning learning with global energy issues. With this approach, students not only gain scientific knowledge but also directly contribute to sustainable innovation in their communities [13], [14].

At Surabaya State University, the implementation of the STEAM project is a form of innovation that encourages to be responsive to global environmental issues. Through project-based activities, not only require understand the concepts of energy physics but also the integration of cross-disciplinary knowledge in developing contextualized education oriented towards sustainable development. Thematic analysis was used to examine perceptions of the experience through the solar panel-based STEAM project. This method allows researchers to identify patterns, key themes, and meanings that emerge from reflections. With thematic analysis, a deeper understanding can be gained of how interpretig their involvement, the challenges they face, and the innovations they successfully develop during the process.

Research on renewable energy education generally uses quantitative approaches. Qualitative research exploring narratives, experiences, and innovative ideas when directly engaging with STEAM-based solar panel projects is limited. Many studies highlight the importance of renewable energy, but not many have looked at how generate innovative ideas in STEAM projects. This research presents a novel approach by applying a qualitative approach to deeply explore experiences, perceptions, and thought processes when interacting with a STEAM-based solar panel project. Focusing not only on cognitive outcomes, this study emphasizes innovation narratives as a manifestation of their creativity and engagement in understanding renewable energy.

2 Method

The research data were obtained from project presentations, which were the output of STEAM courses in the Universitas Negeri Surabaya, and then analysed through a coding process (Codes) to identify units of meaning. Codes that have similarities were then grouped into themes (Themes): Innovation on Solar Panel STEAM Projects, Product and Performance on Solar Panel STEAM Projects, and Perception on Solar Panels during STEAM Projects. These themes were then developed into the conceptualization stage to build a more abstract and comprehensive understanding. Ultimately, this entire process resulted in concepts and interpretations that explain how perceive and innovate through solar panel STEAM projects. Thus, this thematic analysis allows researchers to find patterns, meanings, and an in-depth understanding of qualitative data (see Fig. 1).

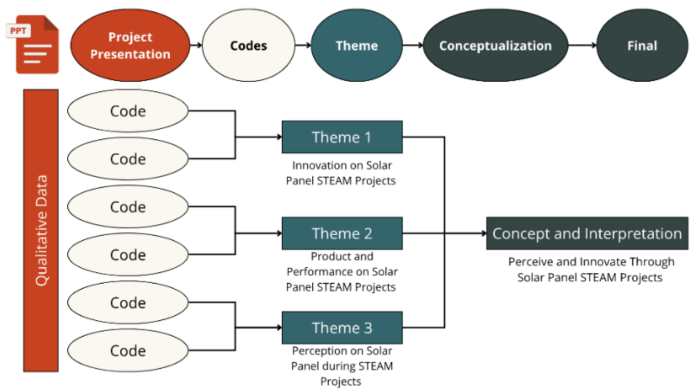
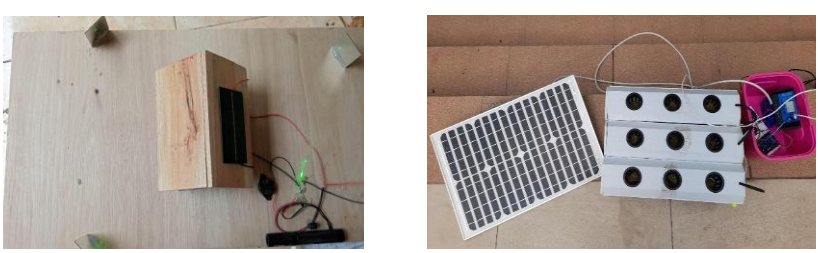


Fig. 1. Qualitative studies method.

3 Result and Discussion

3.1 Result

In integrating solar panels into STEAM project, Fig. 2 illustrate design and develop two projects the Motion Detection with Solar Energy (MDSE) prototype for sustainable home security, and the Solar-Powered NFT Hydroponic System for sustainable agriculture, based on Table 1 both of which demonstrate the practical application of solar panels in different fields.



(a) (b)

Fig. 2. (a) Motion Detection with Solar Energy (MDSE) (b) Solar-Powered NFT Hydroponic System.

Table 1. Comparison of two STEAM projects in terms of solar panel usage.

Aspect	Solar-Powered NFT Hydroponic System (STEAM Project 1)	Motion Detection with Solar Energy (MDSE) (STEAM Project 2)
Project Description	Sustainable agriculture innovation (hydroponic NFT system with solar-powered nutrient control)	Home security innovation (motion detection system powered by solar energy)
Main Focus	Sustainable agriculture system with hydroponics (NFT model) equipped with nutrient sensors	Home security system based on motion sensors
Role of Solar Panel	Provides energy for the water pump and PPM (nutrient detector) sensors in the hydroponic system	Provides energy for motion sensors that operate independently without conventional electricity
Purpose	Support food security and sustainable farming	Reduce dependency on conventional electricity and support home security
Related SDGs	SDG 2 and SDG 7	SDG 7 and SDG 13
Field of Application	Agriculture and food security	Home security

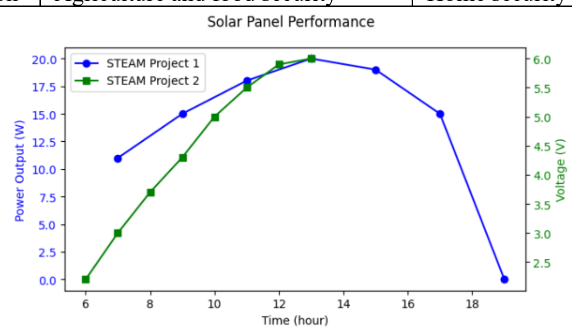


Fig. 3. Solar panel performance on the STEAM Project.

In Fig. 3, the STEAM Project 1 (shown by the blue line), the solar panel's power output begins to increase at around 6 a.m., reaching a peak of over 20 W around 12–1 p.m. Meanwhile, STEAM Project 2 (green line) places greater emphasis on voltage to support electronic devices such as motion sensors and home security systems. The voltage increases consistently from around 2 V at 6 a.m. to over 6 V by midday. Although the output power is relatively lower than Project 1, voltage stability is key to maintaining the operation of sensors that require a continuous but moderate power supply.

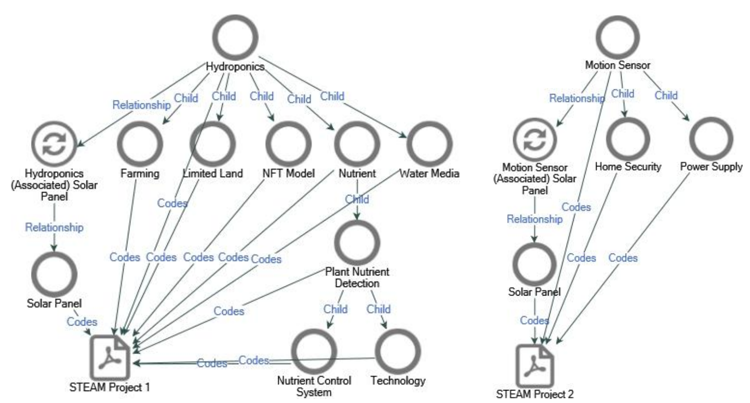


Fig. 4. (a) Project Innovation on using a solar panel on STEAM Project 1 (b) STEAM Project 2

According to the Fig. 4, in the STEAM Project 1, Solar-Powered NFT Hydroponic System, it is described that solar panels can be used as a renewable energy source to support hydroponic systems, particularly in operating water pumps, nutrient control systems, and plant need detection sensors. Meanwhile, In the STEAM Project 2 Motion Detection with Solar Energy (MDSE), it is described that solar panels can be used as a power source to support motion sensor systems, enabling the devices to function independently without relying on conventional electricity supplies.

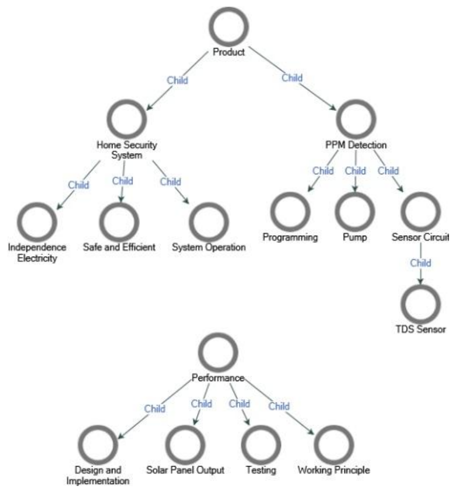


Fig. 5. Product and performance of the STEAM Project in solar panel usage as renewable energy.

The diagram in Fig. 5 emphasizes the role of solar panels as the primary energy source in supporting two product functions, namely the Home Security System and PPM Detection. In the home security system, solar panels enable electricity independence so that the device can work safely, efficiently, and continue to operate even without a conventional power supply. Meanwhile, in the PPM detection system, solar panels supply energy for programming, pumps, and a series of sensors (including a TDS sensor) that function to monitor the quality of plant nutrients.

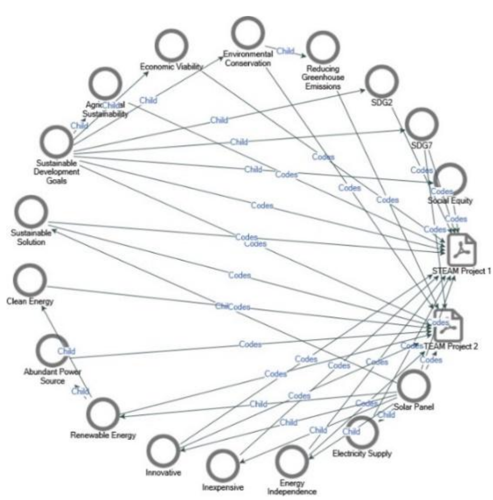


Fig. 6. Perception of STEAM projects using solar panels.

Based on Fig. 6 The use of solar panels in the context of renewable energy plays a strategic role in supporting sustainable development. Solar panels not only provide a clean and abundant electricity supply but also enable energy independence. This is highly relevant for reducing dependence on limited fossil fuel sources while simultaneously reducing long-term operational costs. With their innovative, inexpensive, and environmentally friendly nature, solar panels are a key solution for providing sustainable energy.

3.2 Discussion

The differences in power and voltage output between the two prototypes show that each solar panel configuration supports different operational demands. Project 1 produced higher wattage, making it suitable for systems that require stronger continuous energy such as pumps, nutrient circulation, and sensor operation in hydroponics. Meanwhile, Project 2 demonstrated more stable voltage, which is essential for sensor activation and security devices, confirming its feasibility for low-power electronic systems.

These results are consistent with previous findings that solar-based systems are adaptive across sectors depending on output stability and load requirements [8], [9]. The hydroponic prototype reinforces the view that renewable energy can improve agricultural productivity while minimizing dependence on conventional electricity [6], aligning with SDG 2: Zero Hunger. In parallel, the MDSE prototype demonstrates how solar energy supports low-cost security technology for sustainable smart-home development, contributing to SDG 13: Climate Action.

Solar panels are a renewable energy source that supports various sectors, particularly food security through agriculture and home security from Fig. 7. Utilizing solar energy not only provides an environmentally friendly and sustainable solution, but also aligns with the Sustainable Development Goals (SDGs), namely ending hunger (Goal 2), providing clean and affordable energy (Goal 7), and addressing climate change (Goal 13). With the integration of solar panels, the agricultural sector can increase the efficiency of food production, while home security systems can operate independently, energy-efficiently, and environmentally friendly.

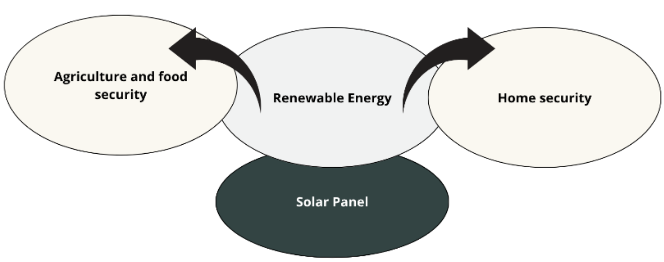


Fig. 7. The role of solar panels in various sectors (home security and agriculture).

By utilizing solar energy, hydroponics becomes more environmentally friendly and energy-independent, reducing dependence on conventional electricity and lowering long-term operational costs. The integration of solar panels with hydroponics also enables sustainability in limited space, supports the Nutrient Film Technique (NFT) model, and maintains stable nutrient distribution, thus increasing plant productivity without harming the environment. Solar energy converted into electricity by solar panels can power motion sensors, home security systems, and power storage units, maintaining energy efficiency and sustainability. With this integration, motion sensors can be operated sustainably in various locations, including open areas or remote areas, while increasing the reliability of security systems with the support of environmentally friendly and low-cost energy.

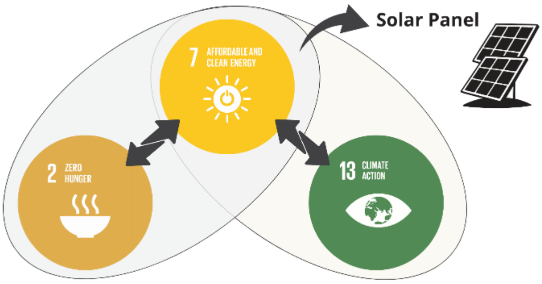


Fig. 8. The role of solar panels in the STEAM Project in supporting the SDGs.

In relation to the Sustainable Development Goals (SDGs) Fig. 8 interpreting solar panels directly contribute to several global goals. First, SDG 2 (Zero Hunger), through the application of solar energy in modern agricultural systems, such as hydroponics, improves food security (agricultural sustainability). Second, SDG 7 (Affordable and Clean Energy), by providing access to affordable and sustainable clean energy for the wider community. Third, SDG 13 (Climate Action), by supporting environmental conservation efforts and reducing greenhouse gas emissions. Thus, solar panels play a crucial role in addressing energy challenges while supporting the global climate change mitigation agenda.

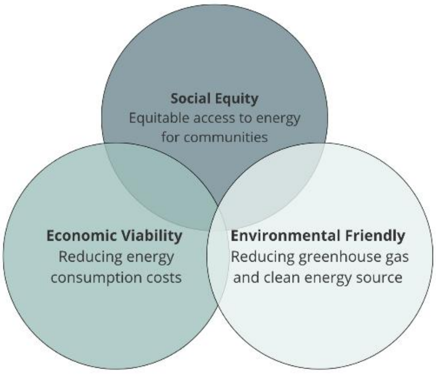


Fig. 9. Key of sustainability (economic, social, environmental) of solar panels in the STEAM Project.

Furthermore, the use of solar panels also has social and economic implications describe in Fig. 9. From a social perspective, the use of solar energy promotes social equity, namely equitable access to energy for communities, including those in remote areas where conventional electricity grids are difficult to reach. From an economic perspective, solar panels increase economic viability by creating new business opportunities, reducing energy consumption costs, and strengthening the competitiveness of environmentally friendly technologies. In other words, solar panels are not merely an energy-supplying technology, but also an instrument for socio-economic transformation towards a more just and independent society.

4 Conclusion

The integration of solar panels in STEAM projects highlights their strategic role in addressing energy challenges and supporting sustainable innovation. In STEAM Project 1, solar panels provided sufficient power output for operating pumps, nutrient detectors, and sensors in an NFT hydroponic system, while in STEAM Project 2, they ensured voltage stability to operate motion sensors in a home security system. These findings demonstrate that solar panels are adaptable to different needs, supporting food security, clean energy access, and climate action (SDG 2, SDG 7, and SDG 13). Important findings indicate that solar panels showed different potency for supporting each sector in this case, specifically, in agriculture and home security. Therefore, it is recommended that future STEAM projects expand solar panel applications to other fields such as transportation and water purification, and conduct long-term performance testing under various conditions.

Acknowledgment

This publication is funded by the Indonesian Endowment Fund for Education (LPDP) on behalf of the Indonesian Ministry of Higher Education, Science and Technology, and managed under the EQUITY Program (Contract No. 4312/B3/DT.03.08/2025).

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