Teaching Renewable Energy Concepts with Portable Solar Panels: A Hands-On Learning Project

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Abstract

This paper presents a hands-on educational project developed at the School of Engineering at Universidade Presbiteriana Mackenzie, designed to teach fundamental renewable energy concepts through the construction and testing of portable solar panel systems. Implemented every semester since August 2022, the initiative offers ten spots per term, with priority given to first-year undergraduate students, although students from other years are also welcomed to participate. The hands-on nature of the project has attracted students from multiple engineering courses. Participants engage in designing and assembling functional solar-powered devices, including mobile phone chargers, lanterns, and solar lamps. The project integrates theoretical instruction on photovoltaic principles with practical experimentation, enabling students to better understand solar energy conversion, system components, and efficiency considerations. Among those who have joined the project, approximately 90% successfully completed the entire eight-week program. However, only about 10% of participants have been women. By working collaboratively to solve real engineering problems, students strengthen technical skills, creativity, and critical thinking. Additionally, the activity promotes environmental awareness and highlights the role of renewable energy in sustainable development. This educational approach demonstrates how hands-on projects can enhance student engagement and deepen comprehension of complex concepts in engineering education.

Keywords: renewable energy education, solar panels, photovoltaic systems, hands-on learning, portable solar devices, engineering education.

1. Introduction

The transition to renewable energy sources has become a global priority, driven by the urgent need to mitigate climate change, reduce dependence on fossil fuels, and promote sustainable development (Bakhsh et al., 2024). Solar energy plays a central role in this transition due to its abundance, scalability, and versatility (Ukoba, et al., 2024). Understanding the fundamental concepts behind solar energy systems is therefore essential for future engineers, who will be responsible for designing and implementing innovative energy solutions. Engineering education must not only convey theoretical knowledge but also foster the ability to apply this knowledge in practical, real-world scenarios (Widyastuti et al., 2020).

A recent study by Forbes and Lord (2023) highlights how place-based sustainability approaches can enhance the learning of photovoltaic solar energy by connecting technical content to students' lived experiences and local contexts. In this study, engineering students engaged in real-world projects on campus, working with photovoltaic systems while exploring not only technical and physical aspects but also social, environmental, and economic impacts.

Similarly, a literature review published by Senthil (2020) emphasizes that advances in solar energy education increasingly rely on practical experiences, interdisciplinary integration, and the inclusion of sustainability and circular economy concepts in engineering curricula. The study notes that common barriers to implementing solar energy educational initiatives include limited resources, lack of real-world connections, and difficulty engaging students in hands-on components.

The integration of renewable energy concepts into engineering education is important for promoting a generation of engineers equipped to address global sustainability challenges. In their work, Heshmati and Elmore (2024) emphasized the importance of hands-on projects for introducing first-year engineering students to sustainable energy production methods, such as wind and solar power. By engaging students in practical activities, the study highlights how experiential learning can enhance understanding and retention of renewable energy concepts.

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Furthermore, Rajesh et al. (2021) discussed the implementation of innovative assessment methods aimed at helping engineering students develop a deeper comprehension of topics covered in the Teaching Solar and Wind Energy Conversion course. The study observed that experiment-based learning improved students' ability to tackle challenges typically encountered in real-world work environments, thereby increasing their confidence in both practical skills and critical analysis.

In this context, hands-on learning experiences have proven to be powerful tools to engage students, enhance motivation, and promote meaningful learning. Active participation in projects that replicate real engineering challenges allows students to connect theory with practice, develop problem-solving abilities, and gain confidence in their technical skills. This approach aligns with modern pedagogical strategies that emphasize experiential learning, teamwork, and interdisciplinary thinking.

To address this need, the School of Engineering at Universidade Presbiteriana Mackenzie developed an educational project focused on teaching renewable energy concepts through the construction and testing of portable solar panel systems. Implemented every semester since August 2022, the initiative offers ten spots per term. While priority is given to first-year undergraduate students, participants from other years and programs are also welcome, fostering a collaborative and diverse learning environment. This inclusive approach encourages peer learning, where more experienced students can share knowledge and skills with those just beginning their academic journey.

Throughout the project, students engage in designing and assembling functional solar-powered devices, such as mobile phone chargers, lanterns, and solar lamps. These applications are intentionally chosen for their simplicity, accessibility, and clear demonstration of photovoltaic principles in action. By integrating theoretical instruction on solar energy conversion, system components, and efficiency analysis with practical experimentation, the activity bridges the gap between classroom learning and engineering practice. Students learn to work with real components—such as photovoltaic panels, charge controllers, batteries, and converters—gaining hands-on experience that reinforces theoretical understanding.

Beyond technical competencies, the project also emphasizes teamwork, communication, and project management skills. Students work in small groups to design solutions, troubleshoot problems, and optimize system performance. This collaborative structure mirrors professional engineering environments and prepares students for future multidisciplinary projects. Moreover, by focusing on renewable energy technologies, the initiative raises environmental awareness and encourages students to reflect on the role of engineering in promoting sustainability.

This educational project demonstrates how hands-on, application-oriented activities can enhance the teaching of renewable energy concepts in undergraduate engineering programs. It provides students with practical skills, fosters engagement and critical thinking, and inspires a sense of responsibility toward a sustainable future.

2. Project Design and Educational Implementation

The Portable Solar Panels: Operation and Applications project is structured as an eight-week integrative course offered every academic semester since August 2022 at the School of Engineering of Universidade Presbiteriana Mackenzie. Each session lasts one hour and follows a progressive methodology that combines theoretical foundations, experimental activities, and practical applications of solar energy. The course is part of the institution's broader strategy to promote active learning and strengthen students' understanding of renewable energy technologies through hands-on experiences.

The first session serves as an introduction to photovoltaic (PV) technology. Students attend a lecture on the basic concepts of solar energy conversion, including the physical principles of photovoltaic cells, semiconductor materials used in panel fabrication, and the behavior of current-voltage (I–V) curves. Key performance parameters—such as open-circuit voltage, short-circuit current, and maximum power point—are discussed in detail. This theoretical foundation provides the conceptual basis for subsequent experimental activities.

The second session is structured around a guided laboratory activity described in the official experimental protocol developed for the course. This initial experiment aims to help students understand how light intensity affects the electrical output of solar panels. Using mini silicon solar panels, a halogen lamp as a controlled light source, and digital multimeters, students measure voltage and current at varying distances between the lamp and the panel. This setup allows them to simulate different irradiance levels and analyze their impact on panel performance. Measurements are systematically recorded in a pre-designed table, and students are guided to calculate the maximum power generated by the panel under each condition.

The experimental procedure, illustrated in Figure 1, is divided into six main parts (A–F), progressively increasing in complexity.

- Part A - focuses on a single panel and investigates the relationship between light intensity and electrical output.
- Part B examines two panels connected in series, highlighting how voltage increases while current remains constant.
- Part C explores parallel connections, illustrating the opposite behavior—current increases while voltage remains approximately constant.
- Part D combines series and parallel configurations, allowing students to evaluate their impact on system performance.
- Part E connects the panels to a small motor, making the conversion of solar energy into mechanical energy visible and tangible.
- Part F investigates the panel's response to different resistive loads, enabling students to plot and analyze the full I–V curve of the system and identify the maximum power point experimentally.

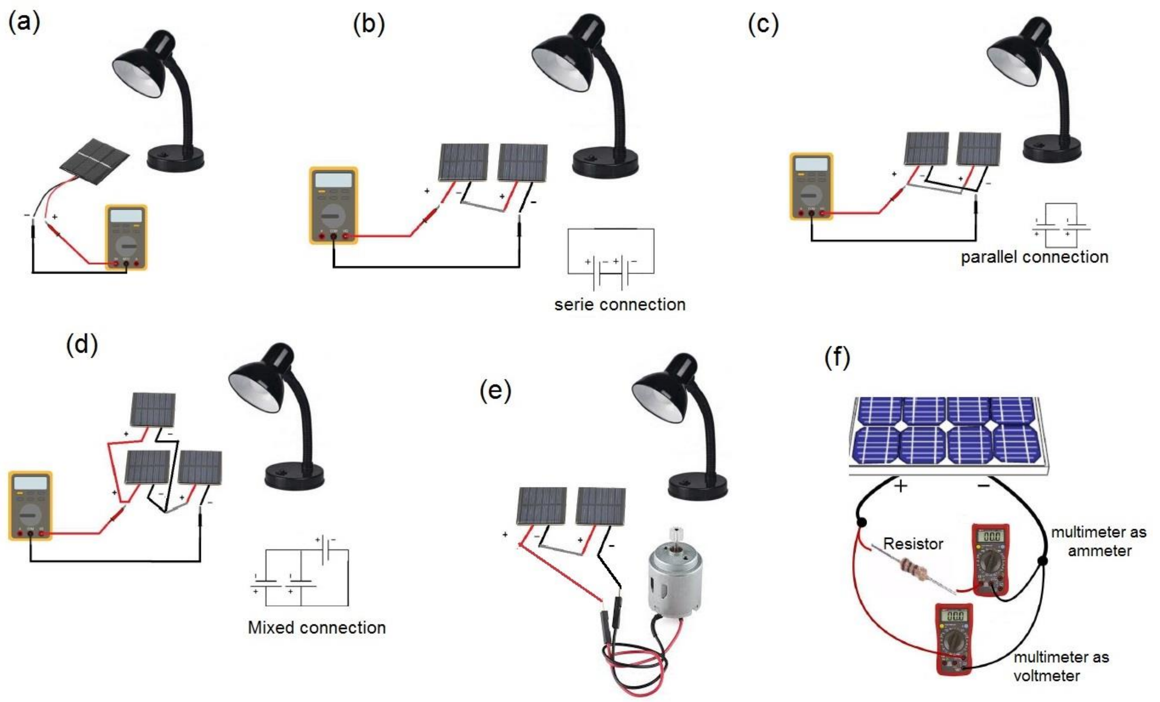

Figure 1. Experimental setup for measuring the electrical performance of mini solar panels under different configurations. (a) Single panel measurement; (b) series connection; (c) parallel connection; (d) mixed series-parallel connection; (e) power a mini DC motor; (f) measurement of the I–V curve using resistive loads.

During the third session, students are introduced to soldering techniques. They practice assembling solar panels in different configurations, following the same series, parallel, and mixed arrangements explored in the previous session. This practical skill is essential for the subsequent construction of functional devices. The soldering activity also reinforces safety procedures and precision in electrical connections, ensuring that students gain technical competence beyond theoretical understanding.

From the fourth to the seventh sessions, the course transitions from structured experiments to independent design and construction. Each student develops a prototype of a solar-powered application of their choice. Typical projects include portable phone chargers, solar lanterns, and solar track. Students are encouraged to adapt and improve upon the basic configurations tested in the lab, considering factors such as power output, component selection, and device functionality. This design stage stimulates creativity, problem-solving, and engineering judgment, as students must make decisions regarding layout, materials, and performance optimization.

Throughout the project, the instructors act as facilitators rather than direct problem solvers, encouraging students to investigate, test hypotheses, and collaborate. Although priority is given to first-year students, participants from other years are also welcome, creating a dynamic and multidisciplinary learning environment where peer learning naturally occurs. More experienced students often assist beginners, contributing to a collaborative atmosphere like real engineering teams.

The final session (eighth week) is dedicated to student presentations and demonstrations. Each participant explains the design choices made, presents their device, and discusses performance results. Many students reflect on the challenges encountered during the assembly and testing process, including issues related to energy storage, component sizing, and environmental factors affecting PV performance. This reflection phase is crucial for consolidating learning, as it requires students to articulate their reasoning and connect theory to practical outcomes.

The methodology adopted in this project emphasizes experiential learning and student autonomy. Rather than relying solely on lectures or pre-defined laboratory activities, the course progressively shifts responsibility to students, allowing them to apply their knowledge creatively. By engaging in measurement, analysis, design, and presentation, students gain a comprehensive understanding of renewable energy systems—from fundamental principles to practical implementation.

Figure 2 illustrates key stages of the hands-on activities, including voltage and current measurements using both natural and artificial light sources, and the soldering process for assembling different panel configurations. The structured yet flexible design of the course ensures that students not only understand how photovoltaic systems work but also develop the confidence to build functional devices independently.

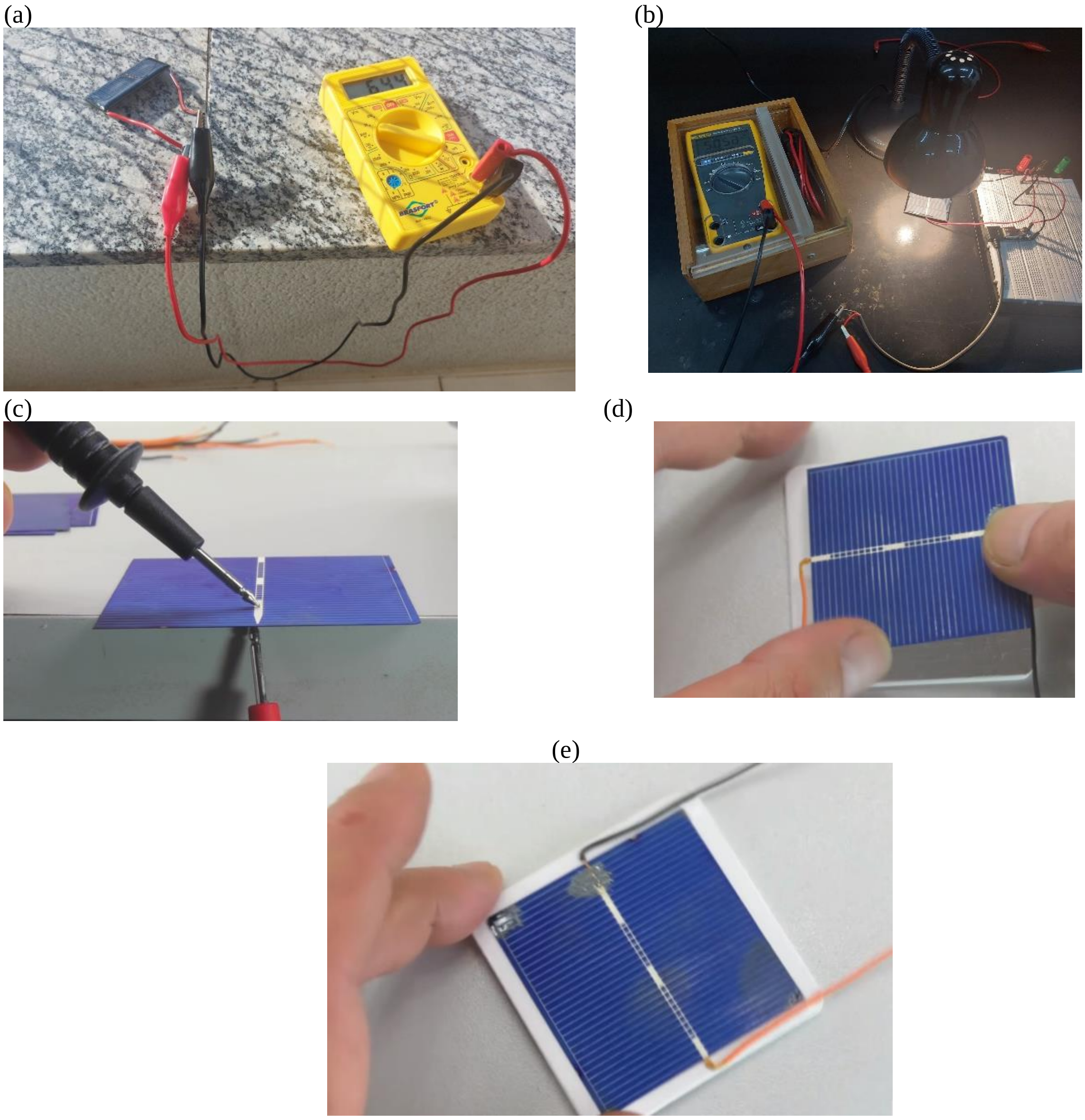

Figure 2. (a) Voltage and current measurements using sunlight; (b) measurements using artificial light; (c), (d), and (e) soldering process for assembling mini solar panels.

3. Participant Profile and Project Engagement

Since its implementation, the Portable Solar Panels: Operation and Applications project has attracted a diverse group of students from different engineering programs at the School of Engineering of Universidade Presbiteriana Mackenzie. Although the project was initially conceived to support first-year electrical engineering undergraduate students, its interdisciplinary and hands-on nature has led to participation from students in multiple engineering courses. To date, participants have come from electrical engineering, computer engineering, civil engineering, production engineering, and mechatronics engineering programs. This diversity contributes to a dynamic learning environment, where students bring different perspectives, technical skills, and problem-solving strategies to the project activities.

Participation rates have remained consistently high throughout the editions of the program. Each semester, the ten available spots are filled, demonstrating strong student interest in renewable energy and hands-on learning experiences. Among those who have joined the project, approximately 90% successfully completed the entire eight-week program, attending theoretical lectures, carrying out experimental activities, and presenting their final functional prototypes. This high completion rate reflects strong student engagement and the effectiveness of the project's active learning methodology in maintaining motivation over time. Many students also highlight the practical and tangible nature of the project as a factor that helps them stay committed from beginning to end.

An important aspect of the participant profile relates to gender distribution. So far, only about 10% of the students who participated in the project have been women. While this proportion is comparable to general enrollment figures in some engineering programs, it also reveals a gender gap that remains common in STEM education. Notably, two editions of the project were composed exclusively of male students with no female participants enrolled. These data underscores the importance of implementing actions to promote gender diversity and inclusion. Actions such as targeted outreach, showcasing female role models in renewable energy, and promoting inclusive learning environments may help address this imbalance in future editions. Creating an inclusive learning environment and actively addressing barriers to participation are key steps toward increasing representation and engagement of underrepresented groups.

The interdisciplinary and collaborative nature of the project is one of its major strengths. Bringing together students from different areas encourages the exchange of ideas and collaborative learning. Participants from electrical engineering often contribute deeper knowledge of circuits and energy systems, while students from computer and mechatronics engineering bring valuable skills in control and automation. Civil and production engineering students, in turn, offer perspectives on practical applications, design integration, and system scalability. This diversity of backgrounds mirrors real-world engineering teams, where multidisciplinary collaboration is essential to developing effective solutions.

By combining diverse academic backgrounds, high engagement and completion rates, and a growing focus on broadening participation, the Portable Solar Panels project not only enhances technical education but also builds a collaborative academic community interested in developing sustainable products and processes.

4. Educational Outcomes and Future Perspectives

Since its first edition in August 2022, the Portable Solar Panels: Operation and Applications project has consistently attracted student interest, with all ten available spots filled every semester. This sustained demand reflects a growing enthusiasm among engineering students for learning experiences that bridge theory and practice. Participant feedback collected through informal discussions, course evaluations, and reflection reports reveals that students value the opportunity to work with real photovoltaic components, observe system behaviour under different conditions, and directly apply theoretical knowledge to solve practical problems.

One of the most frequently reported outcomes is increased student motivation to engage with renewable energy topics. Many participants highlight that working hands-on with mini solar panels and real electrical circuits helps them better understand complex concepts such as the relationship between irradiance, voltage, and current, or the impact of series and parallel connections on system performance. Unlike traditional lectures, the experimental and design-based structure of the course enables students to visualize these effects immediately, reinforcing their conceptual understanding.

Students also report significant improvements in technical and practical skills, particularly in areas that are essential for engineering practice but often underemphasized in early undergraduate curricula. These include soldering, basic electrical measurements, wiring solar panel systems, and assembling small-scale devices. Beyond technical competencies, the project encourages teamwork, communication, and project planning—skills that are crucial for professional engineering environments. The collaborative nature of the course, with students from different academic years working side by side, further enhances peer learning and builds a sense of community within the program.

The final presentations have proven to be a powerful learning moment. In this session, students not only demonstrate their prototypes—such as solar phone chargers, LED-based lighting systems, and USB-powered devices—but also explain their design choices, reflect on encountered challenges, and propose improvements. These presentations highlight the creativity and critical thinking skills developed throughout the project. Many students experiment with design variations, such as optimizing panel angles, exploring different load types, or improving enclosure designs for better portability and weather resistance.

An additional strength of the project is its modular and low-cost structure, which makes it easily replicable in other educational contexts, including outreach activities for high school students or extension programs. The simplicity of the components allows the project to be scaled or adapted depending on available resources, without compromising its pedagogical impact. This adaptability also aligns with current trends in engineering education, which emphasize accessible, flexible, and experiential learning models.

Looking ahead, future developments include expanding the range of possible applications by integrating sensors and microcontrollers for performance monitoring and control. Another planned improvement is the incorporation of data acquisition systems, enabling students to record I–V curves and power output in real time for deeper performance analysis. This enhancement would not only strengthen the technical rigor of the activity but also introduce students to essential engineering tools for research and development.

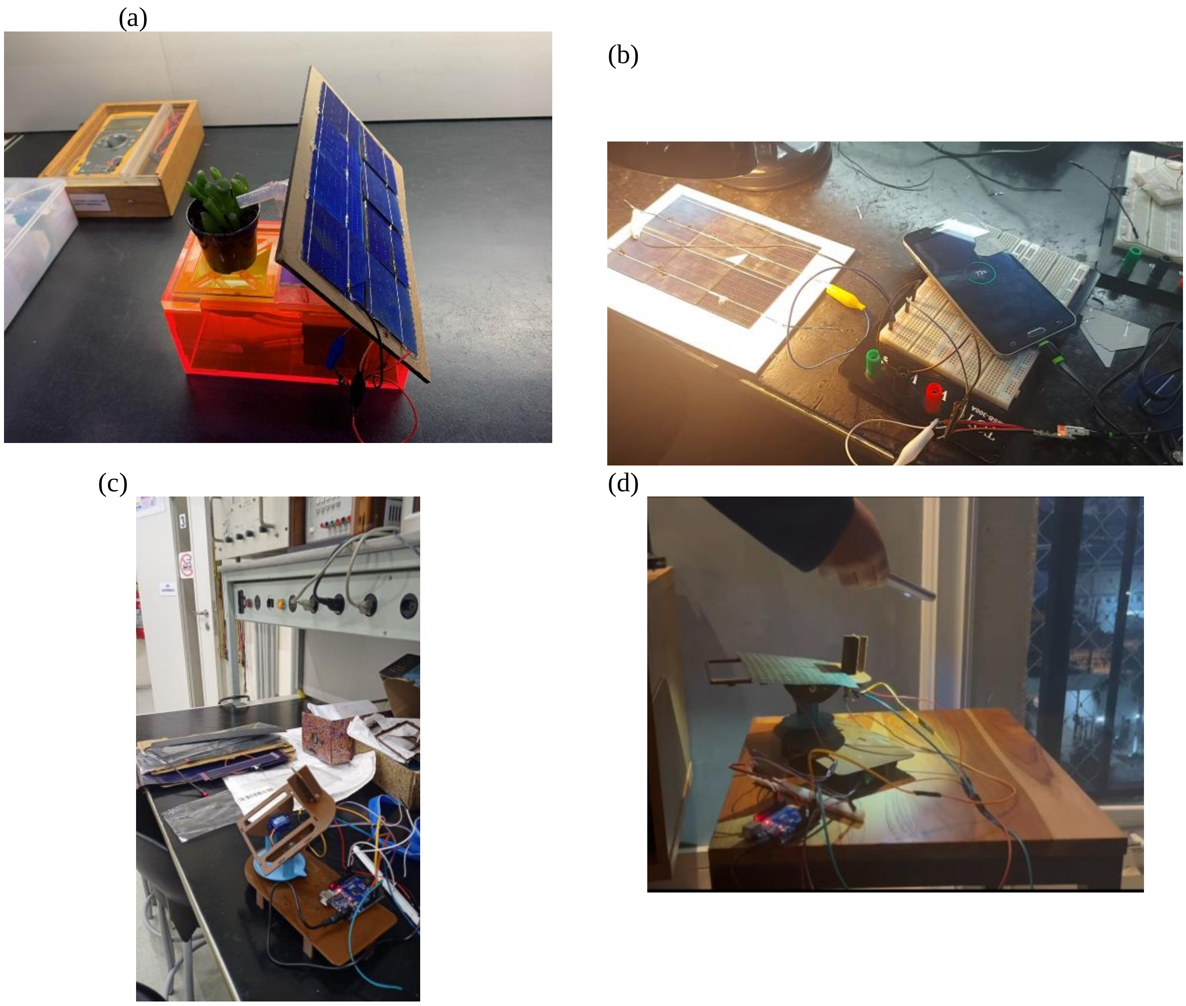

Figura 3. Examples of applications developed by the students during the project: (a) solar irrigation system, (b) solar cell phone charger, (c) and (d) 3D printed solar tracking system Using Arduino.

The project team is also exploring collaborative, group-based prototyping as an evolution of the current individual model. This shift would allow for more complex system designs, encourage distributed task management, and more closely mimic professional engineering team dynamics. In addition, partnerships with external organizations are being considered to connect student projects with real-world applications, such as rural electrification initiatives or community lighting programs.

Overall, this initiative demonstrates how small-scale, hands-on projects can significantly enhance renewable energy education, foster environmental awareness, and empower future engineers to play an active role in the global energy transition. In summary, the Portable Solar Panels project combines theoretical learning with practical experimentation and design providing to the student's technical competence, confidence, and a tangible understanding of how engineering can contribute to a more sustainable future. Examples of student-developed applications are shown in Figure 3, which illustrates functional solar-powered devices assembled using mini photovoltaic panels.

5. Conclusions

The Portable Solar Panels: Operation and Applications project has proven to be an effective educational strategy for teaching renewable energy concepts through hands-on, low-cost, and easily replicable activities. The initiative provides undergraduate engineering students a comprehensive understanding of photovoltaic technology, from the physical principles of solar energy conversion to the design and assembly of functional solar-powered devices.

The consistent demand for participation across multiple semesters demonstrates the project's ability to capture students' interest and sustain their engagement over time. The high completion rate (approximately 90%) further reflects the effectiveness of this experiential learning approach in motivating students to actively participate in all stages of the activity, from basic experiments to prototype design and final presentations. Moreover, the participation of students from various engineering programs, including electrical, computer, civil, production, and mechatronics engineering, highlights the project's interdisciplinary relevance and its potential to promote collaboration across different technical backgrounds.

The gender distribution data, with only about 10% of female participants and two editions composed exclusively of male students, reveal challenges that are still present in engineering education. Addressing these imbalances through targeted outreach, inclusive learning environments, and visible role models will be crucial for promoting broader participation and ensuring that renewable energy education reaches diverse groups of students.

Another important outcome of the project is its replicability. The modular structure, low equipment cost, and short implementation time make it suitable not only for undergraduate programs but also for outreach activities in schools and community settings. Planned future developments, including the integration of data acquisition systems, sensor-based monitoring, and group-based prototyping, will expand the project's technical depth and pedagogical scope.

Finally, the project demonstrates that small-scale, hands-on activities can play a significant role in strengthening renewable energy education, enhancing students' technical and problem-solving skills, and promoting environmental awareness. By connecting theory to real-world applications, the Portable Solar Panels project contributes to preparing future engineers to engage critically and creatively with the global energy transition.

6. Acknowledgments

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