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Jurnal Pengabdian Kepada Masyarakat
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Practical Biogas Production-Based Environmental Education for Students at State Junior High School 3 in Bengkulu City

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Article Information:
Received April 20, 2026
Revised May 20, 2026
Accepted May 23, 2026

Keywords:
Alternative Energy; Biogas; Organic Waste; Renewable Energy

Abstract

Background: Strengthening renewable energy literacy at the secondary education level is a strategic step toward fostering students' ecological awareness and environmental conservation skills. Biogas, as an alternative energy source derived from organic waste, holds great potential for integration into hands-on learning to enhance students' conceptual understanding and scientific skills.
Objectives: This community service activity aims to introduce biogas technology through hands-on, practice-based education and to analyze students' responses to the implementation of environmental learning.
Methods: The implementation followed a comprehensive pedagogical framework consisting of lectures, interactive discussions, and demonstrations, complemented by hands-on biogas production practices. The program involved 50 students who actively participated in all learning activities and practical sessions throughout the implementation process. Students utilized simple teaching aids crafted from fruit waste and microbial activators (molasses and EM4), with program efficacy evaluated through pre-tests, post-tests, and student response assessments.
Results: The activity resulted in a measurable increase in students' knowledge and skills regarding waste categorization and organic waste management. Participants successfully demonstrated an understanding of the fermentation process required to convert organic waste into methane gas using simple teaching aids.
Conclusion: The integration of practical biogas technology into the secondary curriculum effectively bridges the gap between theoretical ecological concepts and real-world environmental skills. Both teachers and students benefited from the hands-on approach, proving that localized renewable energy innovations are viable tools for enhancing scientific literacy.

A. Introduction

Education on the environment, particularly biogas, offers an environmentally friendly renewable energy solution and plays a role in reducing greenhouse gas emissions through the management of organic waste. International studies indicate that biogas makes a significant contribution to supporting the clean energy transition and climate change mitigation, as it converts organic waste into energy while reducing methane emissions from waste (Mignogna et al., 2023). Education and training in biogas projects not only enhance technical and economic knowledge but also foster awareness of the importance of environmental sustainability, thereby optimizing resource use and minimizing negative impacts on ecosystems (Shallo et

How to Cite : Medriati, R., Putri, D.H., Utama, T.H., Ahda, N.V., Sirega, D.J.H., Pajri, A.K., Putri, J.A., & Zareen, S.J. (2026). Practical Biogas Production-Based Environmental Education for Students at State Junior High School 3 in Bengkulu City. *Aktual: Jurnal Pengabdian Kepada Masyarakat*, 4(2), 126-134. https://doi.org/10.58723/aktual.v4i2.698
ISSN : 2987-6052
Published by : CV Media Inti Teknologi

al., 2020). Additionally, the use of biogas helps reduce dependence on fossil fuels and preserves air, water, and soil quality key reasons why environmental aspects must be taught intensively in the development and implementation of biogas technology (Ngabala & Emmanuel, 2024). Environmental education is key to increasing public acceptance of renewable energy and sustainable waste management, including through the integration of such content into school curricula. Environmental education combined with hands-on practice has proven to be more effective in fostering positive attitudes and pro-environmental behaviors among students (Martínez-Borreguero et al., 2020). Furthermore, direct student involvement in renewable energy projects can enhance energy literacy, scientific skills, and a long-term ecological perspective (Lin & Lu, 2018). Therefore, introducing biogas technology as early as the school level is a strategic step toward instilling an understanding of alternative energy, resource conservation, and the importance of sustainable organic waste management.

Bengkulu State Junior High School No. 3 is a school with strategic potential for developing learning innovations based on renewable energy. The school has established partnerships and benefits from its central urban location, as well as an abundant supply of organic waste suitable for processing into alternative energy. Education on biogas is considered crucial to instill from an early age to enhance environmental awareness, reduce reliance on fossil fuels, and utilize local resources such as household organic waste. Previous studies indicate that schools can serve as agents of change in renewable energy education (Altassan, 2023). This is supported by research by Nasrudin et al. (2024), which found that the development of biogas-themed learning materials is highly effective in improving renewable energy literacy within educational settings (Nasrudin et al., 2024). However, SMP Negeri 3 Bengkulu still faces several challenges, such as suboptimal management of organic waste, limited understanding among students and teachers regarding biogas technology, the absence of practical learning materials, and the lack of educators' competencies in the field of renewable energy. Based on Mayanti's research, most students understand the importance of renewable energy, but their understanding of its implementation and long-term impacts including the use of biogas remains superficial (Mayanti et al., 2025). Similar findings are also described by Silaen, who emphasizes that the adoption of small-scale biogas in Indonesia is often hindered by technical, social, and user knowledge factors (Silaen et al., 2020). This phenomenon is exacerbated by the high volume of waste in Bengkulu City, which reaches approximately 400 tons per day (Febriani et al., 2022), demanding innovative solutions for the utilization of organic waste, including through small-scale biogas technology.

These conditions underscore the need for community service programs based on empowerment and hands-on practice. Education on converting waste into biogas is expected to strengthen students' understanding of renewable energy technologies and foster an environmentally conscious culture within the school. This program is also designed to produce outputs such as educational modules, mini biogas demonstration kits, educational videos, and learning materials that can be used sustainably. Given this urgency, the objectives of this community service initiative are to adopt an educational approach in introducing waste-to-biogas processing to students and to assess students' responses to the implementation of biogas education activities.

The novelty of this community service program its integration of renewable energy education, organic waste management, and experiential learning through a school-based biogas initiative tailored to local environmental conditions. This program combines hands-on biogas production practices with educational modules, mini biogas demonstration kits, and multimedia learning resources within a real school setting. Conducted at SMP Negeri 3 Bengkulu, the program utilizes locally available organic waste and addresses actual challenges such as limited biogas literacy, inadequate practical learning tools, and weak technical competencies students. Integrating practical renewable energy education with community empowerment and local waste utilization, the program offers a sustainable model for enhancing students' energy literacy, scientific skills, and environmental awareness from an early age (Hartati et al., 2024; Tahir et al., 2024).

B. Methods

This community service activity was conducted in the form of strengthening bioenergy-based science and physics education as an effort to enhance students' knowledge, skills, and conservation attitudes (Sriatun et al., 2025; Wati et al., 2025). The methods used included lectures, discussions, question-and-answer sessions, experiments, and demonstrations. The program involved 50 student participants who actively engaged in all educational activities and practical sessions. The instruments used consisted of observation

sheets, student response questionnaires, and student worksheets related to biogas-based science and physics education.

Descriptive analysis of student response data and learning outcomes provides a clear picture of increased student participation, conceptual understanding, and positive responses to the learning program (Yongken et al., 2022; Leksono et al., 2021). Environmental education and the environment demonstrate that conservation-based programs are effective in developing conservation attitudes toward environmental well-being, thus serving as a relevant indicator of success in this community service program (Helida et al., 2019). The collected data were analyzed using a descriptive method to evaluate students' responses and learning outcomes (Sugiyono, 2023). The indicators of program success were measured through increased student participation, improved understanding of bioenergy concepts, positive student responses, and the development of students' conservation attitudes toward environmental sustainability.

The implementation of the activity was divided into three main phases. The first phase was preparation, which included coordinating with the school and preparing educational materials and tools, such as biogas demonstration kits, organic materials, and posters. Simple biogas systems were constructed using materials and equipment readily available in the local environment, particularly at the school, such as used plastic bottles as biogas reactors, and a syringe serves as both a delivery device and a gas pressure gauge. This design is suitable and beneficial for learning about and introducing renewable energy (Vogel et al., 2023). Plastic materials (such as used bottles) are effective and easily adaptable for small-scale biogas reactors (Farid et al., 2025). The primary material used to produce methane gas is organic waste in the form of fruit peels, which are fermented inside the biogas reactor bottle. The fermentation process is aided by the addition of an activator solution consisting of a mixture of molasses, EM4, and water in a 1:0.1:5 ratio, which serves to accelerate the activity of microorganisms that break down organic matter (Andrean, 2024; Agustin & Wahyu, 2023; Irawan & Suwanto, 2016). This mixture is placed into the bottle along with the organic material; the container is then tightly sealed and connected to a syringe via a small tube to channel and monitor the volume of gas produced. After being stored for several days at room temperature, the fermentation process produces methane gas, which can be observed through changes in air pressure within the syringe. This methane gas serves as the primary energy source for biogas, which is flammable and environmentally friendly because it does not produce harmful fumes when used (Sinaga et al., 2022). This apparatus demonstrates the basic principles of biogas formation simply and can serve as a contextual learning tool for renewable energy derived from organic waste.

Figure 1. Simple Biogas Digester

The second phase, which involves the implementation of the activities, consists of several sessions, namely: (1) a pre-test to assess students' prior knowledge of biogas; (2) an introduction to the concepts of energy and biogas; (3) a demonstration or simulation of small-scale biogas production; (4) group discussions and Q&A sessions; (5) hands-on practice in simple biogas production by students; and (6) a post-test to measure the improvement in students' understanding after participating in the activities. The third phase, evaluation, is conducted through questionnaires and reflective discussions to assess the effectiveness of the activities by comparing post-test results with pre-test results, and is supported by observations regarding student participation and engagement during the activities. To monitor the progress of the community service program, a monitoring approach is implemented through direct observation, activity documentation in the form of videos, and continuous evaluation. This mechanism is used to ensure the implementation of the program while supporting the achievement of the planned outcomes.

C. Results and Discussion

This discussion begins with an analysis of students' knowledge of biogas prior to receiving instruction. The assessment was conducted to determine the extent of students' initial understanding of the concept of renewable energy derived from organic waste, specifically biogas, as a basis for designing appropriate instructional interventions. The results of the initial survey indicate that students' knowledge remains uneven, both in conceptual and procedural aspects, regarding the process of converting organic waste into alternative energy. This suggests that while some students possess basic knowledge of biogas, they do not yet fully understand its composition, raw materials, or the steps involved in its production. This is similar to Mayanti's research, where most students understand the importance of renewable energy but lack a deep understanding of its implementation and long-term impacts, including the utilization of biogas (Mayanti et al., 2025). Therefore, the following analysis is crucial for assessing the need for more comprehensive education and ensuring the effectiveness of the learning interventions to be implemented.

The results of students' prior knowledge of biogas before the educational program can be seen in Figure 2. The diagram shows a comparison of students' knowledge levels prior to the implementation of the biogas educational activities. Regarding the statement "I know that organic waste can be processed into biogas," it appears that approximately 67% of respondents indicated they were aware of this information. This finding suggests that the majority of students are already familiar with the basic concept of processing organic waste as an alternative energy source. However, the proportion of students who were unaware remained quite significant, at around 33% of respondents. This indicates that while information regarding bioenergy is generally known, conceptual understanding of it is not yet widespread among students. Regarding the second statement, "I know that biogas contains methane (CH_4) that can be burned," student responses tended to be the opposite. In fact, the majority of respondents (44%) stated that they did not know that biogas contains methane as an energy source. The low level of understanding regarding the composition of biogas demonstrates that although students are familiar with the term "biogas," most do not yet understand the scientific principles regarding the gas content that plays a role in the combustion process. This indicates that understanding of renewable energy at the junior high school level remains descriptive in nature and has not yet delved into deeper scientific aspects.

For the third statement, "I know the materials that can be used to produce biogas," the proportions of students who knew and did not know were nearly equal (50%:50%). This finding reinforces the notion that students are familiar with the concept of biogas but do not yet understand how the technology is practically implemented. This phenomenon is supported by Martinez's research, which states that real-world application-oriented learning plays a crucial role in connecting scientific concepts with their practical applications in daily life (Martínez-Borreguero et al., 2020). Furthermore, this aligns with the school's current lack of practice-based learning materials, resulting in limited hands-on experience related to bioenergy. The highest percentage of lack of knowledge appeared in the fourth statement, "I understand the simple steps for making biogas," showing the highest percentage of lack of knowledge at 67%. This percentage indicates that the main obstacle is not the concept of biogas, but practical skills in making and utilizing simple biogas technology. This lack of practical experience is the primary reason for the urgency of project-based (hands-on) training. Practice-based learning has been proven to significantly enhance conceptual understanding, scientific attitudes, and science skill competencies (Kolb & Kolb, 2022). These conditions underscore the importance of practice-based learning methods as a strategy to improve student competencies.

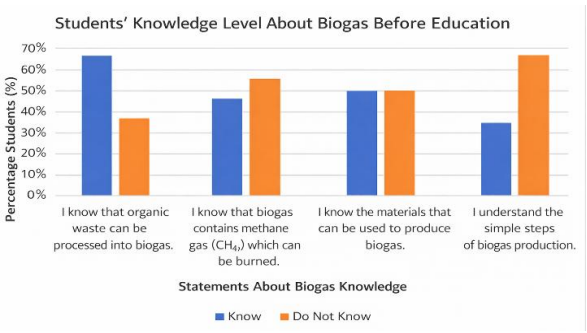

Figure 2. Students' level of knowledge about biogas before the educational session

The results of the basic knowledge test data analysis show that learning about biogas as an alternative energy source significantly improved the cognitive and affective aspects of junior high school students. All students understood that organic waste can be processed into biogas, and 93.33% of them recognized the benefits of biogas as an environmentally friendly energy source. This indicates that the educational intervention successfully strengthened renewable energy literacy starting at the junior high school level. These findings align with research by Norden in 2016, which found that environmental issue-based learning can simultaneously improve students' conceptual understanding and ecological awareness (Norden, 2016).

Figure 3. Educational materials on how to produce biogas from organic waste

A total of 80% of students performed well in identifying all the materials used in biogas production, and 86.67% understood that methane is its energy source. This indicates that the learning process was not only effective in conveying theoretical concepts but also supported the construction of scientific meaning relevant to everyday life. Students' procedural understanding of the steps for producing biogas systematically and correctly reached 66.67%, indicating a need for more intensive reinforcement of psychomotor skills. This pattern aligns with Krajcik's (2006) findings, which show that direct engagement in experiments can enhance procedural retention and problem-solving skills (Krajcik & Blumenfeld, 2018).

Figure 4. Experiment-Based Learning Process.

In terms of attitudes, all students demonstrated a positive response to alternative energy and waste management, as evidenced by their interest in learning about biogas, their concern for waste issues, and their motivation to try producing biogas independently in class or at home. This is supported by research on environmental education, which indicates that integrating real-world action and collaboration leads to positive changes in attitudes, values, and environmental actions (Ardoin et al., 2019). Furthermore, recent findings confirm that pro-environmental attitudes are the most consistent and strongest predictors of youth support for renewable energy systems, including bioenergy (Sardianou & Kougias, 2025). The students' collaboration skills, which were rated as excellent, reinforce the notion that collaborative learning plays a crucial role in the development of social skills, as reported in the STEM education literature (Gillies, 2016).

The learning process is further supported by supplementary materials, namely posters and guidebooks designed interactively by the author, thereby boosting students' enthusiasm and helping them better understand environmental topics related to biogas. The engaging visual design and presentation of information encourage students to read and discuss more actively, which ultimately enhances their knowledge of renewable energy. This finding aligns with the cognitive theory of multimedia learning, which emphasizes that well-designed visual and textual materials improve learner comprehension and motivation. Research has demonstrated that multimedia materials redesigned following evidence-based principles significantly increase both student achievement and situational interest (Bland et al., 2024). This educational media support also aligns with the needs of science teachers in conducting more effective and contextual learning at the junior high school level. The results of the activity have been disseminated in the form of an educational video uploaded to a YouTube channel at the link https://youtu.be/xyIL7hrEWvo , serving as a learning resource and public outreach to the broader community, thereby reinforcing the sustainability and tangible contributions of this community service program in the fields of educational innovation and the environment.

Figure 5. Learning Media

The sustainability of this community service program can be strengthened through continuous integration into school-based learning and environmental activities. The implementation of bioenergy-based science education and biogas practices should not remain a one-time intervention but be embedded into science subjects, project-based learning, extracurricular activities, and environmental programs within the school curriculum. The involvement of teachers, school administrators, and student organizations is essential to maintain continuity and ensure knowledge transfer to future student cohorts. The use of locally available organic waste as learning materials supports sustainability because the resources are inexpensive, accessible, and continuously generated within the school and surrounding community. In addition, educational outputs such as learning modules, mini biogas demonstration kits, worksheets, and instructional videos can function as long-term teaching resources. Establishing partnerships between schools and universities can further strengthen mentoring, technical assistance, and future innovation development. Through this approach, the school can gradually evolve into a sustainable environmental learning center that promotes renewable energy literacy and environmentally responsible behavior among students.

Biogas education not only enhances students' scientific understanding but also fosters the positive attitudes and collaborative skills necessary to support sustainable environmental management practices. These findings underscore the importance of integrating renewable energy topics into the middle school science curriculum as a means of building environmental literacy and preparing the younger generation to address future energy challenges.

Despite its positive outcomes, this program has several limitations that should be acknowledged. Furthermore, limitations in infrastructure, laboratory facilities, and technical resources may affect the consistency and quality of practical biogas activities. Variations in students' prior knowledge and teachers' competencies in renewable energy topics could also influence learning effectiveness. Therefore, future programs should incorporate larger participant groups, longitudinal evaluation designs, more rigorous assessment methods, and stronger institutional support to enhance both program effectiveness and sustainability.

D. Conclusion

Education on converting waste into biogas has proven effective in strengthening students' understanding of renewable energy technologies while fostering an environmentally conscious culture at school. Through hands-on activities using simple biogas demonstration tools, students and teachers gained practical knowledge about waste classification, organic waste management, and the fermentation process that converts organic waste into methane gas, improving both conceptual understanding and scientific skills. Students became more enthusiastic and engaged, actively participating in experiments such as testing the pH of fermented liquid and formulating critical questions during the activity, supported by interactive posters and guidebooks that linked theory to real-world applications. The program has important implications, as it strengthens environmental responsibility, scientific literacy, and awareness of clean energy by showing how waste can be transformed into a valuable alternative energy source. For wider implementation in other schools, similar activities can be adapted using low-cost tools and locally available organic waste, combined with teacher training and well-structured learning materials to ensure effectiveness. To guarantee the sustainability of the program, waste management and renewable energy topics should be integrated into regular classroom learning and extracurricular activities, supported by continuous practice, periodic follow-up experiments, and institutional commitment such as maintaining small biogas units or school-based waste sorting systems so that environmentally conscious education and clean-energy awareness become a lasting part of school culture.

E. Acknowledgment

We would like to express our deepest gratitude to all parties who have contributed to the implementation of this program. Special thanks go to SMP Negeri 3 Kota Bengkulu, our partner in this initiative, for their cooperation, support, and the active participation of all teachers and students in every stage of the program. Deep appreciation is also extended to Bengkulu University and the Faculty of Teacher Training and Education (FKIP) at Bengkulu University for their moral, administrative, and financial support, which made the successful implementation of this activity possible. We extend our gratitude to the lecturers and students who played an active role in the planning, implementation, and on-site guidance of the activities. Thanks to the collaboration and dedication of all parties, this community service activity ran smoothly and provided tangible benefits for improving renewable energy literacy and environmental awareness among students.

F. Author Contribution Statement

RM played a pivotal role in the conceptualization, oversight, and comprehensive management of the community service program. THU and NVA were accountable for formulating the technique and supervising students' training sessions. DHP participated in data collection and aided in organizing student activities. DJ managed logistics facilitated communication with the school and provided assistance with documents. THU and NVA performed the literature review and assisted in the creation of instructional materials. AKP and JAP facilitated the technical execution and coordinated the evaluation process. SJZ helped with the manuscript's linguistic editing and proofreading. All authors contributed to the composition and revision of the work and endorsed the final version

References

Agustin, R., & Wahyu, N. (2023). Pemanfaatan Limbah Kulit Pisang dan Kangkung Air untuk Biogas Menggunakan Bioreaktor Anaerobik. *Seminar Nasional TREnD*. 3(1), 12–20. https://jurnalftijayabaya.ac.id/index.php/TREnD/article/view/242

Altassan, A. (2023). Sustainable Integration of Solar Energy, Behavior Change, and Recycling Practices in

Educational Institutions: A Holistic Framework for Environmental Conservation and Quality Education. *Sustainability (Switzerland)*, *15*, 15157. https://doi.org/10.3390/su152015157

Andrean, M. I. (2024). J-Proteksion : Jurnal Kajian Ilmiah dan Teknologi Teknik Mesin. *J-Proteksion: Jurnal Kajian Ilmiah Dan Teknologi Teknik Mesin*, *8*(2), 70–76. https://doi.org/10.32528/jp.v8i2.588

Ardoin, N. M., Bowers, A. W., & Gaillard, E. (2019). Environmental education outcomes for conservation : A systematic review. *Biological Conservation*, *240*(April), 108224. https://doi.org/10.1016/j.biocon.2019.108224

Bland, T., Guo, M., & Dousay, T. A. (2024). Multimedia Design for Learner Interest and Achievement: A Visual Guide to Pharmacology. *BMC Medical Education*, 24, 113. https://doi.org/10.1186/s12909-024-05077-y

Farid, M. U., Olbert, I. A., Bück, A., & Ghafoor, A. (2025). Heliyon Review Article CFD Modelling and Simulation of Anaerobic Digestion Reactors for Energy Generation from Organic Wastes: A Comprehensive Review. *Heliyon*, *11*(2), e41911. https://doi.org/10.1016/j.heliyon.2025.e41911

Febriani, E., Ekaputri, R. A., & Ridwan, M. (2022). Pemberdayaan Masyarakat terhadap Limbah Rumah Tangga Organik dengan Teknik Komposter. *Kreativasi*, *01*(01), 32–45. https://ejournal.unib.ac.id/index.php/kreativasi

Gillies, R. M. (2016). Cooperative Learning: Review of Research and Practice Cooperative Learning: Review of Research and Practice. *Australian Journal of Teacher Education*, *41*(3). https://doi.org/10.14221/ajte.2016v41n3.3

Hartati, S., Niah, S., Arisandi, D., & Asnawi, M. (2024). Edukasi Literasi Hemat Energi dalam Pendidikan Sebagai Upaya Mengurangi Dampak Negatif Teknologi. *Jurnal Pengabdian Masyrakat Bangsa*, *2*(10), 0–5. https://doi.org/10.59837/jpmba.v2i10.1758

Helida, A., Abubakar, R. A., & Khusumah, R. S. (2019). Penumbuhkembangan Sikap Konservasi pada Siswa Sekolah Dasar di Kota Palembang. *Suluh Abdi: Jurnal Ilmiah Pengabdian Kepada Masyarakat*, *1*(1), 13–18. https://doi.org/10.32502/sa.v1i1.1910

Irawan, D., & Suwanto, E. (2016). Pengaruh Em4 (Effective Microorganisme) terhadap Produksi Biogas Menggunakan Bahan Baku Kotoran. *Turbo : Jurnal Teknik Mesin Universitas Muhammadiyah Metro*, *5*(1), 44–49. http://dx.doi.org/10.24127/trb.v5i1.118

Kolb, A. Y., & Kolb, D. A. (2022). Experiential Learning Theory as a Guide for Experiential Educators in Higher Education. *Experiential Learning and Teaching in Higher Education*, *1*(1), 38. https://doi.org/10.46787/elthe.v1i1.3362

Krajcik, J. S., & Blumenfeld, P. C. (2018). Project-Based Learning. In *The cambridge handbook of the learning sciences* (pp. 317–331). Cambrige University Press. Google

Leksono, S. M., Mahrawi, Dasma, & Nurhapipah, S. (2021). Peningkatan Kesadaran Lingkungan dan Sikap Konserbasi Siswa SMA Negeri 1 Anyer Melalui Program Sekolah Riset. *Biodidaktika: Jurnal Biologi Dan Pembelajarannya*, *16*(2), 109–115. https://jurnal.untirta.ac.id/index.php/biodidaktika/article/view/12871/7813

Lin, K. Y., & Lu, S. C. (2018). Effects of Project-Based Activities in Developing High School Students' Energy Literacy. *Journal of Baltic Science Education*, *17*(5), 867–877. https://doi.org/10.33225/jbse/18.17.867

Martínez-Borreguero, G., Maestre-Jiménez, J., Mateos-Núñez, M., & Naranjo-Correa, F. L. (2020). An Integrated Model Approach of Education for Sustainable Development: Exploring the Concepts of Water, Energy and Waste in Primary Education. *Sustainability (Switzerland)*, *12*(7). https://doi.org/10.3390/su12072947

Mayanti, D., Febrianti, P. A., Girsang, R. N., & ... (2025). Analisis Pemahaman Siswa-Siswi SMK di Cimahi Terhadap Sustainable Development Goal 7: Energi Bersih dan Terjangkau., *Sociology and Law*, *1*(1), 170–178. https://publisherqu.com/index.php/edusola/article/view/2215

Mignogna, D., Ceci, P., Cafaro, C., Corazzi, G., & Avino, P. (2023). Production of Biogas and Biomethane as Renewable Energy Sources: A Review. *Applied Sciences (Switzerland)*, *13*(18). https://doi.org/10.3390/app131810219

Nasrudin, D., Rochman, C., & Diningsih, I. J. (2024). Developing Biogas Digital Comic for Improving Renewable Energy Literacy. *International Conference on Mathematics and Science Education*, *2024*, 407–414. https://doi.org/10.18502/kss.v9i8.15572

Ngabala, F. J., & Emmanuel, J. K. (2024). Potential Substrates for Biogas Production Through Anaerobic Digestion An Alternative Energy Source. *Heliyon*, *10*(23), e40632. https://doi.org/10.1016/j.heliyon.2024.e40632

Norden, B. (2016). Learning and Teaching Sustainable Development in Global - Local Contexts. Lund University.

Sardianou, E., & Kougias, K. (2025). Empowering Future Energy Citizens: How Knowledge, Environmental Attitudes, and Student Characteristics Shape Perceptions of Renewables?. *European Journal of Interdisciplinary Studies*, 17(2), 129. https://doi.org/10.24818/ejis.2025.18

Shallo, L., Ayele, M., & Sime, G. (2020). Determinants of biogas technology adoption in southern Ethiopia. 1–13. https://doi.org/10.1186/s13705-019-0236-x

Silaen, M., Taylor, R., Bößner, S., Anger-Kraavi, A., Chewpreecha, U., Badinotti, A., & Takama, T. (2020). Lessons from Bali for Small-Scale Biogas Development in Indonesia. *Environmental Innovation and Societal Transitions*, *35*(25), 445–459. https://doi.org/10.1016/j.eist.2019.09.003

Sinaga, P. V. H., Suanggana, D., & Haryono, H. D. (2022). Analisis Produksi Biogas Sebagai Energi Alternatif pada Kompor Biogas Menggunakan Campuran Kotoran Sapi dan Ampas Tahu. *JTT (Jurnal Teknologi Terapan)*, *8*(1), 61. https://doi.org/10.31884/jtt.v8i1.348

Sugiyono. *Metode Penelitian Pendidikan*. Alfabeta: Bandung

Sriatun, N., Ardianto, D., Permana, I., & Afriana, J. (2025). Strategies for Promoting Energy Literacy in Physics Education : Insights from A Systematic Literature Review. *Journal of Innovative Science Education*, *14*(1), 54–63. https://doi.org/10.15294/jise.v14i1.20856

Tahir, U., Tanwir, & Fabanyo, A. M. (2024). Inisiatif Energi Terbarukan Berbasis Komunitas (Distrik Sentani , Kabupaten Jayapura). *Jurnal Pengabdian Masyarakat (PENGAMAS)*, *1*(3), 299–311. https://doi.org///doi.org/10.62207

Vogel, F. W., Carlotto, N., Wang, Z., Gonz, R., Bautista, J., Seco, A., & Porcar, M. (2023). Simplicity Hits the Gas : A Robust , DIY Biogas Reactor Holds Potential in Research and Education in Bioeconomy.

Wati, E. S., Hariyono, E., Zakaria, A., & Saphira, H. V. (2025). Preliminary Study : Renewable Bionergy Based On Problem Based Learning as a Recommended Media to Improve Students' Critical Thinking Skills. *Jurnal Pengabdian Masyarakat dan Riset Pendidikan*, *4*(1), 2717–2724. https://doi.org/10.31004/jerkin.v4i1.1781

Yongken, R. Si. S., Asmahasah, S., & Angelina, P. R. (2022). Studi Deskriptif Efektivitas Penerapan Metode Mind Mapping pada Mata Pelajaran IPA Materi Siklus Air Kelas 5 di SDN Nanggewer Mekar Cibinong. *Jurnal Pendidikan Tambusai*, *6*(2), 14845–14852. https://doi.org/10.31004/jptam.v6i2.4763